BSEC

BLACK SEA ECONOMIC COOPERATION AZERI CHAIRMANSHIP

PROMITHEAS NET

## 2nd International Scientific Conference

# Energy and Climate Change

PROCEEDINGS


## 8-9, October 2009, Athens, Greece

## National and Kapodistrian University of Athens

30, Panepistimiou Str, Athens

*Organized by* Energy Policy and Development Centre (KEPA)

*Coordinator of*

P R O M I T H E A S

The Energy and Climate Change Policy Network

Energy Policy and Development Centre (KEPA)

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Proceedings of the 2nd International Scientific Conference
on "Energy and Climate Change", 8-9 October 2009 , Athens, Greece

# Preface

The 2nd International Conference on “Energy and Climate Change” was organized on 8-9 October 2009 in Athens under the auspices of the BSEC Azerbaijani Chairmanship.

The Conference is an annual activity of the PROMITHEAS net consisted of 25 academic institutions from S.E. Europe, Black Sea, Caspian Sea and Central Asia.

It is addressed to the international scientific community while it puts emphasis on the enhancement of cooperation among scientists from EU and the broad area of Black Sea.

A scientific committee, consisted of 20 distinguished professors from the twelve BSEC countries reviewed the received 70 abstracts from 25 countries all over the world.

The Conference covered the thematic areas of Energy and Environmental – Climate Change Policy. The papers presented during the Conference, covered the topics of energy policy, conventional fuels (oil, gas, coal, lignite), electricity, renewables (solar, wind, hydro, geothermal, biomass, tidal wave), biofuels, climate change, energy efficiency and conservation.

The Conference concluded with a round table discussion concerning the follow up activities in joint EU project proposals and measures aiming to further upgrade the quality of the next Conference.

The proceedings of the Conference will be disseminated electronically through the PROMITHEAS web site.

Finally, as coordinator of the PROMITHEAS net I would like to express my sincere gratitude to all colleagues that contributed to the success of the Conference and to the members of the Organizing Committee and especially to Dr. Popi Konidari for her devoted contribution in the successful preparation of the Conference.

The PROMITHEAS net Coordinator

Prof. Dimitrios Mavrakis
Director of KEPA

# Scientific Committee

An International Scientific Committee with members from Greece, EU and BSEC countries ensured the quality of the Scientific Sessions. The synthesis of this committee was:

***Chairman***

Prof. Ioannis KARAKOSTAS, Vice Rector, National and Kapodistrian University of Athens, Greece

***Members***

Prof. Perikles BOURKAS, National Technical University of Athens, Greece

Prof. Mihail CHIORSAC, Academy of Sciences of Moldova, Moldova

Prof. Evangelos DIALYNAS, National Technical University of Athens, Greece

Prof. Dias HARALAMPOPOULOS, University of the Aegean, Greece

Prof. Alexander ILYINSKY, Finance Academy, Russia

Prof. Evgenij INSHEKOV, National Technical University of Kiev, Ukraine

Prof. Nikola KALOYANOV, Technical University of Sofia, Bulgaria

Prof. Konstantinos KARAGIANNOPOULOS, National Technical University of Athens, Greece

Prof. Jorgaq KACANI, Polytechnic University of Tirana, Albania

Prof. Dimitrios MAVRAKIS, National and Kapodistrian University of Athens, Greece

Prof. Ioannis MAZIS, Ionian University, Greece

Prof. Haji MELIKOV, National Academy of Sciences, Azerbaijan

Prof. Nikitas NIKITAKOS, University of the Aegean, Greece

Prof. Agis PAPADOPOULOS, Aristotle University of Thessaloniki, Greece

Prof. Anca POPESCU, University Polytechnica of Bucarest, Romania

Prof. Arthur PRAKHOVNIK, National Technical University of Kiev, Ukraine

Prof. Elmira RAMAZANOVA, National Academy of Sciences, Azerbaijan

Prof. Mustafa TIRIS, Energy Institute TUBITAK MRC, Turkey

Prof. Milton A. TYPAS, National and Kapodistrian University of Athens, Greece

# Agenda

UNDER THE AUSPICES OF THE AZERBAIJANI CHAIRMANSHIP OF THE BLACK SEA ECONOMIC COOPERATION

2nd International Scientific Conference "Energy and Climate Change"

## Day 1 8 October 2009

**9:00 – 9:30** **Registration**

**9:30 – 10:30** **Opening**

**Chair**

Prof. Dimitrios MAVRAKIS, Director of KEPA, National and Kapodistrian University of Athens, Hellas

Prof. Elmira RAMAZANOVA, Corresponded Member of the National Academy of Science, Director of Science Research Institute of GPOGC, Deputy Chief of National Oil Committee, Azerbaijan

Prof. Nikola KALOYANOV, Vice Rector of Technical University of Sofia, Bulgaria

Prof. Evgenij INSHEKOV, National Technical University of Kiev, Ukraine

**Opening addresses**

Prof. Ioannis KARAKOSTAS, Vice Rector, National and Kapodistrian University of Athens, Hellas

Amb. Leonidas CHRYSANTHOPOULOS, Secretary General PERMIS - BSEC

Mr. Anar JANAHMADOV, Counsellor, Embassy of Azerbaijan in Athens

Amb. Dimitrios TSOUGAS, Director, Hellenic Ministry of Foreign Affairs

**10:30 – 11:00** Coffee break

**11:00 – 14:00** ***1. Policies***

**Chair**

Prof. Elmira RAMAZANOVA, Corresponded Member of the National Academy of Science, Director of Science Research Institute of GPOGC, Deputy Chief of National Oil Committee, Azerbaijan

Prof. Ioannis MAZIS, Ionian University, Hellas

Prof. Haji MELIKOV, National Academy of Sciences, Azerbaijan

**Speakers**

*"Energy Conservation Measures in the contexts of climate change mitigation policy in Kazakhstan"* by Lyubov Inyutina and Sergey Inyutin (Turan - Astana University University - Kazakhstan)

*"Energy and Climate Policy of Ukraine as Part of Concept of Sustainable Energy Development"*, by Prof. Arthur Prakhovnyk and Assoc.Prof. Evgenij Inshekov (ESEMI – Ukraine)

*"Energy policy and environmental management in hotel industry"* by Sofia-Natalia Boemi (University of Ioannina – Hellas), Prof. Agis M. Papadopoulos (Aristotle University of Thessaloniki – Hellas) and Giouli Mihalakakou (University of Ioannina – Hellas)

*"The role of the green quota and revenue recycling schemes in the climate change options: a dynamic general equilibrium analysis for Austria"*, by Dr. Todor Balabanov and Dr. Srefan Schmelzer (Institut fuer Hoehere Studien -Austria)

*"Effects of Carbon Tax on Greenhouse Gas Mitigation and Energy Security in a Developing Country"*, by Prof. Ram Shrestha (Asian Institute of Technology – Thailand)

*"Integrated Water Resource management as a part of the Climate change adaptation strategies-the legal approach"* by Vicky Karagiorgou (Panteion University – Hellas)

*"Least Cost Optimisation modelling of the 2020 energy and environmental targets in EU27 – The PanEuropean TIMES model"* by Dr George Giannakidis (Centre for Renewable Energy Sources and Saving – Hellas)

*"Implementing the G8 80% target with the macro-econometric E3MG model"* by A. S. Dagoumas (Hellenic Transmission System Operator S.A. (HTSO) - Hellas) and T.S. Barker University of Cambridge – UK)

*"Premises for large-scale implementation of distributed generation in Romania"* by George Lavrov and Camelia Vasile (ISPE – Romania)

*"Evaluating policy options for increasing the RES-E penetration in Hellas"*, by Dr. Harry D. Kambezidis (NOA – Hellas), Barbara Kasselouri (Open University – Hellas) and Dr. Popi Konidari (KEPA – NKUA – Hellas)

*"Using the AMS method to evaluate the policy framework for potential CDM projects in the BSEC countries"* by Dr. Popi Konidari (KEPA – NKUA – Hellas)

**14.00 – 15.00** Lunch Break

**15:00 – 18:00**

## *2.* Energy

### Chair

Prof. Konstantinos KARAGIANNOPOULOS, National Technical University of Athens, Hellas

Prof. Ahad JANAHMADOV, Azerbaijan Engineering Academy, Azerbaijan

Prof. Evgenij INSHEKOV, National Technical University of Kiev, Ukraine

### Speakers

*"The introduction of new reagents, jobs, raising to efficiency, at production and transportation of high paraffin oils"* by E.E. Ramazanova, A.N. Zeynalov (GPOGC – Azerbaijan)

2nd International Scientific Conference "Energy and Climate Change"

*"Information – analytical system of complex diagnosing and estimation of risk for good safety transportations of hydrocarbons of the main pipeline"*, by A.T.Jamalov, E.E.Ramazanova, O.A.Dyshin,I.A.Habibov (GPOGC – Azerbaijan)

*"Assessing the impact of traffic regulations on the waiting queues of maritime straits; the Bosporus example"*, by Nikolaos KONTINAKIS (KEPA– Hellas)

*"Quantifying the chance for releasing of a hazardous substance owing to accidents"*, by Argirov J. P. (Institute for Nuclear Research and Nuclear Energy – Bulgaria)

*"Problems of repair and renewal operations in oil and gas industry"* by A.M.Pashayev, A.Sh.Mehtiyev, J.J.Asgarov, A.Kh.Janahmadov, N.G.Javadov (Azerbaijan Engineering Academy)

*"Energy and Environmental Impacts from an extensive use of VSDs in Uzbek Industry"* by Prof. Khashimov Aripdjan Adilovich (Tashkent State Technical University – Uzbekistan) and Prof. Rampias Ioannis (Technological Educational Institute of Athens – Hellas)

*"Research on plant fibre-reinforced polymer composites"* by Steve K. Ales and K.E.D. Sumanasiri (PNG University of Technology - Papua New Guinea)

*"New composition of high inhibited drilling mud for use of unstable clay deposits"*, by Tatliyev Kh.S., Malikov Q., Rasulov S.R., Zeynalov N.E. (GPOGC – Azerbaijan)

## Day 2 9 October 2009

**9:00 – 11:00**

### *3.* Electricity – Renewable Energy Sources

**Chair**

Prof. Evangelos DIALYNAS, National Technical University of Athens, Hellas
Prof. Miltiadis TYPAS, National and Kapodistrian University of Athens, Hellas
Prof. Nikitas NIKITAKOS, University of the Aegean, Hellas

**Speakers**

*"Sustainable Energy Planning for Autonomous Power System of Crete"*, by Emmanuel Karapidakis, Nikos Zografakis and Emmanuel Thalassinakis (Technological Educational Institute of Crete, Hellas)

*"Biogas a secure and sustainable energy source: Obstacles and perspectives of biogas projects in Hellas"* by Sioulas Konstantinos (CRES – Hellas)

*"Potential of floating wind turbines in Aegean Sea"*, by Prof. Nikitas Nikitakos and Dr. Theodoros Lilas (Aegean University – Hellas)

*"Barriers on renewable energy sources in Hellas"* by A.M. Papadopoulos, S.N. Boemi, S. Kontogianni and A. Karagiannidis (Aristotle University of Thessaloniki - Hellas)

*"Solid state fermentation of sweet sorghum by Saccharomyces cerevisiae to*

*bioethanol production"* by Karamousantas, D., Th. Varzakas (Technological Educational Institution of Kalamata – Hellas), D. Arapoglou, C. Israilides (Institute of Technology of Agricultural Products – Hellas)

"Solar recharging stations: Selling hours of solar lighting" by Dr. Leon Gaillard (Lao Institute for Renewable Energy – LAO PDR)

*"The use of renewable energy sources in agricultural greenhouses and the Technological Educational Institute of Kalamata's greenhouse case study" by* D.Ch. Karamousantas (Technological Educational Institution of Kalamata – Hellas)

**11:00 – 11:30** Coffee break

**11:30- 14:00**

## *4.* Climate change

**Chair**

Prof. Nikola KALOYANOV, Vice Rector of Technical University of Sofia, Bulgaria

Prof. Agis PAPADOPOULOS, Aristotle University of Thessaloniki, Hellas

Mr. Bolat MENSHIK, Vice Chairman of the Board, JSC "Science Fund", Kazakhstan

**Speakers**

*"Energy efficiency in Residential Buildings. The Comparison between Degree Day Calculation and Simulations"*, Teet-Andrus Kõiv, Hendrik Voll, Allan Hani (Tallinn University of Technology – Estonia)

*"Molybdenum (VI) determination in natural waters from polarographic catalytic current of chlorate-ions and thiosemicarbazone 2,3-dihidroxybenzaldehyde"* by Ludmila Chiriac, Tatiana Cazac, M. Revenco and I. Povar (Moldova)

*"A POD model for the concentration field of gases instantaneously released in the atmosphere"*, by Anastasios ANTYPAS (OR Consultant – Hellas)

*"Investigate via internet the consumer's willingness to pay for the sake of the environmental protection"*, Stefanos Oikonomou, George Drosatos, Maria Oikonomou (Democritus University of Thrace – Hellas)

*"Estimation of mean maximum summer and mean minimum winter temperatures over Hellas in 2070-2100 using statistical downscaling methods"*, Anastasios Skourkeas, Fotini Kolyva-Machera, Panagiotis Maheras (Aristotle University of Thessaloniki-Hellas)

*"A new type of the diagrams of distribution for evaluating the ion-molecular buffering capacity of acidic natural waters in the equilibrium with the mineral phase gibbsite"* by Igor Povar and Vasile Rusu (Institute of Chemistry - Moldova)

*"A new type of the diagrams of distribution for soluble and insoluble forms of aluminium in natural heterogeneous aquatic systems"* by Igor Povar and Vasile Rusu (Institute of Chemistry - Moldova)

**14:00 – 15:00** Lunch Break

**15:00 – 16:30**

*"Use of two activated carbons for treatment of textile wastewater containing dyes and surfactant contaminants"* , by Nina Timbaliuc and T. Lupascu (Institute of Chemistry - Moldova)

*"Investigate via internet the personal values of life and how determine the consumer's environmental behaviour"*, by Stefanos Oikonomou, George Drosatos, Maria Oikonomou (Democritus University of Thrace – Hellas)

*"The influence of 4-Phenylthiosemicarbazide on cadmium ion determination in the prut river waters by cathodic stripping voltametry"* by Tatiana Cazac, Ludmila Chiriac, M. Revenco and I. Povar (Institute of Chemistry - Moldova)

*"Environmental evaluation of the hotels and renting rooms at Thasos Island"*, by Stefanos Oikonomou, George Drosatos, Maria Oikonomou (Democritus University of Thrace – Hellas)

*"Sorption performance of activated carbons after oxidation and metal impregnation treatments" by* Ion Dranca, Tudor Lupascu and Oleg Petuhov (Institute of Chemistry – Moldova)

*"National projections of GHG emissions by sources and their removal by sinks for the years 2010, 2015 and 2020"* by Anca Popescu and Anca Bardici (ISPE – Romania)

**16:30 – 18:30**

## 5. Round Table

### Aim

The discussion aims to enhance the bonds of scientific cooperation among the participants and their institutions in the frame of PROMITHEAS Network activities.

***The procedure is open to all participants***

### Chair

Prof. Dimitrios MAVRAKIS, National and Kapodistrian University of Athens, Hellas

### Panelists

Prof. Evangelos DIALYNAS, National Technical University of Athens, Hellas

Mr. Marcos Dos SANTOS, Director General of the Secretary of State for Energy Policy, Timor Leste

Mrs. Tereza FOKIANOU, Flow Energy

Mr. Andreas GIANNAKOPOULOS, Maxima Energy S.A.

Prof. Ahad JANAHMADOV, Azerbaijan Engineering Academy, Azerbaijan

Prof. Nikola KALOYANOV, Technical University of Sofia, Bulgaria

Prof. Konstantinos KARAGIANNOPOULOS, National Technical University of Athens, Hellas

Dr. Popi KONIDARI, National and Kapodistrian University of Athens, Hellas

Prof. Ioannis MAZIS, Ionian University, Hellas

Prof. Haji MELIKOV, National Academy of Sciences, Azerbaijan

Mr. Bolat MENSHIK, Vice Chairman of the Board, JSC "Science Fund", Kazakhstan

Prof. Nikitas NIKITAKOS, University of the Aegean, Hellas

Dr. Igor POVAR, Institute of Chemistry, Moldova

Prof. Agis PAPADOPOULOS, Aristotle University of Thessaloniki, Hellas

Prof. Evgenij INSHEKOV, National Technical University of Kiev, Ukraine

Prof. Elmira RAMAZANOVA, Corresponded Member of the National Academy of Science, GPOGC, Azerbaijan

Prof. Miltiadis TYPAS, National and Kapodistrian University of Athens, Hellas

**Venue**

*(Day 1)* *Central Building - Neo Amphitheatro*
*30 El. Venizelou (Panepistimiou) Av., Centre area*
Athens

and

*(Day 2)* "*Kostis Palamas*" Cultural Centre of NKUA
48 Akadimias and Sina str.
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# Contents

# Session 1: Policies

# The role of the green quota and revenue recycling schemes in the climate change options: A dynamic general equilibrium analysis for Austria

Todor Balabanov[(b)] , Stefan Schmelzer [(a)]

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*(b)*

**Abstract**

*By simulations with the dynamic equilibrium model TD-BU-E3 DGEM the long term impacts of two alternative policy instruments for responses to climate change were assessed: green quota and double dividend.Electricity demand growth was de-coupled from the economic growth. 3 economic sectors, 5 existing and three new vintage electricity production technologies were considered.*

*By 2050 the share of renewables in the electricity production could be reaching 0,289 and there are sufficient potential renewable resources. The economic burden is bearable and the welfare is growing.*

*Checking the double dividend hypothesis (trade-off b/n environmental benefits and gross economic costs): the reduction in the labor tax is increasing consumption; the reduction of consumption tax to a lesser extent so but the reduction in the lump-sum refund to the representative household is detrimental to consumption.*

*Hence, only for the case of labor tax recycling, we could assume the existence of a strong double dividend.*

**Keywords:** climate change, $CO_2$ taxation, abatement strategies, general equilibrium models

## 1. Introduction

The aim of the paper is to quantitatively assess the macroeconomic and sectoral impacts of future responses to climate change by evaluating policies for adaptation and mitigation aiming at promoting increased market penetration of electricity produced from renewable energy sources in Austria.

The term adaptation is to be related to de-coupling of electricity demand from the economic growth by energy and resources conservation in the sense of sustainable development, by changing consumption pattern and habits, etc. – all that are long term measures related to socio economic changes.

For the long-term mitigation options for the electric power sector will focus on $CO_2$ reduction by the mean of a set of the technological options where strong potentials for $CO_2$ reduction exist.

To grasp synergies in climate policy the adaptation and mitigation options must be analyzed within a consistent, dynamic framework allowing for carrying out of integrated analyses of alternative scenarios for adaptation and mitigation strategies.

Mitigation and adaptation policies should be assessed on their full effects and their quantification calls for the use of the newly developed Top/Down -BU for Bottom-up E3 (energy, environment, economy) dynamic general equilibrium model (TD-BU-E3 DGEM) allowing for systematic trade-off analysis of environmental quality, economic performance and welfare (consumption).

As to policy measures related to mitigation by promotion of renewable energies there had been a shift - as more generally in environmental policy design - from command-and-control policies to market-based instruments such as taxes, subsidies, and tradable quotas. A recent impact assessment by the European Commission, 2008, shows that feed-in tariffs in Austria are the preferred promotion measure. In addition, direct subsidies for renewable energy have been enacted – typically differentiated by the type of green energy, i.e., wind, biomass, solar cells, etc.

A relatively new strand of policy regulation is the use of tradable green quotas where energy supplies are required to produce a certain share of energy services from renewable energy but are flexible to trade these shares between each other in order to exploit potential difference in specific compliance costs.

In this paper, focus on two alternative policy instruments which may be quite relevant to the Austrian strategy for promotion of renewable energy sources: quota obligation systems and Carbon Taxation (double dividend) instruments.

Methodological the focus is set on novel CGE (Computational General Equilibrium) modeling approaches. The methodological objective is to consistently describe the role of specific energy related technologies within a total analytical economic modeling framework. CGE is used as an analytical Top-Down framework that is enhanced by representation of specific technology descriptions.

The paper is structured as follows: Section 2 provides a background to the TD-BU-E3 DGEM and its algebraic representation in the MCP framework, followed by its adjustment to the study's specifics and application to the particular case studies in Section 3 that is dealing with Scenario definition and policy analysis starting with benchmark assumptions, then the description and analysis of the Baseline Scenario followed by the Green quota scenario and respective analysis and ending with the Carbon Taxation (double dividend) Scenario. Section 4 concludes.

## 2. The TD-BU-E3 DGEM

Our modeling work was motivated by recent theoretical and practical developments in algorithms for nonlinear complementarity problems and variational inequalities based on the GAMS/MCP modeling format (Rutherford, 2002).
The TD-BU-E3 DGEM (here TD stands for Top/Down, BU for Bottom-up, E3 for energy, environment, economy and DGEM for dynamic general equilibrium model) provides a basis for evaluating economic impacts of the chosen energy policies both at macroeconomic and at the sectoral level – indicating the effects of the energy decisions on the economic environment. This approach permits an energy-economy model to combine technological details of an energy system (bottom-up) with a characterization of the overall economy market equilibrium (top-down).

TD-BU-E3 DGEM applications include the impacts of scenarios on country´s economic variables, e.g., changes of the main real economic indicators, in the consumption of the households, in the sectoral employment levels, in the energy consumption, of the emission levels, the energy price indices, etc., but TD-BU-E3 DGEM is also used for applied energy and environmental policy analysis, e.g., the impacts of the Green Quotas and the Environmental Tax Reform

### 2.1 TD-BU-E3 DGEM: algebraic representation in MCP framework

In our formulation of an integrated top-down / bottom-up model we consider a competitive (Arrow-Debreu) economy with n commodities (including economic goods, energy goods and primary factors) indexed by i, m production activities (sectors) indexed by j, and one infinitely living representative agent, or household (including government). Later this concept will be put into a dynamic intertemporal setting, using the standard Ramsey model of savings and investments.
We are making use of the MCP framework suggested by Boehringer (2007) formulation of market equilibrium problems as mixed complementarity problems (MCP) thus permitting integration of bottom-up programming models of the energy system into top-down general equilibrium models of the overall economy. The classic "mixed-complementarity problem" (MCP) is defined as:

Given: $F : R^N \rightarrow R^N, l, u \in R^N$ (1)

Find: $z, w, v \in R^N$ (2)

st:

$$F(z) - w + v = 0 \qquad (3)$$

$$l \le z \le u, w \ge 0, v \ge 0 \qquad (4)$$

$$w^T \cdot (z - l) = 0, v^T \cdot (u - z) = 0 \qquad (5)$$

in which $-\infty \le l \le u \le +\infty$. F must be continuously differentiable in order to express a model using GAMS/MCP algebra. It is not hard to see that the model, as laid out in the following, exactly suits the concept of an MCP as described in equations (1) to (5).

The decision variables of the economy can be classified into the following categories:

*p* denotes a non-negative *n*-vector in prices for all goods and factors,

$y$ is a non-negative $m$-vector for activity levels of constant-returns-to-scale (CRTS) production sectors,
M is a scalar, denoting consumer income level,
$e$ represents a non-negative $n$-vector of net energy system outputs (including, for example, electricity, oil, coal, and natural gas supplies), and
$x$ denotes a non-negative $n$-vector of energy system inputs (including labor, capital, and materials inputs).

As in Mathiesen's model, a competitive market equilibrium for this economy is represented by a vector of activity levels, a non-negative vector of prices, and a non-negative vector of incomes such that the following criteria are fulfilled:

- **Zero-profit condition**: No production activity makes a positive profit.

$$-\Pi_j(p) \geq 0 \quad (6)$$

  Where $\Pi_j(p)$ denotes the unit profit function for constant returns to scale production activity j, which is the diference between unit revenue and unit cost.

- **Market clearance conditions:** Excess supply is non-negative for all goods and factors.

$$\sum_j \nabla\Pi_j(p) \cdot y_j + \omega + e \geq d(p,M) + x \quad (7)$$

  Here $\omega$ indicates the initial endowment vector and $d(p,M)$ is the utility-maximizing demand vector, of the representative agent.

- **Income balance**: Household expenditure does not exceed income.

$$M = p^T \cdot [\omega + \theta \cdot (e-x)] \quad (8)$$

In this equality $\theta$ represents the share of energy-sector rents that accrue to the household(rents depend on household ownership of energy resources). The equation which defines consumer income level is conceptually distinct from the zero profit and market clearing conditions in that there is no explicit complementarity at work in this part of the model. The income variable is added to the equilibrium system solely as a means of simplifying the expression of household demand.

Furthermore, we assume that the equilibrium levels of energy sector outputs and inputs are consistent with profit-maximization, taking market prices as given:

- **Integrated bottom-up model:** Energy sector supply and demand vectors are profit-maximizing choices subject to technical constraints. That is, e and x solve a linear programming model. For concreteness, we will assume that this bottom-up model can be written as:

$$\max\{p^T \cdot (e-x)\} \quad (9)$$

  st:

$$Ax + Bz \geq Ce \quad (10)$$

$$e, x \geq 0, \quad (11)$$

$$l \leq z \leq u \quad (12)$$

  Where $A, C \in R^{M \times n}$ and $B \in R^{M \times N}$ characterize technical constraints and $z \in R^N$ denotes decision variables of the energy system with $l, u \in R^N$ upper and lower bounds respectively.

In the integrated model formulation the linear program is incorporated through the associated Kuhn-Tucker conditions and solved simultaneously with the equilibrium conditions (6)-(8).

Policy interference can substantially affect investment and savings incentives. Assessment of the adjustment path and long-term equilibrium effects induced by policy constraints may therefore call for an explicit intertemporal framework.
Dynamic modeling requires an assumption on the degree of foresight of economic agents. In a deterministic setting, one logically consistent approach is to assume that agents in the model know as much about the future as the modeler: Agents' expectations of future prices then correspond to realized future prices in the simulation. Within the standard Ramsey model of savings and investment, the notion of perfect foresight is coupled with the assumption of an infinitely-lived representative agent who makes explicit choices at the margin between the consumption levels of current and future generations. The representative agent maximizes welfare subject to an intertemporal budget constraint. Savings rates equalize the marginal return on investment and the marginal cost of capital formation. Rates of return are determined such that the marginal productivity of a unit of investment and marginal utility of foregone consumption are equalized.

Extending the above mathematical setting into an intertemporal (dynamic) model version only requires a few technical additions (most of the underlying economic relationships hold on a period-by-period basis), following the ideology of the already mentioned Ramsey model, often represented as a linear optimization problem:

$$\max \sum_{t=0}^{\infty}\left[ \left(\frac{1}{1+\rho}\right)^{t} \cdot \frac{C_t^{1-\vartheta}-1}{1-\vartheta} \right] \quad (13)$$

st:

$$C_t = f(K_t) - I_t \quad (14)$$

$$K_{t+1} = (1-\delta)K_t + I_t \quad (15)$$

Here C indicates consumption, K capital stock, I investment for each time period t, and $\rho, \delta, \vartheta$ indicate time preference of consumption, depreciation rate of capital and intertemporal elasticity of substitution respectively.

The idea is to add investment and capital stock for each production activity, as well as the according prices, i.e. capital purchase price and capital rental price, as decision variables to the model. In this way the previously described integrated Bottom-up Top-down model is solved for each time period t, linking each period through the additional zero profit and market clearance conditions for investment and capital stock formation (introduced through equations (14) and (15)), which relate the cost of a unit of investment, the return to capital, and the purchase price of a unit of capital stock in period t.

For calibration of the TD-BU-E3 DGEM we make use of the three sectoral social accounting matrix for 2005, which is derived from Austria's input-output table published by Statistic Austria, as well as the following data:

| | |
|---|---|
| Intertemporal elasticity of substitution | 0,5 |
| Baseline interest rate | 5 %/year |
| Baseline growth rate | 0.9 %/year |
| Depreciation rate | 7 %/year |

The top-down nesting structure of the production functions is exemplified in Annex 1.

Specified data on the energy sector, used in the bottom-up part of the model, is derived from the Austrian input output table as well as the energy balances of Statistic Austria, which are both given in Annex 2.

## 3. Scenario definition and policy analysis

### 3.1 Some technological considerations

In TD-BU-E3 DGEM we have eight different technologies for electricity production, divided into existing and new vintage technologies, and also categorized as renewable (or green) or not renewable.

The existing electricity production technologies are: Gas Power Plants, Oil Power Plants, Coal Power Plants, Hydro Power Plants, and Bio-Wind Power Plants, where the latter accounts for a composite of existing Biomass and Wind electricity production power units. At the Figure 1 the benchmark production shares of the existing technologies for the year 2005 are shown.

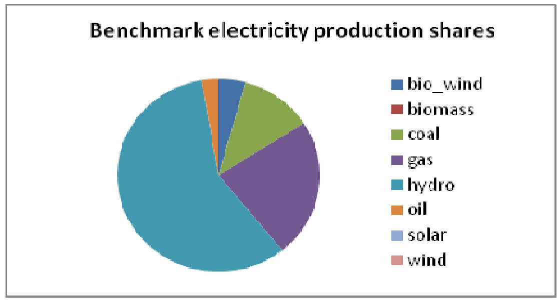


Figure 1: Benchmark electricity production shares.

For the future power production we are envisaging the so called new vintage technologies, namely, new wind, new biomass and solar/photovoltaic.

Here the terms new wind and biomass should be understood to be tentative names more the end-of-the pipe technologies that are assumed to be more efficient than the existing but also more costly.

We made assumption that the existing power plants will be functioning in the future and the new technologies will be entering the market after the old have exhausted the limit of their resource allocation. For the existing Bio-Wind technology we have imposed a limit at a level of 2.5 times the value of its benchmark electricity production. Similarly, based on the limiter resource availability, the Hydro Power production was limited to 1.4 times its benchmark production level. According to the trend analysis the production of the coal power plants does not change much and oil power plants are going out of market.

The new renewable technologies have an imposed potential of their maximal contribution to the total electricity production, namely, the new Wind - 7%, new biomass - 15%, and the new solar - 20%.

For the technologies the relative prices per unit of electricity produced have been ranked from the cheapest, hydro power, to the most expensive, new solar which is assumed to be 2.2 more expensive than the hydro. The other technologies are lying in between this range.

The advanced renewables are assumed to be not active at the beginning of the period mainly because they are supposed to be technologically available at a later stage and because they are relatively quite expensive.

**Baseline Scenario**

Scenario assumption related to the **adaptation** is the de-coupling of electricity demand from the economic growth. This is assumed to be done by energy and resources conservation in the sense of sustainable development, by changing consumption pattern and habits, etc. – all that are long term measures related to socio economic changes. The growth of total electricity production, shown at Figure 3, is assumed to be 0.7% per year, hence decoupled from the assumed economic growth of 0.9%/year. Just for comparison – till 2008 electricity demand in Austria were growing with 1% per year.

The Scenario assumptions for the main fuel inputs in the power production till the year 2050 are based on energy supply analysis by Kratena and Wrüger (2005) (Figure 2).

The main features of this scenario are:

- doubling the natural gas input for power production,
- hard coal use - almost constant,
- quadrupling the wind and biomass use and
- gradual extinction on fuel oil use in the power plants.

The quadrupling of fuel wood and wind electricity seem to be realizable because the available wind energy potential has been evaluated at 14 - 50 PJ and the fuel wood availability at 30 Mio m3 or 232 PJ (Hantsch and Moidl 2007; Balabanov 2008).

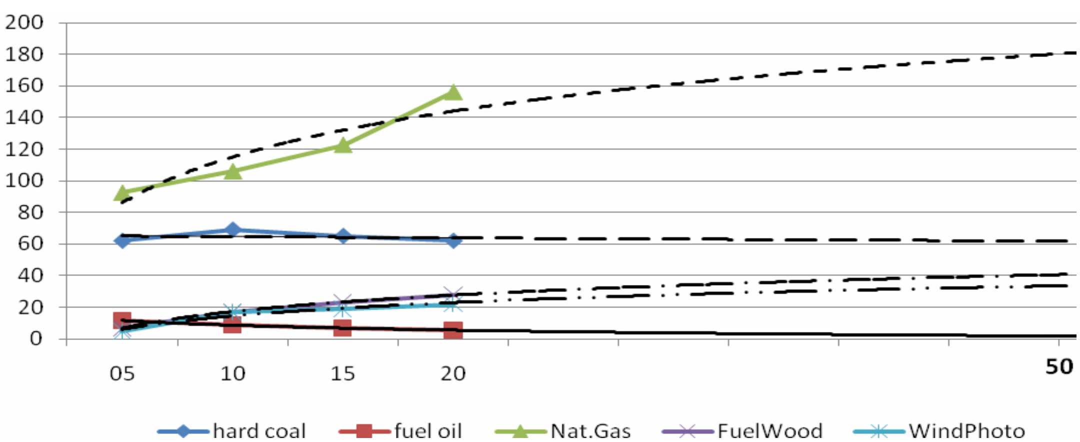


Figure 2: Assumptions for the main fuel inputs till the year 2050 (in PJ).

As said the growth of total electricity production, at Figure 3, is assumed to be decoupled from the economic growth of 0.9%/year so that we are coming to a growth index of 1.64 for electricity production over the 50 year period. In the baseline scenario renewables will increasing their part of the production but at the historical growth rate – reaching approximately 9% by 2050.

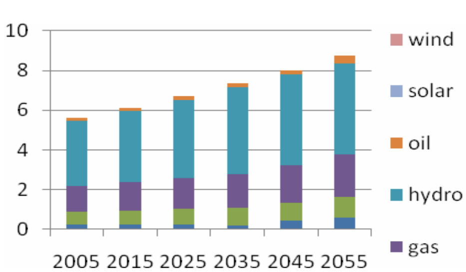


Figure 3: Structure of the power production.

**Green quota scenario**

A part of the integrated energy and climate change policy guidelines, as adopted by the EU in December 2008 (DG for Energy and Transport 2008), is the obligation by the member states for covering an average of 20% of their total energy needs from renewable sources. Therefore each country agreed to fulfill a different renewable energy quota by 2020.

The target for Austria by 2020 is 34% whilst for the year 2005 it was 23.3% of the total energy use. In so far as this target is recognizing the hydro power as green energy and the *Hydro share for 2020 is projected to be 14.73%* in fulfilling the quota obligation an accelerated growth rate of other renewables would be need in order to reach around 20% by 2020 which is seen by WKOE (2008) as difficult.

In this paper the green quota scenario is attempting to simulate the impacts on the technology mix of the Austrian electricity sector of increasing the share of renewables in the electricity production up to 30% by 2050.
By running the TD-BU-E3 DGEM under the above assumption we have as an output the changes in the main indicators as shown at Figure 4. The growth of the power production indexed with 1.66 is following quite closely the scenario assumption and around 2030 there is a small bump. This is result of the exhaustion of the conventional hydro and bio-wind resources and the slum is due to the significant subsidies needed for the start up of the new wind and biomass technologies.

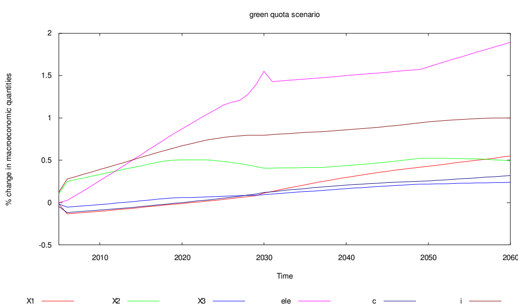

Figure 4: Model output for the main indexes.

The accelerated development of the agricultural sector (X1) is a result of the demands of agricultural inputs by the biomass technologies while heavy industry´s production (X2) is slightly declining due the general trend in exporting/downsizing the energy intensive industries.
The growth of investment is following closely the growth of the electricity output and this is due to the high capital intensity of the power sector. It is quite indicative that the consumption is growing, albeit at a lower rate, despite the significant investment demand.
Here is to be said that by 2030 the share of renewables (without hydro) is reaching 0,184 and by 2050 - 0,289.
To summarize: achieving the quota of close to 30% by 2050 is feasible and there are sufficient quantities of potential renewable resources for that purpose. It also seems that the economic burden is bearable and the welfare is growing.
The next figure shows the electricity production structure by the different technologies in TWh for graphical reasons the dominating Hydro power production is not shown at Figure 5, since it would be depressing the view. The scenario run resulted in steady increase of hydro power production of up to 50 TWh by 2020 when in it reaches its imposed production limit.

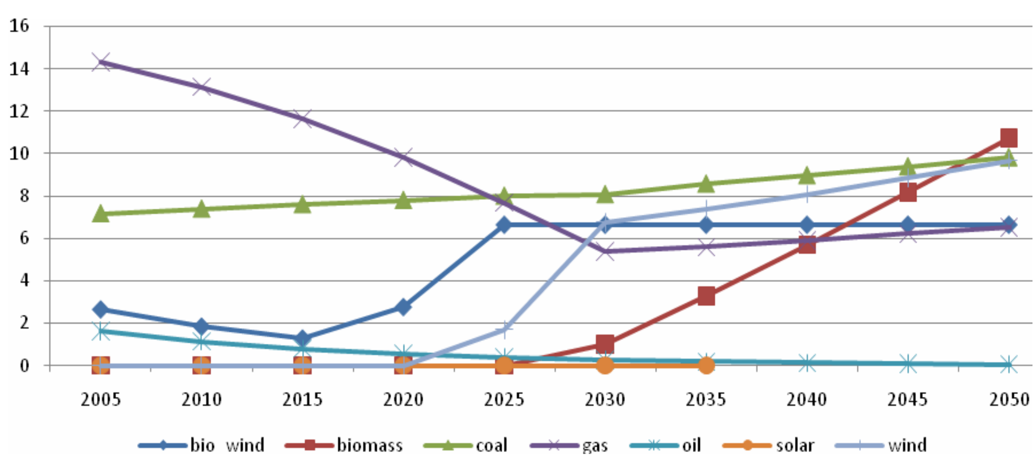

Figure 5: Production (in TWh) of the conventional and renewable energy technologies.

Few years later – by 2025 - the bio-wind is also reaching its production limit which results in the output rise by the conventional bio-wind technologies and that is opening the way to entering the market for the new wind and new biomass – the so called backstop technologies.

This start up of the new and expensive technologies result in a jump of the subsidy rate for green technologies, see Figure 6, first in 2025 at the level of 8% from the electricity production cost. When new Vintage reaches its potential, in 2030 there is another jump in subsidy rates reaching to 14%, so that new biomass technologies could start producing electricity.

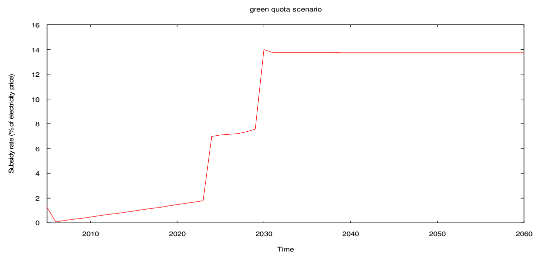


Figure 6: The subsidy rates for the green technologies.

As a result of these developments by 2030 the share of renewables in the electricity production (including hydro) is reaching **0,825** or without hydro **0,184** and by 2050 the same share without hydro is **0,289,** while the share (including hydro) remains at 0,825.

### Carbon Taxation (double dividend) Scenario

The **greenhouse gases** are measured in megatons of Carbon dioxide equivalency ($MCO_2eq$) and there are a number of alternative tax instruments for reducing its emissions.
Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of $CO_2$ that would have the same global warming potential (**GWP**), when measured over a specified timescale (generally, 100 years). Carbon dioxide equivalency thus reflects the time-integrated radioactive forcing, rather than the instantaneous value described by **$CO_2$e**.
For example, the GWP for methane over 100 years is 25 and for nitrous oxide 298. This means that emissions of 1 million metric tons of methane and nitrous oxide respectively are equivalent to emissions of 25 and 298 million metric tons of carbon dioxide.
Over the last decade, several EU Member States have levied some type of carbon tax in order to reduce greenhouse gas emissions from fossil fuel combustion contributing to anthropogenic global warming (OECD 2001).
In this context, the debate on the **double dividend** hypothesis has addressed the question of whether the usual trade-off between environmental benefits and gross economic costs (i.e. the costs disregarding environmental benefits) of emission taxes prevails in economies where distortionary taxes finance public spending.
Emission taxes raise public revenues which can be used to reduce existing tax distortions. Revenue recycling may then provide prospects for a double dividend from emission taxation (Goulder 1995):
Apart from an improvement in environmental quality (the first dividend), the overall excess burden of the tax system may be reduced by using additional tax revenues for a revenue-neutral cut of existing distortionary taxes (the second dividend).
If – at the margin – the excess burden of the environmental tax is smaller than that of the replaced (decreased) existing tax, public financing becomes more efficient and welfare gains will occur.
The setting of TD-BU-E3 DGEM for simulating Carbon Taxation Scenario differs slightly from the original setting for the Baseline Scenario, e.g., final consumption is being split into public (governmental) and private (household) consumption, where public consumption is estimated at a level of 25% of total consumption.
Therefore a new production activity is defined, indicating a public good (e.g. infrastructure, healthcare, etc.), which is then consumed by the Private households or firms in the economy.
In our dynamic policy simulations, we investigate the economic effects of carbon taxes that are set sufficiently high to reduce carbon emissions by 20% compared to the base year emission level.
The figure bellow is showing the rate of decarburization of the produced electricity, namely the reduction of $CO_2$ emissions per TWh of produced electricity.

While keeping public good consumption at the base-year level, the additional carbon tax revenues can be recycled in three different ways:

(i) a reduction in the distortionary labor tax (labeled as "TL")
(ii) a cut in the distortionary consumption tax (labeled as "TC")
(iii) a lump-sum refund to the representative household (labeled in the Figure as "LS").

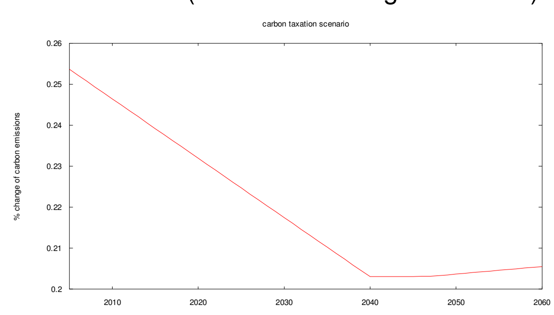


Figure 7: Trajectory of $CO_2$ emissions per unit electricity produced.

As seen at the Figure 8 – in line with the undisputed weak double dividend hypothesis

(Goulder 1995) - the reduction of the distortionary consumption or labor taxes (TL) is superior in efficiency terms as compared to a lump-sum recycling of carbon tax revenues. In our dynamic simulation, we even obtain a strong double dividend from revenue-neutral cuts in distortonary taxes (TL): Reflecting the larger marginal excess burden of the initial labor tax vis a vis the initial consumption tax, labor tax recycling is distinctly more beneficial than consumption tax recycling. The Figure 8 provides the consumption trajectories for the three different recycling options. In the case of reduction in the distortionary labor tax (**TL**) the consumption levels are increasing over a long period of time. To a lesser extend the same applies to the case of a cut in the distortionary consumption tax (labeled as "TC"): The reduction in the distortionary lump-sum refund to the representative household (labeled as "LS") tends to reducing consumption and respectively the welfare.

Hence, only for the case of labor tax recycling, we could assume the existence of a strong double dividend.

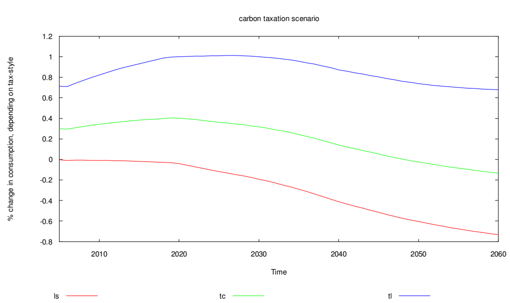


Figure 8: Carbon Taxation Scenarios.

Figure 9 shows the associated carbon tax rates, or the marginal abatement cost (MAC), to achieve the target emission reductions. The computed maximum MAC of bellow EUR 100 that correlates very well with other multi country studies for the EU region, e.g. the Marginal Abatement Costs (MAC) levels have been estimated by the EU´s "Impact Assessment of the EU's objectives on climate change and renewable energy for 2020" (EC 2008) to be around € 90/t $CO_2$.

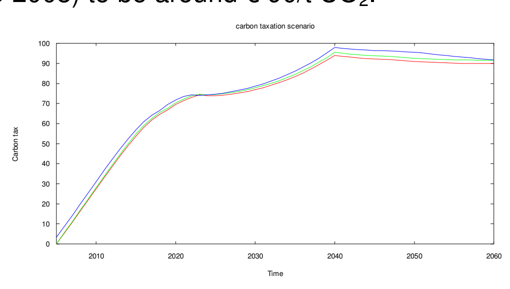


Figure 9: Dynamics of the carbon tax rates/MAC.

MAC – as the direct incentive for emission mitigation in production and consumption – increase with the stringency of the emission constraint but hardly differ across recycling variants.

In the dynamic analysis of environmental tax reforms, we impose a linear reduction of carbon emissions compared to baseline emission levels by 20% between 2005 and 2040, holding the percentage reduction vis--vis the Baseline and keeping it constant thereafter.

## Conclusions

By adapting and extensively validating the newly developed Top/Down -BU for Bottom-up E3 ( energy, environment, economy) dynamic general equilibrium model (TD-BU-E3 DGEM) we assessed the long term impacts on the macroeconomic and sectoral structural components of two alternative policy instruments for responses to climate change and for promotion of renewable energy sources:

Green quota, and

Carbon Taxation (double dividend)

In our baseline Scenario, as a part of the adaptation strategy, we assumed de-coupling of electricity demand growth from the economic growth.

In the model we have introduced 5 existing electricity production technologies, namely: Gas Power Plants, Oil Power Plants, Coal Power Plants, Hydro Power Plants, and Bio-Wind Power Plants (a composite of existing Biomass and Wind electricity production power units).

The new vintage technologies, namely, new wind, new biomass and solar/photovoltaic – are tentative names and should be better seen as the end-of-the pipe technologies that are assumed to be more efficient than the existing but also more costly.

The model runs for the Green quota scenario have shown that as a result of the inversing demands of agricultural inputs by the biomass technologies there is accelerated development of the agricultural sector while heavy industry´s production is slightly declining due the general trend in exporting/downsizing the energy intensive industries.

The growth of investment is following closely the growth of the electricity output and this is due to the high capital intensity of the power sector. It is quite indicative that the consumption is growing, albeit at a lower rate, despite the significant investment demand.

Here is to be said that by 2030 the share of renewables in the electricity production (without

hydro) is reaching 0,184 and **by 2050** - **0,289** and the renewables share (including hydro) is 0,825.
To summarize: achieving the quota of close to 30% by 2050 is feasible and there are sufficient quantities of potential renewable resources available for electricity production. It also seems that the economic burden is bearable and the welfare is growing.
The **double dividend** hypothesis has addressed the question of whether the usual trade-off between environmental benefits and gross economic costs (i.e. the costs disregarding environmental benefits) of emission taxes prevails in economies where distortionary taxes finance public spending.
Emission taxes raise public revenues which can be used to reduce existing tax distortions. Revenue recycling may then provide prospects for a double dividend from emission taxation.

While keeping public good consumption at the base-year level, the additional carbon tax revenues can be recycled in three different ways:

(i) a reduction in the distortionary labor tax
(ii) a cut in the distortionary consumption tax
(iii) a lump-sum refund to the representative household

The results of the simulations are showing that the reduction in the distortionary labor tax is leading to increases over a long period of time of the consumption levels. To a lesser extend the consumption increases in the case of a cut in the distortionary consumption tax. From the other side the reduction in the distortionary lump-sum refund to the representative household tends to reducing consumption and respectively the welfare.
Hence, only for the case of labor tax recycling, we could assume the existence of a strong double dividend.

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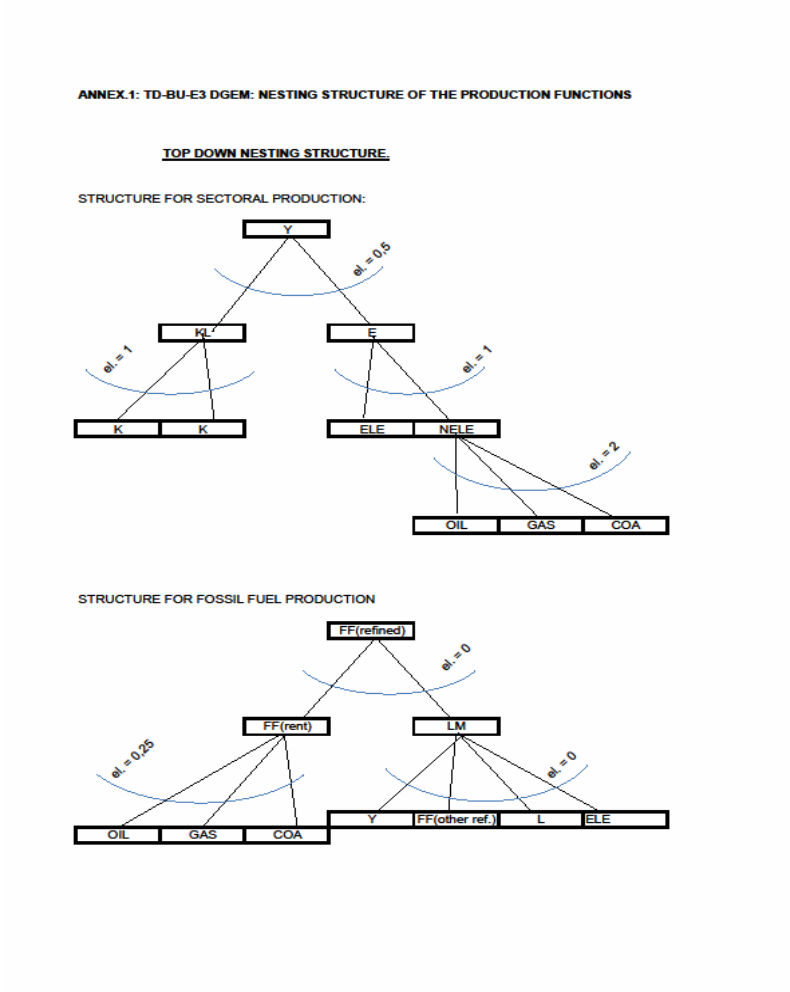

# Energy policy and environmental management in hotel industry

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**Abstract**

*An energy management system (EMS) can be used as a tool to shape the energy policy of a hotel. Even though various EMS differ significantly in their methodological approach, they all aim at designing a systematic environmental upgrade for the end user i.e. a hotel. The adoption of an EMS can be an economically viable option and can also be used as a marketing tool. Furthermore, it can contribute in order to comply with present and future changes of legislation. The most widespread EMS are the ISO 14001 and the Eco Management and Audit Schemes (EMAS). Recently the European Eco-LABEL, a voluntary scheme designed to encourage businesses to market products and services that are more environment-friendly, has been introduced. Within the frame of this paper is to discuss the adoption of an EMS, in order to support a sustainable touristic development by improving the quality of its facilities and its services.*

**Key words:** Energy management system (EMS), Eco-labelling, Sustainable tourism

## 1. Introduction

Over the last decades concerns related to the environmental aspect of the hotel sector have progressively escalated (Han et al., 2009). In the increasingly environmental conscious marketplace, consumers have realised the impact of their purchased behaviours, which are strongly associated with environmental problems (Laroche et al., 2001). Such markets are the various types of lodging operations which have become increasingly proactive in following green practises and developing environmental programs (Brawn, 1996).

Those voluntary approaches are increasingly considered as relevant policy instruments to control and regulate the hotel branch towards environmental protection, by developing a diverse set of efforts. These are considered voluntary initiatives, since they have two basic characteristics: promoters of the initiatives are not obligated by law to launch these schemes, and target groups are not obligated to join (WTO, 2002).

According to empirical studies, tourism-related uses of natural resources are increasingly significant and nature-based tourism has turned out to be the fastest growing segment of the global tourism market (UNEP, 1998; Blanco et al., 2009). The relevance of the close link between tourism and the ecological systems has been widely recognised in the field of environmental economics (Patterson et al., 2007; Bimonte, 2008). Still, and despite this relevance, the efforts to bring attention to the benefits that can be gained by broader and deeper voluntary commitments to the environment, and all that accompanies those, remain rather limited (Foster et al, 2000).

A green hotel is an environmental friendly lodging property that applies and follows ecologically sound programs and practices, like water and energy saving measures, reduction and management of solid waste and structural mesures in order to promote sustainability. With the growing number of customers seeking green operations, environmental friendly practices can help not only in characterising a hotel as "green" but in providing a basis for good marketing strategies with a view to help position it differently in the competitive arena. Thus, the green hotel business is believed to be a growing niche in the current competitive lodging industry (Manaktola and Jauhari, 2007).

Environmental management practices, green strategies related to the environmental policies and customers' green preferences and attitudes toward green practises have been examined in previous studies of the hotel industry. Still, little research has focused on the hoteliers decision-making process for adopting a voluntary scheme, with a view to use it as an energy management system (EMS). Voluntary schemes are complex systems, because they are influenced by customers' awareness and responsibility toward environmental issues and energy use and act as a tool to increase hotel's economic finance importance (Beccali et al., 2009).

In the present work a different approach is proposed, by assuming energy as a relevant issue for the evaluation of a hotel's sustainability. This is a reasonable approach, as due to the significant amounts of energy consumed in hotel buildings, there have been growing concerns regarding energy performance and the promotion of good operational practices in hotels (Boemi et al., 2009).

## 2. Features of the Greek hotel industry

Greek tourism industry is among the most dynamic branches within the services' sector. According to a statistical survey of the Greek hotel industry, it is in a steady grow, presenting a rise in annual turnover of about 5.8% for 2006, which corresponded to a rise from 2.54 bn € in 2005 to 2,69 bn € (Hellastat, 2009). That represents 15% of the Greek Gross Domestic Product, underlining the role of the branch as an essential development tool for the national economy. The next years, despite the worldwide economic crisis, tourism in Greece is expected to develop with an annual growth rate of 6-7% (ITEP, 2009). The fact that all over the country there are more than 9,000 hotels in operation, demonstrates the importance of the branch also for the regional development of the country.

As Greece is on its way to transform itself to an upmarket tourism destination, the need for an increase in high quality, resort accommodation becomes apparent. The government has identified this high quality therefore tourism infrastructure development as a priority target and encourages the creation of integrated resorts, which offer a wide variety of touristic services. In the last decade this led to an overconcentration in four main areas. Therefore, a strategic plan for spatial development has been into consultation in order to have a balanced touristic growth.

Furthermore, and aiming at the improvement of the existing infrastructure, the lengthening of the operational season and the improvement of alternative forms of tourism, a series of structural, financial and administrative measures were adopted by the state. With respect to the aforementioned role of sustainability, the measures are based on the EU's encouragement towards the improvement of the environmental performance of services and products. Concerning these new approaches elaborated by the EU, in order to improve the energy performance of the tourism sector, one cannot fail to underline the voluntary environmental quality labelling schemes.

Within the tourism sector, hotel enterprises are the major energy consumer. Surveys made by the Center of Renewable Energy Sources (CRES) and the Ministry of Development have shown that although hotels represent only 0.82% of the whole building stock, they consume 6% of the total primary energy consumption, with an average specific annual consumption of 407 kW/m$^2$.

If energy demand is analyzed with respect to its time variation, then one cannot fail to notice that the peak values are recorded in the summer season, due to the use of air-conditioning for space cooling, a fact that is enhanced by the seasonal character of Greek tourism. Energy performance in hotels varies significantly, depending on their category, the use of the buildings, their architectural and constructive features, their maintenance, the existing heating, cooling and lightning systems (type, number, efficiency, size), the other equipment and services provided etc. As a rule, hotels perform in a rather inefficient considering energy, as other parameters (thermal comfort, indoor air quality, quality of services, aesthetics) are considered to be more important. As a result high energy costs occur, representing an important fraction of the annual running costs of a hotel.

An in depth investigation on present energy uses of the sector is presented with the aim to highlight the potential and the importance of voluntary schemes for tourism and to prove that adoption of an EMS leads to a sustainable touristic development by improving the quality of its facilities and its services.

## 3. Defining environmental clusters of hotels

The basic aim of the touristic sector is to provide qualitative services. But tourism has social and ecological impacts on touristic destinations, because it implies many activities that may have negative impacts. Those impacts are usually caused because the traditional development followed the basic tourism model of the early post war era, which leads to disproportionally high concentration of tourism activities inn specific, restricted period and in rather constrained spatial areas. Affects are beheld in the environment and cultural carrying capacity of tourist destination (Boemi et al., 2007).

The selection of an EMS system is implemented mainly in order to cope with financial criteria and not with in order to control or reduce energy consumption. The willingness and the ability of facility management and staff to adopt greater environmental awareness is crucial in striving towards a higher degree of sustainability. There are conflicting results about the nature of the industrial practices. Still, there are some studies which have revealed that hotel operators generally recognise the need for environmental protection and are involved in a number of activities (Edrogan and Baris, 2007).

Environmental programs such as reducing energy consumption, installing recycling schemes and composting food scraps so as to reduce solid waste and minimize energy costs are steadily increasing. Also, environmental management has become an important issue in the hospitality, with a number of hotels adopting environmental management practises to the growing concern for sustainable tourism products. Environmental policy plans, which include protection activities, to reduce consumption of energy, waste and materials are included, as a statement by the Greek National Tourism Organisation (EOT) has never been adopted by Greek hotels.

*ISO 14001*

ISO 14000 has been developed as a new international standard series for promoting environmental protection and sustainable development. There are a total of 21 standards and guidance documents in the ISO 14000 family. ISO 14001 specifies the requirements and procedures for establishing an environmental management system. An increasing number of organizations from various industrial sectors have actively participated in implementing this new standard.

ISO 14001 is referred to as the specification document and is the only standard designed for purposes of audit and certification in the ISO 14000 series. The EMS is likely to stimulate and initiate a substantial change in environmental attitudes in every industry. It outlines the basic elements and functions of an effective EMS including establishing an environmental policy, determining environmental aspects and impacts of products/activities/services, planning environmental objectives and measurable targets, implementation and operation of programs to meet objectives and targets, checking and corrective action, and management review.

Sustainable construction at an operational level includes recycling construction material and construction debris, using renewable materials and materials with high recycled content, designing efficient building systems, and informing building owners and managers how best to conserve energy and resources in the operation and maintenance of facilities. It calls for a systematic approach and continuous effort within the industry in order to achieve the objectives of sustainable construction (Zhang et al., 2008).

*Eco- Label*

European Eco-Label for tourist accommodation service is a joint initiative from Competent Bodies of the European Members. It's a voluntary scheme designed to encourage businesses to market products and services that do not harm the environment and are easily to be identified by European's.

Eco-Label for tourist accommodation was created in April 2003 to reward tourist accommodation services and tourists that respect the environment. It includes different categories of mandatory and optional criteria that the accommodation must respect in order to be awarded the Eco-Label scheme. There are 34 mandatory and 47 optional criteria, aiming to ensure the use of energy efficient heating and electrical devices, saving water, training staff in order to put in implement environmental management behaviour, such as proper use of chemical substances and disposal of waste etc. Finally, criteria aim at improving management measures toward a more conscious and efficient environmental performance from lead, staff and guests.

The reasons for choosing Eco-label scheme are:

- A display of the high quality and environmental performance of the company, by using an official logo from the European Commission.

- To unveil ecological and economic weaknesses in the enterprise and to enable innovations to be implemented.
- To reduce the consumption of natural resources like energy and water in order to reduce operational costs.
- Environmental commitment stands for healthy lodgings, healthy nutrition and a healthy environment for the guests and the employees.
- An Eco-labelled accommodation service is entitled to be used for a number of marketing tools (e.g. advertising brochures, leaflets)

The "Flower" is the only European official environmental label contrary to ISO 14001 and EMAS certification. Also, it is recognised in all countries and there are also synergy effects in interaction with EU Eco-label for products.

There is a real synergy between the EU ISO 14001 and Eco-Labels and criteria. Applicants with an Environmental Management System registered or certified according under the ISO 14001 regulation automatically fulfil several criteria required for EU Eco-Label. Those programs are promising market-placed approaches for improving environmental performance of tourist accommodation services and facilities.

*General discussion about EMS*

The use of those two well-known EMS is targeted to the determination of an energy policy and environmental managing energy. Specifically, EMS aim at:

- Defining a hotel's energy policy in connection to the environment;
- Identifying and analysing activities that deal with environmental issues;
- Purchasing and budgeting policies and a corresponding energy plan;
- Training hotel's operational and key staff in energy management;
- Training hotels' customers;
- Periodically performing environmental monitoring or auditing for managers as well as assessment and evaluation of energy use and associated costs (Deng and Burnett, 2002).

According to Green Hotel Association, hotels reported a guest participation of 70-90% in voluntary schemes corresponding to savings of € 4 per day per occupied room (Bohdanowics, 2005). Furthermore, empirical evidence form an audit carried out in the last two years by the Laboratory of Hate Transfer and Environment Engineering agrees with Blanco et al. (Blanco et al, 2009) which stated that 5% of the hotel customers agree to pay a premium for sustainable packages.

Managing energy use is generally seen as a part of overall EMS. In fact, successful environmental management examples are often related to energy use because there are apparent financial gains from conservation (Erdogan and Baris, 2007). Energy consumption in hotels is clearly a factor for their competitiveness and reducing costs and increasing sensitivity to environmental factors in hotel design will lead to introduction of elements with less environmental impact and with more competitive profit at the hotel market. PATA's (2007) regional results show that 52% of visitors would be prepared to pay an extra 10% for environmental-friendly tourism products. Other studies provide both theoretical and managerial implications for comprehending the determinants of hotel's customers' intentions to visit a green hotel (Han et al., 2009).

## 4. Conclusions

Marketers should find ways to turn their hotel into "green" ones, by actively finding ways for determining environmental concerns which potentially contribute to building their favourable attitude toward green-consumption in the long term. However, most of the studies indicate that the hotel industry's environmental policies arise generally form immediate economic gains. Those are resulting from minimizing expenses by means of cost reduction measures that also bring conservation and prevention.

By means of achieving synergies with the interest of customers willing to pay for green services, the adoption of EMS can lead to a rationalization of energy use in the hotel sector. Hoteliers have a strong sense of the public awareness toward environmental, in that sense hotel companies can prove environmental responsibility to improve their profit levels. In that sense, and even if the development of policies and practices demonstrated in the tourism industry are not genuinely interested in the protection of the environment, they can lead to energy conservation.

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# Implementing the G8 80% target with the macro-econometric E3MG model

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**Abstract**

*This paper examines the implementation of the G8 80% emissions reduction target using a macro-econometric hybrid model E3MG of the global economy, which stands for Energy-Economy-Environment Model at the Global level. The E3MG combines a top-down approach for modeling the global economy and for estimating the aggregate and disaggregate energy demand and a bottom-up approach (Energy Technology subModel - ETM) for simulating the power sector, which then provides feedback to the energy demand equations and the whole economy. The ETM submodel uses a probabilistic approach and historical data for estimating the penetration levels of the different technologies, considering also their economic-technical and environmental characteristics. Following the fruitless Copenhagen Summit, where the expectations for a global agreement on deep emission reduction target have wiped out, the G8 commitment on 80% reduction by 2050 seems to be the current realistic political framework. The E3MG model is used to implement this target and to compare it with a reference scenario, where no reduction target is pursued. Both scenarios consider that impact of the financial crisis, with updated information to summer 2009. This paper aims to provide evidence that such a deep reduction target can be met providing gains for the economy.*

**Keywords:** G8 80%, Carbon Pathways, post-Kyoto, $CO_2$ reductions

## 1. Introduction

Very recently (June 2009) G8 committed to reduce their emissions by 80% by 2050 reduce their greenhouse gas emissions 80% by 2050, and to work towards keeping temperature levels from rising 2 degrees Celsius. The EU has announced (September 2009) its will to provide up to 15 billion euros a year to help developing countries fight climate change and adapt to its predicted devastating consequences. Specific countries, such as the UK, passed new legislation (2008) to reduce its emissions by 80%, less than one year from its previous commitment to reduce emissions by 60%. More recently the new Obama Administration expressed its commitment to a new climate policy. The same concerns with even more ambitious plans characterize the new Government in Japan, towards finding a new direction for its economy. The EU has been active the whole decade introducing a number of green policies, such as the Emission Trading System and a number of Directives, across its Member States.

All these actions can be considered as coordinated efforts from the developed countries, aiming to prepare the framework for a new global agreement on the Copenhagen Summit in December 2009. The results of the Summit show that such an agreement seems to be unlikely in the short-term at least, as the developing countries are demanding a stronger support. Considering the uncertainties produced by the still ongoing financial and economic crisis, any projection for a binding global agreement seems to be stale. Therefore, the realistic political framework for the time being is the G8 commitment to reduce emissions by 2050.

This emission reduction target has been examined using the macro-econometric hybrid model E3MG of the global economy, which stands for Energy-Economy-Environment Model at the Global level. The E3MG model, where the G8 countries are individual regions within its 20 regions, has been used to implement this target through a portfolio of policies. The paper contributes by adopting a novel hybrid modeling approach of the energy system and the whole economy and therefore providing an alternative approach to the traditional economic equilibrium modeling. Moreover the paper aims to provide evidence that there exist pathways for meeting deep reduction targets and also helping the economy to grow, even when those targets are implemented among the developed countries only. The need for such evidence has been noted by the IPCC (2007a) in its assessment of the literature on stringent mitigation targets. Such evidence can inform the international negotiations for a post-Kyoto global agreement.

## 2. Modeling Framework: E3MG Model Description

In projecting the future, the approach is first to consider the past. Looking back over the last 200 years, the socio-economic system seems to be characterized by ongoing fundamental change, rather than convergence to any equilibrium state. Maddison (2001) takes a long view of global economic growth over the last millennium. He finds growth rates to be very different across countries and over time, and ascribes the comparatively high rates of growth to technological progress and diffusion. He also finds that inequalities between nations in per capita GDP have increased (in particular since WW2), not diminished over time. These three features of growth (technological progress, diversity across nations and time periods, and increasing inequalities) are also characteristic to our modeling approach.

E3MG represents a novel approach to the modeling of technological change in the literature on the costs of climate stabilization. It is based upon a Post Keynesian economic view of the long-run. In other words, in modelling long-run economic growth and technological change, the "history" approach of cumulative causation and demand-led growth (Kaldor, 1957, 1972, 1985; Setterfield, 2002), focusing on gross investment (Scott, 1989) and trade (McCombie and Thirwall, 1994, 2004), and incorporating technological progress in gross investment enhanced by R&D expenditures, has been pursued. Other Post Keynesian features of the model include: varying returns to scale (that are derived from estimation), non-equilibrium, not assuming full employment, varying degrees of competition, the feature that industries act as social groups and not as a group of individual firms (i.e. no optimisation is assumed but bounded rationality is implied), and the grouping of countries and regions has been based on political criteria. The exception to the Post Keynesian approach is that at the global level various markets are closed, e.g. total exports equal total imports at a sectoral level allowing for imbalances in the data.

The model has been developed in the traditions of the Cambridge dynamic model of the UK economy MDM-E3 (Barker and Peterson, 1987) and the European model E3ME (Barker, 1999) (also see www.camecon.co.uk/e3me/intro.htm). In addition, the approach has been developed to include the bottom-up energy technology model, ETM (Anderson and Winne, 2004), within the top-down highly disaggregated macroeconomic model, E3MG. Thus, like the studies (Nakicenovic and Riahi, 2003; and McFarland, Reilly and Herzog, 2004) which are also based on the linkage of top-down and bottom-up models, our modelling approach avoids the typical optimistic bias often attributed to a bottom up engineering approach, and unduly pessimistic bias of typical macroeconomic approaches. The advantages of using this combined approach have been reviewed (Grubb, Köhler and Anderson (2002). Energy-economy-environment interactions within E3MG's hybrid (top-down/bottom-up) structure are presented in Figure 11, whereas the structure of E3MG's energy sub-model is displayed in Figure 12.

E3MG incorporates endogenous technological change in three ways:

- The sectoral energy and export demand equations include indicators of technological progress in the form of accumulated investment and R&D
- The ETM incorporates learning curves through regional investment in energy generation technologies that depend on global scale economies
- Extra investment in new technologies, in relation to baseline investment induces further output and therefore investment, trade, income, consumption and output in the rest of the world economy through a Keynesian multiplier effect.

Mitigation and/or Policy Options and Instruments

The model is capable of explaining how low-carbon technologies are adopted as the real cost of carbon rises in the system, with learning by doing reducing capital costs as the scale of adoption increases. The model includes the economic instruments of $CO_2$ emission allowances (auctioned or grandfathered), energy and carbon taxes, employment taxes, and other direct and indirect taxes. A rise in the costs of fossil fuels resulting from increases in $CO_2$ permit prices and carbon taxes thus induces extra investment in low-carbon technologies, and this is larger and earlier than the investment in conventional fossil technologies in the baseline. The carbon tax revenues and part of the permit revenues are assumed to be recycled in the form of lower indirect taxes. The outcome is that the extra investment and implied accelerated technological change in the stabilization scenarios leads to extra exports and investment more generally, and higher economic growth.

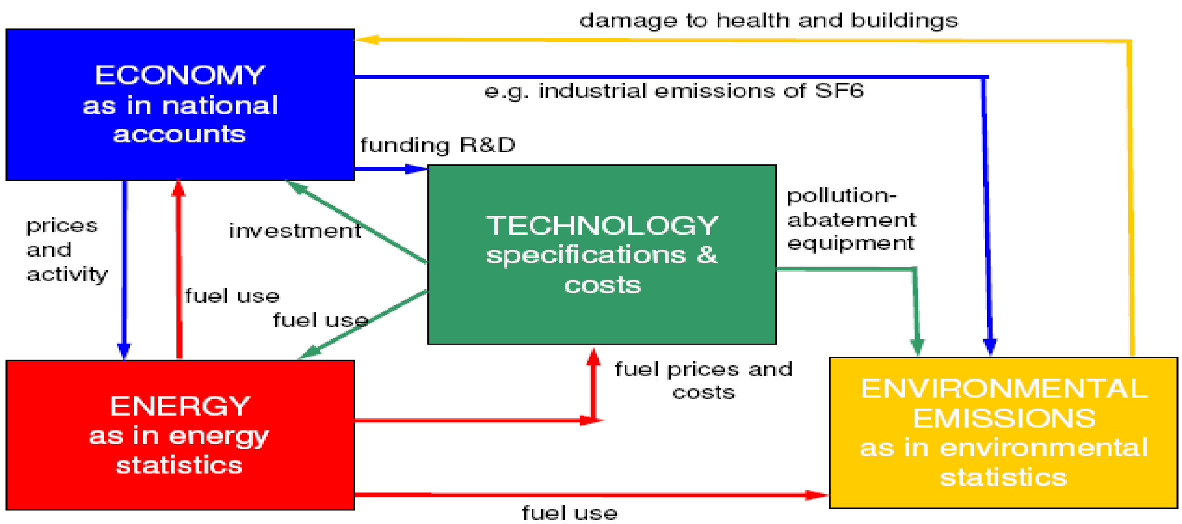


Figure 1: The hybrid (top-down/bottom-up) structure of the E3MG model.

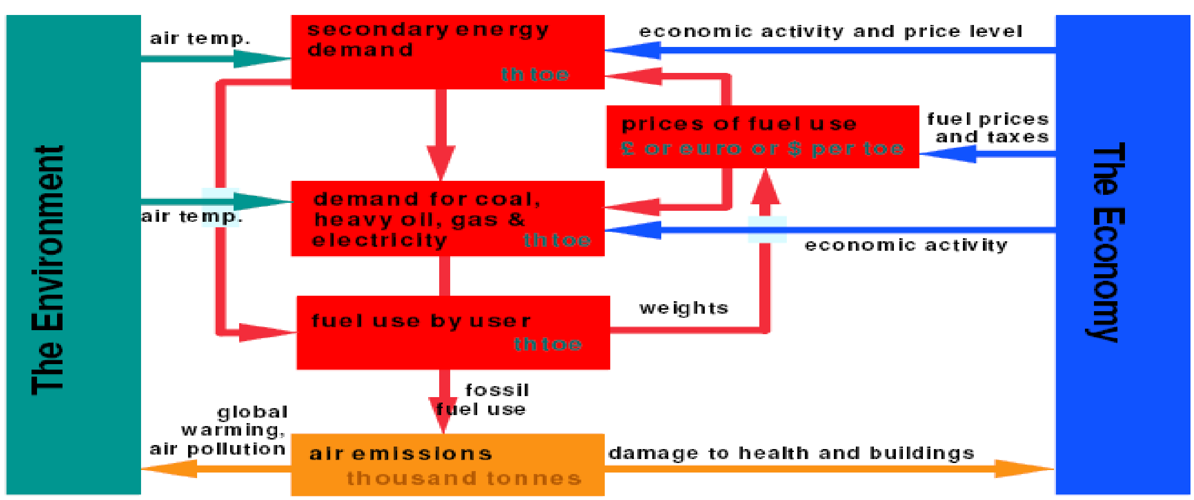


Figure 2: The structure of E3MG's energy sub-model.

The policy instruments that are explicitly in the model to promote GHG abatement are

- carbon taxes
- emission permit schemes are at regional and global levels by any mix of energy sectors
- revenue recycling
- R&D expenditures in total by sector and region.
- incentives
- regulation

These need to be supplemented by policy instruments associated with technological agreements between countries need to be included to allow for reductions in costs brought about by adoption of common standards and reduction of market barriers.

ETM - The Energy Technology Sub-model

Although E3MG is a complex econometric, simulation model, it originally lacked a representation of the array of non-carbon energy options that could potentially emerge in the future. To fill this gap, a hybrid modelling approach has been implemented by linking with E3MG an annual, dynamic technology model, referred to here as the ETM model. The ETM sub-model has been built to generalize earlier work by Anderson and Winne (2004) to form the basis of a new energy technology component of E3MG. Although the ETM is not specifically regional and is not estimated by formal econometric techniques, it does model, the switch from carbon energy sources to non-carbon energy sources over time. It is mainly designed to model electricity supply technologies, but incorporates also technologies that cover other type of energy demand e.g heat.

The ETM model was designed to account for the fact that a large array of non-carbon options is emerging, though their costs are generally high relative to those of fossil fuels. However, costs are declining relatively with innovation, investment and learning-by-doing. The process of substitution is also argued to be highly non-linear, involving threshold effects. The ETM models the process of substitution, allowing for non-carbon energy sources to meet a larger part of global energy demand as the price of these sources decrease with investment, learning-by-doing, and innovation, learning –by-researching.

One component of the ETM is the learning curve. The importance of including a learning curve in the model cannot be underestimated, as the technology costs do not simply decline as a function of time, but decrease as experience is gained by using a particular technology. The learning curve in the ETM has the form

$$C_t = C_0 (X_t / X_0)^{-b} \qquad (1)$$

where $C_t$ are the unit costs at time t, $C_0$ initial costs, $X_t$ the cumulative investment (taken as an indicator of experience) in the technology by time t from the time of its first introduction and b is the 'learning-curve parameter'. This relationship is highly non-linear, especially in the early phases when $X_t$ is small and experience accumulates rapidly. Figure 13 below shows the effect, in which market share is taken as a proxy for $X_t$.

As investment is made in 'new' technologies, learning takes place and the cost of the new technology lowers so that it becomes competitive with the 'old' technologies. For each type of energy demanded there is usually a technology or fuel 'of choice'—what might be termed a 'marker' technology—against which the alternatives will have to compete. In the ETM, the capital, operating and maintenance costs are being used to estimate the net present value of the different technologies, which is used for expressing the relative costs of the alternatives. Operating costs consider fuel and carbon prices. Those relative costs are readjusted based on the incentives or taxes that are applied to the different technologies. Even though the numeraire technology may comprise the majority of the market, there are always so-called niche markets and opportunities where the non-carbon technology is cheaper than then numeraire. Photovoltaics, although their relative costs were several times higher compared to a marker technology, took a small share in the market, even without the presence of a favorable policy e.g. feed-in tariff. This can be justified, concerning cost-effectiveness, in case of off-grid installations, but this is not always the case. Historical data show that several energy investments can not be justified by using cost optimization techniques, adopted by most energy system models. On the other hand, energy investments consider a number of critical issues, sometimes contradicting with each other. Such factors are political decisions (nuclear in France), volatility in prices, energy security issues, technology transfer agreements being part of intergovernmental agreements for wider economic cooperation, social issues (public opposition), technical and environmental issues that create a high uncertainty in investing to a single technology, based on its cost-effectiveness compared to the others. This reason has led to an examination of the penetration capability of different technologies (Anderson and Winne, 2004), by estimating their substitution elasticities. This approach is in correspondence with similar approaches adopted to examine regional interdependencies in our globalized economy (Pesaran et. al. 2004)

Figure 14 shows the Market Share of marker technology and technology i and the Rate of Change of Market Share vs Relative Prices of marker technology to alternative technology i. The left scale shows the market share of the technologies (marker and technology i) based on their relatives prices. If they cost the same (considering their capital, operating and maintenance costs and also any incentives or taxes), they take the same share of the new investments. The right scale shows the substitution elasticity α between the technologies (marker and technology i), based on the frequency distribution of relative prices. Narrow distribution means small standard deviation and large value of the parameter α. The distribution presented in this table is symmetrical, but historical data lead in several cases to unsymmetrical distribution figures.

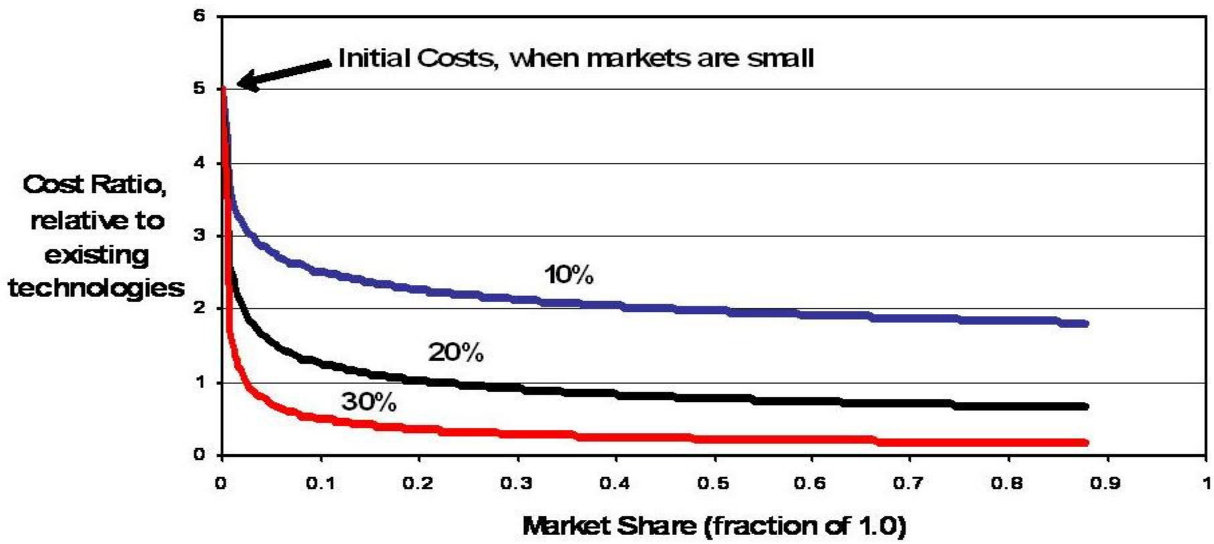


Figure 3: Threshold effects in Technology Development (learning rates in percentages).

The General Structure of the ETM

Some of the substitute technologies are restricted for technical reasons, for instance the amount of intermittent renewable energy that can be permitted on the electricity grids, and others for economic reasons, for instance the rising costs of land use by biomass or onshore wind. In the ETM, these restrictions are represented by a rising cost of use as the limits are reached or by imposing an upper level of penetration.

The main equations used in the ETM to model the switch from carbon technologies to non-carbon technologies, as costs decrease are listed below. For the electricity sector, the marker technology (n) or numeraire is the Natural Gas IGCC technology. The superscript E refers to the electricity sector.

Substitution equations for new technologies:

$$S_{it}^{E} = S_{it-1}^{E} + a_i^{E} S_{it-1}^{E}\left(\hat{S}_{it-1}^{E}(1+S_{it-1}^{E} - \sum_i S_{it-1}^{E}) - S_{it-1}^{E}\right)\left(P_{it}^{E} - P_{it-1}^{E}\right)$$

(2)

where S is market shares in new investment.

Marker technology:

$$S_{nt}^{E} = 1 - \sum_i S_{it-1}^{E} \qquad (3)$$

Investment:

$$I_t^{E} = D_t^{E} - D_{t-1}^{E} + \delta_n U_{nt-1}^{E} + \sum_i \delta_i U_{it-1}^{E} \qquad (4)$$

where $D_t$ is the demand for electricity at time t and $\delta$ is the retirement rate of technology i.

Cumulative net investment:

$$U_{it}^{E} = U_{it-1}^{E} + S_{it-1}^{E} I_{t-1}^{E} - \delta_i U_{it-1}^{E} \qquad (5)$$

Ditto, marker technology:

$$U_{nt}^{E} = U_{nt-1}^{E} + S_{nt-1}^{E} I_{t-1}^{E} - \delta_n U_{nt-1}^{E} \qquad (6)$$

Cost dynamics:

$$C_{it}^{E} = C_{it-1}^{E} - \frac{b_i^{E}}{W_{it}^{E}}\left(W_{it}^{E} - W_{it-1}^{E}\right)\left(C_{it}^{E} - C_{it-1}^{E}\right) \qquad (7)$$

The ETM sub-model besides the electric system expansion, it estimates the dispatch of the power units, providing non-linear solutions as also as in the electric expansion problem. This considers the electricity generation cost of the different thermal units in the form of:

$$C_i = a_i + b_i P_i + cP_i^2 \qquad (8)$$

where $P_i$ is the power output of each unit. The neoclassical cost-optimization modelling approach faces the same problem (divergence from real data), when implemented in the estimation of the mix in the electricity generation as in the electric capacity. For this reason, historical data is also used in the dispatch problem in order to consider the imperfection of markets. But we don't model in detail the causes of this imperfection for the different regions, e.g. different technical issues, oligopolistic conditions, speculation of the market, use of resources for different purposes (use of water for irrigation, water supply and electricity generation). In order to catch the effect of market imperfections (Skytte, 1999), we implement the economic dispatch problem (under any environmental constraints) for the last 5-10 years. This shows the divergence with the real data, which is attributed to a market imperfection factor. This factor, although it may have different actual meaning for the different regions, is not disaggregated any further for the time being, as this is done in other approaches (Martinsen and Krey, 2008) to model external factors. Therefore we consider the historical data as the starting point for the electricity generation, on which the different units readjust their electric output based on the operating (including fuel and carbon prices) and maintenance costs as the electric demand evolves.

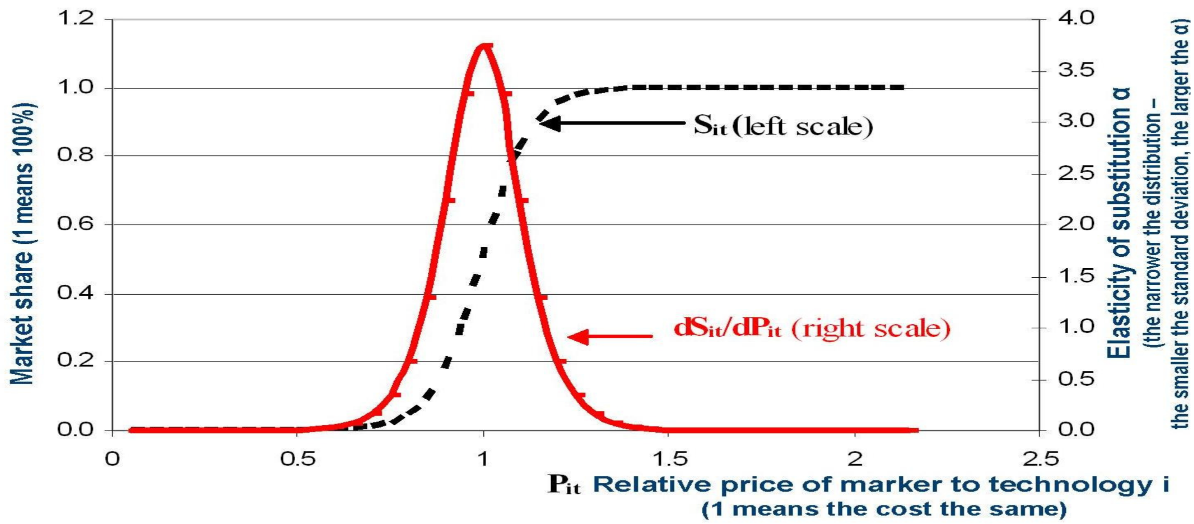


Figure 4: Market Share of marker technology and technology i (black line) and Rate of Change of Market Share vs Relative Prices of marker technology to alternative technology i (red line).

## Energy demand equations

The energy demand equations For energy demand, a 2-level hierarchy is being adopted. A set of aggregate demand equations on annual data covering 19 fuel users/sectors and 20 regions is estimated and is then shared out among main fuel types (coal, heavy fuel oil, natural gas and electricity) assuming a hierarchy in fuel choice by users: electricity first for “premium” use (e.g. lighting, motive power), non-electric energy demand shared out between coal, oil products and gas. The energy demand for the rest of the 12 energy carriers is estimated based on historical relations with the main 4 energy carriers. All energy demand equations use co-integrating techniques, which allow the long-term relationship to be identified in addition to the short-term, dynamic one. A long-term behavioural relationship is identified from the data and embedded into a dynamic relationship allowing for short-term responses and gradual adjustment (with estimated lags) to the long-term outcome. The equations and identities are solved iteratively for each year, assuming adaptive expectations, until a consistent solution is obtained.

The economy aggregates, such as GDP, are found by summation. This enables representation of the wider macroeconomic impacts of policies focused on particular sectors, including rebound effects. These long-run energy demand equations are of the general form given in equation (1), where X is the demand, Y is an indicator of activity, P represents relative prices (relative to GDP deflators for energy), TPI is the Technological Progress Indicator, the β are parameters and the ε errors. TPI is measured by accumulating past gross investment enhanced by R&D expenditures (Lee et al. 1990, p. 117) with declining weights for older investment. The indicators are included in many equations in the model, but only those for energy are analysed here. All the variables and parameters are defined for sector i and region j.

$$X_{i,j} = \beta_{o,i,j} + \beta_{1,i,j} Y_{i,j} + \beta_{2,i,j} P_{i,j} + \beta_{3,i,j} (TPI)_{i,j} + \varepsilon_{i,j} \quad (9)$$

In the equations, β2,i,j are restricted to be nonpositive, i.e. increases in prices reduce the


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demand. In the energy equations β3,i,j are estimated to be negative, i.e. more TPI is associated with energy saving. These parameters are constant across all scenarios. Further information on the energy demand equations can be found on a recent paper (Barker at. al. 2009). The E3MG model is under development and a detailed description of the whole model is expected in the medium term. However, information on the theory of the model can be found on several publications (Barker et. al. 2009; Barker and Scriescu, 2009; Barker at. al. 2006) and also on the description of the MDM-E3 (Barker and Peterson, 1987; http://www.camecon.com/suite_economic_models/mdme3.htm) and E3ME (http://www.camecon.com/suite_economic_models/e3me.htm) models, as all three models share similar structure and theoretical approach.

### 2.1 Assumptions

For the purposes of this paper a range of data updates and technical adjustments have been made.

Fossil resource costs

E3MG, as a demand driven model, does not have fossil resources supply curves. Considering recent projections of global fossil fuel prices (IEA, 2007, 2008), fossil resources costs for coal, oil and natural gas has been shifted upward. These reflect long term drivers in rising energy demands and constrained supplies. Base prices are shown in Table 1.

| *Original units* | | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Crude Oil | 2005$/bbl | 31.38 | 50.62 | 57.50 | 55.00 | 55.00 | 57.50 | 60.00 | 65.00 | 70.00 | 70.00 | 70.00 |
| Gas | 2005$/MMBTU | 4.77 | 7.46 | 6.75 | 6.75 | 7.00 | 7.32 | 7.64 | 8.27 | 8.91 | 8.91 | 8.91 |
| Coal | 2005$/tonne | 35.89 | 60.48 | 55.00 | 55.00 | 57.04 | 59.63 | 62.22 | 67.41 | 72.59 | 72.59 | 72.59 |

Table 1: Updated fossil resource costs.

Electricity technologies

E3MG has a sub-model for the treatment of the electric system expansion, as mentioned above. It includes 28 energy technologies, each of them is represented by 21 technology characteristics. These technologies and their characteristics have been recently updated in order to represent new options e.g. air capture. A comprehensive revision of economic and technical data on CCS, nuclear, wing, biomass and marine technologies has been undertaken (Winskel et al., 2008). CCS technologies are considered to account for capture efficiency (90%).

Transport technologies

E3MG does not have a detailed representation of the transport system. It has three fuel options (petrol, diesel and electricity), with biofuels not being considered. Recent technical developments from the automanufacturers have been considered in the modelling by adopting a positive feedback approach. This means that once the electric vehicles start penetrate in the market, the alternative options (e.g. hydrogen vehicles) have to become much more competitive than the electric vehicles to penetrate in the market. Considering that hybrid vehicles are already market available and plug-in vehicles will enter the market in the next decade, the transport sector is moving towards electrification. The penetration of new technologies e.g. electric vehicles is assumed to be made through regulation which forces auto producers to develop advanced plug-in electric vehicles. Moreover the penetration of electric vehicles is modeled to work in favour of certain renewables. Wind and tidal plants are considered to increase their capacity factor by up to 10%, depending on the penetration level of plug-in electric vehicles. It is assumed that the electrification of the transport sector will be accompanied with tariff policies that encourage cars to be charged during off peak times. This can lead to a further use of specific renewables, which have the capability to operate at their maximum output during off-peak times (e.g. night), but for technical reasons (the base plants can not be switched off), the renewables are otherwise underused.

EU-ETS

For the reference scenario the EU Emissions trading scheme is imposed with an EU-ETS price of €20/tCO2 from 2010 onwards in the electricity and industrial sectors - broadly on EU-ETS Phase 2 coverage. This price level and coverage is maintained through 2050. The carbon price is exogenous in the model. Carbon pricing is considered as one of the policies that are applied for helping financing energy investments. So, the carbon price can be considered as a price signal required helping towards meeting deep emission reduction targets.

$CO_2$ constraint curve

In contrast with most energy system or general equilibrium models, emission reduction targets are not implemented by imposing this target exogenously in the model. A number of policies (described in the next session and the discussion of the results) are implemented at different strengths and in different timing so as to meet the targets.

Calibration

Base year 2000 $CO_2$, final energy, and primary energy calibration has been fine-tuned to exactly match with calibration sources (IEA, 2008).

### 3. Scenarios

The E3MG model is run for the G8 80% reduction target by 2050 compared to 1990 levels and for a reference case. An important advantage of the E3MG model is that it is an energy-economy-environment model of the global economy, allowing for the global reduction in costs of technologies if adopted by many countries. The cumulative investments on alternative technologies at global level, allow their faster penetration. Deep emission reduction targets, such as those examined at this paper, could be achievable at much lower costs when implemented internationally. $CO_2$ reduction targets are achieved through a portfolio of policies. This is in contrast with most energy system models or general/partial equilibrium models which impose a reduction target exogenously and the models estimate the marginal abatement cost for meeting this target. The policies considered in E3MG are:

- Carbon price (either through Carbon trading for the Emission Trading System (ETS) sectors or Carbon Tax for the rest of the economy) is implemented. The revenues are recycled via the following policies.
- Incentives for electricity technologies through revenue recycling. These revenues are raised from the auctioning carbon permits. This subsidy is spread across new technologies i.e. renewables and CCS (excluding nuclear and hydro).
- Accelerated diffusion of electric plug-in vehicles is assumed through technological agreements and behavioural shifts in transport demand.
- Revenues raised from carbon permits auctioning are recycled to energy-intensive industries in order to incentivize the conversion to low-carbon production methods.
- Carbon tax revenues from households are recycled via investments in energy efficiency by providing incentives for improving the energy efficiency of domestic dwellings and appliances and for introducing new ones such as low-emission dwellings and solar appliances.
- Accelerated carbon price increase at an earlier year e.g. 2020

It should be mentioned that energy efficiency policies for electricity consumption are considered as no-regret options (IPCC, 2007), as they lead to reduction in electricity demand and so reduce the need for investment in new generation and infrastructure. Assumptions on the no-regret options have been based on a recent study (IEA/ETP 2008), where as can be seen in Figure 5 the energy efficiency policies have negative marginal abatement cost. These scenarios are assumed to be implemented first in the period 2010-2020 for all emission reduction scenarios. Based on the revenues from permit auctioning that are recycled via investments in energy efficiency at the consumption side, these measures can lead to significant demand reduction even in the medium term.

Moreover the rate at which plug-in vehicles replace conventional vehicles will affect the mix of electricity technologies in favour of some renewables e.g. wind. This comes from the fact that it assumed that tariff policies are implemented that encourage plug-in vehicle users to charge their cars' batteries at night when the electric demand is at low levels. Such tariff policies combined with control systems allow the user to select when their cars' batteries will be charged so as to allow a new peak before midnight and lead to a more balanced load curve. Such policies reduce the need for investment in new capacity, and raise the load factors of the existing equipment. This works in favour of stochastic generation, such as wind farms, which normally have to operate at low levels during the night, although they could operate at higher output due to higher wind speeds at that time.

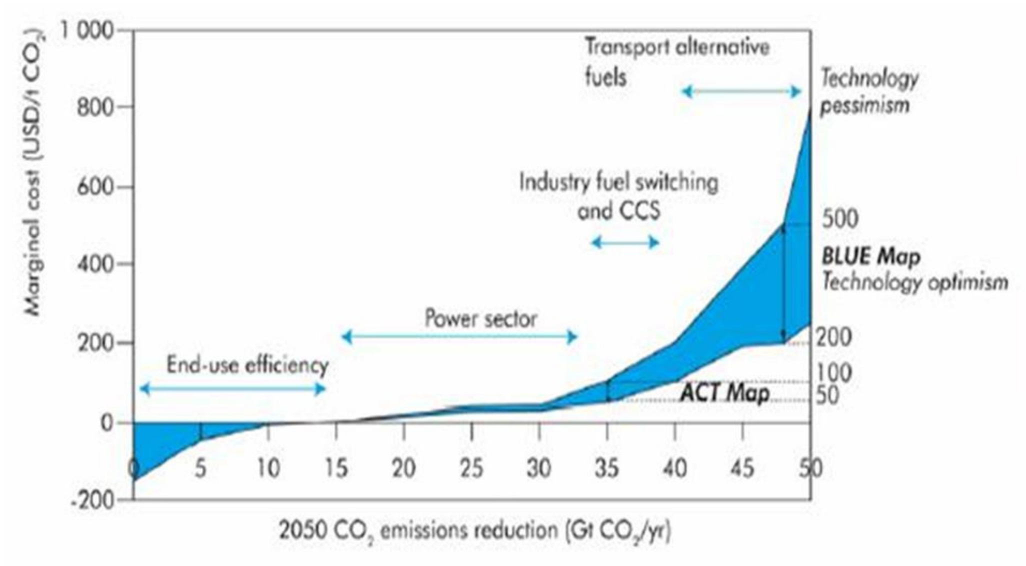


Figure 5: Marginal abatement cost of different policies, source: IEA Energy Technology Perspectives (IEA/ETP) 2008.

The above scenarios are implemented under the following main modeling assumptions:

- The discount rate is required only in the energy technology sub-model (10%), for estimating the net present value of the different technologies.
- Penetration of technologies in electro-production is based on (Anderson and Winne 2007): the theory combines the estimation of net present value and a probabilistic approach fro the diffusion of technologies compared to a marker technology.
- Reduction targets are implemented through a set of polices. These reduction targets are not set, but achieved via specially designed policy packages.
- International drivers are assumed.
- Macro effects are assumed e.g. in energy efficiency policies the direct plus macroeconomic rebound effect is considered.
- Economy is not treated as being in equilibrium.
- Full utilization of resources (e.g. no unemployment) is not assumed.

### 4. Results- Meeting the G8 reduction target

E3MG focuses on the implementation of policies rather than on the reduction targets. The different polices interact in a complex way, which can be analyzed through the non-linear nature of the E3MG model. Results for the USA and the EU-27 are selected to be presented, as those regions are representative in the whole analysis. EU-27 constitutes of all major European countries (Germany, France, UK, Italy) as sole regions and other two regions (rest of EU-15 and the new 12 EU countries that have recently entered the European Union). Although the scenario concerns reduction efforts for the G8, similar assumptions for the other two sub-regions of the EU-27 have been made, as these countries are influenced by the decisions made at the European level.

$CO_2$ Emissions

Figures 6 & 6a provide the $CO_2$ emission levels for the 2 scenarios over the projection period. $CO_2$ emissions for the reference scenario are estimated to have a small increase compared to 1990 levels for both presented regions. The increase is observed mainly in the last two decades 2030-2050, more obviously for the USA, and is attributed mainly to an increase in energy demand which is covered mainly from natural gas either for electric production or for heating purposes. The energy demand is estimated to fall in the period 2010-2020 due to current directed energy efficiency. Then the economic activity forces the energy demand to be increased, as the demand and the economic activity are positively correlated.

The energy demand and emissions level in the reference scenario is reduced in the medium term, resulting from the effect of the global recession. This scenario develops earlier and ongoing work (Dagoumas et al. 2009) examining the financial crisis, which outlines some of the causes of the current crisis and suggests a global co-ordinated policy response focused on investment. The financial crisis affects the economic activity, the saving rates, the consumption, the access to the credit and so the investments leading to a lower economic growth for the medium term, after the recovery of the global economy. But in the long term (beyond 2020) the impact of the recession is partly offset from the policies that have been directed. The reference scenario considers all structural changes and investments directed until the mid-2009, when the scenarios were constructed. The investments are treated as green energy investments that lead to tackling the climate change and also boosting the economy, (Dagoumas et. al. 2009). However, the reference scenario does not consider additional long-term policies or the implementation of further energy investments, reported in several official publications in the medium term (IEA WEO 2008; IEA 2008). Such policies are considered in the $CO_2$ reduction scenario.

At sectoral level, the consumption sectors (buildings, industry) decrease emissions in the first decade and later stabilize their emissions due to the implementation of energy efficiency measures, while the power sector is the first to reduce significantly its emissions up to 2035 even for the reference scenario. Alternative technologies prove to be competitive to the traditional ones and dominate almost the whole system in the carbon reduction scenarios. Crucial to the results is the emission reduction of the transport sector, due to the penetration of electric vehicles and behavioural shifts. As described above, the shift to electricity in the transport sector works in favour of some renewables, such as the wind, the availability of which is significant in the UK. The transport sector leads to an important reduction in overall emissions, resulting also from a behavioural shift that locks in the energy and emissions reduction resulting from the higher prices and the regulation. The rebound effect (Sorrell 2007), i.e. the increase in energy use arising from the implicit reduction in costs of energy as a result of energy-efficiency improvements, is offset by the increase in energy prices due to the emission trading scheme and the carbon tax. All the end-use sectors (transportation, residential, services and industry) are covered by policies that decrease their emissions sharply, especially for very strict targets such as the 80% reduction.

Energy Demand

The above described energy demand functions predict that the energy demand (Figures 7a & 7b) will remain almost stable in the period 2020-2030 and then be increased up to 2050 for the reference scenario, affected mainly from the economic activity and from the fact that energy efficiency investments are considered for the first decade of the examined period. The emission reduction scenarios are implemented through increased investments in energy efficiency measures and also through behavioural shifts with neutral rebound effect. Such measures lead to a significant decrease in energy demand by about 50-60% for the G8 80% scenario compared to 1990 demand and even more compared to the reference demand in 2050. Demand for gas is increased for both scenarios, while the demand for oil remains almost stable for the reference scenario and decreased sharply for the reduction scenario. The penetration of renewables is impressive in case of the G8 80% reduction scenario, which is affected by the international effort –leading to lower costs-, to carbon pricing and other measures e.g. regulation – enhancing the related energy investments and to other factors e.g. electrification of transport. The demand for nuclear is considered to remain almost stable in both scenarios, as it is considered that there is a concern for energy safety issues, eliminating its potential to dominate the market, and a concern on energy security issues, allowing nuclear to keep a certain amount in the energy mix for diversification purposes. The demand for coal is decreased for the reference scenario, but for the emission reduction scenario, the political will of the European Union to support the Carbon and Capture Storage technology allows coal to keep an important part of the energy mix, by either new plants or retrofitting old units. This is not so obvious for the USA, where the coal demand is decreased even in the G8 80% reduction scenario, which is characterized by a higher share of renewables and nuclear in the energy mix.

The results show that the electric mix can be diverse which, considering the significant penetration of renewables, increases the energy security of the country. This diversity comes from the fact that the electric system expansion is not modeled as a classic cost optimization problem, where once one technology is slightly cheaper than the others is dominates the system. The different candidate technologies can penetrate into the system, by increasing their cost effectiveness through incentives, learning by doing and learning by R&D, based on a probabilistic approach (Anderson and Winne, 2004). This approach considers the market penetration of the different technologies in the history and estimates acceleration factors for them, allowing them to penetrate at a small or higher extent depending on their net present value.

Transport demand is decreased more compared to other sectors. This is attributed to behavioural changes and to a shift to electric vehicles through the implementation of relevant regulation. Electric vehicles are more efficient compared to conventional fuel vehicles and their penetration works in favour of renewables such as wind resources as they increase their capacity factor. The significant decrease in the transport demand is attributed to changes in citizens' behaviour in two directions. The first is a positive feedback in the adoption of the new technologies by the consumers. This means that once the electric vehicle become the dominant technology, alternative options such as the hydrogen cars have to be cheaper enough and not just competitive, so as to gain percentage of the market. The second change is a behavioural shift of citizens to a different lifestyle by preferring cycling and public transport, which is considered as a policy with neutral rebound effect. But for the time being such policies are not modeled in great detail within the E3MG model.

Economic results

Carbon permit price (Figure 9) is increased steadily to a high price. The results show that the carbon price is not very high (IPCC 2007), when accompanied with several policies. As discussed above if the portfolio of policies were implemented with other priorities e.g. further electrification of the transport sector and further support on renewables, then the economic growth would be higher and the required carbon price lower. It has to be mentioned that in all scenarios, carbon price is implemented as a carbon tax or by auctioning emission permits, which both lead to gains for the government. These gains were recycled to energy sector investments. The current Emission Trading System in EU where the emissions producers get free permits, have lead to increase in consumers' prices for electricity but not to significant investments in alternative technologies for most countries.

Probably the most important conclusion arising from this paper is that there exist different pathways implementing deep reduction targets that also lead to an increase in economic growth (Figures 8a & 8b). But this requires that there exist policies to guarantee that the revenues from the energy sector or other policies e.g. green fiscal measures will be recycled to energy efficiency investments and low carbon technologies. Once this is ensured, it can be taken out that revenue recycling can lead to a rise in economic growth. Figure 8a & 8b show that consumers' expenditure and investment is slightly higher for all G8 80% reduction scenario compared to the reference scenario.

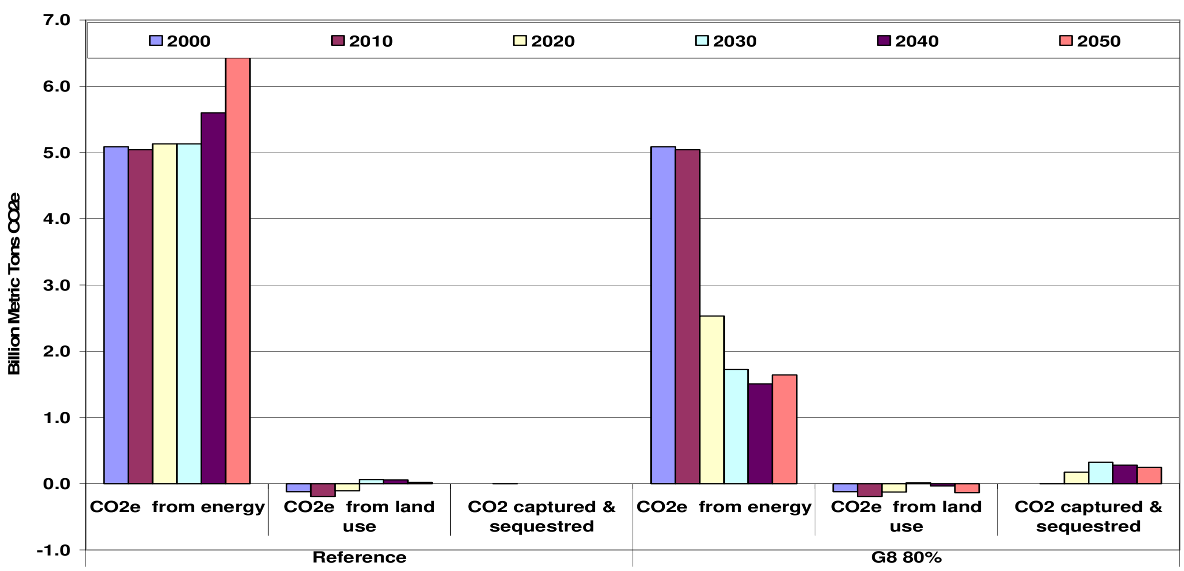


Figure 6a: Emissions for the EU-27 in Billion Metric Tons CO2e.

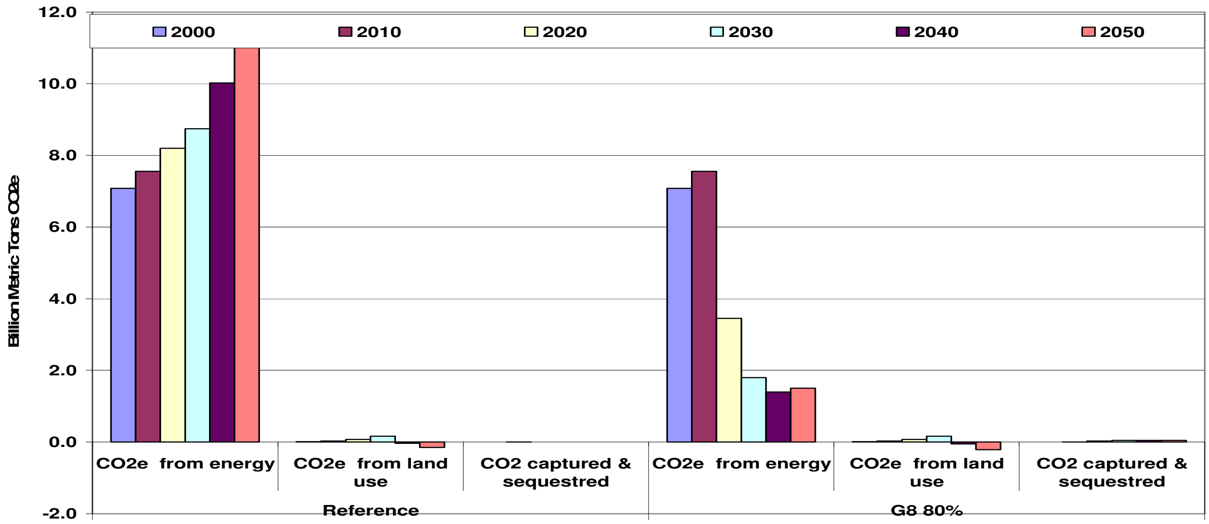


**Figure 6b**: Emissions for the USA in Billion Metric Tons CO2e

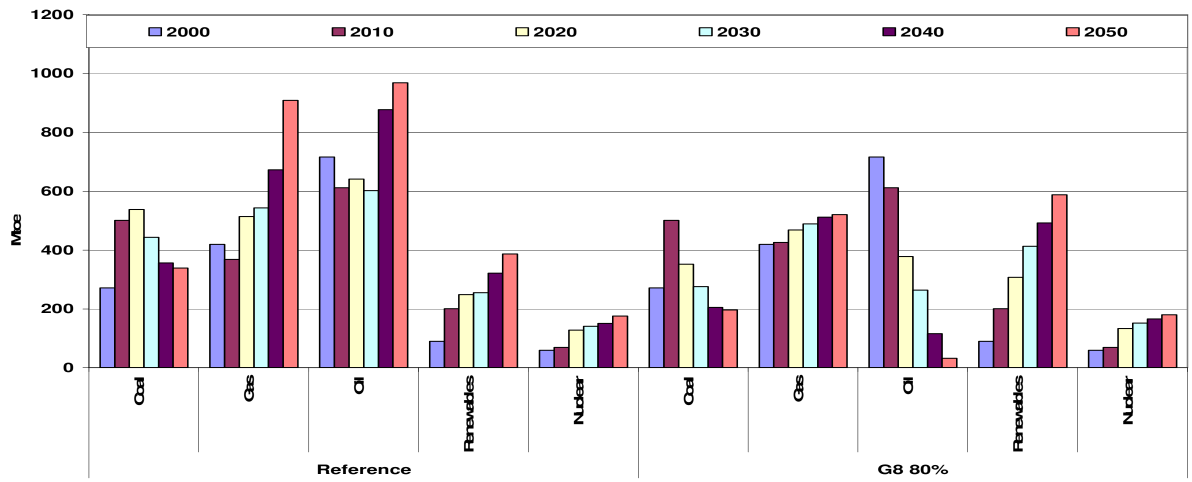


Figure 7a: Energy demand for the EU-27 in Mtoe.

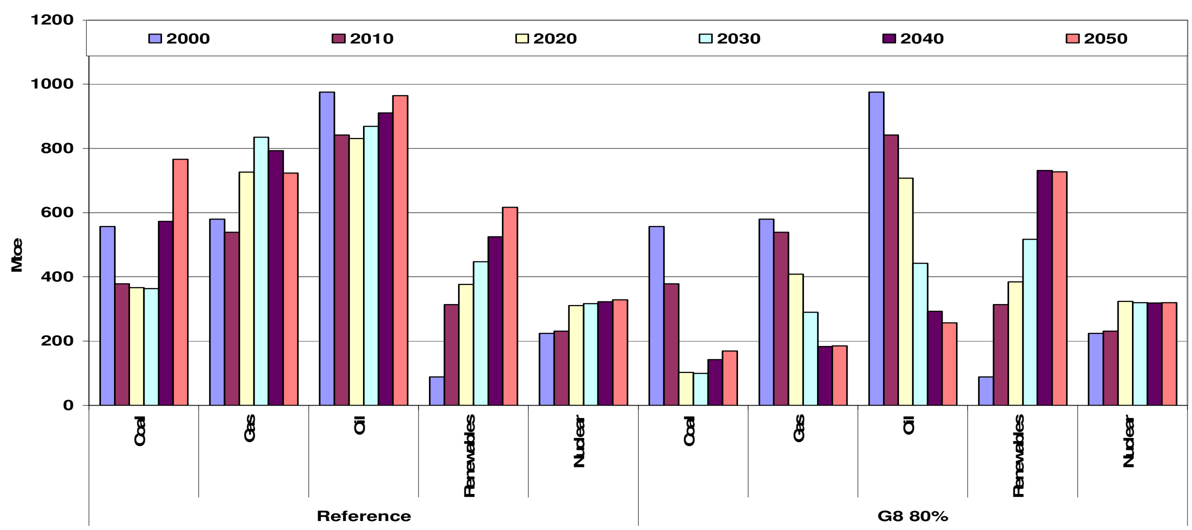


Figure 7b: Energy demand for the USA in Mtoe.

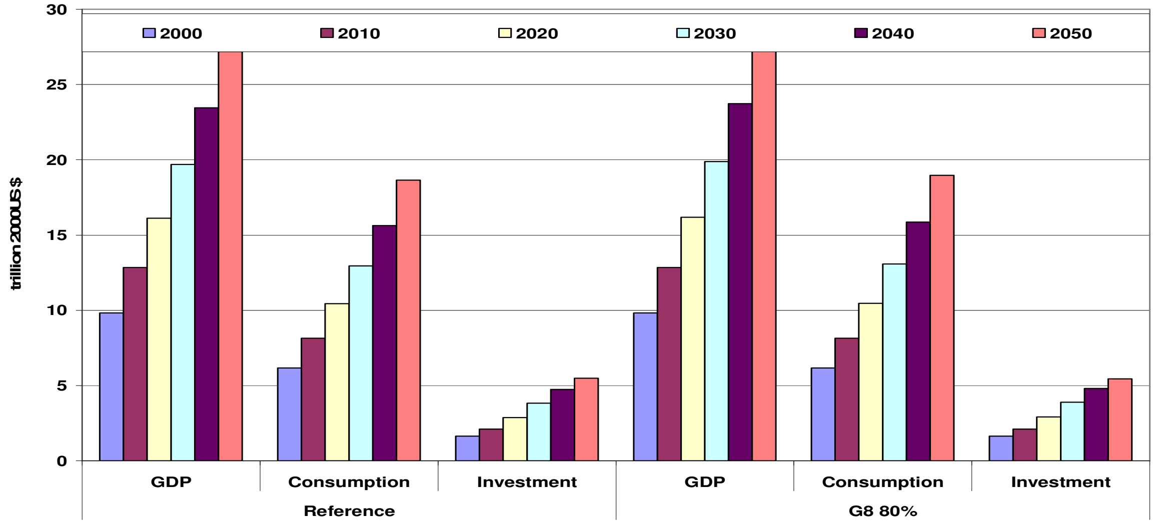


Figure 8a: GDP, Consumption and Investment for the EU-27 in trillion US$.

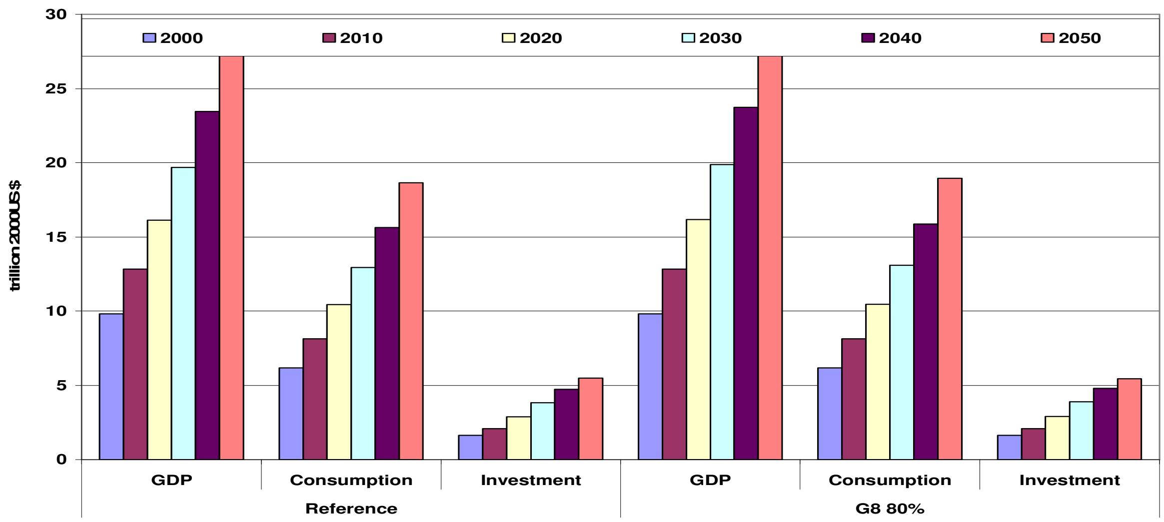


Figure 8b: GDP, Consumption and Investment for the USA in trillion US$.

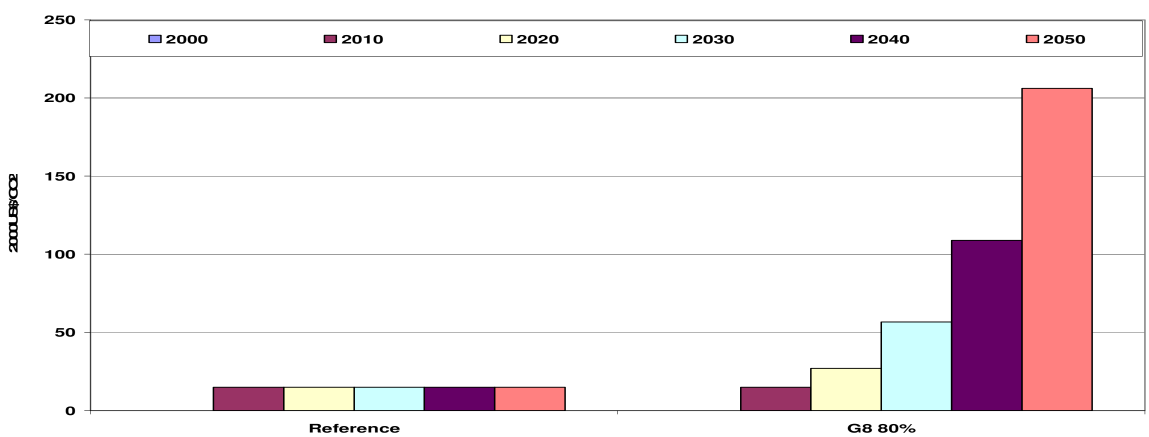


Figure 9: Carbon Pricing for the EU-27 and the USA in US$/tCO2.

## 5. Conclusions

The E3MG model adopts a hybrid approach. The aggregate and disaggregate energy demand is estimated using econometric techniques, allowing for fuel switching for the 12 different fuel types and for the 19 fuel users, while the power sector is simulated using a probabilistic approach which considers the economic, technical, environmental characteristics of the power units but considers also the history. The electric system expansion is modeled by estimating parameters for the different technologies based on historical data, which allows new technologies to gain a share in the market even when their cost is higher than conventional technologies. Moreover the dispatch of the different technologies to meet the electric demand, although using the cost optimization approach comparing the penetration of the different technologies, takes historical data as its starting point. Both the energy demand system and the energy technology options are implemented so as to model market imperfections which exist in all markets and are not usually considered in the classical cost optimization techniques. These market imperfections, resulting either from socio-political factors or from the presence of oligopolies that speculate on the electricity price, cause differentiation in the electricity mix across countries, and lead in many cases to significantly different profiles from those projected from models assuming perfect market conditions.

The G8 80% scenario is implemented in this framework, allowing the cumulative investment at international level for alternative technologies so their faster penetration provides solutions with a more diverse electric mix. It is also important to mention that the emission reduction scenario is modeled not by imposing a reduction target and estimating the marginal abatement cost for meeting this target, but by applying different policies at different strengths and different timing, which is consistent with the theoretical background of the space-time economics adopted in the E3MG model. The reduction scenario has been implemented by applying in different strengths and timing the policies of carbon pricing, direct investment and revenue recycling in the form of investments in the power sector, investments in the transport and other consumption sectors. The aim was all of them to have a positive effect, by reducing emissions whilst maintaining economic growth. This proves to be the most important conclusion of this paper, that there exist several portfolios of policies that can have large emissions reductions and also help the economy to grow. This finding is in contrast with those from many models predicting that energy investments will have an important negative effect on the economic growth, deriving from the assumptions in the neoclassical approach of full employment (so that there are no extra resources available to produce extra output) and of optimization of the baseline economy by a central planner (so that any shift away from the optimal solution will reduce GDP). But it is consistent with recent political decisions at EU, USA and Japan to invest on green technologies and infrastructure so as to boost their economies out of the global recession.

The power and the transport sector show the highest decrease in emissions and so constitute the most critical sectors for meeting deep reduction targets. The decarbonisation of the power sector happens in two directions: in the replacement of conventional units with gas, nuclear or CCS plants and in the further penetration of renewables. The extent and the timing of the incentives for these technologies are critical. Renewables penetrate at levels lower than 50%, based on the assumptions on technical restrictions. Recent research work under the IEA on the penetration rates of renewables suggests levels up to 40% (Holttinen et. al. 2006) due to stability and power quality issues. But the electrification of the transport sector allows an increase of the capacity factor of stochastic renewables such as wind, if accompanied by the proper tariff policies. So their penetration level in the electricity production has been allowed up to 50%, generated mainly from wind farms and secondly from biomass, marine and solar plants. In all scenarios the model produces solutions with higher energy diversity than expected from a cost-optimization solution. In that way the model's probabilistic approach resolves the problem of energy security.

The decarbonisation of the electric and transport sectors leads to significant emission reductions and also maintains economic growth. But it has to be mentioned that very deep reduction targets such as the G8 80% target can only be achieved through stronger regulation, encouraging faster adoption of new carbon-reducing technologies and higher investment. This scenario implies a global technological revolution in favour of low-carbon products and processes, achieving lower costs through economies of specialization and scale. Decarbonising the energy system is a space-time problem with the different portfolios of policies becoming preferable depending on the final and intermediate targets. Achieving the stringent 80% target for 2050 appears feasible, while maintaining economic growth, but implies adoption of a portfolio of policies including strong regulation and high emission permit prices.

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# Least Cost Optimisation modelling of the 2020 energy and environmental targets in EU27

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**Abstract**

*The TIMES model is used to analyse a number of future options for policies and measures in order to study the quantitative effects on the RES development in each of the EU27 countries in view of the renewable energy targets and emission reduction targets set for 2020. Four alternative scenarios are examined, namely the Business as Usual Scenario, the RES Reference Scenario where the target for renewable energy sources per Member State and the corresponding targets for CO2 emission in 2020 are enforced, the RES Statistical Transfer Scenario which includes the statistical transfer mechanism described in the Renewable Energy Directive and finally the RES-30 Scenario which enforces a 30% reduction for CO2 emissions over the whole of the European Union.*

*The results obtained per country for these four scenarios show the least cost allocation of the target per source of renewable energy and sector of energy consumption. According to these results, on the EU27 level, renewable electricity should account for about 36% of the net electricity production and renewable input for heat production should account for 20% of the total input for heat production in order to achieve the target.*

## 1. Introduction

The model and results presented in this paper are the outcome of the project "RES2020" –which was funded under the Intelligent Energy for Europe programme. The RES2020 project aims at supporting the policy debate on renewable energy strategies in the EU until 2020. The modelling part of the project focuses on:

- Calculating how the targets for renewables as specified in the Renewable Energy Directive can be met, given different specific boundary conditions;
- Examining the implications of the different ways for achieving these targets to the European Economy.

Future options for policies and measures are studied with the use of the TIMES energy systems analysis model, in order to analyze the quantitative effects on the Renewable Energy System (RES) development. The results are combined to provide recommendations of optimal mix scenarios for policy measures, in order to ensure the achievement of the targets.

TIMES (an acronym for The Integrated MARKAL EFOM System) is one of the tools developed and used by the Energy Technology Systems Analysis Programme (ETSAP 2009) an Implementing Agreement of the International Energy Agency. It is an economic model generator for local, national or multi-regional energy systems which provides a technology rich basis for estimating the development of the energy system over a long-term time horizon. TIMES is defined as a bottom-up technology rich optimisation model generator, with exogenously defined energy services demands (ETSAP 2005).

## 2. The PanEuropean TIMES model (PET)

*2.1 Model Description*

In the framework of the NEEDS project which was funded by the 6th Framework Programme (NEEDS 2008), a model for EU-27, Iceland Norway and Switzerland was developed, using the TIMES model generator. In this model the energy systems of each one of the thirty countries are modelled separately in detail. The Pan European Model is then synthesized by allowing trade of energy commodities among the countries. This model has been used as a starting point for building the RES2020 PET model.

The level of analysis per sector of economic activity in each country, in the Pan European model (NEEDS 2005), is rather detailed. On the energy demand side the useful energy demand per use in the residential, commercial, agricultural, industrial, and transport sectors is analysed in detail:

• *Residential Sector*

The energy service demands that are being considered in the residential sector are space heating, space cooling, water heating, cooking, lighting, refrigeration, cloth washing, cloth drying, dish washing, other electric uses (equipment) and other energy uses. Furthermore three building categories are used for the demands for space heating, space cooling and water heating, namely multi apartment building, single house in urban areas and single house in rural areas.

• *Commercial Sector*

The energy service demands considered in the commercial sector are quite similar to the residential sector and include space heating, space cooling, water heating, cooking, refrigeration, lighting, public lighting, other electric uses (equipment), other energy uses. Furthermore the energy service demands for space heating, space cooling and water heating are divided into two building categories, namely small and large commercial buildings.

• *Agriculture*

Agriculture is not analysed in detail, but is represented as a single energy service demand satisfied by a single technology that consumes a mixture of fuels.

• *Transportation*

The transportation sector is analysed into road and rail transport of passengers and freight, domestic and international navigation as well as domestic and international aviation.

Passengers' road transport is further divided into short and long distance car transport, urban busses, intercity busses and motorcycles. Passenger's rail transport is further divided into urban Metro transport and intercity train transport.

Freight transport is divided into road transport by trucks and intercity rail transport.

The aviation and navigation are split to domestic and international, without further analysis of alternative technologies.

• *Industry*

The industrial sector is analysed in detail following an initial division into energy intensive industries and other industries.

The energy intensive industries are: Iron and Steel, Aluminium, Copper, Ammonia, Chlorine, Cement, Lime, Glass, Paper. For each one of these industrial branches a detailed description of the production processes is being used in the model.

**3.** The industrial branches of other non-ferrous metals, other chemicals, other non-metallic minerals, and the remaining industries are not modelled in detail on a process basis but they are represented using the same generic structure with the energy uses of steam, process heat, machine drive, electrochemical processes and other processes.

On the energy supply side, the electricity and heat production is analysed in detail, the refineries are modelled using a generic refinery structure and the mining and extraction of primary energy resources are modelled using a cost-supply curve.

• *Electricity and Heat production*

The electricity production sector is divided into public power plants and CHP plants, and auto production electricity power plants and CHP plants in the industrial and commercial sector. Nuclear power plants are modelled separately as well as discrete heating installations.

The high, medium and low voltage grids are included in the model, with different type of technologies being able to produce at different voltage, modelling distributed generation in this way. There are also two separated heat grids for high temperature and low temperature heat.

• *Primary resources*

The mining of each primary energy resource is modelled using a supply curve with three cost steps. Biomass is modelled, but not in detail regarding the production processes.

In framework of the RES2020 project, the NEEDS-TIMES Pan-European model has been enhanced in the representation of Renewable Energy Sources.

A more detailed analysis of the availability factors for wind turbines has been performed using data from the production of the existing wind parks. Monthly data for wind power are available from Union for the Coordination of Transmission of Electricity (UCTE) and Nordel for most countries from 2005 onwards. These data are easily converted to seasonal data following the time slices allocation used in the model. For all countries with a significant capacity of wind power there is a common pattern of seasonal variation of the capacity factor which is for Winter: 20-30 %, Fall: 20-25 % , Spring 15-25 %, and Summer: 10-20 %. Statistics for diurnal variations are available for a limited number of countries (e.g Denmark and Greece). Although the average daytime availability tends to be slightly higher than night-time availability, it was not recommended to consider this variation in the model.

Data for installed capacities by the end of each year are available from European Wind Energy Association (EWEA) since 2004. At the end of 2006, offshore wind farm installations represented 1.8% of total installed wind power capacity, generating 3.3% of Europe's wind power. The largest share of offshore wind capacity is 13% in Denmark. For countries with coasts to the Atlantic Ocean and the North Sea the annual availability factor is set as 40 % with seasonal variations similar to onshore wind power. For countries in the Baltic Sea the Finnish assumption of 34 % is used (RES2020 2008a).

New decentralised electricity production technologies have been included in the technology database of the model. These include CHP power plants and IGCC power plants using black liquor in the Pulp and Paper Industry, wave power plants, tidal power plants, and small CHP power plants using biomass as a fuel.

Further enhancements were made in the representation of biomass and biofuels in the model. Regarding biofuels most of the enhancements are made on the supply side, for instance on the differentiation of crop types and waste and residues sources to be used for the production of biofuels. The basic enhancements are:

- Differentiation of potentials of energy crops with different costs, taking into account land-use competition between different crops.
- Rape oil as an intermediate product that also can be imported or traded.
- Ethanol production from sugar as well as from starch crops.

One of the most important issues regarding bioenergy is the available potential, especially taking in mind sustainability issues. The main sources of data for bioenergy are a number of studies the references of which are presented in detail in the next section on Data Sources.

*2.2 Data Sources*

The main source for the base-year energy balances of all countries of the model is the Eurostat database provided by the Statistical Office of the European Communities. The Eurostat database covers the European Union, its Member States and its partners, and is organised under a variety of Themes and Collections, all accessible free of charge. The section ‘Energy and Environment’ of this database provides all the energy flows (production, transformation, consumption, trade) for the base-year (2000, 2005), as well as the net installed capacities for power plants, several technological parameters for nuclear plants (efficiency, availability, etc.) and import/export figures. The Eurostat values for 2005 where also used to calibrate the model for this year.

Table 1 shows in brief the main common data sources used in the templates to build the country models. These sources provided either the official statistics (e.g. Eurostat), or in some cases provided the defaults values (e.g. the MATTER database) which were then adopted by the country modellers to their country situation, based on country specific data.

For the biomass use, the technology characterisation, the estimation of potentials for biofuels on the level of individual technologies, and the renewable heating/cooling is based on the BRED study (Gielen et al 2000) and ECN’s BIOTRANS model (REFUEL 2008).

The sources used for the Renewable Energy Sources technology characterization and corresponding potential are:

- Data for Hydropower is an EURELECTRIC forecast which can be found in: “EURELECTRIC (2006): Statistics and prospects for the European electricity sector, EURPROG 2006”

Table 1: Data sources for the model.

| Sector | Data sources |
|---|---|
| Residential and Commercial | 'Trends in Europe and North America". The statistical Yearbook of the Economic Commission for Europe 2003. http://www.unece.org/stats/trends/register.htm<br>UN-Demography and Social Housing and its environment Compendium on Human Settlements Statistics 2001.<br>http://unstats.un.org/unsd/demographic/sconcerns/housing/housing2.htm |
| Electricity and Heat | International Energy Agency<br>Electric Information 2005.<br>Renewable Information 2005.<br>Eurostat Data on Installed capacities, http://ec.europa.eu/eurostat/<br>Euroelectric http://public.eurelectirc.org<br>EuroHeat&Power www.euroheat.org<br>EIA – Energy Information Administration (www.eia.doe.gov), electricity and CHP technology capacities by type (public/auto-production) and by fuel for all countries. |
| Industry | ECN- The Western European MATTER database, for the default inputs and outputs of energy intensive technologies. |
| Transport | Eurostat – Transport data<br>PRIM model of MEET projects (1995 data) |
| Mining data | World Energy Council |

- Wind data is an EWEA forecast (with good policies implemented) from the TRADEWIND project (TRADEWIND 2007).
- Data for the potential of Geothermal, PV, Biogas and Ocean power (Wave and Tidal technologies) come from the OPTRES forecast (OPTRES 2006).
- Data for the potential of Concentrated Solar Power come from the EREC/Greenpeace scenario with good policy implemented (EREC/Greenpeace 2008).

### 3. The RES2020 Scenario Definitions

In the framework of the RES2020 project, it was decided to run four alternative scenarios in order to examine the achievement of the renewable targets set by the European Union for 2020. The scenarios that were elaborated are:

*Reference Scenario:* where there is no enforcement of the targets for renewable energy sources in 2020.

*RES Reference Scenario:* where the target for renewable energy sources per Member State and the corresponding targets for $CO_2$ emission in 2020 are enforced.

*RES Statistical Transfer Scenario:* where the target for renewable energy sources per Member State and the corresponding targets for $CO_2$ emission in 2020 are enforced as in the RES Reference scenario, and the statistical transfer mechanism proposed in the Directive is also modeled.

*RES-30 Scenario:* with the same assumptions as the RES Reference Scenario, but enforcing a 30% reduction target for $CO_2$ emissions over the whole of the European Union.

The model runs for the period 2000-2025 in five year intervals, and is calibrated to the statistics for 2000 and 2005. A brief description of the assumptions for each of these scenarios follows:

*The BaU scenario*

The baseline or business as usual (BaU) scenario keeps close to EU and national policies that are currently in place (RES2020 2009a).

*The RES reference scenario (RES)*

In this scenario, the proposed EU policies as specified in the Renewable Energy Directive have been implemented. This means:

- An overall binding 20% RES objective, which is allocated over the different member states as in the Directive
- A binding 10% biofuels target[1].
- A 20% greenhouse gas emissions reduction target, leading to a further overall limitation in emission rights within the EU-ETS system, and additional national targets for non-ETS sectors.

*The RES Statistical Transfer scenario(RES-T)*

The RES-T scenario shares most assumptions with the RES reference scenario, with one exception. While in RES reference, renewable energy can only be traded in physical terms (electricity, biomass, biofuels), the RES-T scenario also allows for a virtual trade mechanism. For all renewable power, heat or biofuels produced, a 'certificate'[2] is generated.

[1] Note that the Directive formulates this as a target for 'alternative fuels in transport'. As the bulk of this target will need to be met by biofuels, we redefined it as such.

[2] Not to be confused with 'green certificates' as we know them: these certificates are merely used to administer renewable energy generation.

These are used for the accounting to check whether a country reaches its renewable energy target. Surplus certificates, however, can also be transferred between countries. This approach is consistent with the statistical transfer mechanism that is foreseen in the Directive. So this scenario calculates the least cost optimised distribution of the Renewable energy statistical transfers between the member states.

*The RES Climate scenario (RES-30%)*

The RES Climate scenario shares also most assumptions with the RES reference scenario, with one other important exception. While in RES Reference, the climate policy target is a 20% reduction of greenhouse gas emissions by 2020, the Climate scenario sets this at 30%. This is the ambition of the EU, provided that the Copenhagen agreement will include ambitious reduction levels for other countries in the World.

Regarding the international oil prices, which is one of the most important parameters that affect the model, these are taken from the forecast of the World Energy Outlook 2008 (IEA 2008).

### 4. Scenarios Results

The results of the four scenarios defined in the previous section are presented here at the aggregate level of EU27. The Final Energy use of renewable energy per source can be seen in Figure 1.

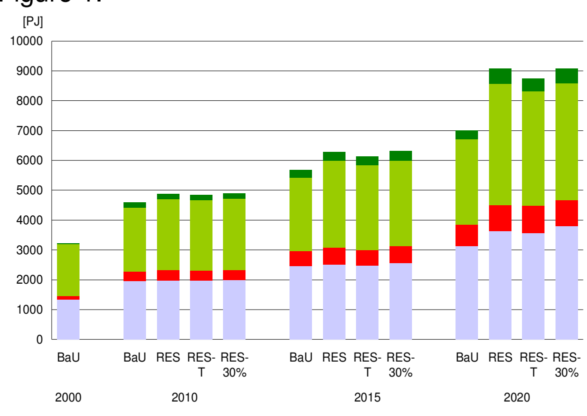


Figure 1: Final Energy use of renewable energy sources in EU27.

The relative shares of the different non-renewable energy carriers remain the same across the scenarios. This means that since oil, gas and non-renewable electricity are the non-renewable energy carriers with the highest consumption, in absolute terms, they also make up for most of the reductions that result from the policies. The non-renewable shares in 2000 are also very close to those of all scenarios in 2020.

The use of renewable final energy is more than doubled already in the BaU scenario. By 2020, a renewable policy will have brought in another 30% more renewables on top of what is achieved in the BaU scenario.

In the BaU scenario, renewable electricity and biofuels have the largest absolute increase. The additional renewables induced by specific targets is mostly coming from bioenergy, covering more than 50 % of the additional renewable energy beyond the baseline.

In the RES-T scenario, slightly less renewables are introduced when compared to the RES scenario. In RES, it appears that some countries introduce more renewables than required by renewable target alone, possibly induced by the GHG reduction objective. In the RES-T case, this ‘surplus’ additional renewable energy can be virtually traded as credits, leading to countries with less cost-effective renewable energy potential to meet their target. In short, the RES scenario may have some surplus RES production compared with the 20% target, while the RES-T scenario meets this target exactly.

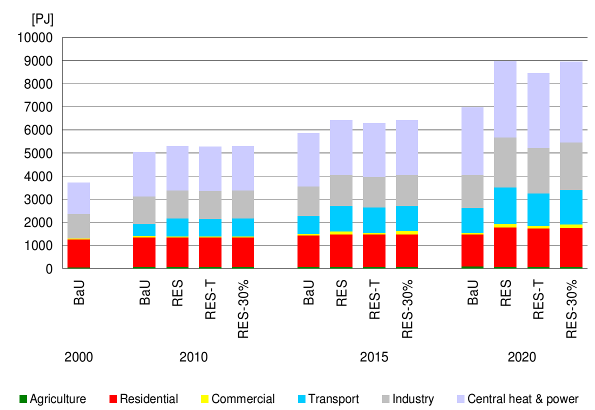


Figure 2: Consumption of renewable energy per sector in EU27.

Figure 2 shows the allocation of renewables use over the different sectors. In the BaU scenario, the use of renewable energy sources increases between 2000 and 2020, especially for the centralized heat and power production and for the transport sector. All sectors have at least 15 % more renewables by 2020 than they had in 2000. In relative terms, the residential and industrial sectors have lower shares of the direct use of renewables in 2020 than they had in 2000.

Renewable policies and climate targets have further impacts on the use of renewable energy sources:

- In the RES scenario, the use of renewables is increased by circa 25% in 2020 compared with the BaU scenario.
- A more stringent climate policy has a contrary effect, with the share of RES increasing to circa 28%. This is partly caused by a minor increase in RES application, but also by a further reduction in overall energy demand.
- The growth in renewables use in the policy scenarios occurs in all sectors, except in the commerce and agriculture, which contribute only modestly.
- The industrial sector reacts strongest to the policies, contributing by more than a third of the additional renewables (beyond BaU) in all policy scenarios in 2020.

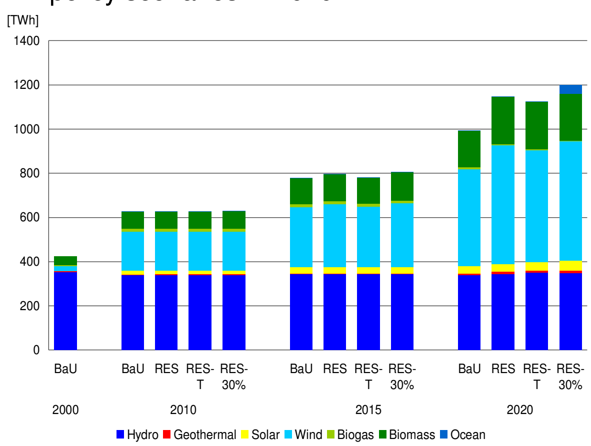


Figure 3: Net Electricity production from renewable energy sources in EU27.

As given in Figure 3, the mix of renewable technologies in power production is mainly based on wind, hydro and biomass. Renewable electricity generation increases across the scenarios and the structure of this production across the different energy sources changes considerably by 2020. In 2000 more than 80% of all renewable electricity generation was based on hydro. Since there is little further potential for increasing hydro power, its production in absolute numbers remains almost constant and its relative share decreases to slightly over 30% by 2020. In all scenarios, wind power is the main renewable electricity source by 2020, covering about 45% of total renewable generation in all scenarios by 2020. In the RES scenarios, policies further increase renewable electricity generation, and especially generation from wind. Also the use of biomass for power generation becomes more important. Other non-hydro sources play a small role.

Overall, more than 35% of the net electricity should come from renewable energy, the highest share of which is due to wind and hydro power plants.

The introduction of virtual trade of surplus renewable certificates leads to less renewable electricity production, at the expense of biomass and wind[3]. As mentioned earlier, this seems to be the result of virtually trading renewable power that would also be generated in the RES scenario, simply because it is cost efficient. In the 30% GHG scenario, there is some reduction in fossil power generation (particularly coal). Of the total electricity production from coal power plants, 55% is produced in plants equipped with $CO_2$ capture and storage. The use of solar and ocean energy increases in the electricity generation so is the overall renewable electricity by a small amount.

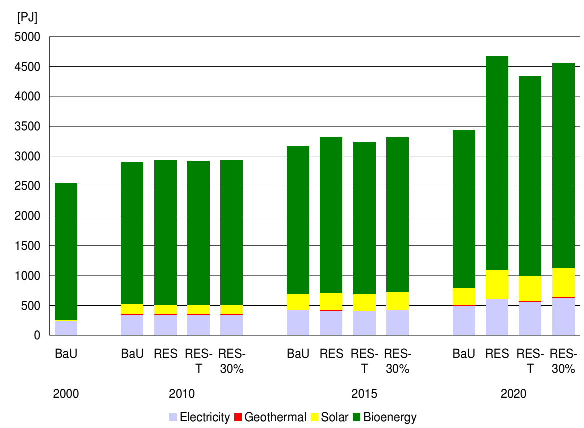


Figure 4: Consumption for heat production in EU27.

In Figure 4, consumption for renewable heat production is further specified. It appears that renewables are used in the heating sector mainly due to the renewables constraint; a further increase in the emissions target does not increase the use of renewables within the heating sector and if statistical transfer is allowed, use of renewables is reduced (implying that it may be an efficient measure to reach the renewable target, if it has to be reached domestically). Bioenergy is the most important source for renewable heat across the scenarios and timeframes, covering some 90 % in 2000 and 75 to 78 % in 2020, in all scenarios. Although the share of bioenergy goes down, it is still, in absolute terms, the source that has its use increased the most between 2000 and 2020. Although solar and renewable electricity for heating also contribute, the additional renewables

[3] At a national level for some Member-States this is not the case, but this is the picture for the whole of the EU.

used due to the policy targets still mainly come from bioenergy (70 to 80% of the additional renewables, beyond the baseline, come from bioenergy in 2020).

The non-conventional fuel consumption in transport technologies can be seen in Figure 5. In absolute terms, the growth of non-conventional transport fuels is significant already in the baseline; from 2000 to 2020 the increase is almost seven fold. Additional increases due to policies are in the range of 25 to 33 % beyond the baseline

Biofuels provide the largest share of renewables (with a dominant share of 1st generation over 2nd generation biofuels), while in all scenarios a very minor contribution of hydrogen is projected. This is consistent with the general expectation that hydrogen will start playing a significant role in transport only after 2020 (HyWays 2008).

An additional greenhouse gas reduction slightly decreases the use of biofuels, because the total use of energy in transport slightly decreases and therefore also the amount of biofuels required for meeting a 10% mandatory target.

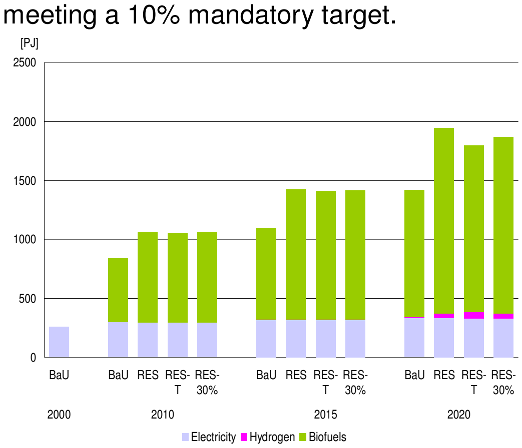


Figure 5: Non-conventional fuel use in transport in EU27.

The introduction of renewables aims to the improvement of energy security, but also to the reduction of $CO_2$ emissions. Figure 8 shows the $CO_2$ emissions from the different sectors in the different scenarios up to 2020.

In the BaU scenario, total $CO_2$ emissions increase quite modestly, by around 5% over the 20-year time frame. In the ETS sectors, emissions by 2020 are almost exactly what they were in 2000. However, the emissions from the non-ETS sector increase by slightly over 10% during the same time frame.

In the ETS sector, the reduction in emissions happens mainly in the power production sector, where the emissions are reduced by 13%. Emissions in industry (ETS part) increase at the same time, resulting to a net change close to zero. Looking at the non-ETS sectors, most of them increase their emissions slightly, with the transport sector showing the highest increase.

In the RES scenario, in which the EU climate (and renewable) policies are implemented, the power sector is responsible for at least 55% of the emission reduction efforts. Other sectors of importance are the residential sector and industry (ETS), both contributing about 10 % of the mitigation needs. Analysing the model results it is seen that the shadow price of $CO_2$ emissions in order to reach this emission reduction, is around 50 €/ton. The difference between the RES and RES-T scenarios are almost negligible[4], indicating that virtual trade of excess certificates does not affect overall $CO_2$ emissions. When mitigation requirements are increased to 30 %, the relative importance of the power sector increases even more, its share being now around 65% of the total reduction. Of the next two most important sectors, the importance of industry increases with the more ambitious climate target, whereas the relative contribution from the residential sector is reduced. These emission reductions correspond to a $CO_2$ shadow price of 80 €/ton.

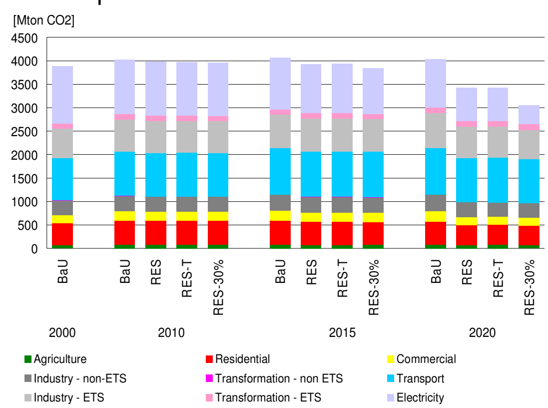


Figure 6: $CO_2$ Emissions in EU27.

As was expected, a transfer to an energy system with more renewable energy and less $CO_2$ emissions comes at a certain cost. Examining the cost figures in the model results one can see that in terms of discounted costs, the overall increases caused by the policies are quite small. The total discounted system costs increase 0.22% in the RES-ref scenario, with its RES target and 20% emission reduction target. With statistical

[4] At national level for some Member-States this is not the case, although true for the whole of EU.

transfers, this difference is even smaller, some 0.18%. This means that a virtual trading platform for excess renewable energy, saves 0.04%, or almost a fifth of the total additional costs of the RES-ref scenario. If the emission target is made stricter, the costs are 0.49% higher than in the BaU scenario. This means that increasing only the GHG reduction target from 20% to 30%, the discounted costs are more than doubled compared with the scenario with a 20% target for both GHG emission reduction and renewables. This indicates that the overall marginal GHG abatement curve is much steeper in the region between 20% and 30% reduction than in the 0-20% region.

In terms of the costs specifically related to renewable technologies, the differences between the scenarios are quite clear (see Table 2). By 2020, the annual costs related to renewable technologies in the RES-ref scenario are over 40% above the BaU numbers. If statistical transfer is allowed, less money needs to be spent on renewables, some 30% more than in the BaU scenario. If no statistical transfer is allowed and the more ambitious climate target is pursued, compared to the BaU scenario over 50 % more needs to be spent on renewables in 2020. This fairly moderate renewable increase over the RES-ref scenario implies that of the further emission reductions needed, only a part is achieved through additional use of renewables and also other technologies, such as Carbon Capture and Storage (CCS), are implemented more ambitiously.

Table 2: Investment and O&M costs of Renewable Energy technologies in 2020.

| | Scenario | | | |
|---|---|---|---|---|
| | *BaU* | *RES-Ref* | *RES-T* | *RES-30* |
| Costs [mln $€_{2000}$] | 87453 | 124702 | 115981 | 131788 |
| Costs as % of GDP in EU27 | 0.59% | 0.85% | 0.77% | 0.86% |

## 5. Conclusions

A least cost optimisation model has been applied in thirty countries in Europe, with the possibility of endogenous trading of physical commodities (electricity, bioenergy etc), $CO_2$ emissions and statistical transfers of renewable energy use. The model has been used for the calculation of four scenarios in order to examine the alternatives of achieving the targets set by the Renewable Energy Directive in EU27.

According to the model results, the costs of the 20% renewable energy and GHG reduction targets are relatively small; the total discounted system costs increase 0.22% in the RES-ref scenario.

The application of the statistical transfer mechanism can lead to moderate changes in renewable energy production among the Member States. On average, about 6% of the target in the EU member states can be met by statistical transfer from another member state, with some individual member states fulfilling up to 20% of their national RES target through this mechanism. While the amount of trade may not seem very significant, cost reductions are important: statistical transfers lead to a reduction of additional costs for renewables of more than a quarter, and a reduction of almost one fifth of the total additional costs for meeting the 20% renewable energy and GHG reduction targets. However it must be noted that the concept of statistical transfer in the directive is implemented in the model as a virtual trade, including an equilibrium price, which corresponds to a fully transparent and open market for statistical transfers. This assumption might lead to an optimistic estimate of the cost reductions through statistical transfer, particularly if this transfer in practice will be limited to bilateral agreements.

Overall the efforts needed to meet the RES target of 20% by 2020, are divided to slightly more than 40% in the heat sector, about 40% comes from power production, while around 15% is delivered as biofuels. These shares are relatively robust: neither virtual trade nor higher greenhouse gas mitigation ambitions change them substantially. The shares of RES-Electricity, RES-Heat and RES-Transport are fairly consistent with earlier studies with e.g. recent PRIMES (Capros et al 2007) and GREEN-X (Resch et al 2008) model studies. For example, the latter projects a division between RES-E, -H and -T of 45%, 43% and 12%, respectively.

The Renewable Energy Sources target is achieved with renewable energy supplying more than 35% of the total net electricity production by 2020, almost 20% of the total heat production, and 10% of road transport fuels. These shares do not change significantly when virtual trade or a higher GHG reduction target are enforced, and are consistent with the results of Resch et al (2008).

**Acknowledgements**

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# Climate Change policy and Energy Conservation Measures in Kazakhstan

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**Abstract**

*Republic of Kazakhstan is a Party of UNFCCC since 1995. In 2009 Kazakhstan ratified the Kyoto Protocol, passed the law "On development of renewable energy sources", and is developing a new law "On energy conservation". On the threshold of Copenhagen 2009 updating Climate Change policy at near-term and long term outlook is a key feature of general renovated path of country's development with drive to low carbon economy. Paper presents the comparative analysis of scenarios of GHG emissions for post-Kyoto provided with different models, recent renewal which took into account the effects of new state innovative policy and the crisis phenomena in the world economy and estimation of energy conservation potential in context of climate change. According to results of modeling and our calculations, CO2 emissions in power industry by 2024 will not reach 90% of the base year level, and introduction of energy efficient technologies gives an even more time in reserve. At the same time more than 40% of all fuel and energy resources are spent for heating, the considerable share of energy consumption accounts for housing-and-municipal sector. Thus development of energy conservation in this field is the most actual. The real potential of energy saving in central heat supply systems is estimated within limits of 6-7 million t.c.e., or approximately 35% of the actual fuel consumption. Complex approach and portfolio of measures is necessary to realize the potential effectively. In conclusion: reliable forecasting will help to define post 2012 target and understand how a changing climate will alter the shape of development programmes in Kazakhstan; the realization of energy conservation options will bring co-benefits and ancillary benefits, will promote development of energy security and other strategic economic goals. Actions could include reforming legislation in the field of GHG emissions, tariff policy improvement and energy saving projects implementation.*

**Keywords:** Climate Change policy

## 1. Introduction

The Human civilization on the current stage requires immediate and simultaneous solving a number of the accumulated problems - ecological, political, economic, social, scientific, philosophical, ethical, etc. Herewith, the broader area of competencies, possibilities, responsibility and level of affection of this or that state, the more essential necessity of complex analysis of the prospects, trends and monitor of changes. Definitely, solving of the complex global problems related to Climate Change requires system approach and coordinated actions of all states on international level.

The Climate Change and Sustainable Development (SD) issues are in focus of attention in Kazakhstan and are integrated into governmental programs. The legislative provision is the most important supporting component in transition of Kazakhstan to SD. In 2007 "Ecological code" was accepted, where the governmental regulation of GHG emissions and sinks was incorporated into Chapter 45, the "Concept on SD for a period of 2007-2024" was signed; the "Strategy of Efficient energy and renewable resources use in the Republic of Kazakhstan in conjunction of SD up to 2024" is under consideration of the President, the main vector of which is certainly a prevention of climate change impact. The "Law on renewable energy resources development support" was accepted in 2009, the "Law on energy conservation" is under consideration of the Parliament. These and other documents represent the integration of ecological, social and economic aspects into national policy for assistance to sustainable development, in particular, rational use of energy resources, ecological clean energy technologies promotion and energy efficiency improvement. Development of energy conservation including the field of heat supply is of special urgency for Kazakhstan.

The Republic of Kazakhstan (RK) as independent state participates in all UN conferences defining the future world community development since 1992. Kazakhstan is a Party of the United Nations Framework Convention on Climate Change (further — the UNFCCC) since 1995. Kazakhstan has signed the Kyoto Protocol (further – KP) in 1999 and ratified it at March 2009. Three important decisions have been made regarding to the status of Kazakhstan on international level: according to Marrakesh Accords[5] upon ratification of the Kyoto Protocol by Kazakhstan and its entry into force, Kazakhstan becomes a Party of the Annex I for the purpose of the Protocol in accordance with Article 1, paragraph 7 of the Protocol; according to Nairobi decision, 1992 has been defined as the base year for Kazakhstan; according to Poznan decision, Kazakhstan undertakes the voluntary quantitative obligations not to exceed emissions level of 1992 during report period of 2008-2012. In 1998 Kazakhstan issued the First National Communication to UNFCC (FNC) and the Second National Communication (SNC) in 2009 [1].

The reliable forecast of GHG emissions is important for planning and implementing the effective mitigation policies and measures in climate change and adaptation. The analysis of scenarios of GHG emissions dynamics in 2008-2012 was important for making decision on KP ratification and develop strategies how to use the quota.

In this article we shall present the comparative analysis of the forecast of GHG emissions developed in Kazakhstan using different models such as GGE, ENPEP (in 1998-2004) and MARKAL (in 2005-2007) with our recent correction (in 2008-2009) taking into account the innovation cycles, crisis in economy and recommendations on definition of the indicative goal of GHG emissions levels on the prospect and also on energy conservation measures in context of climate change policy. The results of the studies will help to define the volume of free quota for the purposes of its efficient realization while implementing the international agreements obligations in the field of climate change.

## 2. GHG emissions modeling in Kazakhstan for the period of 1998-2005

GHG emissions modeling in Kazakhstan is being taken up during more than 10 years, it's possible to track results since the First National Communication (FNC) was issued in 1998. The inventory of GHG emissions for 1990 and 1994 and forecast up to 2020, developed with use of ENPEP model[6], were presented in the FNC. The first trends of GHG emissions forecast were built taking into account the existing research works, expert studies and the main indicators of energy development Program. In the baseline (Figure 1) no measures on climate change mitigation were planned, while in the integrated scenario they planned to introduce following technologies: nuclear, wind, solar and hydro energy. According to the evaluation on the baseline, $CO_2$ emissions will reach the level of 1990 in 2011 and exceed it by 37% in 2020[7], and on the integrated scenario the growth of emissions will make only 20% in 2020 regarding to the level of 1990. The total annual potential for $CO_2$ emissions reduction due to implementation of all the options ("Integrated scenario") considered increases from 3% in 2000 to 11% in 2020.

As it could be seen at the Figure1, scenarios imitated nearly linear growth of $CO_2$ emissions, pro rata ambitious growth of economy factors, as a result, level of uncertainty estimated by experts as 20%, look to be much above.

[5] Article 4, paragraph 2 (g), Kyoto Protocol

[6] ENPEP model, model of the Argonne National Laboratory (USA).

[7] First National Communication of the Republic of Kazakhstan under the United Nations Framework Convention on Climate Change, Almaty, 1998, ch.4, page 57.

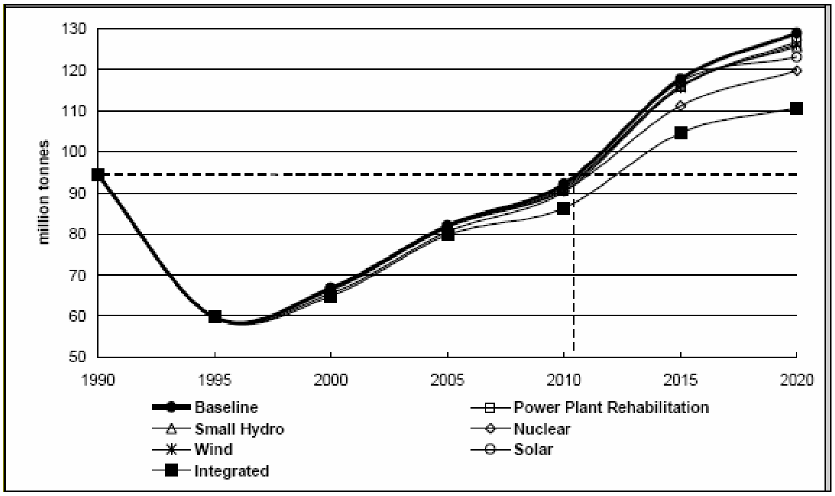


Figure 1: $CO_2$ emissions for the baseline and mitigation scenarios.

The authors took part in several studies related to climate change and KP, conducted during 2000 - 2008 within the framework of UNEP, the Climate Change Coordination Centre, UK, CIDA, TACIS, REEP, UNDP, JAPAN (NEDO) as well as on regional, national and sectoral level, in particular they were involved into the "Development Program of the United Electric Energy System of the Republic of Kazakhstan for a period of before 2010 with a prospect up to 2015" (in cooperation with institute KAZNIPIENERGOPROM) [2], Analysis and forecast of the advantages/losses of Kazakhstan from participation in Kyoto Protocol in the short-, middle-, long-term prospect (the analytical report with calculation, on order of the Ministry of economy and budgetary planning of the RK [4] and others [5], [6].

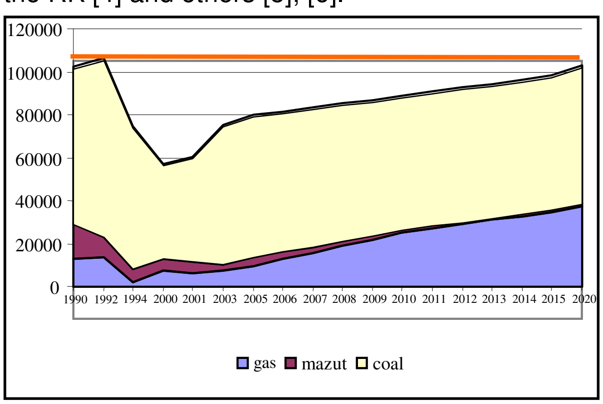


Figure 2: $CO_2$ emissions structure from different types of fuel, scenario 2A ("self-balance") [3].

In 2004 the authors used the Russian experience of GHG emissions modeling [7]. For description of the dynamics of $CO_2$ emissions for economies in transition the interfiled economic balance model was used. Initially it was developed by Gordon Hughes, it was later reworked by E. Gurvich, A.Golub and others. Later this model was used for researches on "National Strategy of GHG emissions reduction in Russia". The given model was complemented with several exogenous parameters such as GDP structure, energy-carriers prices, and environment pollution payments.

The econometric model uses various exogenous parameters to calculate the share of new technologies and energy sector structure (fuel mix). The main model assumption is replacement of old technologies by new ones after economical reforms started. New technologies are characterized by less use of resources and GHG emissions reduction. During transaction period old and new technologies work in parallel.

Since 2005 the resilience factor proposed in work [7] was used for revision parameters in Kazakhstan model. Probabilistic model for $CO_2$ forecast had the following type:

$$CO_2^t = CO_2^{0*}(e^* \alpha/100+1)^t \qquad \textbf{\textit{(1)}},$$

Where

**$CO_2^t$** - $CO_2$ emissions in t year;

**e** - $CO_2$ resilience factor on GDP;

**α** - annual GDP growth rate in percentage.

Energy consumption resilience[8] per GDP is one of the fundamental factors of national economy. Authors calculated and analyzed resilience factors for Kazakhstan. The following results regarding to ratio of growth rates of total primary energy supply

[8] Resilience factor: growth rate of energy consumption per GDP (TPES/GDP).

(TPES), electricity consumption, $CO_2$ emissions to GDP are presented at the Figure 3.

Let us compare the dynamics of GDP and energy consumption in the RK in 2001- 2006 in the period of intensive economic growth (GDP growth in those years was more than 10%). Resilience factor of electricity consumption in average is 0,3 (at the Figure 3 it is marked by the dotted line). Its value remained practically constant during 2001-2006. This demonstrates that economy structure of Kazakhstan was changing slowly in recent time.

The situation with resilience factor of TPES and $CO_2$ emissions is similar. GDP growth in Kazakhstan nowadays is not accompanied by the same energy consumption growth rates as in soviet times (at GDP growth of 1% energy consumption growth will make 0,3%).

Kazakhstan $CO_2$ forecast results are presented on the Figure 4. The forecast trend is made in relative unit – baseline emissions are estimated as 100%, base year for Kazakhstan is 1992.

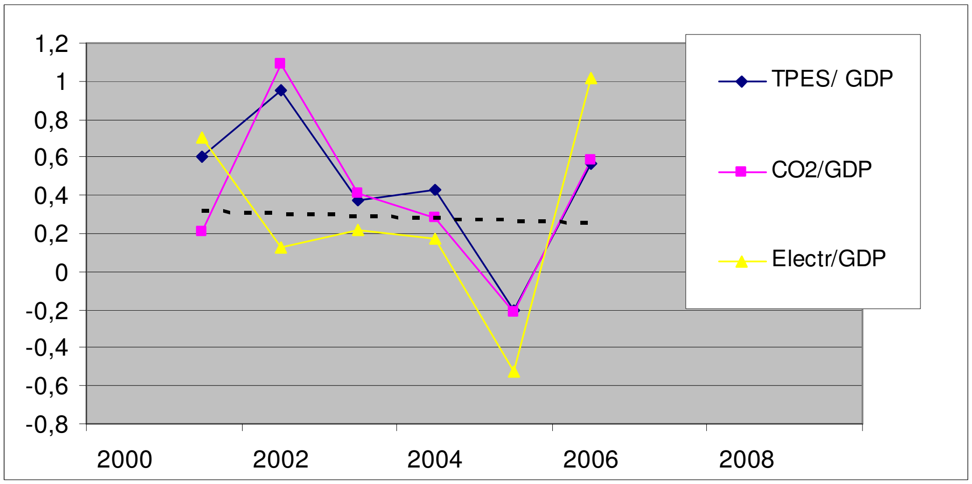


Figure 3: Dynamics of changes of energy consumption growth rates to GDP (TPES/GDP), electric energy consumption growth rates (Electr/GDP), emissions growth rates (CO2/GDP), results of the authors.

Source: GDP – Data of the Statistics Agency of Kazakhstan, $CO_2$, TPES, Electr - IEA

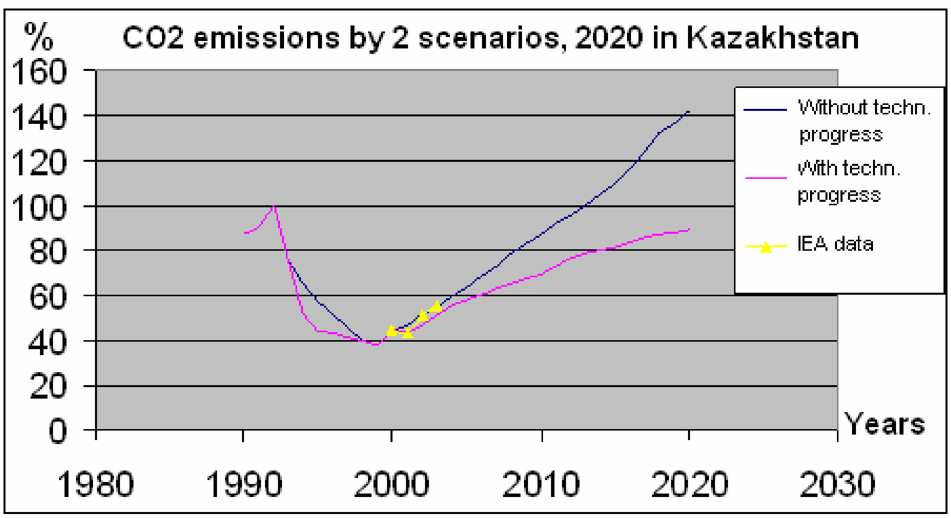


Figure 4: $CO_2$ emissions forecast in Kazakhstan (results of the authors): “with technological progress” (lower path) and “without technological progress” (upper path). While calculating in the case of innovative scenario “with technological progress” they used resilience factor e= 0,2.

Two scenarios - "with technological progress" and "without technological progress" - are presented at the Figure 4, the International Energy Agency (IEA) statistics data for 2000-2004 [9] was contributed for comparison. The analysis of the estimations made in research lets us to make the following conclusion: according to the scenario "without technological progress" the emissions from energy industry will not exceed the level of 1992 by 2014. From the point of view of the least influence on environment the most profitable scenario is the scenario "with technological progress", under which supposed emissions from the energy industry will reach 90% from 1992 level by 2024. According to the conservative estimation of the IEA, the data for that time period corresponded to the baseline "without technological progress" (IEA data are marked with yellow triangles on the graph).

We would like to notice that results of the forecast, reflected in a number of official documents (e.g. The First National Communication), have influenced upon making the political decision on KP ratification, so additional undertaking research on GHG emissions modeling was required.

While defining climate change mitigation policy and measures the countries use expert conclusions and computer facilities. The following general facilities were used for energy sector analysis: the System of the long-term planning of alternatives in energy sphere (LEAP), Standard Program of estimation in energy sphere (ENPEP), macroeconomic model of energy distribution on a market (MARKAL), model of calculation of expenditures for GHG emissions reduction (GACMO)[10] and others.

The MARKAL[11] family of models is among the most widely used tools in energy-environmental analysis. Current users of the model total amount more than 80 institutions in over 45 countries. The widest current applications are used for the analysis of policies designed to reduce carbon emissions from energy consumption. The studies targeted on safety of the provision after crisis, change the oil prices, mitigation and prevention fallouts of the acid rains, GHG emissions reduction or stabilization corresponding to atmospheric concentrations. In Kazakhstan MARKAL has been introduced since 2005.

### 3. MARKAL KZ is a model for analysis and forecast of the different sectors of economy development in the Republic of Kazakhstan

In the course of preparation of the "Second National Communication to UNFCCC" (SNC) in Kazakhstan GHG emissions scenarios were researched by means of MARKAL models, which we shall consider hereinafter.

Standard MARKAL is a" bottom-up" modeling instrument using linear programming techniques. The main method used in design analysis is a discount cost method. This method is based on determination of the future costs of the year t + 1 ($C_{t+1}$) as costs of the year t ($C_t$), enlarged on value equal to the bank percent rate ***r*** [8]:

$$C_{t+1}=C_t\times(1+r) \qquad (2)$$

MARKAL is a tool of the analysis for cost evaluation on following of the supposed development policy based on the energy sector and selection of the optimum measures on change legislative, regulative and institutional framework for increasing of efficiency in long-term prospect. MARKAL-TIMES generates models for prospective analysis of the future scenarios (not a forecasting model).

Building the “optimistic” models in Kazakhstan the parameters of the “Concept of the transition of the Republic of Kazakhstan to sustainable development by 2024” were used, which was approved in 2006. These parameters are: reduction of GDP energy intensity twice by 2015-2020, GDP growth twice by 2015, saving of annual growth rates of the country’s economy not less than 10 % by 2012, 12 % by 2018, 14 % by 2024[12]. The “pessimistic” development scenarios were used as well, as follows, annual growth rate of the country’s economy from 5 to 7%. The results of the calculations are presented at the Figure 5.

[9] key_stats_2001, 2002,2003,2004, source: http://www.iea.org/

[10] Sixth compilation and generalization of the initial national communications of the Parties, not included into the Annex 1 to the Convention. Note of the secretary *AUXILIARY IMPLEMENTATION BODY. Twenty third session. Montreal, 2005. source: FCCC/SBI/2005/18/Add.3

[11] For an overview of the MARKAL family, please see Goldstein, G.A., L.A. Greening, and the Partners in IEA ESAP, 1999

[12] A number of indicators of SD in the Concept are too optimistic (note of the authors).

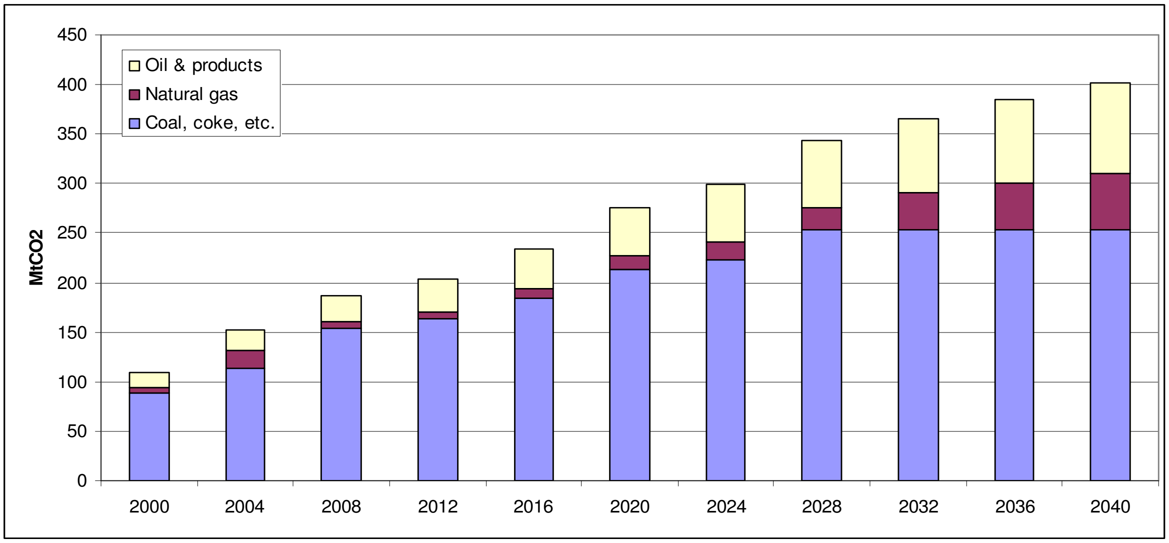


Figure 5: $CO_2$ emissions by fuel in the baseline scenario (A-MK-BAU) (energy sector of the RK) [9].

Hereinafter authors with group of local experts used MARKAL modeling tool for baseline scenario analysis of GHG emissions within the framework of regional TACIS project [8-9], this research was important for final determination of the base year. The 1992 level of 252.9 $MtCO_2$ would be reached by 2018 (see Figure 5). The relation between the reduction and the cost is explored with the model by building scenarios accepting new technologies that have an increasing $CO_2$ mitigation cost. The year, when emissions from fuel combustion grow back to the 1992 level, is pushed back to 2020 by using new technologies with the cost below 5US$'2000/$tCO_2$. The average long-term level gives an approximate estimation of the cost of 70 KZT/'2000/$tCO_2$[13] for the country to achieve the corresponding mitigation level with domestic policies and measures. This will occur if we shall begin to reduce the emissions on 5% immediately after 2010, this corresponds to GDP early loss about 0,2% [8] by 2020-2024.

## 4. Innovative development is a key factor in the policy of Kazakhstan

At present, a number of new documents to include RK within the leading developed countries of the world are being intensively developed. The Government of Kazakhstan is developing a program on forced industrial-innovative development of the republic till 2014 by December 1, 2009, which will be based on provisions of the documents: "Strategies of Industrial-innovative Development for 2003-2015", "30 Corporative Leaders of Kazakhstan". Large-scale use of innovation in the economic activity is becoming one of the main sources of increasing competitiveness and sustainable economic growth in the modern world.

The oil-and-gas sector remains to be a locomotive of our economy, which makes the greatest contribution into the wealth of the country. In the chain of added costs, the greatest profit is received by the companies that use the technologies of high raw material processing. Optimization of innovative technology choice in the field of polymeric material is considered by us in work [9]. It should be mentioned that considered projects with innovations have associated advantages: reduction of pollutants and greenhouse gasses discharges.

At present, projects in the field of heat supply are being realized, so use of foampolyurethane and other modern materials instead of mineral cotton wool as heat insulation at laying of heat pipelines allows reducing general heat losses at its transportation in the condition of Kazakhstan from producer to consumer from 30%-40% to 2%-4%, annual saving of fuel reaches 20-25% [10] that is correlated with the graph, provided in Figure 8 (refer to below).

Totally, 382 projects of the total cost of 9.5 trillion tenge (the current rate is 150 53KZT/$1) are being implemented and developed in the country within the framework of the plan on industrial-innovative development under the supervision of the government, along with that it is planned to employ 59.2 thousand people. Of which 37 projects are defined as breaking out ones in the

[13] 0,6 USD at the rate as it was in 2000

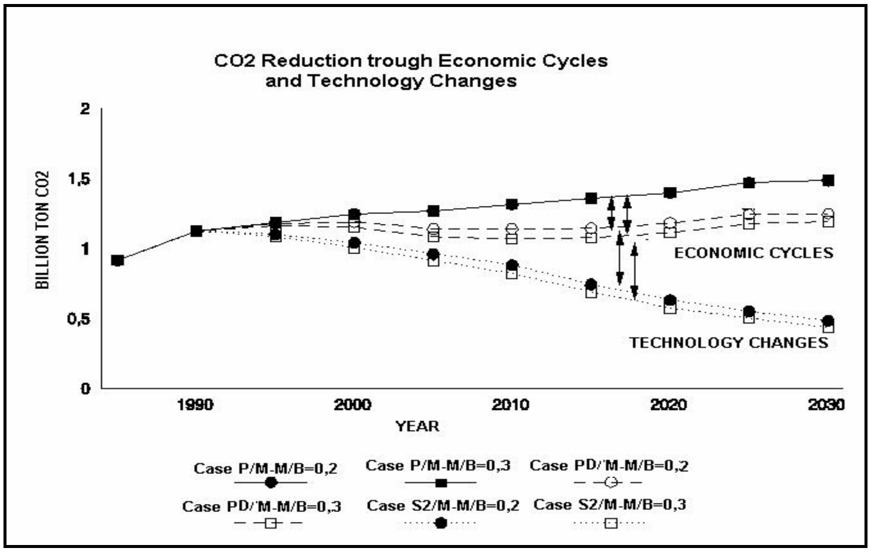

Figure 6. Japanese model with use of two resilience values 0.2 & 0.3.
Source: Summary of Annex V (1993-1995) April 1997, ETSAP-97—1 http://www.etsap.org

total amount of 6.5 trillion tenge employing 11.4 thousand people[14]. They are being implemented within the framework of the program on "30 Corporative Leaders of Kazakhstan", new technologies and the directions of the development are being searched for, the international experience in the field of energy efficient technologies in the field of energy should be used.

In 2009, IEA prepared a special report [11] comprising integrated and detailed analysis of key technology concerning future energy development. The analysis shows that energy generation without $CO_2$ emissions (due to the application of the technologies on its catchments and disposal), use of renewable energy sources and in the countries, where it is possible, use of atomic energy, will be of great importance. The scenario analysis shows that global $CO_2$ emissions may returned to the present level by 2050, and oil consumption growth may be half reduced, energy efficiency is of paramount importance to achieve such results. It is stated in the conclusions that more sustainable energy of the future is attainable. Immediate steps on research work incentives, demonstration and introduction of perspective technology; introduction of clear and predictable measures on promotion of technology with low $CO_2$ emissions and diversification of energy sources are required.

These findings are also confirmed by the studies made in different countries of the world, so impact of scenarios with technological innovations on $CO_2$ emissions reduction in the energy and economic changes and measures were considered in Japan. In spite of appreciable contribution of economic regulation in the achievement of goals on environmental protection, $CO_2$ emissions were considerably reduced due to exactly technological changes within the energy system, refer to Figure 6. The MARKAL model, which was interconnected with MACROEM macro economic economy model, was used for making the studies.

## 5. Correction of trend considering crisis

The persons making decisions at a planning stage, both on the regional and the national level must constantly assess potential possibilities and threats. So, analysis of the environment allows choosing a right direction in the condition of the restrictions created at the international market.

The history of human civilization development was always accompanied by crisis. In early ages that was expressed in insufficient food stuff production, and since the middle of the19th century - in the loss of the balance between demand, which decreases because of population solvency reduction, and in continuing production of goods, products of public consumption and services. New situations connected with reduction world economy growth pace, certainly, will influence the policy in the field of climate change.

[14] Astana. 2009. INTERFAX- KAZAKHSTAN, source: http://www.rfca.gov.kz/

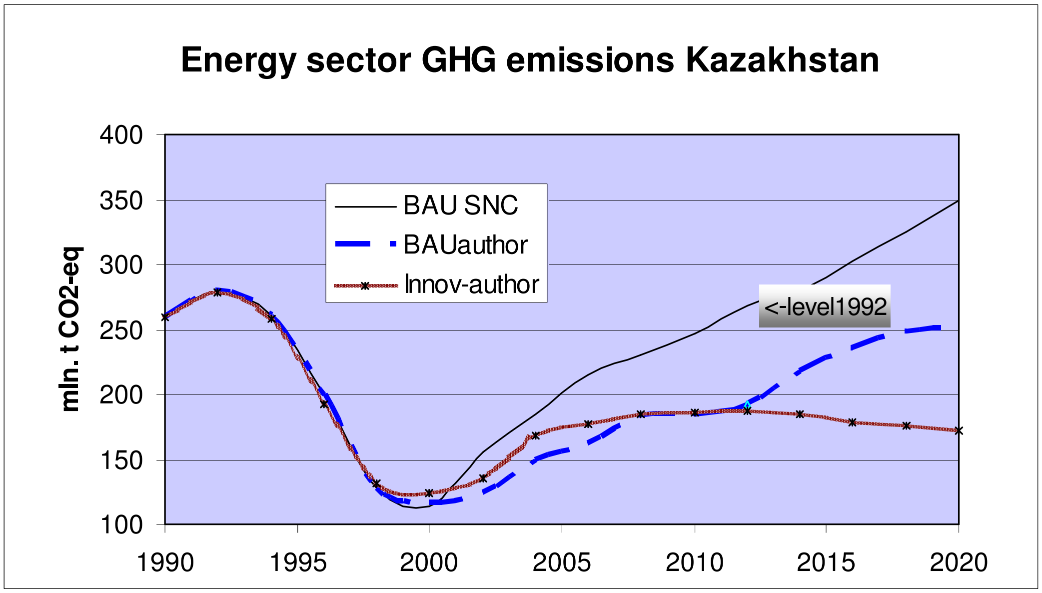


Figure 7: Analysis of GHG emissions scenarios in RK taking into account innovative cycles and the crisis phenomena in the economy of PK.Source: Authors' calculations using MARKAL Kz model

Experts have defined three main sources, which made the greatest contribution into GDP of RK: external loans, incomes from export and money mass. Along with that, an economic metrical model designed in the course of studies, has revealed that 80% of GDP increase in those years was achieved due to attraction of external credits. So, each $1 milliard borrowed abroad enlarged GDP of the country by $915 million at the average [15]. In this case deficit of economy financing could be filled due to export receipts from sale of resources, which previously provided only 8.9% increase of GDP, since the bigger part was allocated for the National Fund establishment. However, at present the prices for the main raw material goods have fallen and, as effect, income of Kazakhstan from export has decreased.

We suggest considering energy efficiency as one of the directions of financing searching, as sources - a budget and international ecological funds. It is expected that considerable means will be attracted after ratification of the Kyoto Protocol by Kazakhstan. At the 21st plenary session of the Foreign Investors Council held on June 12, 2009 the President of Kazakhstan stressed "that ratification of the Kyoto Protocol provides for us new possibilities in the filled of energy efficient technology development that will allow attracting up to 1 milliard dollars of investment" [16]. So, raising of RK market attractiveness at low risks in the economy is very timely.

Fundamental macro economical analysis is very complicated. In most cases it is impossible to take into account all factors making impact on the market. That has been demonstrated by the current moment - nobody could describe a real threat of the expected crisis and even assess it because of uncertainty of the information. The potential impact of the world crisis on the economy and on the calculated level of GHG emissions in Kazakhstan was not taken into account in calculations used at SNC scenarios development. In this connection, analysis of GHG emissions considering crisis and introduction of innovative technology is to the point, particularly before Copenhagen 2009.

The authors made analysis of situational $CO_2$ emissions scenarios taking into account crisis phenomena in the economy and innovative cycles making essential impact on GDP growth and the whole economy as a whole. Corrections of forecast greenhouse gasses trends were introduced into the model designed with use of MARKAL KZ instrument according to the experience of Japan (refer to above) and the data received from SNC compared. We have considered three scenarios for comparison: “BAU SNC”, “BAU author” and “Innov author” (refer to Figure 7).

[15] Business Forum. “Searching for Panacea” International Business Magazine KAZAKHSTAN #5/6, 2008, http://investkz.com/

[16] 24.06.2009 / policy: www.eco.gov.kz, 23 June

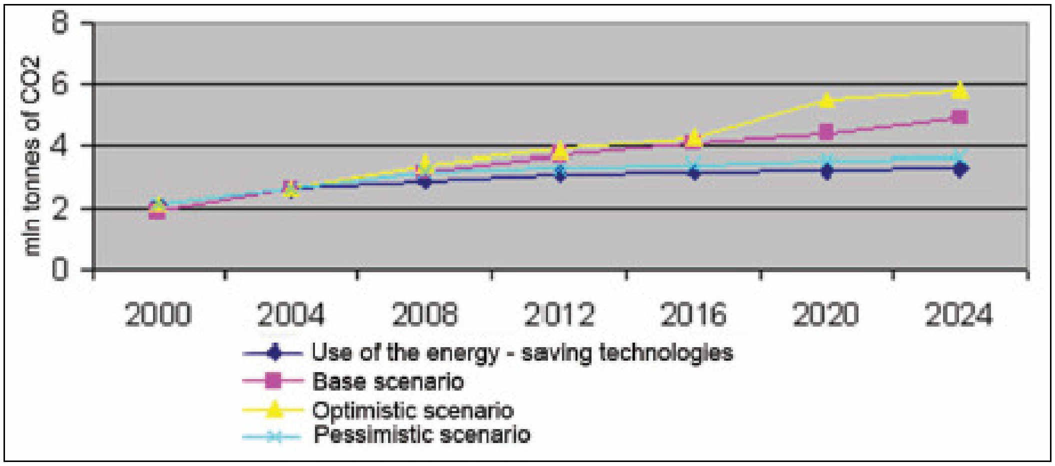


Figure 8: Dynamics of GHG emissions from the municipal housing sector of RK at different development scenarios using MARKAL model [11].

The scenario (BAU SNC) corresponds to the basic scenario presented in SNC, it is designed on the basis of data in table 1.1, Fig. 3.3, fig.4.6 and raw data on emission inventory 2005[17]. According to SNC the level of GHG emissions from energy sector must reach the level of the base year in 2012-2014: on Figure 7 this point is shown by an arrow (<-level1992).

"BAU author" and "Innov author" scenarios were designed by the authors in 2005, provided in Figure 7, and were elaborated in 2007 using MARKAL, a forecast trend was corrected in 2008-2009 taking into account the crisis phenomena in the economy, as follows: (BAU author) – considering innovative cycles, but (Innov author) - with use of the best technology.

There is no GHG emissions growth in accordance with the scenario (BAU author) in crisis years - 2008-2010, also GHG emissions growth is not expected in the period 2018-2020, moderate emissions growth by 1% per annum is expected after that, in this case GHG emissions in the energy sector will reach the level of the base year in 2028.

[17] Total emissions of gasses with direct greenhouse effect in 2005 constituted 243.2 million tCO2-equivalent, including 196.9 million t of emissions from energy activity, 15.3 million t from industrial processes, 22.8 million t from agriculture, and 8.2 million t from wastes; Specific GHG emissions constituted 16 t per capita, of which $CO_2$- 12.4t), total GHG emissions were 29.8% less than in 1992, SNC page 51). source:http://unfccc.int/national_reports

In case of RK transfer to the way of innovative development that corresponds to the scenario (Innov author), stabilization of emissions at the level of 2016-2019 is expected, after that we shall reach 260 million tons of $CO_2$ at moderate growth by 0.5% per annum by 2030.

GHG emissions analysis made by us does not allow agreeing with some conclusions from SNC, in particular with the fact that at the existing technology and the general condition of the branch according to base scenario (BAU SNC) GHG emissions will reach the level of 1992 by 2012-2014, and at introduction of more efficient technology - by 2024 [1] page 76 SNC and Fig. 4.6, Fig. 3.3 page 51. According to our calculations, even according to the conservative basic scenario (BAUautor) emissions from energy will reach 90% of the base level by 2024 only. Therefore we propose to define an indicative goal as follows: - the level of GHG emissions by 2020 - 12% below the level of the base year.

### 6. Prospects of energy saving in Kazakhstan, calculations

As it has been mentioned already, energy efficiency has been incorporated into the official policy in Kazakhstan as the most optimum way to achieve energy safety. This problem has become very urgent in connection with rapid growth of a number of cities, particularly Astana new capital. In particular, work on GHG emissions reduction in the municipal heat supply is being realized and new technologies are being defined within the framework of UNDP GEF Project. Under the Project it is planned to reduce emissions in the amount of 150 thousand tons $CO_2$ for the period of 5 years. New laws are being introduced in Kazakhstan: "On State Support of Renewable Energy Sources Use", "On Energy Saving ", changes to the law "On Natural Monopolies" have been introduced - these measures[18] " will allow reducing GHG emissions in atmosphere for the period 2010-2024 approximately by 75 million tons in $CO_2$ equivalent substituting power energy from coal stations".

Integrated introduction of legislative and economic mechanisms and innovative technology will allow realizing the existing potential on energy saving, which is evaluated as 30% in the sector of energy generation and transmission, and not less than 20% in housing-public sector (ZHKH).

We have made analysis of different scenarios in purpose of energy saving using MARKAL model. Let's consider the dynamics of GHG emissions from the housing sector of RK at different development scenarios for clarity and assessment of the capacity from using energy saving technology, (Figure 8).

We shall not stop on the analysis of each of scenarios provided in Figure 8, but we shall note only that on expert level, the potential on energy saving in district heat supply systems (DHS) is evaluated within 4,2-4,9 million t.o.e. that constitutes approximately 35% of actual fuel consumption at DHS and according to Figure 8 the GHG emissions reduction potential will be 1,0 million tons of $CO_2$ in 2020 because of use of energy saving technologies.

As it has been stated in the report of IPCCC[19], the major part of energy saving potential in the sector of buildings in the countries with the economy in transition is characterized by negative expenses - i.e. provides profitable investment possibilities. The existing barriers restrain active promotion of energy efficiency, and therefore energy efficiency improvement will depend on strong policy of the state and technological progress. Early investments determine long-term future, and both international investors and the state should be attracted for that. To realize the defined tasks, an integrated approach should be applied in Kazakhstan, which will allow realizing the existing potential effectively, more so that realization of energy efficient measures will result in additional accompanying and associate advantages such as:

- o fuel saving (on consumer side),
- o reduction of specific fuel consumption (on producer side),
- o reduction of usual pollutants emissions (reduction of enterprise payments for pollution),
- o improvement of environmental quality,
- o reduction of population diseases;
- o reduction of produced product prime cost at increasing of their quality.

## 7. Conclusions

1. Refining of macro economic forecast is an established practice of the governments of many countries, depending on the situation created in the world economy. Modeling of GHG emissions in Kazakhstan considering many factors will allow introducing efficient policy at the national level in the field of climate change.
2. Active participation of Kazakhstan in Kyoto mechanisms will be rather favorable for the image of the country at negotiations on entering in WTO. Financing and introduction of energy saving projects may be achieved through realization of mechanisms [20] for attraction of foreign investors.
3. It is recommended to realize energy saving potential in relation to greenhouse gasses emissions through:
   - *Optimization of an energy consumption structure trough introduction of renewable energy sources in the energy balance;*
   - *Revision of the normative base and updating it in accordance with international standards promoting energy efficiency measures;*
   - *Attraction of additional investment for implementation of JI/ CDM projects including introduction of new cleaner technology, modernization of the existing equipment for energy generation and consumption.*
4. Preferences or restrictions for definite types of projects, encouragement of associate advantages and introduction of discounting or raising coefficients for projects mostly contribute to sustainable development[21].

[18] National Report on Human Development 2008, Climate change and its impact on the development of Kazakhstan in relation to human development, Kazakhstan 2008, UNDP, page 32

[19] IPCCC, Climate Change 2007, http://www.ipcc.ch/publications_and_data/

[20] Joint Implementation (JI), Clean Development Mechanism (CDM), Emission Trading

[21] A. Kokorin, G. Safonov. Is it possible to calculate the energy development in Russia for future 15-20 years in order to design a reliable scenario of greenhouse gasses emissions changes? "World Energy", issue 4 (63), April 2009.

5. The economic potential on impact mitigation, which, as a rule, is higher than the market potential on mitigation may be reached only at introduction of corresponding policy and removal of barriers [12]. Energy saving potential defined as 30% could be realized in the frames of innovative scenarios.
6. A considerable part of Kazakhstan quota for emissions, according to different forecasts, from 75 to 90% is used by Kazakhstan for its own needs. The remained part may be sold at the world quota market or preserved for use in future budgetary periods following the Kyoto period (2008-2012). Efficient management of Kyoto quota requires reliable emission forecast.
7. Even under the worst scenario Kazakhstan will not exceed the Kyoto quota in the amount for the period of 2008-2012. The development of Kazakhstan on the way of technical renovation also will be accompanied by low pace of GHG emissions growth. Entering the mechanisms of the Kyoto Protocol will transform the quotas in a new resource of economic value. This will create additional incentives for GHG emissions reduction on the basis of new technology (realization of the 3rd innovative scenario) so, in the opinion of the authors the Kyoto emissions budget will not be an obstacle for economic development of the RK.

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# Evaluating policy options for increasing the RES-E penetration in Greece

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**Abstract**

*The new Directive 2009/28/EC for the promotion of energy from Renewable Energy Sources (RES) sets mandatory national targets for the overall share of RES in gross final consumption of energy by 2020 and for the share of RES in transport. The Hellenic target is set at 18%, 11% higher compared to the share of RES in gross final consumption of energy in 2005. This paper focuses on the most suitable policy mix for Greece in achieving the aforementioned target. For the determination of this policy mix two research tools are used, the Green-X simulation model and the multi-criteria evaluation method AMS; the latter is the combination of the standard AHP, MAUT and SMART methods.The Green-X simulation model is used to create three different scenarios about Greece regarding policy mixes aiming to increas the percentage of electricity produced by RES (RES-E). Outcomes of the model along with information from official reports are used as inputs to the AMS method. The results of the AMS method concerning all scenarios show which scenario ensures an effective policy framework for achieving the new target. Sensitivity analysis is used to examine the robustness of the final results. The last session of the paper discusses the results.*

**Keywords:** RES-E, Green-X, AMS, Greece

## 1. Introduction

The new Directive 2009/28/EC for the promotion of energy from renewable sources sets mandatory national targets for the overall share of Renewable Energy Sources (RES) in gross final consumption of energy by 2020 and for the share of RES in transport. These national targets are consistent with the 20% share in energy from RES and the 10% share of energy from RES in transport for the European Community energy consumption by 2020. Furthermore, the Directive establishes a common framework for promoting energy from RES regarding statistical transfers between Member States and third countries, guarantees of origin, administrative procedures, information, training and access to the electricity grid for RES.

Particularly for Greece, as an EU Member State, the main RES targets are now the following: (i) 20.1% of its gross electricity consumption will be produced by 2010 using RES and 29% by 2020 (including large hydro power plants), (ii) a biofuel target is set to 5.75% until 2010 (iii) 18% participation of RES in gross final energy use and 10% minimum share of biofuels in transport by 2020 (Directive 2009/28/EC; MD, 2007; NBG, 2008; Coenraads et al., 2008). The accomplishment of this 18% participation of RES in final energy use by 2020 imposes the following minimum secondary targets: (a) wind: capacity of 6 GW in the mainland system and 600 MW in the non-interconnected island systems, (b) hydro: capacity of 3.9 GW (including large hydro power plants (HPPs)), (c) solar (photovoltaic - PV): capacity of 800 MW, (d) biomass: capacity of 300 MW, and (e) biofuels: 10% of final consumption in the transportation sector (Agapitidis, 2009; ELKE, 2009). The 18% target is also equivalent to approximately 35% of total national electricity production (Tigas, 2009; ELETAEN, 2008).

This paper focuses on the identification of the most suitable policy mix for Greece that will facilitate the achievement of the aforementioned 18% target. For the determination of this policy mix two research tools are used, the Green-X simulation model and the multi-criteria evaluation method AMS. Details about the two tools and the whole approach are quoted in Section 3. The scenarios and their evaluation are discussed in Section 4. Section 5 includes the discussion of the outcomes and the respective policy recommendations based on them.

## 2. The Hellenic policy framework

### A. *Legislative framework*

The new Directive is not yet integrated into the Hellenic legislative framework. The power generation from RES and co-generation of heat and power is currently regulated by Law 3468/06 regarding "*Electricity production from RES and Co-generation of Heat and Power (CHP) high-efficiency plants and other provision*s". This law integrates Directive 2001/77/EC for "*the promotion of power generated from renewable energy sources in the national legislation*" (CEC, 2001). Additionally to this law the following regulations and decisions have been issued: (i) regulation to permit electricity production from RES and CHP high-efficiency plants (Governmental Gazette B 448/3.04.2007), (ii) Ministerial Decision regarding the type and the content of contracts for the purchase of RES-E (Governmental Gazette B 1442/02.10.2006 and Governmental Gazette B 148/06.02.2007), (iii) Ministerial Decision regarding the procedure of issuing permits for installation and operation of electricity power plants using RES (Governmental Gazette B 1153; KEPA, 2009; MIA, 2008).

### *B. Production*

Primary energy production from RES was 1793 Mtoe in 2006 corresponding to a 5.7% share in the national gross inland consumption (Eurostat, 2008a,b; 2009). Energy production from RES was 7.2 TWh in 2007 – including 4.5 TWh from large hydropower plants – (corresponding to 12% share in total energy production) and estimations refer to 8.6 TWh in 2008 (equivalent to 8.6% of total energy production in 2008) (DEI Renewables, 2007; Coenraads et al., 2008).

Based on recent past performance and the current installation schedule, it is estimated that by 2010 a further 600-650 MW will be installed, primarily in hydropower and wind (ELKE, 2009). The total potential for CHP is more than 700 MW in the industrial sector and 100-300 MW in the services sector under current CHP policies according to estimations of the Hellenic Association for the Co-generation of Heat and Power (HACHP, 2009).

### *C. Production*

The cost for the installation of RES is reduced from year to year due to technology development and exploitation of scale economies. The most intensive reduction of the installation cost is expected for PV. Its production cost is estimated approximately at €70/MWh by 2020 without any subsidy, but still it remains more expensive compared to the price of 1MWh produced by conventional fuels (NBG, 2008).

Table 1: RES tariffs according to Law 3468/06. Sources: NBG (2008); RAE (2008a, b); RAE, (2009).

| **Power generation** | **Price in 2006 (€/MWh)** | | **Price in 2007 (€/MWh)** | | **Price in 2008 (€/MWh)** | |
|---|---|---|---|---|---|---|
| | **Mainland** | **Non-interconnected islands** | **Mainland** | **Non-interconnected islands** | **Mainland** | **Non-interconnected islands** |
| Wind parks | 73 | 84.6 | 75.82 | 87.42 | 80.14 | 91.74 |
| Offshore wind parks | 90 | | 92.82 | | 97.14 | |
| Small hydropower plants (<15 MW) | 73 | 84.6 | 75.82 | 87.42 | 80.14 | 91.74 |
| Geothermal/Biogas/Biomass | 73 | 84.6 | 75.82 | 87.42 | 80.14 | 91.74 |
| Other RES and CHP of high efficiency | 73 | 84.6 | 75.82 | 87.42 | 80.14 | 91.74 |
| Photovoltaics with power ≤100 $KW_{peak}$* | 450 | 500 | 452.82 | 452.82 | 457.14 | 507.14 |
| Photovoltaics with power >100 $KW_{peak}$ | 400 | 450 | 402.82 | 402.82 | 407.14 | 457.14 |
| RES, other than photovoltaics, utilising solar energy ≤5 $MW_e$ | 250 | 270 | 252.82 | 272.82 | 257.14 | 277.14 |
| RES, other than photovoltaics, utilising solar energy >5 $MW_e$ | 230 | 250 | 232.82 | 252.82 | 237.14 | 257.14 |

Table 2: Type of subsidy.

| Type of subsidy | Geographical zone | | |
|---|---|---|---|
| | A | B | C |
| Capital subsidy | 20%** | 30%** | 40% |
| Tax exemption | 60% | 100% | 100% |

** The subsidy percentage for investments in wind and solar power is increased in Zone A by 10% for intermediate (with turnover between 10 M€ and 43 M€) and by 20% for small enterprises (with turnover less than 10 M€) and in Zone B by 10% for intermediate and small enterprises.

Energy produced by RES is purchased by the Hellenic Transmission System Operator (HTSO) in favorable price. Table 1 shows the tariff prices for the last three years.

Producers select between two types of subsidies:

- Capital subsidy: it covers separately or in combination the cost of the investment plan, the leasing cost, and/or the labour cost for a period of two years.
- Tax exemptions up to a certain percentage of the credits of the first operational decade.

Subsidy percentages differ depending on the type of RES and the geographical zone (Table 2). Zone A includes the Prefectures of Attica and Thessaloniki (excluding the industrial areas and the islands of these Prefectures that are included in Zone B). Zone C includes the Prefectures of Eastern Macedonia and Thrace, Peloponnese, Epirus, West Greece and the islands of North Aegean. Zone B includes all the remaining areas. The investment has to be self-financed at least by 25% (NBG, 2008).

### 3. Methodology

The *Green-X Simulation Model - Deriving optimal promotion strategies for increasing the share of RES-E in a dynamic European electricity market* - was the core objective of the *Futures-e* project (EEG, 2006). The model can be used for each EU Member State individually or for any group of them. It allows the economic assessment of different policy instruments, which are oriented to the increase of the RES-E penetration, based on minimisation of generation costs and reduction of producer profits so as to avoid the transfer of costs to consumers. It also takes the relative EU legislation into account (Huber et al., 2004a).

In this paper Green-X is used for developing scenarios about Greece based on already implemented and on selected RES-E policy instruments.

The simulation period extends from 2006 up to 2020. Two basic choices constitute the first steps, which need to be done when the user starts working with *Green-X*. The first is named *country specific scenario option* and concerns three different possibilities regarding the development of the prices for fossil fuels. The second is named *technology specific scenario option* and concerns the removal or not of the non-economic barriers. Regarding the first option **a moderate price** was selected for all scenarios following the price projections of the World Energy, Technology and Climate Policy Outlook (WETO) (Huber et al., 2004b). The moderate price also includes a constraint of 15€/t-$CO_2$ for the tradable emission allowance (Faber et al., 2007). The case of not removing non-economic barriers has been selected for the second option.

Some of the scenario results constitute the inputs of the multi-criteria evaluation method AMS, which is the combination of three standard multi-criteria methods: the Analytical Hierarchy Process (AHP), the Multi-Attribute Utility Theory (MAUT) and the Simple Multi-Attribute Ranking Technique (SMART) (Konidari and Mavrakis, 2006; 2007). AMS was developed for the evaluation of climate-policy instruments; with suitable modification, it is used for evaluating their interactions as well. The AHP procedure provides the values of the weight coefficients of the criteria /sub-criteria. The other two (MAUT and SMART) provide the normalised grades for the performance of instruments under the selected criteria/sub-criteria. The MAUT procedure is used when the user of the method has available and credible data for all the evaluated instruments and under the same criterion/sub-criterion, while the SMART procedure when the user, due to the absence of data, uses his/her own judgement or the opinion of experts. Table 3 shows the grades that correspond to the experts assessments when using the SMART procedure (Konidari and Mavrakis, 2007).

The method consists of four basic steps. First comes the creation of the criteria-tree. Second is the determination of weight coefficients for criteria/sub-criteria. Third follows the grading of the performance of the instrument under a criterion/sub-criterion. Finally, the fourth step concerns the collection of the previously produced grades and the formation of the aggregate grade for each evaluated instrument. Consistency and robustness tests are performed within the relevant steps.

For the first step the criteria-tree has already been defined and is used in this paper as it is defined in previous applications (Figure 1) (Konidari and Mavrakis, 2006; 2007).

The criteria-tree is presented in Figure 1. The second step regarding the determination of the values of the weight coefficients for the aforementioned criteria/sub-criteria has already been done in previous work (Konidari and Mavrakis, 2007). The values are presented in Table 5. The consistency test was also performed for these weight coefficients with very good results (Konidari and Mavrakis, 2007).

The third step will be presented analytically in a following session. For the fourth step a grade (commonly measured performance) - determined in the third step - of the assessed instrument for a certain sub-criterion is multiplied by the respective weight coefficient of the sub-criterion. All products (concerning all sub-criteria) are added and form the grade of the criterion that is supported by the sub-criteria. The sum of these products is the grade of the policy instrument under the criterion. This criterion grade is multiplied by the respective weight coefficient of the criterion. All new products are added and form the final grade, which expresses the effectiveness of the evaluated instrument.

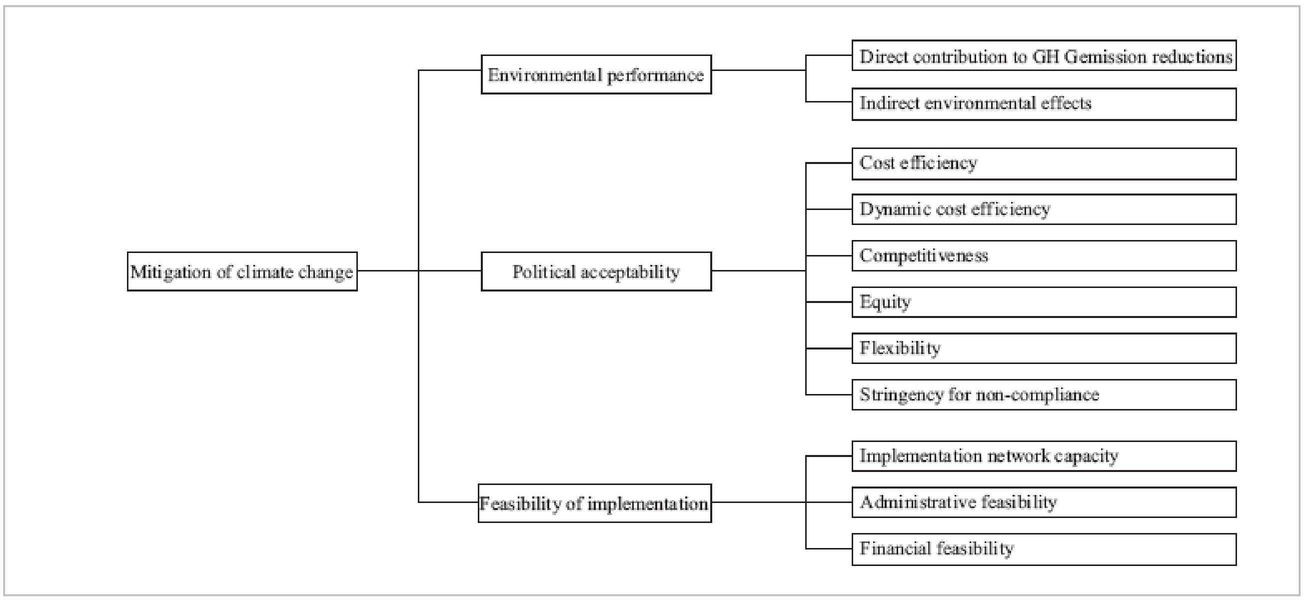


Figure 1: The AHP hierarchy.

Table 3: Assessment for the instrument under a sub-criterion.

| Assessment of performance | Grade by DM | Grade equivalent to MAUT scale |
|---|---|---|
| Null | 0 | 1 |
| Slightly more than null, less than very bad | 1 | 1.58 |
| Very bad | 2 | 2.51 |
| Bad | 3 | 4.01 |
| More than bad, less than moderate | 4 | 6.25 |
| Moderate | 5 | 9.98 |
| More than moderate, less than good | 6 | 15.81 |
| Good | 7 | 25.05 |
| More than good, less than very good | 8 | 39.69 |
| Very good | 9 | 62.88 |
| Excellent | 10 | 99.62 ≈ 100 |

## 4. The scenarios and their evaluation

### 4.1. Green-X scenarios

The simulation runs up to year 2020 for all the developed scenarios and for the RES technologies that are mentioned in Law 3468/2006. The large scale HPPs are excluded, since they are not included into the FIT support scheme of this Law. The solar thermal technology is also not included in the scenarios due to its very low penetration percentages (Agapitidis, 2007).
The electricity generation concerns only that of the mainland, since it represents more than 90% of the Hellenic electricity generation (RAE, 2008b).

*1st scenario: Business As Usual (BAU)*
This scenario is set up so as to reflect the situation due to the implementation of Law 3468/2006. For the first three years of simulation – 2006, 2007 and 2008 – the FIT prices for RES-E used in Green-X are those presented in Table 1. Starting from year 2009 FITs follow an annual increase of 2%, a typical increase as assumed in similar developed scenarios (Capros et al., 1999).
The FIT prices of PV technology are used for the time interval 2009-2014 as they are mentioned in Law 3734/2009 (Governmental Gazette 8/28-01-2009). PVs are the only type of RES for which FITs decrease, starting from year 2010. More specifically for the time period 2015-2020, these tariffs are decreasing by 9.5% annually, an average decrease for the previous time period 2009-2014. Additionally, these prices concern PVs with power less or equal to 100 kWp, since they represent the majority of the pending applications submitted to RAE (NBG, 2008).
The investment subsidy was selected at 30% for all RES technologies as the average value of the three types of subsidies that are applied (Table 2).

*2nd scenario: Improved BAU (Im-BAU)*
The configuration of the FIT scheme remained as it was in the first scenario. The investment subsidy was selected now at 50% for wind and PV technologies for the time period 2010-2020. This assumption was based on the fact that these two types of technologies have higher percentages in energy production and in total installed capacity compared to those of other RES technologies as mentioned in Section 2 (Agapitidis, 2009). Additionally, the investment interest is mainly expressed for wind power and PVs. A wind power of 854 MW is already installed, 3475 MW have secured a preliminary environmental approval, while 2900 MW in the mainland have already connection offers (RAE, 2008a; HTSO, 2009). A study of HTSO/RAE/CRES and the National Technical University of Athens showed that by 2012 under the appropriate technical requirements wind power of 5,500 MW could operate covering 18% of the total consumption (RAE, 2008a; MD, 2008a, b). Furthermore, the increase in the investment subsidy constitutes an additional incentive for exploiting the considerable wind potential of the country.
The investment subsidy for the PV technology aims to the long-term decrease of generation costs through a production increase.

*3rd scenario: Quota obligation for all RES technologies (Q-RES)*
The policy instrument is changed in this scenario. FITs are implemented only up to 2012. After that year and for the last eight years of the simulation period quota obligations based on TGCs are applied for all the RES technologies and the four CHP cases (biogas, biomass, landfill gas, and sewage gas). This change was made in order to realize the performance of a supporting scheme, consistent with Directive 2009/28/EC, which encourages cooperation mechanisms between EU Member States at all levels, bilaterally or multilaterally (Directive 2009/28/EC). TGCs are standardised, i.e., they can be traded internationally without any additional burden (Faber et al., 2007). Consequently, the possibility of *International trade* is set to *Yes* regarding the settings of the Green-X model.
Tendering schemes were not selected since FITs are the most common promotion measure for RES-E followed by the quota obligation system with TGC. Tender schemes play a minor role and as aforementioned, are less successful (Brick et al., 2009; Bohringer et al., 2006).
Taking into account the targeted 35% contribution of RES to the total electricity generation and the fact that large-scale HPPs are excluded, the quota obligation percentages were set up as follows: 20% of total production for the year 2013, 21% for 2014, 22% for 2015, 23% for 2016, 24.5% for 2017, 26% for 2018, 27.5% for 2019 and finally 29% for the year 2020. Plants constructed after 1999 are included, because that year Law 2773/1999 on "Liberisation of the electricity market - Regulation of energy policy issues" was set in force.
The period of certificate validity was set up here to ten years, based on cases of other countries (Belgium, Italy, Poland, Romania, Sweden, United Kingdom) that are included in the Green-X model. The penalty amount was set up to €173.5/MWh. This figure was selected due to the following

justification. 11 out of 13 technologies, which participate in this quota obligation scheme, have a FIT of €86.75/MWh in 2012. The two exemptions are the FIT for wind offshore, which is €105.15/MWh and that for PVs at €364.55/MWh. Since these two technologies constitute a percentage of 3.47% in year 2012, they were not considered in obtaining a FIT average. The price of €86.75 has been considered as a FIT average; this price was doubled according to the aforementioned characteristics of this scheme (Huber et al., 2004a, b).

Finally, the investment subsidy remains at 30% for all RES technologies except for biogas, landfill and sewage gases and PVs. In order to promote these non-mature technologies a gradual increase of the subsidies has been applied as following: 50% investment subsidy for the years 2013, 2014 and 2015, 40% for the years 2016, 2017 and 2018, ending up to the overall subsidy percentage of 30% for the last two years of the simulation period. This gradual decrease of the subsidy increase was used taking into account that these technologies are becoming less non-mature from year to year.

*Results of Green-X scenarios*

As shown in Table 4 the *Q-RES* scenario allows the higher RES penetration, though the differences are small compared to the other two scenarios. Regarding the penetration of the various RES technologies it is worth mentioning that in the *Im-BAU* scenario the subsidy of PVs is effective. In the *Im-BAU* scenario the PVs have a 1.78% share in the total electricity generation, while in the *BAU* scenario 1.07% and in the *Q-RES* 1.47%. Additionally, the biomass percentages are approximately 8.1% in *BAU* and *Im-BAU* scenarios, while in the *Q-RES* it is 9.9%. The wind power (onshore and offshore) has a share of about 80.28% in the *Im-BAU* scenario, 78.94% in the *Q-RES* scenario, while it is slightly more in the *BAU* one with 80.85%, regardless that the investment subsidy remains at 30%. Wind power is considered as the most mature RES technology in Greece.

For the rest technologies there is no other remarkable difference in any of the scenarios. As shown in Table 4, the extra economical means in the *Im-BAU* scenario have a direct effect in the costs for society, while for the generation costs it seems that the difference of 0.13% in the share of RES with the *BAU* case reduces the total generation costs.

Although the *Q-RES* scenario ranks first regarding the share of RES in the total electricity generation, it ranks last regarding its total cost for society.

Table 4: Results from the Green-X model.

| Results | BAU | Im-BAU | Q-RES |
|---|---|---|---|
| Share of RES in total electricity generation (%) | 24.58 | 24.71 | 25.01 |
| Total generation costs due to RES (M€/year) | 772.48 | 697.35 | 805.56 |
| Total cost for society due to all-policy instruments (M€/year) | 186.73 | 323.38 | 2,167.23 |

## 4.2. AMS application

The three scenarios are evaluated as three different policy mixes against the three basic criteria of the AMS method. More specifically, under the first criterion of the environmental performance, the scenarios are evaluated against the two sub-criteria that support this criterion. Their score in “Direct contribution to reduction of GHG emissions” is calculated with the MAUT procedure. A linear function y=ax+b is determined using the respective results in Table 4. The higher their share is in the total electricity generation, the higher will be their contribution to the national effort for reducing this type of emissions. The scenario with the highest share is assigned with grade 100 and the scenario with the lowest share with 0. Indirect environmental effects are expected, but they are not determined in quantities nor is there a respective outcome from the model. The increase of RES-E penetration is expected to eliminate pollution associated with electricity services (Resch et al., 2005). Therefore, the same grades with the previous sub-criterion are assigned considering these effects proportional to their direct contribution in reducing GHG emissions.

The next criterion is political acceptability. Each scenario is evaluated against each of the five sub-criteria of this criterion. For cost effectiveness, the MAUT procedure is used again along with the estimations of the Green-X model for the total generation costs due to RES. The scenario with the lowest costs is the most cost effective. Grades are presented in Table 5. For dynamic cost efficiency, there are no available data from the

Green-X model so the SMART procedure is used. The BAU scenario is assigned with grade 3 for its dynamic cost efficiency, Im-BAU with 2 and Q-RES with 4. The first scenario does not create or offer options for the promotion of innovative RES technologies. The wind and PV technologies are considered “mature” for the Hellenic national framework, while developments in these technologies follow with a relative delay those occurring aboard.

For competitiveness, the three scenarios were assigned the grades 4, 5 and 4, respectively. A FIT does not promote competition among investors and does not lead to reductions in electricity costs (Brick et al., 2009). On the other hand, a quota obligations scheme encourages competition among renewable electricity generators given that the market is sufficient large (Brick et al., 2009). The Hellenic market is not large yet. The Im-BAU scenario received a slightly higher grade due to the increased investment subsidy for wind and PV technologies. This increase improves competitiveness of these technologies. Particularly for wind power it improves the current situation as described above.

For equity, the evaluation is based on the third result of Green-X model (Table 4). Here the MAUT procedure is used again for assigning the grades. The scenario with the highest total costs for society due to all policy instruments is assigned to grade 0, while that with the lowest, to grade 100.

For flexibility, the grades are assigned with the SMART procedure. The scenarios received grades 3, 4 and 6, respectively. The Q-RES scenario offers a wider range of compliance options for the target groups (RES producers) such as subsidies, certificate validity and international trade cooperation among EU Member States (Faber et al., 2007). The Im-BAU offers a higher investment subsidy compared to the BAU scenario.

For stringency, non-compliance, and non-participation, the grades were 3, 3 and 7, respectively. The Q-RES scenario is the only one that imposes a penalty, while the other two have no such provisions.

For the third criterion “Feasibility of implementation”, the scenarios are evaluated against its three sub-criteria. For the first sub-criterion “Implementation network capacity” grades 6, 4 and 3 were assigned respectively to the scenarios. Under the BAU scenario, the current structure of the implementation network has responded sufficiently and problems mentioned during previous years have been handled (Mavrakis and Konidari, 2003). The IM-BAU would need an improved technological infrastructure and additional number of trained personnel. The Q-RES scenario will need better trained and experienced personnel due to the insertion of a new supporting scheme.

Table 5: Results from the AMS.

| **Criteria** | **Scenarios** | | |
|---|---|---|---|
| | **BAU** | **Im-BAU** | **Q-RES** |
| Direct contribution to GHG emission reductions (0.833) | 0.00 | 30.233 | 100.00 |
| Indirect environmental effects (0.167) | 0.00 | 61.905 | 100.00 |
| Environmental performance (0.168) | 0.00 | 61.905 | 100.00 |
| **Sub-total from criterion 1 (A)** | 0.00 | 10.4 | 16.8 |
| Cost efficiency (0.276) | 31.193 | 100.00 | 0.00 |
| Dynamic cost efficiency (0.108) | 31.402 | 19.655 | 48.943 |
| Competitiveness (0.084) | 27.802 | 44.395 | 27.802 |
| Equity (0.359) | 100.00 | 93.131 | 0.00 |
| Flexibility (0.118) | 15.382 | 23.974 | 60.644 |
| Stringency for non-compliance (0.055) | 12.126 | 12.126 | 75.748 |
| Political acceptability (0.738) | 41.568 | 72.679 | 16.837 |
| **Sub-total from criterion 2 (B)** | 30.677 | 53.637 | 12,426 |
| Implementation network capacity (0.309) | 60.644 | 23.974 | 15.382 |
| Administrative feasibility (0.581) | 55.866 | 35.265 | 8.869 |
| Financial feasibility (0.110) | 53.054 | 33.490 | 13.456 |
| Feasibility of implementation (0.094) | 57.033 | 31.581 | 11.386 |
| **Sub-total from criterion 3 (C)** | 5.361 | 2.969 | 1.070 |
| **Total (A+B+C)** | 36.038 | 61.685 | 30.296 |

The scenarios against administrative feasibility are graded with 6, 5 and 2, respectively. More work from the part of the competent authorities is required in the Q-RES scenario due to the lack of experience for its implementation and to the short-time period remaining until 2020. The possibility of international trading due to the TGCc imposes additional administrative work.

For financial feasibility, the competent authorities will need less overall costs in implementing the first scenario. FITs are also considered as easy to install and with minimal administrative costs (Brick et al., 2009). The costs will be higher in the Im-BAU scenario, but restricted since the investment subsidy concerns only two types of RES technologies. The costs are higher in the Q-RES scenario due to the issue of certificates, the monitoring of compliance and the imposition of penalties. The revenues due to the penalties are expected to limit the costs. The assigned grades are 6, 5 and 3. The final grades of the three scenarios are presented in Table 4.

The robustness of these results was tested using sensitivity analysis. Two cases were developed. First, out of three weight coefficients, one is increased gradually by a certain percentage, the second decreases by the same percentage and the third is adjusted properly to these changes (case 1). Second, one weight coefficient remains stable, another increases gradually and the third is adjusted to these changes (case 2). In all cases the Im-BAU scenario shows to be superior. The changes affect, in certain cases, the positions of BAU and Q-RES. This is attributed to the fact that the second weight coefficient is more sensitive to these changes (Konidari and Mavrakis, 2007).

## 5. Conclusions

The use of both tools Green–X and AMS allowed the evaluation of the three scenarios. The advantage of using them was that Green-X allowed the calculation and production of homogenous data that were used by the AMS. For the sub-criteria that the Green-X model could not produce outcomes the AMS method used credible information for assigning the grades. The flexibility of the method allows the usage of data and information.

The evaluation of the three developed scenarios showed that the Im-BAU scenario is more effective compared to the other two for increasing the RES-E penetration in Greece. This scenario scored higher compared to the other two in the political acceptability and more specifically in the cost efficiency and equity. The Im-BAU scenario allows a sufficient contribution in accomplishing the 18% target by 2020 and is consistent with the expected RES distributed technology.

The combination of FITs with investment subsidies is more effective compared to the quota obligation scheme with TGCs. This policy mix allows the promotion mainly of two RES technologies, wind power and PVs. In all scenarios, wind power (onshore and offshore) has the largest penetration, which is justified since this RES type constitutes the most mature RES-E technology nowadays in Greece. However, the effort to promote the PV technology, which has the highest generation cost, is more effective in the Im-BAU scenario despite the fact that a special subsidy for wind power is also applied. The share of wind power decreases slightly in the Q-RES scenario, since biogas, landfill gas, sewage gas and PVs are promoted.

This policy mix is also more cost efficient for the target groups compared to the other two scenarios despite the fact that investment subsidies are higher. It is also financial feasible regarding the costs that the implementation network has to set it in force.

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# Integrated and Adaptive Water Management as part of the climate change adaptations strategies –the legal approach

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**Abstract**

*Climate change will impact significantly the hydrological cycle and water resources worldwide. An increase in the frequency and intensity of extreme weather events (floods, droughts) as well as long term shifts on water availability are expected. Changes in water availability will have significant impacts on key economic activities, such as agriculture, energy and industry.*

*The main aim of the presentation is to analyze how adaptive elements can be embedded into water legislation and policies and how coordination with various laws related to the management of other natural resources can be achieved within the concept of sustainable development. The analysis will also focus on the legal instruments that can be used in order to encourage efficient water use and to achieve balance among competing uses under circumstances being characterized by uncertainty due to climate change. The design and application of any instruments relating to water demand (fees, pricing policies) should not in any case provide an obstacle to ensuring access to basic water services for all parts of the society, taking into consideration the dimension of water as a public good. The interaction between climate change and water has also to be taken into account, when certain mitigation policies, such as the biofuel production are designed and applied. Certain conclusions are to be drawn in order to indicate that the adaptation challenge will be addressed to some extent through a series of changes in the way that societies manage and use their water resources.*

## Introduction-The impact of climate change on water resources

The world is facing changes at a faster rate than ever seen before. Changes, such as population growth, migration, urbanization and climate change will have significant impacts on the way that water resources need to be managed in the future. Climate change is regarded, though, as the major catalyst for re-orienting water management, because it will impact significantly the water cycle, the water resources and the relevant services worldwide [22] . Furthermore, there are sound reasons to expect an increase in the frequency and intensity of extreme weather events[23], such as floods and droughts, as well as long-term shifts on water availability.

Water is a critical core sector, so that changes in water availability and quality are expected to have significant impact on key economic activities, such as agriculture (increased demand for irrigation), energy (reduced hydropower potential and cooling water availability) and tourism (recreational activities). It becomes evident that the broader dynamics of the national economies can be influenced and the capacity of societies to pursue sustainable development can be put at risk. The challenges of climate change to water sources have thus to be understood and addressed in an interactive way, if societies are to adapt effectively to climate induced changes. Therefore, just as the gradual change of our energy habits, namely the way that societies produce and use their energy, constitutes the cornerstone of any legal and policy framework aiming at avoiding or even limiting the consequences of climate change (mitigation policies), a series of fundamental changes of the way that societies use and manage their water sources has to become an integral part of any policies aiming at coping with the unavoidable effects of climate change (adaptation policies)[24].

At this stage, a critical question comes to the fore. This question relates to whether the existing legislative and institutional framework, on which

[22] IPCC Report 2007, *Climate Change 2007 : Climate Change Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the IPCC.

[23] United Nation Development Programm (UNDP), Human Development Report 2006: *Beyond Scarcity –Power, Poverty and the Global Water Crisis*, Macmillan Palgrave 2006, p. 8.

[24] Global Water Partnership, Technical Advisory Committee (TAC), *Climate Change Adaptation and Integrated Water Resource Management-An Initial Overview*, Policy Brief No 5, 2008, p. 6.

water management practices and protection measures are based, is sufficiently adapted to cope with the newly emerged climate-induced challenges on water resources. As a starting point for answering this question it should be mentioned that the majority of the current water practices, not only in developing but also in many developed countries, are –despite the different degrees of their effectiveness- not robust enough to cope with the impacts of climate change on water supply availability, flood risk, agriculture and aquatic ecosystems. This means subsequently that also the legislative framework in place at international, regional and national level should be to some extent reformed, in order to provide the necessary impetus for dealing with these changes.

The scope of the paper is to analyze the capacity of the existing water-relevant legislative framework at international, regional and local level vis a' vis its capacity to support adaptation, with the aim of providing certain suggestions about how and to which extent water legislation should be reformed in order to become sufficiently adapted. The structure of the analysis can be described as follows: The first section of the paper focuses on adaptation as a strategic policy response to climate change as well as its linkages with water issues. In the second section a preliminary analysis of the existing legislative framework for freshwater at international, regional and national level is conducted, with the aim of searching for the directions given and the approaches adopted in order to make water legislation adaptive. The third section of the paper pays attention to the paradigm shift that has already started taking place in environmental law in general and in water law in particular and has been accelerated due to climate change. In this context, the enhancement of the flexibility of the water allocation regimes at national and transboundary level is presented as one key area, on which efforts for making water legislation adaptive should focus. Finally, certain remarks are made, which relate to the challenges that the water law of the 21st century is facing.

## I. Adaptation as a policy response to climate change and linkages to water management

### A. The International level

Since its inception, the international climate policy has focused predominantly on striving as far as possible to reduce greenhouse gases in order to prevent dangerous climate change. This policy approach can be described under the key word "mitigation". However, the existing legal framework for climate change, namely the United Nations Framework Convention on Climate Change (UNFCCC)[25] and the Kyoto Protocol[26], does not provide an official definition for mitigation. Therefore, the relevant definition given by the Intergovernmental Panel on Climate Change[27] (IPCC), which defines mitigation "an anthropogenic intervention to reduce the *sources* or enhance the *sinks* of greenhouse gases", has become predominant in the international literature. Increasingly, however, the climate-driven changes are being recognized as irreversible and societies must take necessary measures to adapt to the impacts of these changes. This policy approach is described under the keyword "adaptation". The action to be taken to deal with the unavoidable effects of climate change is, though, not only a matter of necessity. It is also a matter of equity, as the impacts fail disproportionately on those least able to bear them[28]. The international climate change regime recognizes the need for adaptation, by setting several obligations to the countries to take adaptive action. As the legislative framework in place does not provides an official definition for adaptation, the definition given by the Intergovernmental Panel on Climate Change (IPCC), which defines adaptation as "adjustment in natural or human systems in response to the actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities", also is chosen in this case for the purpose of the analysis[29].

From a systematic point of view, mitigation and adaptation should be thus seen as complementary policy approaches, both necessary for an effective climate policy[30]. Mitigation and Adaptation strategies employ institutional, technological and behavioral options, the use of a wide range of

[25] 1992 United Nations Convention Framework Convention on Climate Change available at: http ://unfccc.int /2860htp (last accessed 3 November 2009)

[26] 1997 Kyoto Protocol to United Nations Convention Framework Convention on Climate Change, available at http://unfccc.int/kyoto-protocol/items/2830.php (last accessed 3 November 2009).

[27] IPCC, *Climate Change 2001 – Impacts, Adaptation and Vulnerability*, Cambridge University Press, p. 992

[28] See W.N Adger/J. Paavola/S.Huq/M.J Mace (Eds), 2006, *Fairness in adaptation to climate change*, MIT Press, p. 335pp.

[29] IPCC, *Climate Change 2001 – Impacts, Adaptation and Vulnerability*, Cambridge University Press, p. 992.

[30] For the complementary relationship between mitigation and adaptation see R.J. Klein/S. Huq/F. Denton/T.E Dowing/ R.G Richels/J.B Robinson/F.L. Toth, 2007, *Inter-relationships between adaptation and mitigation,* Climate Change 2007 – Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on climate change, Cambridge University Press, p. 750.

regulatory and economic instruments with aim to encourage the use of certain mainly behavioral and technological options as well as research and development initiatives for reducing uncertainty and increasing resilience of the ecosystems and the communities, although they have to some extent different orientations.

Besides the guidance provided by the definitions and the relevant analysis, the legislative framework establishing certain adaptation- related obligations for the Contracting Parties constitutes the critical source, where several directions of regulatory nature can be extracted concerning the *modus* and the *focus* of adaptation. The majority of the provisions related to adaptation can be found in Article 4 of the UNFCCC, as described bellow: 1) Article 4 par. 1 b in association with par. 8 and 9 of the same Article establish the obligation for the Parties to develop national plans to facilitate adequate adaptation to climate change (National Adaptation Plans) 2) Article 4 par. 1 e requires the cooperation of Parties in preparing for adaptation and requests to elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture as well as for the protection and rehabilitation of areas affected by floods or drought and desertification 3) Article 4 par. 4 establishes the obligation to the developed country Parties and other developed countries included in the Annex II of the Convention to assist developing country parties that are particularly vulnerable to the adverse effects of climate change. Furthermore, relevant in terms of providing the legal basis for establishing mechanisms to finance adaptation are also the provisions included in Article 11 of the Convention as well as Article 11 par. 2 b of the Kyoto Protocol[31] to the Convention.

The systematic analysis of the afore-mentioned provisions of the Convention as well as the methodologies and the tools applied by the relevant Work Programmes developed in this field[32] can thus, be helpful to draw up to certain conclusions relating to the approach and the directions to be followed, when elaborating and implementing adaptation strategies. The first conclusion relates to the recognition of *vulnerability* as the most crucial factor for assessing the adaptive capacity of the societies in the sense that society' exposure to climate change and subsequently its capacity to adapt are closely related to the level of its development[33]. There is no official definition for vulnerability in the UNFCCC and the definition given by IPPC[34], although enlightening, does not address the factors that determine vulnerability. With the help of the systematic analysis of the relevant provisions of the UNFCCC (article 4 par. 4) and the Kyoto Protocol (Article 12 par. 8), one can reach the conclusion that the vulnerability concept within the broader UNFCCC framework is used to describe those Contracting Parties that are in need of financial, technological and other forms of assistance. The second conclusion relates to the importance of adopting a strategic and integrated approach to deal with adaptation, which is a cross-cutting issue. In particular, a strategic

[31] Article 11 par. 2 of the Kyoto Protocol establishes the obligation to the developed country Parties to provide financial resources, including the transfer of technology, to meet the agreed full incremental costs incurred by developing countries in advancing the implementation of the commitments of Article 4 of the Convention. The afore-mentioned costs mainly include the adaptation cost to the adverse effects of climate change. In this context, it is worth mentioning that there are three funding mechanisms operating under the broader framework of the UNFCCC and the Kyoto Protocol to finance adaptation actions especially in the developing countries. These are the following : 1) The Special Climate Change Fund, which operates under the framework of the UNFCCC and finances long-term adaptation measures that increase resilience of national development sectors, such as water resources management, agriculture and health to the impacts of climate change 2) The Least Developed Countries Fund, which also operates under the UNFCCC umbrella, and finances the world's least developed countries to elaborate and implement the National Adaptation Programmes of Action 3) The Adaptation Fund, which is a quite innovative funding mechanism, firstly because its revenue is generated to certain extent through a 2% levy on the emission reduction projects under the Kyoto Protocol' s Clean Development Mechanism and secondly because there is a strong representation of the developing countries in its executive body, namely the Adaptation Board. For an assessment of the effectiveness of the Funds operating under the UNFCCC umbrella see M.J. Mace, *Funding for Adaptation to Climate Change: UNFCCC and GEF Developments since COP-7*, RECIEL, vol. 14, no. 3, 2005, p. 236-240. For a first assessment of the Adaptation Fund see B. Müller, *The Nairobi Climate Change Conference: A breakthrough for adaptation funding*, Oxford Energy and Environment Comment, January 2007

[32] There are two main UNFCCC Work Programmes, namely the Buenos Aires Programme of Work on Adaptation and Response Measures and the Nairobi Work Programme, that deal more broadly with adaptation and its interdependencies with several sectors, such as the coastal zones, agriculture and water resources. The main aim of the programmes is to help all countries to improve their understanding of the impacts of climate change and to make informed decisions on the appropriate adaptive measures. See UNFCCC 2007, Background Broschure on the Nairobi Work Programme.

[33] See Christoplos/S. Anderson/M. Arnold/V. Gataz/M. Hedger/R.Klein/K.de. Goulven, *The Human Dimensions of Climate Adaptation : The importance of local and institutional issues,* Stockholm Environment Institute, April 2009, p. 14ff.

[34] The IPPC defines vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. IPCC, *Climate Change 2001 – Impacts, Adaptation and Vulnerability*, Cambridge University Press.

response to the increased impacts of climate change should reach the full breadth of economic and development decision-making processes and the adaptation priorities and concerns should be subsequently streamlined into sectoral policies, such as energy, tourism and agriculture[35]. The National Adaptation Plans of Action (NAPA), which contain the basic directions and the specific adaptation measures, should subsequently reflect the afore-mentioned strategic and cross-sectoral approach. Finally, the third conclusion relates to the requirements that the adaptation strategies in several sectors as part of the general strategic framework (NAPA) should fulfill as well as their specific measures that should contain. In particular, as vulnerability is the key factor to assessing the adaptive capacity of communities or eco-systems, adaptation strategies and measures should be based on the results of the Vulnerability Assessments[36], which have to identify vulnerable areas and immediate and future adaptation priorities as well. Furthermore, in view of the scientific recommendations [37] that have been made, an adaptation strategy can be successful only if includes measures in all the steps of adaptation chain: 1) prevention measures 2) measures for improving resilience of the impacted system or sector 3) preparation measures 4) reaction measures and 5) recovery measures.

The question that can be raised at that point is whether the UNFCCC framework (legislative provisions and COP decisions) provide the regulatory basis for the integration of water issues into the core of the adaptation policies, taking into consideration that water is not only a source of life but also a key transmitter of climate change effects. The answer to the question cannot be any other than negative.

The lack of integration between water issues and adaptation policies within the existing legal and policy framework at the international level becomes obvious after a systematic analysis of the relevant legal provisions within the UNFCCC and the COP Decisions. In particular, only a reference for the elaboration of integrated plans for water resources as a means for adaptation can be found among the relevant provisions of the Convention, while there is not one single mention of water in any of the outcome documents from COP-13 and COP-14[38]. Furthermore, although the Nairobi Work Programme and other initiatives in this field constitute a remarkable effort to integrate water issues in the core of the adaptation policies, their contribution is not enough for placing water in the center of the adaptation agenda.

Therefore, future negotiations are of crucial importance in terms of raising the profile of water issues within the adaptation policy framework and ensuring the inclusion of a clear reference in the new climate agreement that is hoped to be agreed next December in Copenhagen.

**B. The regional (European) level**

As was the case at the international level, the focus of the European climate policy at its initial phases was on mitigation. The gradual recognition of the need for strengthening the adaptive capacity of the european countries to the adverse impacts of climate change has led to the publication of the Green Paper ''Adapting to Climate Change-Possibilities for EU action"[39]. This Green Paper was a first attempt to examine the impacts of climate change effects in several european regions and sectors and to identify possible adaptation actions at the EU level. Adaptation was recognized as a cross-cutting issue, so that it was acknowledged that the expected outcomes cannot be delivered by a single policy. Instead, concerted action in different policy areas deemed required. With regard to

[35] See I.Burton/E. Diringer/J. Smith, *Adaptation to Climate Change: International Policy Options*, Pew Center on Global Climate Change, November 2006, p. 12, available at : http://www. Pewcenter.org/docUploads/PEW _Adaptation.pdf, (last accessed 3 November 2009).

[36] See Draft Guidance on Water and Climate Adaptation elaborated by the Task Force on Water and Climate of the Convention of the Protection and Use of the Transboundary Watercourses and International Lakes, Geneva 24.4.2009, p. 61, where as vulnerability assessments defined the systematic efforts to delineate the places, human groups and eco-systems that are at highest risk, the sources of their vulnerability and how the risk can be diminished or eliminated. The draft Guidance is available at :http://www.unece.org/env/water/meetings/Water.and.Climate/second.meet/Guidance_on_Water_and_Climate_Adaptation_draft_for_Task_Force_03_04.doc (last accessed on 5 November 2009).

[37] See Draft Guidance on Water and Climate Adaptation, *supra* note 15, p. 67; I.Burton/E.Malone/H. Saleemul, *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures* in : B.Lim/E.Spranger-Siegfried (Eds), United Nations Development Programme, Cambridge University Press 2004, (Technical Paper 8 on Formulation an Adaptation Strategy).

[38] See Global Public Policy Network on Water Management on Water Management, *Water and Climate Change Adaptation-Key Messages for the 15th Conference of the Contracting Parties of the UNFCCC,* March 2009, available at : http://gppn.stakeholderforum.org (last accessed 3 November 2009).

[39] Green Paper from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of Regions, *Adapting to Climate Change-Possibilities for EU Action,* COM 2007, 354 final, Brussels 29.06.2007.

water policy, the Green Paper emphasized the importance of applying economic instruments and the user pays principle across all the water-related sectors, with the aim of providing incentives for reducing water consumption and increasing the efficiency of water use.

Following the Green Paper, the European Commission has published the White Paper on Adaptation to Climate change[40], which aims to increase EU' s resilience to the impacts of climate change by establishing a cross-cutting policy framework. In this context, a series of actions, focusing, among others, on human capital (e.g awareness raising, capacity building) and green infrastructure[41] are proposed. The White Paper recognizes water, including linkages to coastal and marine waters, as a key sector for applying adaptation measures and stresses the need for the proper implementation of the existing legal instruments (EU Water Framework Directive and EU Floods Directive) for increasing the resilience of water eco-systems.

At this point it has become evident that the linkage between climate change adaptation and sustainable water management is clearly recognized in the majority of the EU adaptation policy documents in comparison to what is the case at the international level.

## II. Freshwater Regulation at international, regional and national level-Directions and trends

Water Law creates the backbone of an effective water management at all different levels, from the international (mainly transboundary) to the local level[42]. A systematic analysis of the many regional and national water regimes leads to the conclusion that water law has at least to some extent incorporated the paradigm shift that has already started taking place in the water sector due to economic, societal and environmental changes (population growth and increasing water demand as well as increased water pollution). This gradual adoption of a more integrated regulatory approach in the protection and management of water resources has to be supplemented by new mechanisms and tools or by the enhancement of the existing ones, so that the legal and institutional regimes in place can provide the framework for dealing effectively with the new risks and uncertainties caused by climate-induced changes. At this point, a preliminary research in some important International and Regional Agreements as well as the relevant EU legislation is conducted in order to assess the impetus given to the national legislators to reform water law, where necessary, in order to support adaptation.

### A. The global level

The management and protection of shared water is regulated by an emerging regime of international law on freshwater, which is based on International Treaties, soft-law documents[43], such as declarations, customary law and general principles of international law. In terms of geographical coverage, there is only one *global* agreement with regulative focus on the management of international watercourses, their conservation and use for purposes other than navigation. It is the United Nations Agreement on the Law of the Non-Navigational Use of International Water Courses ("UN Watercources Convention")[44], which has not yet entered into force. Although it is not legally binding[45], the

[40] European Commission, White Paper, *Adapting to Climate Change-Towards a European Framework for Action,* COM (2009), 147 final, Brussels 1.04.2009.

[41] As green infrastructure is defined in the White Paper the interconnected network of natural areas, including some agricultural land, such as greenways, wetlands, parks, forest preserves and native plant communities, and marine areas that naturally regulate storm flows, temperatures, flooding risk, and water, air and ecosystem quality. See White Paper, *supra* note 19, p. 5.

[42] See A. Iza/R. Stein (Eds), RULE-Reforming Water Governance, IUCN, Gland-Switcher land 2009, p. 49 ff.

[43] Since the early 1990s international discourse has started focusing on the management and protection of water resources at transboundary and national level in quite a different way by adopting a more integrated approach and by incorporating sustainability into water management. This new approach is captured in a series of soft law documents, such as the Dublin Statement on Water and Sustainable Development, the Chapter 18 of the Agenda 21 and the Berlin Rules on Water Resources. See J. Dellapennna, *The Berlin Rules on Water Resources: The new Paradigm for International Water Law,* available at :http://www.ualg.pt (last accessed 4 November 2009).

[44] The Convention was adopted by the United Nations General Assembly on 21 May 1997. The concept of the Convention was based –to significant extent- on the Helsinki Rules on the Uses of the Water of International Rivers developed by the International Law Association. For the background of the evolution of the Convention see G. Eckstein, *Development of International Water Law and the UN Watercource Convention* in : A. Turton/R. Henwood (Eds), Hydropolitics in the developing world-A Southern African Perspective, African Water Issues Research Unit 2002, p. 81-96.

[45] The International Court of Justice cited the Convention as evidence of International Customary Law and underscored its importance when it referred to a number of its provisions within the Gabcikovo-Nagymaros case, a dispute between Hungary and Slovakia over Danube. See Case concerning the Gabcikovo-Nagymaros (hung/Slov) 1997, I.C.L 92 (Sept. 25), 37 I. L.M 162 (1998), available at : http ://www.icj-cij.org/idocket/his/ihsjudgment/ihsdocument/html7 (last accessed 4 November 2009).

Convention provides guidelines for establishing bilateral or multilateral transboundary water regimes, as it has codified a series of principles of customary law for management and protection of shared water, with the principle of equitable and reasonable utilization and participation (article 5) and the no harm rule (article 7) being the most important ones[46]. From a systematic point of view it was correctly argued [47], the drafters of the Convention limited their intensions and their efforts mainly in codifying existing customary law and did not focus on developing it progressively.

In this context, there is no any explicit reference for establishing an obligation to the riparian states to support adaptation within transboundary water management. This is quite understandable, especially when man takes into consideration the long period for the drafting of the Convention at which the climate change impacts on water sources had not been –even to a limited extent- recognized. The concept of optimal and sustainable utilization of a shared watercource set in Article 5 of the Convention is, though, open-ended, so that it can constitute the legal basis for any adaptation strategies and measures elaborated and implemented by the riparian states.

**B. The regional (European) level**

An important example of regulation of transboundary water courses at regional level is the 1992 Convention on the Protection and Use of Transboundary Watercourses and International Lakes ("Helsinki Convention"). In particular, the "Helsinki Convention" provides a sound legal framework for cooperation on shared water resources within the UNECE Region[48], which is more specific and sophisticated in comparison to the rather abstract and general rules of the UN Watercource Convention [49] . The "Helsinki Convention" does not provide any explicit reference relating to the impacts of climate change on water resources and subsequently the obligation for the Contracting Parties to take action. Despite the lack of a clear reference, the set of the guiding principles established in the Convention as well as the specific obligations foreseen for the Contracting Parties can constitute the basis for taking measures to support adaptation. In particular, the basic concept of the Convention relates to the establishment of a specific framework of cooperation with the aim to prevent, control and reduce the transboundary impacts relating to international watercourses and lakes (Article 2 par. 1 and 2 and Articles 9-16 of the Convention). To the trandboundary impacts defined as significant adverse effects on the environment resulting for a change in the condition of the transboundary waters caused by a *human activity* or physical origin (Article 1 nr. 2) are also included those impacts related to adaptation to or mitigation of climate change[50], although this is not mentioned explicitly. This is due to the fact that there is a far-reaching consensus in the scientific community that climate change is at least to certain extent caused by human activities. In this context, adaptation measures, such as construction of dams and reservoirs, can contribute substantially to avoiding negative transboundary impacts and to generate the best possible effects for the shared basin.

Furthermore, a strong regulatory basis for taking measures in the direction of the so-called proactive adaptation[51] provides the recognition of the precautionary principle (Article 2 par.5 lit a) as one of the guiding principles for the transboundary water management. This principle, which requires

[46] The principle of equitable and reasonable utilization is based on the recognition of the right of all riparian States to use water from a shared source only to the extent that these uses do not come in contradiction with the uses in another riparian State. Article 6 of the UN Convention sets a list of factors that have to be taken into account when balancing reasonable uses of a shared water resource. The principle of no harm, which is set in a quite weak formulation in Article 7, requires that riparian States have to take the appropriate measures to prevent the causing of any significant harm to the neighbouring states. See J. Dellapena, *The Customary International Law of Transboundary Fresh waters*, International Journal of Global Environmental Issues, Vol. 1, Nos 3/4, 2001, p. 264 (284ff).

[47] See J. Dellapena, *supra* note 25, p. 288; J. Dellapena, supra note 22.

[48] The Convention was concluded under the auspices of the United Nations Economic Commission of Europe ("UNECE"). The Convention has entered into force on October 1996 and has 36 Contracting Parties so far. The text of the Convention is available at :http://www.unece.org/env/water/pdf/watercon.pdf (last accessed 5 November 2009).

[49] See P. Patronos, *International Law, the EC Directive 2000/60 and the Protection and Use of Transboundary Watercources*, paper available at : http://www.nomosphysis.org.gr/articles.php?artid=1182&lang=2&catpid=12 (last accessed on 5 November 2009).

[50] See J. Timmerman/F. Bernadini, *Adapting to Climate Change in transboundary water management*, Perspective Paper developed to be presented in the 5th World Water Forum, p. 6, available at ttp://www.waterandclimate.org/index.php?id=5thWorldWaterForumpublications810 (last accessed on 5 November 2009).

[51] The *stimulus* is the crucial criterion for defining adaptive action as proactive or reactive. In particular, when actions are in response to observed climate impacts, we speak about reactive adaptation, while in cases that action is taken in anticipation of future climate change impacts, we speak about proactive adaptation. For the distinction see I.Burton/E. Diringer/J. Smith, *supra* note 14, p.10.

that action should be taken even before adverse effects are fully scientifically proven, is of immense importance in climate change adaptation, as high uncertainties exist regarding the exact impacts on water availability and quality. Relevant in terms of supporting a proactive adaptation approach in the field of transboundary water management is also the explicit recognition of the sustainability principle both in its broader context (Article 2 par. 5 c) with a distinctive future dimension [52] and in its narrow context as ecological sustainability (Article 2 par. 2 lit.b).

Another characteristic legal instrument EU Water Framework Directive (WFD) constitutes the central piece of legislation in the field of water policy. Although the WFD sets a consistent framework for Integrated and Sustainable Water Management[53], it does not, however, include any obligation for adaptation to climate change. Despite the lack of any explicit reference to climate change, the Directive provides the framework to address climate change impacts through the river basin planning process for a variety of reasons. First of all, it obliges Member States to assess environmental pressures in each river basin district (article 5 and Annex II), including subsequently pressures, which constitute the direct or indirect impact of climate change [54]. Furthermore, the Programmes of Measures which constitute an integral part of the RBMP and are designed to achieve the environmental quality objectives set for each river basin district, can include specific measures for climate change adaptation and also give emphasis to "no regret measures". Finally, the Directive provides that for the calculation of the level of the cost-recovery of the water services long term forecasts of supply and demand for water in each river basin district have to be taken into account.

In conclusion, it should be underlined that the rule-making at the global level is subject to lower common standards than in the more homogeneous regions[55]. This becomes evident in the case of the European Union, which as one of the most integrated regions, economically and politically, has also developed a more advanced framework for water management in legal, institutional and financial terms. This undoubtedly relates also to its capacity to support adaptation.

### C. National Water legislation and Regulatory trends

Not all the rivers are international and not all the aspects of transboundary river management are regulated at the international level. Almost every state in the world has set in place a legislative framework regulating the use of water resources in their territory and being to a larger or smaller extent influenced by the relevant legal developments at international and regional level. Most of the recent water law reforms at national level focus on the application of the so-called Integrated Water Resources Management (IWRM) concept [56], which has been promoted internationally in various fora. Sustainability in terms of respecting the carrying capacity of the eco-systems and being recognized as a core value of the broader sustainable development concept as well as social welfare concerns are incorporated into the concept of IWRM, which is defined as: "A process that promotes the coordinated development and management of water, land and related resources to maximize the economic and social welfare in an equitable manner without compromising the sustainability of

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[52] Article 2 par.5 c foresees the following : Water resources shall be managed so that the needs of the present generation are met without compromising the ability of future generations to meet their own needs.

[53] The basic regulatory choices of the Directive can be described as follows : 1) the adoption an integrated approach of all water-related aspects in terms of regulation, planning and governance 2) the protection of all kinds of water (surface and groundwater) 3) the choice of the river basin district as the organizing unit for river basin management 4) the setting of ambitious environmental quality objectives to be achieved within a defined timeframe (2015) 5) the introduction of an integrated planning process at each river basin district, which will result in the adoption of a management plan (river basin management plan-RBMP) 6) the participation of the public and the stakeholders in the planning and management process and 7) the recognition of water as an economic good (Article 9- the cost recovery principle). As regards transboundary river basins, the Directive provides (Article 17) that join environmental objectives should be set and that the elaboration and the implementation of Programmes of measures should be coordinated for the basin as a whole.

[54] It is correctly argued that, although direct climate impacts on water resources cannon be classified as "anthropogenic pressures" (Annex II of the Directive) in the sense that they cannot be mitigated by water manager's action, they can at least be considered as such, because these impacts interact with or aggravate other anthropogenic pressures. Moreover, pressures on water from human activities may change as a result of climate change mitigation efforts. See Ecologic, *Climate Change and the EU Water Policy –Inducing Climate Change in River Basin Planning*, November 2007, p. 4, available at : http://ecologic.eu/download/projekte/1850-99/1877/1877_climate_change_and_eu_water_policy.pdf (last accessed on 5 November 2009).

[55] See P. Patronos, *supra* note 28, p. 5.

[56] For the most important regulative concepts that have influenced national legislations see A. Iza/R. Stein (Eds), supra note 21, p. 20ff.

vital ecosystems [57] ". Unquestionably, the philosophy and certain elements of the methodology of IWRM are reflected not only in many national laws but also, to some extent, in many provisions of the UNECE Convention on Transboundary Waters and International Lakes and the Water Framework Directive, as described above.

Certain key attributes of IWRM suggest that it is an appropriate approach not only for an effective and sustainable water management but also a potential framework for streamlining adaptation concerns into water legislation. In particular, it can support decision-making in complex situations including cases with high uncertainty relating to water availability, because it provides both an analytical framework, which identifies the components and different steps in the analysis process, and a computational framework, which establishes capacity for data processing and quantitative comparison of alternatives. Furthermore, it encourages the structured engagement of communities, stakeholders and sectors impacted upon water in the planning and decision-making process, giving emphasis to the participatory approach in water management[58].

The other regulatory approach that has gained importance in the international discourse quite recently is the human-rights approach to water management, which asserts that humans have a right to water. The recognition of a human right to water[59] is associated with a state obligation to guarantee access to water services and mainly to potable water for all of its citizens. In spite of the fact that the human rights approach can raise certain questions about its regulative concept and the practical ways for its implementation, it seems to be helpful in order to set certain limits to any efforts to privatize basic water services, without safeguarding water security for the most vulnerable and marginalized people.

These two approaches do not seem to be mutually exclusive. This means that there are opportunities to seek synergies between them, with the aim to strengthen the social dimension of an effective, sustainable and adaptive water management. The main point though, is how to use the framework provided by these concepts and especially by the IWRM in order to make national water laws as well as bilateral and multilateral agreements adaptive by removing existing barriers and embedding new elements, where necessary. This will be analyzed in the next section of the paper.

## III. Making water legislation adaptive

### A. The paradigm shift in environmental law and its general influence

One of the major challenges that the environmental law currently faces, relates to the *modus* to be adopted and the instruments to be introduced, so that the law can develop its regulatory impacts ("Steurungwirkung [60] ") for pursuing legitimized objectives, such as environmental protection and public health under changing circumstances and a high level of uncertainty. In particular, law came up with a change in the "paradigm", on which environmental regulations at the initial phase were grounded and was based on the condition that natural ecosystems maintained a "relatively stable dynamic equilibrium" [61] . When the so-called "equilibrium paradigm" became invalid, the then laws fostering environmental protection were confronted with the challenge to set a framework that takes into account the inherent uncertainties associated with the complex and non-linear

[57] See Global Water Partnership, Technical Advisory Committee (TAC), *Integrated Water Resource Management*, Background Paper No 4, 2000.

[58] See Global Water Partnership, Technical Advisory Committee (TAC), *Catalyzing Change : A handbook for developing Integrated Water Resource Management and water efficiency strategies,* 2004.

[59] The United Nations Committee on Economic, Cultural and Social Rights has adopted in November 2002 the General Comment Number 15 (GC 15), "The Right to Water", according to which governments have several obligations in order to guarantee the enjoyment of the right by everyone without discrimination. See A. Iza/R. Stein (Eds), *supra* note 21, p. 22-23.

[60] The approach of the regulative impact (Steurungswirkung) of the legal norms was developed in the German legal theory. The basic idea on which this concept is grounded, focuses on the impacts which the implementation of the legal norms "produces", which in some cases are not those that the legislator had intended to, when the laws were adopted. This comes true, when the legal norms set do not meet the society' s expectations related to context of the regulation or when the implementation comes in contradiction with special economic or social interests that try to set obstacles. In accordance with the philosophy of this approach, one of the major challenges that the law has to come up with, relates to the formation of the legal norms in such a way, so that the "desired" effects are realized. See G.F Schuppert, *Grenzen und Alternativen von Steurung im Recht* in: Grimm (Hrsg), Wachsende Staatsaufgaben-Sinkende Steurungsfähigkeit des Rechts, 1990, p. 217ff.

[61] For the shift from the "equilibrium" to the "nonequilibrium" paradigm and its consequences on the regulatory context of the environmental regulations see Dan. A. Tarlok, *The "Non Equilibrium Paradigm" in Ecology and the Partial Unraveling of Environmental Law*, Loyala of Los Angeles Law Review, Vol. 27, 1994, p. 1121 ff; J. B Ruhl, *Thinking of Environmental Law as a Complex Adaptive System : How to Clean up the Environment by Making Mess the Environmental Law,* Houston Law Review, Vol. 34, 1997, p. 933 ff.

functions of the ecosystems. Environmental regulations, which are grounded on the "non-equilibrium paradigm", should be subsequently flexible enough to accommodate the ongoing environmental challenges and to adapt to unforeseen changes in the future. Moreover, modern environmental law has to regulate the risks [62] that constitute the "byproduct" of the scientific and technological development, a fact that has also influenced substantially its regulative concept. Furthermore, climate change and its wide-ranging effects related to precipitation, climate variability and extreme weather events have substantially intensified the challenges posed to the legal systems to cope with risk and uncertainty[63]. This becomes more than evident in the case of water law due to the already mentioned effect on water resources.

One of the major challenges that water law currently faces is to facilitate equitable and consistent adaptation to climate-induced changes in the water sector by incorporating new elements or strengthening existing ones, where necessary. The regulative context of water laws should also reflect in a clear way the adoption of a new "paradigm" for regulating issues regarding the protection and management of natural resources, as it will be described in the next section of the analysis.

### B. Conceptual elements of water legislation within the framework of adaptive management

From a systematic point of view, it should be at first underlined that any efforts undertaken to reform national water laws have firstly to take into consideration the directions contained in the relevant legislative provisions as well as the methodologies and approaches developed in the scientific community about the concept of the adaptation strategies and the types of measures to be used (preventive or recovery measures or measures to improve resilience). Furthermore, the coherent, comprehensive and progressive freshwater regimes at regional level, with the EU Water Framework Directive and the UNECE Convention on Transboundary Waters and International Lakes being viewed as leading examples, can play a role model function in terms of providing a framework concept, which leaves room for embedding adaptive elements into water legislation. The efforts to seek synergies between the directions given under the broader context of the international adaptation regime and the regulatory trends for water management and protection at the international, regional and local level can lead to certain conclusions relating to the approach to be adopted and the strategic priorities to be achieved, when reforming national water laws with the aim to become sufficiently adapted.

The first conclusion relates to the importance of adopting a strategic approach instead of undertaking piecemeal adaptation efforts. This should be reflected not only in the coordination of the designed measures but also in the streamlining of the regulative concept of water laws with the relevant laws regulating land-use or other natural resources. The second conclusion relates to the strategic priority goals[64] that have to be achieved, when reforming national water laws. These priority goals, which also indicate the basic directions on which adaptive water legislation should focus, are the following: 1) The reduction of the vulnerability of the societies and particularly of its more marginalized parts to shifts in hydro-meteorological trends and extreme weather event [65]. 2) The protection and restoration of ecosystems, which are critical for water resources and services[66]. 3) The matching of water demand with water supply mainly by increasing water efficiency[67].

Moreover, as already mentioned, the described concept of water law should reflect the new "paradigm" on which the laws regulating the

[62] For the definition of risk see U. Beck, *Risikogesellschaft-Auf dem Weg in eine andere Moderne*, Frankfurt a. Main, 1986, p. 25 ff; European Environmental Agency (Eds), Late lessons from early warnings, 2001, p. 168f. For the role of law to management of risks see C. Sunstein, *Risk and Reason, Safety, Law and Environment*, Cambridge University Press 2002; A. Scherzberg, *Risikosteurung durch Verwaltungsrecht: Ermöglichung oder Begrenzung von Innovationen*?, VVDStRL 63 (2003), p. 214ff.

[63] See B.H Thompson, Jr., *Tragically difficult : The obstacles to governing the commons*, Environmental Law, Vol. 30, 2002, p. 241 (253); M. Zinn, *Adapting to Climate Change: Environmental Law in a warmer world*, Ecology Law Quarterly, Vol. 34, 2007, p. 82.

[64] See G. Bergkamp/B. Orlando/I. Burton, *Change Adaptation of Water Management to Climate Change*, IUCN, Gland, Switzerland and Cambridge, 2003, p. 21-26.

[65] To achieve this strategic goal, better coordination between land and water planning in association with measures, such as risk zoning for floods or droughts, the use of early warning systems and the flood and drought preparedness programmes seems to be necessary. See G. Bergkamp/B. Orlando/I. Burton, *supra* note 43, p. 22.

[66] Towards this direction measures to restore downstream wetlands, such as flood storage areas and restoring or preserving mountain forests to reduce erosions and peak flows should be introduced. See G. Bergkamp/B. Orlando/I. Burton, *supra* note 43, p. 23.

[67] Towards this direction, the prioritization of water uses, the reform of water allocation regimes, where necessary and other demand-side measures, such as the re-use of return flows and desalination are deemed necessary. See G. Bergkamp/B. Orlando/I. Burton, *supra* note 43, p. 25..

protection and management of natural resources should be based. This new paradigm, except for the consideration of the non-linear function of the eco-systems, should incorporate especially in the field of water law, the philosophy and the methodology of the so-called "adaptive management" as an approach of dealing not only with environmental but also with quantifiable uncertainties. The concept of "adaptive management" is based on the fundamental assumption that the human ability to predict the future key drivers of any given eco-system and the system behavior and responses is inherently limited[68]. This assumption becomes even more relevant due to the added uncertainty caused by climate change. As a response, adaptive management requires a structured process of active learning by all stakeholders and the continuous improvement of management practices and measures by incorporating the insights of the experience gained from the outcomes of the implemented policies.

Reasoning from the logic of adaptive management in general in conjunction with the concept of Integrated Water Resource Management,, one can reach the conclusion that key features of adaptive and integrated water legislation can be the following 1) the setting of certain quality objectives that have to be in line also with the carrying capacity of the aquatic ecosystems and the limited water supplies 2) the establishment of a management regime preferably at river basin level to achieve the quality objectives, which should be characterized by an experimental character 3) the setting of data collection and monitoring mechanisms for the water quality and availability 4) the establishment of "intelligent" institutions that can go beyond day to day management and can also have an open dialogue with the scientific community and society 5) the introduction of policies and instruments flexible enough to incorporate and respond to the continuous flow of scientific information. In particular, among the variety of instruments used, water allocation regimes should be assessed and, where necessary reformed, in order to be more responsive to change[69]. It becomes obvious that evident that the legislation and the policies introduced have an "experimental" and "provisional" nature in the sense that they are substantially based on a "learning by doing" process[70]. After the description of the directions and the conceptual elements that adaptive water legislation should include, emphasis is placed on searching for directions with the aim to enhance the flexibility of water allocation regimes at national and transboundary level. This is due to the fact that it is being viewed as one of the most difficult tasks within the broader framework of adaptive water management.

### C. Flexible water allocation regimes as a cornerstone of adaptive water legislation

#### 1. The national level

As the most profound impacts of climate change on water resources relate to the changes in precipitation and subsequently to the reduction of the water available, flexible and equitable allocation of this scarce natural source becomes one of the hardest tasks. In this context, existing allocation regimes established in the majority of national water laws worldwide should be assessed in terms of their capacity to adapt to annual or seasonal changes in water availability. A systematic overview of the different allocation regimes leads to the conclusion that there are two principal approaches to water rights. The first approach is that of the private water rights that confer on the holder the full set of property rights and are the closest approximation to the so-called "ownership" of the water. One constellation of this system of water rights is applied in the South-Western USA and is governed by the "prior appropriation" doctrine, which gives priority to the older rights ("first in time, first in right"). This means in particular that the first rights holder acquires the superior legal right, while the junior water rights holders are the first to lose access in times of water shortages[71]. Although at this point no comprehensive analysis for the advantages and disadvantages of this concept from an economic, social or environmental perspective can take place, it should be underlined that serious doubts can be raised about its

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[68] See C. S Holling, *Adaptive Environmental Assessment and Management*, New York 1978; C.J Walters, *Adaptive Management of Renewable Resources*, New York 1986; W.T Coleman, *Legal Barriers to the Restoration of Aquatic Systems and Adaptive Management,* Vermont Law Review, Vol. 23, 1998, p. 177ff.

[69] See J. C. Neuman, *Adaptive Management: How Water Law needs to change,* Environmental Law Reporter, Vol. 31, 2001, p. 11432 (11434).

[70] See J. C. Neuman, *supra* note 48, p. 11434; C. Bruch, *Adaptive Water Management : Strengthening Laws to cope with Uncertainty* in : A.K. Biswas/C. Tortajada/R. Izquiero (Eds), Water Management Beyond 2020, Springer Verlag 2009, p. 89 ff.

[71] See St. J. Shupe, *Waste in Western Water Law: A Blueprint for Change*, Oregon Law Review, Vol. 61, 1982, p. 483ff; D. Tarlok, *How well can International Water Allocation Regimes Adapt to Global Climate Change,* Journal of Land Use and Environmental Law, Vol. 15, 2000, p. 423 (429).

compatibility with the concept of adaptive and sustainable water management, mainly because it cannot enable the consideration of ethical, environmental and legal limitations relating to water use and consumption[72]. It can be thus assumed that due to the incapability of the private water rights regimes to support sustainable and adaptive water management, new or reformed water laws should keep water rights under the public domain[73].

The second approach is that of the use or usufruct water rights, which is based on the concept of the "public ownership" of water. The right of water abstraction is granted through an allocation licensing system [74] and is thus relative and conditional, because the licenses given determine clearly how much water can be taken and for which purposes. Licenses are also of limited duration. It becomes thus obvious that the concept of the usufruct rights with the licensing system as its cornerstone sets certain limits and conditions to the water use and can unquestionably contribute to the conservation and protection of waters by preventing over- allocation and pollution. Furthermore, abstraction licensing system provides the appropriate framework for an enhanced implementation of any decided prioritization of water uses, which is a crucial component of water policies as a response to the unforeseen climate-induced changes relating to water availability. Moreover, it can make licenses for water abstraction more flexible by introducing options for relief, in cases where water levels are low and by incorporating low flow values, below which abstraction would be not possible[75]. Taking into consideration the strengths of the concept of the usufruct water rights, it can be assumed that this regulatory regime has a high degree of compatibility with the model of sustainable and adaptive water management. This does not imply that all the existing licensing allocation schemes are already flexible enough but only that the philosophy and the methodology of the concept will allow build in flexible options without further constraints.

In this context, one of the major tasks of the national legislators when introducing or reforming water laws is to establish a transparent water licensing system, which not only enables the orderly allocation of a scarce resource but also leaves room for modifications of the sharing water rules as response to changing circumstances. The ultimate goal of any effort to introduce or mainly reform water allocation schemes is thus to establish effective and equitable risk regulations, being characterized to some extent by a provisional and experimental character. Towards this direction, central elements of a flexible and simultaneously fair allocation regime could be the following: 1) the setting of clear-cut criteria on which the prioritization of water uses should be based, including also the consideration of social and environmental needs 2) the detail setting of the standards conditions for granting licenses 3) the introduction of the periodic review of water allocation as the rule governing allocation regimes in association with the possibility to include special provisions in water licenses addressing both quantity and quality variability 4) the establishment of registries of the granted licenses and of strong mechanisms to regularly monitor the compliance of the users' withdrawals with the terms set in the licenses as well as the condition of the scarce resource 5) the introduction of penalties mainly of administrative nature provided for the cases of breaching the licenses' terms[76]. Finally, it should be emphasized that the legislative framework in place also has to include certain provisions so that a fine balance is struck between the flexibility in water allocation and the relative security of the water-related investments[77].

## 2. The transboundary level

Similar issues relating to the necessity to build in flexibility are also raised within the concept of transboundary water agreements, which not only establish the legal and institutional framework for the management and the protection of the shared

[72] One of its most important disadvantages is that it cannot provide the framework for setting limits to over-abstraction and subsequently cannot contribute to avoiding the quality degradation of the scarce resource. Moreover, it does not seem flexible enough to respond to changes in water availability and to the aquatic needs of the environmental eco-systems (i.e environmental flows). See J.C Neuman, *Beneficial Use, Waste and Forfeiture: The inefficient search for Efficiency in Western Water Use,* Environmental Law, Vol. 28, 1998, p. 919;

[73] . See A. Iza/R. Stein (Eds), *supra* note 21, p. 54.

[74] The European Water Framework Directive requires every Member State to have an abstraction licensing system in place (Article 11 par. 3 lit (e)).

[75] See E.Levina/H.Adams, *OECD, Domestic Policy Frameworks for Adaptation to Climate Change in Water Sector, Part I :Annex I Countries*, (COM/ENV?EPOC/IEA/STL (2006) 2, May 2006. p. 32.

[76] See A. Iza/R. Stein (Eds), *supra* note 21, p. 55 ff; E.Levina/H.Adams, OECD, supra note 54, p. 32-33.

[77] See T. Le Quense/G. Pegram/C. von der Heyden, Allocating Scarce Water, A primer on water allocation, water rights and water markets, WWF UK, 2007, Godalming UK, available at: http://assets.wwf.org.uk/downloads/scarce_water.pdf (last accessed on 18 January 2010) ,

resource but also often set the amount of water the upstream riparian delivers to the downstream[78]. Typically, such treaties are used to allocate water on the grounds of the assumptions of water availability drawn from historical precipitation patterns. These patterns are, though, no longer valid. Since either climate-induced changes or other socio-economic factors can hinder the (upstream) riparian's ability to supply the volume of the water provided in the transboundary water agreement, it is of crucial importance to establish the appropriate mechanisms within agreements in order to accommodate the changes in water availability[79]. The inclusion of mechanisms into the treaties for enhancing the flexibility to cope with water variability is, though, a task even harder than the similar task at the national level. This is due to the fact that the difficulties caused by uncertainty and climate-induced changes are added to those that are the consequence of the historical, cultural and legal differences already existing in the shared basins, which are regulated by the relevant transboundary water agreements. Therefore, the absence of such mechanisms in the majority of the trnasboundary agreements can be interpreted mainly as a lack of political will and not as a lack of awareness[80]. Yet as water crisis (raising numbers of extreme weather events and changes in water availability), have started to emerge in the shared basins, political and legal approaches that do not take sufficiently into account the new circumstances, would not only be ineffective, but they could even lead to major political crises.

Although at this point no extensive analysis about the variety of the relevant mechanisms as established in the Treaties can take place, certain remarks are made, which focus on the *modus* to be adopted and the options available towards enhancing the flexibility of water allocation regimes. The first remark relates to the significance of considering not only the optimistic water availability scenarios but also the extreme hydrological values, when negotiating or reviewing existing transboudary water agreements[81]. Furthermore, options for making more flexible the water allocations to be delivered from the upstream to downstream riparian countries should be examined during the negotiation process and then consensus for one of them should be reached. Another option, which reflects the approach of the water allocation rules regarded as risks regulations and subsequently emphasizes the "periodical" and "experimental" character of the norms, is the one that provides for the periodic review of the allocation rules by setting a specific provision in the Treaty[82]. Finally, it should be underlined that any effort to pursue a more flexible and equitable water allocation at transboundary level can be successful only if it is undertaken and implemented by joint institutions (i.e river commissions) in the shared basin. These institutions should be granted a strong mandate and a wide scope and jurisdiction, which goes far beyond their basic competencies (i.e control and monitoring of water uses or the regulation of water infrastructure development) and can even include a conflict-resolution mechanism, in order to have the capacity to handle effectively delicate issues with important political implications[83]. The adoption of a participatory management approach by the joint bodies and the promotion of a continuous and active dialogue with all relevant stakeholders is also important in terms of increasing the legitimacy and the efficiency of the decisions taken.

## IV. The Epilogue

Climate change and its wide-ranging effects have accelerated the paradigm shift that has already started taking place in environmental law. This is more than evident in the field of water law, where the assumptions on which regulations were based, are no longer valid due to the intensification of extreme weather events and the unforeseen changes in water availability. Despite the difficulties that the climate change, which it is

[78] See E. Benvenisti, *Collective action in the utilization of shared freshwater : the challenges of international water resources law*, The American Journal of International Law, Vol. 90, 1996, p. 384-415; I. Fischhendler, *Legal and institutional adaptation to climate uncertainty : a study of international rivers*, Water Policy, Vol. 6, 2004, p. 281 (282-284).

[79] See P. Gleick, *Water and conflict, freshwater resources and international security*, International Security, Vol. 18, p. 79ff; I. Fischhendler, *supra* note 57, p. 282.

[80] See I. Fischhendler, *supra* note 57, p. 298.

[81] See Draft Guidance on Water and Climate Adaptation, *supra* note 15, p. 33.

[82] See G.T.Raadgever/E.Mostert/N. Kranz/E.Intewies/J.G. Timmerman, *Assessing Management Regimes in Transboundary Rivers : Do they support adaptive management ?*, Ecology and Society, Vol. 13 No.1, Art. 14, available at : http: //www.ecologyandsociety.org/vol13/iss1/art14 (last accessed on 5 November 2009).

[83] See E. Feitelson/M. Haddad, *Identification in Joint Management Structures for Shared Aquifers, A comparative Palestinian-Israeli Effort*, World Bank Technical Paper No 415, The World Bank, Washington D C 1998, p. 10ff. Swedish Ministry for Foreign Affairs, *Transboundary Water Management as an International Public Good,* Stockholm, 2001, available at: http://docs.watsan.net/Downloaded_Files/PDF/ODI-2001-Transboundary.pdf (last accessed 9 November 2009); I. I. Fischhendler, *supra* note 57, p. 283-284.

regarded as the most important pressure on water resources, as well as other factors (e.g increasing population and increasing water demand), pose on the water management institutions, they should be seen not as threats but as catalysts for better water management.

Water law is the most important means for pursuing the goals of an efficient, equitable and sustainable water management under the newly emerged circumstances. Towards this direction, national water laws should adopt a more integrated and “learning by doing” approach. The relevant regulations have thus to be reformed substantially in order to improve their responsiveness to climate change impacts and to provide a flexible and effective framework for robust management practices, while taking strongly into account social and environmental needs. At the transboundary level, the water crises that are expected to be intensified as consequence of the increasing water scarcity, make it more than necessary to promote a culture of trust among riparians. This should eventually result in the adoption of clear-cut and simultaneously flexible (allocation) rules within the transboundary agreements and in the establishment of joint bodies that not only have strong mandates and but also promote new forms of collaborative governance.

# Premises for Large-Scale Implementation of Distributed Generation in Romania

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**Abstract**

*In the recent years a remarkable turn from centralized systems for electricity generation to decentralized ones has been observed due to the technological innovations and to the radical changes in the economic and regulatory fields. Distributed generation is gradually introduced as an alternative solution to confront with serious issues which have emerged from the traditional development and operation of power systems. Mainly, these issues regard the high cost and time consuming infrastructure required for the construction of new generation plants and transmission lines and their proven environmental consequences. Additionally, these facilities are related with centralized planning policies, which is an obvious contradiction with the new trend guided by the electricity market liberalization.The benefits from the development of DG mainly come up from its flexibility in the new liberalized market and the environmental friendliness it exhibits. Since power reliability is one of the major concerns especially for customers with important loads (e.g., industries, hospitals) the liberalization of electricity market gives them the opportunity to invest in DG facilities in order to reassure their power needs and therefore increase the overall system reliability. However, some important difficulties are met towards the direction of DG development. First of all the specific technical issues have to do with the drastic influences brought by DG to the grids. While DG may provide adequate support to power quality, the large-scale implementation of DG schemes can create problems related with voltage stability, reactive power support and short-circuit levels. Additionally, financial reasons impede a fast and wide-spread evolution of DG. The capital costs/kW required for the construction of DG units is still high compared to large central plants mainly due to the fact that DG technologies are considered new (microturbines, PV).The paper presents the economic and technical barriers for the penetration of DG in Romania, the necessary regulatory measures that would contribute to a secure and economical integration of DG and the priorities for further research that has to be carried out for fundamental innovations in the Romanian grid.*

**Keywords:** distributed generation, decentralized systems

## 1. Introduction

Mitigating climate change and achieving the reduction of greenhouse gas emissions requires development and dissemination of new or improved low-carbon energy technologies. In addition to R&D efforts, effective policies, regulations, market deployment strategies and economic tools need to be part of a comprehensive approach.

Distributed generation have, in the long term, the potential to make a large contribution to the EU energy supply, achieving security of energy supply and environmental sustainability. The main targets are to:

- Decrease the cost of electricity and fuel supplies to competitive levels developing highly efficient concepts and achieving major cost reductions in the entire production chain;
- Improve reliability, safety, availability, system efficiency and durability with long maintenance intervals of electricity supply.

Transforming the conventional power transmission and distribution grid into a sustainable, unified and active energy service network with a large share of DG requires new concepts and systems for planning, control and supervision.

In Romania DG utilization is making its first steps. In the last years the interest of investors in installing wind power plants (WPP) has increased considerably. It is expected that the investments in such DG technologies will grow even more due to Romania's efforts to comply with the new European energy policy and to promote the use of RES and DG.

The potential for renewable energy sources is very high and some successful projects are in place, but the investment rate in the renewable sector is quite low. Romania has seen improvements in energy efficiency and energy intensity, yet it has a long way to go from this perspective when compared to the EU Member States.

## 2. Structure and prospects

In the total participation of RES to the power balance hydro energy has the biggest share. Romania has a long tradition in using hydro energy for electricity production. Hidroelectrica, the state-owned company that dominates the field of power generation by hydropower sources, has 275 power plants and power pumping stations summing up an installed capacity of 6,374 MW with a power generation in an average hydrological year of 19,772 GWh. The main output comes from large hydropower plants. From the total installed capacity 91.5 MW is in power pumping stations and 244.5 MW in power plants with an installed capacity less than 10 MW. In 2008 the electricity production in hydropower stations was 17 TWh.

Until 2011 Hidroelectrica has plans to put in operation 26 new hydro plants that could enhance the installed capacity with 392 MW and increase the electricity production with 1,400 GWh/year. Also until 2016 Hidroelectrica intends to refurbish power capacities with a total installed capacity of 3417 MW meaning 333 GWh/year.

According to the development strategy of Hidroelectrica it is forecasted that 70% of the hydro potential will be used up to 2025 (compared to 50%, which is today) and the electricity production will reach 24 TWh for an installed capacity of 9,000 MW.

At present in Romania the installed capacity in wind turbines is 11 MW. The wind power is the only renewable source for which there are important projects because there is a great number of private investors interested in installing new wind generation capacities. So far the TSO has received requests for grid connection for about 7,000 MW. In the present situation the NPS cannot integrate such a high wind generation capacity. For the safe operation of NPS, the installation of a certain wind capacity with a variable power generation means the existence of some reserve units of similar capacity and with high flexibility in operation. In these conditions it is estimated that in a first phase only 1,000 – 1,500 MW will be integrated into the NPS. So far the TSO has issued connection agreements for an installed capacity of 900 MW.

In the last years there was a certain increase in solar electric utilization but it is not expected to have a significant contribution in the power balance mainly due to the high investment costs.

## 3. RES-E targets

**GD 443/2003 regarding the promotion of electricity production from renewable sources** settles for 2010 a target of 33% quota (including large hydro) for the electricity produced from renewable sources in the gross domestic electricity consumption.

Additional to the 33% quota for 2010, **the Energy Strategy of Romania for the period 2007 – 2020** settles a target of 35% in 2015 and 38% in 2020 of RES-E in the gross domestic electricity consumption.

## 4. Existing legislation

Despite the great renewable potential of Romania the investments in this field are in a pioneering phase due to the fact that the legislation for RES promotion has been developed only recently.

The Romanian energy market is regulated by the new Energy Law no 13/2007 and the secondary legislation issued by the National Authority for Energy Regulation. The secondary legislation includes:

- Wholesale Electricity Market Commercial Code (revised version)
- Network Codes (Grid Code – revised version, Distribution Code)
- Metering Code
- Technical and commercial regulations
- Tariffs methodologies
- Authorizations and licenses
- Rules regarding the connection to the networks
- Performance standards

The Romania's main energy regulatory framework is summarized below:

| Act | Main content |
| --- | --- |
| Law 220/2008 | Establishes the promotion system for RES electricity generation |
| GD 750/2008 approving state subsidies for RES utilization | Approves state subsidies in order to support initial investments in RES projects for heat and electricity. |
| GD 90/2008 | Regulation regarding the interconnection of generators to the power grids of national interest |
| Energy Law no 13/2007 | Creates the regulation framework for activities from the sector of electricity and heat produced in cogeneration, taking into account the security of supply, the optimal utilization of primary energy resources and the environmental protection. Also provides general provisions regarding promotion of electricity produced from renewable energy and cogeneration.<br>Transposes articles from the EU Directive 2003/54/CE concerning common rules for the internal market in electricity and repealing Directive 96/92/EC and provisions of Directive 2004/8 CE on promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EC |
| GD 1844/2005 on promoting the use of bio-fuels and other renewable fuels for transport amended by GD 456/2007 | Transposes into the national legislation the provisions of the Directive 2003/30/EC for promoting the use of bio-fuels and other renewable fuels for transport |
| GD 1535/2004 approving the *National Strategy for Renewable Energy Sources Utilization* | Calculates the renewable energy potential in Romania and defines the strategy for RES utilization up to 2015. |
| GD 1892/2004 completed by GD 958/2005 | Establishes the promotion system for electricity production from renewable sources |
| GD 1429/2004 | Approves the regulation regarding the origin certification for the electricity produced from RES |
| GD 443/2003 *regarding the promotion of electricity production from renewable energy sources* - amended by GD 958/2005 | It was adopted in order to comply with the EU RES-e Directive 2001/77/EC. Establishes the legal framework needed for the promotion of the program for increasing the RES contribution to the electricity production having in view the actual potential of these sources. |

## 5. Promotional prices for RES

In Romania the mandatory quota system combined with the green certificate trading system is applied. The mandatory quotas settled vary from 8.3% for the period up to 2012 to 16.8% in 2020.

The electricity producers receive from the transport and system operator (TSO):

a) one green certificate for each MWh of electricity produced in new HPPs or refurbished HPPs with an installed power up to 10 MW and delivered into the network
b) one green certificate for each 2 MWh of electricity produced in HPPs with an installed power between 1 and 10 MW, other than those mentioned at a), and delivered into the network
c) two green certificates for each MWh of electricity produced in HPPs with an installed power up to 1 MW and delivered into the network
d) two green certificates up to 2015 and one green certificate starting with 2016 for each MWh produced in WPPs and delivered into the grid
e) three green certificates for each MWh produced from biomass, biogas, bioliquids, geothermal energy, etc. and delivered into the grid
f) four green certificates for each MWh produced from solar energy and delivered into the grid.

The green certificates can be traded on the green certificates market aside from the RES electricity produced.

The price of green certificates varies in a range established by the National Energy Regulatory Authority (ANRE). For the period 2008-2014 the annual minimum and maximum values for green certificates trading is 27 Euro/certificate, respectively 55 Euro/certificate.

The suppliers that fail to cover the annual quota of green certificates must pay to the TSO the value of the certificates they did not purchase (70 Euro/certificate). The penalties are collected by the TSO and used annually for investments in the national grid for facilitating the access of electricity producers.

## 6. Regulatory obstacles to the deployment of DG and necessary legislative and regulatory measures

The main regulatory framework for promotion of power generation from RES (including DG) has been created in Romania. Also the Regulator issued the entire regulation package needed for applying the promotion mechanism for RES electricity production.

Analyzing the legislation in force a number of elements that can negatively influence the deployment of distributed generation have been identified. These obstacles can be removed by the application of a number of appropriate legislative and regulatory measures:

a) Responsibilities in the promotion of energy from RES

*Obstacle*

Analyzing the regulations enacted so far we have noticed that responsible for RES energy promotion are mentioned a number of institutions and state administrative authorities (Ministry of Economy, local authorities, ANRE, ARCE) that are not appointed by law to execute economic activities (execution of pilot projects in the RES field, implementation of new execution projects for new capacities, etc.) and do not have a specific apparatus for developing such activities. The established responsibilities and competencies in the field of RES are not clear. The management of such activities of a special importance for the country can only be achieved by dedicated structures.

*Measure*

- Creation of a management body within the Ministry of Economy and Finances dedicated to the activity of RES energy promotion and achievement of RES strategy goals.

b) Elaboration of national potential for CHP

*Obstacle*

Romania adopted into its national legislation the provisions of EU directive 2004/8/EC by enacting GD 219/2007 concerning the promotion of cogeneration based on a useful heat demand. So far secondary legislation has been elaborated for the:

- adoption of the harmonized reference values and of applicable correction factors;
- procedure for issuing the guarantees of origin for the electricity produced in cogeneration of high-efficiency;
- approval of bonus-type support scheme applied to the cogeneration electricity production.

However no steps have been made towards the elaboration of an analysis for the national cogeneration potential of Romania.

*Measure*

- Analysis for the national potential of high-efficiency cogeneration of Romania

c) Cost allocation

*Obstacle*

The electricity suppliers are obliged to purchase the electricity produced in cogeneration or by RES, then the grid operators have to ensure the priority connection of all RES or cogeneration units. This means that the grid operators have to make investments for the integration of such generators.

There is a number of disaggregated cost components describing total integration costs of intermittent DG generation technologies: DG power plant, grid connection, grid reinforcement/upgrading, short-term system balancing, long-term system adequacy. The costs that affect the grid operators are related to:

- grid strengthening and development
- back-up capacities from other power plants that have to be kept in reserve for cases of total generation outages of DG, such as WPP, as well as for balancing variations in wind energy injections
- development of new activities.

All these costs are submitted to the regulator for approval and then they are reflected in the price of the consumers.

The regulations related to DG integration into the grids should take into consideration future responsibilities and corresponding investment needs of grid operators (e.g. for the “transformation” of existing passive distribution grids into actively managed distribution networks absorbing large-scale distributed and intermittent RES generation) including an adequate cost allocation solution to encourage a large DG integration at a minimum cost to society.

*Measure*

- Approval of a procedure for DG integration into the grids and development of a mechanism for determining a fair cost allocation to distribution and transmission companies for distributed generation integration

d) Inventory of RES

*Obstacle*

The potential for renewable sources is quite old and its values are calculated at country level. No updating of the RES potential maps has been done so far and the protected areas are not excluded from the potential maps. The lack of knowledge about the protected areas on which constructions are not allowed creates many times problems to the DG investors in obtaining the environmental permit.

Also there is no centralized database regarding the areas with RES potential or a portfolio of RES projects to help the investors in selecting their investment location. In many situations, foreign investors had to "visit" many organisms of the local and central administration without finding an answer to their questions.

*Measure*

- An inventory of renewable energy sources by sources and regions and exclusion of protected areas from the RES potential maps

e) Improvement of administrative procedures

*Obstacle*

Project developers need to obtain an entire package of permits and approvals from a series of state and municipal authorities, depending on the project specifics. Having to deal with the Romanian administrative system this process of obtaining all approvals is very heavy and time consuming and could take up to two years, which brings to delays for the investment project. This could be a serious obstacle in the deployment of DG, therefore it is important to achieve a reduction of bureaucracy in the process of obtaining environmental and local permits.

*Measures*

- Establishing procedures for DG project proposals and diminishing the response times
- Improvement of the "Guide for RES electricity producer" with information related to the authorization procedure for a RES generation capacity construction. This Guide, recommended by the EU Directive 2001/77/CE, needs to be improved and completed for a better information of the investors in DG capacities

## 7. Research priorities

In order to integrate DG to the Romanian power system there is a need for sustained research and measures to overcome the obstacles of regulatory, economic and technical nature. The following research priorities have been identified:

### 7.1 Assessment of the RES and CHP potential

The RES potential studies are quite old and they need to be updated by taking into account the actual Romanian economic premises and the latest technologies available.

It is also important to make an inventory of the renewable sources existing in Romania at present, by sources and regions. Within this inventory all the regions with maximum exploitable potential by type of RES should be identified. All this information is necessary to be made available for the DG investors for their good orientation and support.

On the other hand, CHP is used in Romania at district heating companies and at large industrial enterprises where there is large-scale heat demand. The economic prospects of CHP are very good in all sectors and the acceptable price for heat delivery allows good competitiveness at the final consumers. With the new GD on the promotion of cogeneration based on a useful heat demand it is expected an increase in CHP potential utilization. Therefore studies for CHP potential need to be carried out.

### 7.2 Technical priorities

Romania is confronted with a huge request for electricity production in wind power plants with installed power ranging from 2 MW up to 255 MW grouped in wind farms. The solution studies carried out by ISPE (for more than 4,000 MW) emphasized a series of problems related to mainly two important issues:

- the connection possibilities;
- how the NPS grid should react when it has to deal with a power source with random and intermittent operation mode.

The problems signaled in relation to the grid connection are the following:

- limited possibilities of the existent networks (distribution as well as transport) to evacuate the power produced by the wind farms;
- the effects of wind farms connection to the grids, especially regarding the voltage level and the power quality

***a) Impact of DG on the design and operation of the grid***

The search for technical solutions has started in Romania by solutions studies regarding the DG connection to the grid that have been carried out as a response to the recent large interest of investors in wind power.

The solution studies highlighted the following aspects:

- At MV level (20 kV)
  - connecting WPP of maximum 10 MW - due to the reduced capacity of the evacuation line or due to the risk of overpassing the short circuit capacity of the interconnection substations
  - difficulties in maintaining the flicker effect in the limits set by the technical norms for the 20 kV grids
  - problems in keeping the voltage in its admissible limits
- At HV level (110 kV)
  - need of tele-transmission means on the 110 kV lines (e.g. optical fiber) which requires additional expenses for the connection options of a WPP directly to an existing line
  - Romanian HV grid is apparently well developed but it will not be sufficient for all DG producers, therefore the distribution network needs to be developed and research is needed for its transformation from a passive network into an active one
- At transport network level (220 kV, 400 kV)
  - The Romanian power system does not have enough quick start tertiary reserves which are required not only for wind operating systems. So far technical connection permits have been issued for 1,650 MW but according to the analyses of the National Dispatch Center (DEN) quick start tertiary reserves are available for only 800 MW

***b) Research in grid elements***

Having in view the recent orientation of investors towards the production of electricity in wind power plants it is very important to make efforts in the direction of using last generation of power electronics and invertors available in countries with better experience in DG in order to improve the reliability and flexibility of the distribution system

Also the Romanian research community needs to focus on the improvement in manufacturing, design and technology in order to achieve the performance targets.

Together with researches in converter topologies and control, the use of new materials for semiconductors and magnetic components could significantly contribute to the increase of performance.

On the other hand, Information Communication Technology (ICT) is a compulsory requirement for a performant grid management. In Romania there is a foundation for this type of management – the dispatching system is organized on levels (national, territorial, zonal, local, enterprise level) but the existing communication means are generally suitable for 110 – 400 kV grids. Due to the limited possibilities for financing innovations in the network, ICT implementation should be carried out gradually, after a preliminary plan taking into account the priority of urgent needs, expenses and time needed for their introduction.

***c) System research***

- *Assessment and improving the grid possibilities to integrate DG*
  - studies regarding the impact of WPPs on the national power system (NPS) emphasized that the use of dimensioning criteria applicable in the case of classical power plants is not conclusive. For instance, the connection solution analysis cannot be done only at peak load - DGs like WPPs cannot be planned so that they cannot be correctly considered in covering the load curve; the distribution and transport grids require strengthening investments for wide penetration of DG
  - Another problem that is not yet solved in Romania is the calculation of the transitory stability
- Another very important issue that is still in discussions phase is the wind forecast - no proper solution for this issue – for instance, a cooperation between the TSO, the National Agency for Meteorology and wind dispatch operators
- *Active Design Concept for the Grid Structure* - even though in Romania there are requests for the installation of over 12,000 MW in WPPs up to 2012, it is not exactly known if all this power could be installed. This creates difficulties to the grid operators in planning the development of

the distribution and transport grids. Having in view the rise of DG level it is important that grid operators develop active network management for integrating DG to the grid.

- *Demand Side Management* - DSM programs consist of the planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify their level and pattern of electricity usage. The various opportunities for including the consumers into the grid operation are not used in the Romanian electric system and need to be properly researched
- *Micro-grids* - The micro-grid concept allows for local control of distributed generation thereby reducing or eliminating the need for central dispatch. During disturbances, the generation and corresponding loads can separate from the distribution system to isolate the micro-grid's load from the disturbance (and thereby maintaining high level of service) without harming the transmission grid integrity. Intentional islanding of generation and loads has the potential to provide a higher local reliability than that provided by the power system as a whole. At EU level there is a high level of interest and research on the utilization of micro-grids concept and research is also needed to be done in Romania towards its implementation.

***d) Electricity Storages*** - Widespread deployment of DG in the future will face the fundamental difficulty that they are intermittent, requiring demand flexibility, backup power sources, and very likely enough electricity storage for days to perhaps a week. Strategically-placed storage systems can increase the utilization of existing transmission and distribution (T&D) equipment and defer or eliminate the need for costly T&D additions. In Romania the most common storage technology is pumped hydro storage. With the expected construction of wind parks and cogeneration plants in the field of storages the research priorities for Romania should be concentrated on the use of the best fitting technologies for DG.

***e) Research in Distributed Generators Technologies*** - the equipment manufacturing is done on a very small-scale and for the new DG investments imported equipment and systems are preferred.

### 7.3. DG Economics

It is difficult to assess, even in general terms, the attractiveness of DG to electric utilities, since the economics vary widely based on the utility's actual system configuration and the loads to be served.

Distributed generation has some economic advantages over power from the grid, particularly for on-site power production, such as:

- On-site production avoids transmission and distribution costs
- Production can be limited to parts of the day when grid electricity is expensive, with grid power purchased at less costly periods
- DG can be available in the case of a power system outage to assure a more reliable supply
- Distributed generation may also be better positioned to use inexpensive fuels such as local biomass

In addition to this technological flexibility, a distributed generator may add value to the power system by delaying the need to upgrade a congested transmission or distribution network, by reducing distribution losses, and by providing support or ancillary services to the local distribution network.

On the other hand, DG has higher unit capital costs per kilowatt than a large plant due to high combined capital, running, and maintenance costs of DG systems. The economics of distributed generation therefore depend on complex mix of economic factors.

In Romania DG technologies are not sufficiently developed and researches on the economic characteristics of the distributed generation are totally lacking. An understanding of the fundamental economics of DG is essential for policymakers to address concerns, such as allocation of benefits, levying of added costs and other competitive issues and to arrive at sound decisions regarding the future of DG.

### 7.4. Pricing and allocation of the costs

The support scheme selection is the key for success in DG promotion because this is what establishes the profitability of investments in creating new capacities and is the main element for attracting the investors.

Romania has adopted as promotion mechanism for RES power generation the mandatory quota combined with the green certificate trading system. Due to the fact that in the last four years since this promotion mechanism is in force the results are quite modest, an analysis should be done towards finding whether the feed-in-tariff would be a better support scheme for RES investments encouraging.

On the other hand the research on the development of a mechanism for proper allocation of costs to distribution and transmission companies for DG integration to the grids is needed.

### 8. Priorities timing

From timing point of view, the research priorities of Romania can be divided in short-term, medium-term and long-term.

| | |
|---|---|
| *Short-term priorities* | Updating of the potential of RES |
| | Assessment of the potential of CHP |
| | Impact of DG on the design and operation of the grid |
| | Pricing and allocation of the costs |
| *Medium-term priorities* | Contemporary power electronic interface |
| | ICT for network management |
| | Assessment and improving the grid possibilities to integrate DG |
| | Active Design Concept for the Grid Structure |
| | Demand Side Management |
| | DG Economics |
| *Long-term priorities* | Microgrids |
| | Electricity storages |
| | Research in DG technologies |

### 9. Conclusions

In Romania DG utilization is in its very beginning. After four years since the creation of the regulatory framework for the RES-E promotion mechanisms the results are modest. It is expected that the investments in DG technology applications will grow due to Romania's efforts to comply with the new European energy policy and to promote the use of RES and CHP. It is necessary to take more active measures for accelerating RES utilization for power generation. One of these is the creation of a management department within the Ministry of Economy and Finances responsible for the implementation of the national RES strategy.

In order to integrate DG to the Romanian power system there is need for sustained research and measures to overcome the obstacles of regulatory, economic and technical nature.

Strategically important areas in which research should be concentrated in Romania are:

- application of new technologies and concepts for the operation and exploitation of the networks to be able to cope with the integration of RES and other DG
- use of key technologies providing the distribution networks with high power quality and security of service
- improvement of DG technologies

With the recent "rush" for wind power in Romania additional measures are needed in order to ensure the security and stability of the national power system in accordance with the UCTE methodology on system adequacy. In this respect a procedure for DG integration into the grid including a mechanism for adequate allocation of the cost of transmission and distribution companies for integration of DG should be elaborated with respect to a long-run optimization of the system.

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# Session 2: Energy

# Quantifying the chance for releasing of a hazardous substance owing to accidents

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**Abstract**

*The number of hazardous installations in use and their diversity constantly increases in time. Each of those technological facilities is a potential source of major accidents with huge or catastrophic impacts on the environment, on the climate or directly on the human health. The paper briefly comments on an approach for addressing the uncertainty about the unacceptable consequences expected from a particular hazardous unit. The first stage of the approach is discussed in a case study. This part of the methodology is capable to search for and rank those likely abnormal situations having high potential to progress further on into major accidents.*

**Keywords:** Hazardous installation, technological risk, major release scenarios

## 1. Introduction

Nowadays, the natural phenomena like earthquakes and volcanoes are only some of the hazards, which can affect seriously human live and the environment. Modern society relies on various fixed and movable facilities as those of process industries, the energy sector and offshore platforms, also on vehicles for land and marine transport, and airplanes. Many of these engineering systems (ES) use, produce and store hazardous materials. Both moving vehicles and fixed technological installations can be responsible for distinct health effects on their personnel and off-site population, so for various impacts on the flora and the fauna.

While operating normally, some installations of the energy sector and process plants emit permanently distinct substances. In general, continuous emissions of dangerous substances from any ES, are easier for observing and predicting. There is no doubt that the effective techniques for capturing of specific dangerous substances, escaping from an ES at a continuous rate, may be neither simple nor cheap to implement. However, the uncertainty, about the negative effects on the human health and the environment due to permanent emissions, can be reduced simply by monitoring the daily production rate of the dangerous substances. Thus, efficient protection measures against the continuous pollution of air or poisoning of the soil and waters are easier to implement than against the accidentally occurring harmful impacts, which fixed installations and vehicles also can give rise to.

After the start of the industrial era (in about 1750 B.C.), the "capacity" of ES to utilize diverse hazardous substances in civil and military industries enhances from a day to a day. Since unexpected releases from hazardous installations (HI) keep occurring, accidents at such ES can turn into sources of shocking impacts, whose potential for damaging of smaller or larger regions of the Earth, may increase constantly. A list of accidents ending with catastrophic health and environmental effects can be too long. The accidents at: Bhopal chemical plant in 1984 (e.g. Khan & Abbas, 1997*)*, Chernobyl NPP in 1986 (see IAEA, 2006), offshore platform Piper Alpha in 1988 (e.g. HSE, 2004) etc. are only several from those occurred in the recent 25 years all over the world.

Although major accidents at HI rarely happen, due to their huge or catastrophic immediate and long-term consequences, they are risk-significant. On the other hand the accident consequences are too diverse and should be assessed in terms of human deaths and injuries, financial losses, ecological damages etc. Actually, the experience shows that accidents can never be entirely prevented. However, implementing different means to reducee the chance for severe consequences is a reasonable strategy for minimizing the resources that should be spent for post accident activities.

Since the ionising radiation damages living cells and the half-life of some radioactive materials is thousands of years, living beings must be protected as effectively as possible from the products of nuclear fission. Specific nuclear legislation also the design concepts, application of several levels of strictly independent defensive barriers, redundant safety systems and various organizational procedures, guarantee high safety of a Nuclear Power Plant (NPP) unit although it is a source of radioactivity.

Indeed, keeping acceptably low the chance for no adverse impacts on the human health and the environment needs several defense barriers to isolate radioactive substances. Although, the accidents stemming from non-nuclear HI usually cannot lead to extremely long-lasting consequences, the release of some toxic substances may cause both immediate and long-term damages. The Seveso disaster in 1976, in which the surrounding area near Milan was contaminated with tetrachloro dibenzo dioxin, is such an example.

Taking care about high level of safety for the non-nuclear establishments, the EU Council defines in 1996 the Directive 96/82/EC (known as Seveso II). The Seveso II lists many requirements for installations, operating with big amounts of non-nuclear dangerous substances which the legislation of each of the member states should implement. The philosophy of the Seveso II directive is discussed in many works for instance (Hawksley, 1999), (Kirchsteiger, 1999), (Mitchison, et al, 1999), etc.

From 2002 the first edition of the Bulgarian law for "Environmental protection" is in force and it is under permanent updating. Chapter 6 of the law obliges all individuals and organizations, before starting whatever activities, to obtain special assessment specifying their possible impacts on the environment. The chapter 7 of the same law directly applies the Seveso II directive to everyone whose activities in the country poses non-nuclear hazards. It specifies that every operator of a large scale facility must classify it as a unit with low or one with high risk potential for the environment. The operator of a highly risky installation needs a safety report that should be periodically updated.

The non-nuclear installations of the energy sector contain mainly big amounts of combustible or flammable materials. Some toxic substances also can be present in those ES. Thus, the potential of major accidents, emerging form such installations, to generate big quantities of pollutants, including GHG, is huge.

Section 2 of this paper briefly presents a method for identifying those zones at a certain establishment from which accidental scenarios can emerge. The section also discusses the ranking of likely release scenarios by the release rate of certain hazardous substances. Section 3 comments on a simple case study showing how the method can be applied. The section 4 lists some conclusions.

## 2. Generic features of the approach

A hazardous substance is free to escape in the vicinity of a hazardous unit after all barriers installed to isolate it have lost their integrity. Thus, the first stage of predicting the frequency of severe undesired consequences in all directions from a HI is to quantify the chance for emerging of situations that turns in major accidents. Once an accident has emerged the proper action of all mitigating systems and procedures, designed to prevent the progress of accidental phenomena, determines the chance that dangerous substances will escape and harm a target region. Finally, the frequency of huge consequences in any target zone can be quantified correcting the occurrence frequency by a number of conditional probabilities.

The paper comments on some elements of the entire methodology. It very briefly considers the method for quantifying the frequency for emerging of major accidents at a HI. Actually, the paper focuses on quantifying the chance that the disturbances with a high risk potential can emerge from each part of a hazardous facility.

The frequency for arising into a given zone X of the HI of accidents whose risk potential is higher than a given threshold can be formally assessed as:

$F_{J\text{-}x} = F_J{}^{*}P(\mathbf{A_x}|F_J)$, where $\mathbf{A_x} \equiv (\mathbf{R_x} \cap \mathbf{D_x})$

$F_J$ – Occurrence frequency of specific type of accidents in all zones of the installation J of interest. This entity is considered in many references (e.g. Bier & Yi, 1995; Argirov, 1999) etc., and there is no discussion on it here;

$P(A_x \equiv (R_x \cap D_x)|F_J)$ - The chance that the complex event $\mathbf{A_x}$ addresses sufficiently well the uncertainty associated with emerging of accidents of a given type in the zone X of the installation J. Probability theory helps for quantifying this chance;

The event $\mathbf{A_x}$ specifies those random and deterministic factors that determine the risk potential of abnormal events in whose further progress hazardous substances escape out of the defensive barriers. The symbols $\mathbf{R_x}$ and $\mathbf{D_x}$ indicate sets (vectors) consisting of the values of the random and the deterministic parameters, respectively. Members of both sets can deviate in the space and time and can be complexly related logically each other. A simple case is considered here in which none of the random parameters varies after the time t>0 and each of them is also independent from the deterministic ones. Actually, this is a reasonable assumption if the emerging accident is running too fast and the feedback impacts by automatic and operators cannot prevent the accidental phenomena helping the hazardous substances to bypass defensive barriers.

The set $R_x$ includes values of such random factors that identify how those barriers, which are available at the zone X of the HI J, can fail at the time t=0. The initial values of the deterministic variables, $D_x[t=0]$, should be known to predict how the indicators for severity of the potential accidents vary. Using the symbol $D_x[t]|R_x$ for the zone X shows that the time variation of any deterministic parameter can depend on anyone of the random ones.

Due to the assumptions and conventions mentioned above the following relation can be written:

$$P( (\mathbf{R_x} \cap \mathbf{D_x}[t])|F_J )=P(\mathbf{R_x}|F_J)P(\mathbf{D_x}[t]|F_J, \mathbf{R_x}) \qquad (1)$$

$P(\mathbf{R_x}|F_J)$ – Conditional probability specifying the severity of initial disturbances by using a vector of random parameters whose value $\mathbf{R_x}$ falls into a particular region of a corresponding hyperspace. This term identifies the vague damaging potential of this fraction of the likely accidents, which for a unit time emerge just at the zone X of the facility J. The values of the random parameters identify that "holes" in a barrier inducing particular fractions of accidents;

$P(\mathbf{D_x}[t]|F_J, \mathbf{R_x})$ – Probability specifying those abnormal events that, after arising from the zone X with the potential identified by the values of $\mathbf{R_x}$ and $\mathbf{D_x}[0]$, progress later on in such a way that can overcome defense barriers. This means that for this fraction of possible accidents as the $\mathbf{R_x}$ so the $\mathbf{D_x}[0]$ are known to the accuracy of a small region within their high dimensional spaces.

In fact, the final consequences are those indicating how severe an accident scenario is. However, while an abnormal situation progresses from a stage to a stage its magnitude can be "measured" by using some "intermediate" indicators. For instance, using the release rate of a hazardous substance as an indicator we can find those potential disturbances, which can develop further on into major accidents. Indicators of every stage take values depending on what has happened in previous stages in the propagation of accidents. The time variation of the indicators, suggesting that major accidents are possible, depends strongly on the $\mathbf{D_x}[t]$. On the other hand for similar scenarios the deterministic variables never accept the same values $\mathbf{D_x}[t]$ at the time t. The initial values $\mathbf{D_x}[0]$ of deterministic factors change from a scenario to a scenario since the value of every random parameter is predictable only to the accuracy of a certain range. In case the sets of values $\mathbf{R_x}$ and $\mathbf{D_x}[0]$ plus those deterministic laws of nature that govern the evolution of the dominant accidental phenomena are exactly known, predictions are obtainable in terms of single values. However, it is impossible in the real word because of the uncertainties which both the parameters and the models introduce. Quantifying the indicators the analyst should consider that random factors are inherently vague and also he is unable to identify exactly the real initial values of all deterministic variables. Since mathematical expressions for deterministic laws of nature more or less adequately approximate but very rarely entirely reproduce the real progress of phenomena of interest they also contribute to the uncertainty. Being unable to assess with zero error how the indicators vary in space and the time the best we can do is to address the uncertainty which dominant factors introduce in the analysis.

The formal mathematical relations discussed so far suggest that the uncertainty about the indicators, for arising of high risky abnormal situations, can be addressed varying suitably in their hyperspaces the factors, identifying the potential of the zone X, to induce accidents. It is assumed that the values $\mathbf{R_x}$, which the random parameters takes at the time t=0, stay unchanged while accidents progress. Also, that the initial values, $\mathbf{D_x}[0]$, of the deterministic variables can depend on the $\mathbf{R_x}$ but the reverse is not true. The approach here presented supposes that the real world accidental scenarios are expressible sufficiently well by the following logical order:

$$\mathbf{R_x} \rightarrow \mathbf{D_x}(0) \rightarrow [\mathbf{D_x}(t)=f(\mathbf{R_x}, \mathbf{D_x}(0))] \rightarrow [{}^{I}M_x(t)=f(\mathbf{D_x}(t))]$$

the symbol $f(\cdot)$ shows a function of a number of arguments;

the symbol ${}^{I}\boldsymbol{M_x(t)}$ points out the value taken by the vector of the indicators, given the initial values of the random and deterministic factors are restricted within small regions of their hyperspaces. Altering the values of both type of parameters into all sub-regions they can fall into the components of the matrix $\mathbf{M_x(t)} \equiv [{}^1\boldsymbol{M_x(t)}, {}^2\boldsymbol{M_x(t)}, \ldots, {}^{Imax}\boldsymbol{M_x(t)}]$, where $I_{max}$ is a big number, are calculated.

In order to address the vague potential of the abnormal events, occurring from the zone X of the J, the first step is to quantify the joint probability distribution – $P_x(R_1, R_2, \ldots, R_N|F_J)$, for n = 1, 2, …. , N, of those N random parameters having dominant contribution. The hyperspace, in which these parameters vary, is an ordered N-tuple Cartesian product. An appropriate inferential model is needed to identify this joint probability distribution. Then the likely initial values, $\mathbf{D_x}[0]$, which the deterministic parameters take into their hyperspace, should be identified. Once the hyperspaces of the both types of parameters are divided on a reasonable number of sub-regions the components of the matrix $\mathbf{M_x[t]}$, are assessable by using appropriate expressions for the laws of nature. Finally, the fraction of the abnormal events, arising with big potential, can be assessed as the ratio of the number of those values ${}^I\boldsymbol{M_x(t)}$, which fall outside the safety region into the indicators hyperspace, to the all number of trials $I_{max}$.

There is no more discussion on the generic features of the methodology in this work. Also none of the issues related with the model uncertainty are commented on due to the lack of space. Some specific methods that the approach uses are considered in the next section.

## 3. Case study

*The case specific discussion on the approach*

A vertical cylindrical storage tank filled with a liquid flammable fuel is analyzed to identify the land areas around the tank from which huge fires and explosions can occur. Although the tank is no part of an installation processing hazardous substances it is surrounded by other vessels. Thus, at the site in which the tank of study is situated the domino effect is highly possible.

The wall of the vessel is the single barrier separating the fuel form the environment. Therefore, any time when the wall has lost its integrity release scenarios occur and liquid fuel and its vapors will be emitted around the tank. The mass flow rate of fuel through the tank's wall is used as an indicator showing that the wall failures can grow further into huge fires or explosions. The magnitude of velocity through the ruptured place and the cross-section of this hole uniquely determine the mass of fuel released for any given period. The direction of velocity from the hole is also important parameter since contents of both the vulnerable items and the ignition sources in the vicinity of the tank can vary largely from one to another target area. It is well know that the meteorological conditions and local topology dominantly determine how the fuel will disperse first in the air and then on the land but this stage of accidents progression is outside the scope of this work.

The restricted analysis, here presented, aims to identify the most severe release scenarios. The fuel mass that has left the tank for a certain period $[0, t_1]$ is an indicator for those wall's failures, which later on can turn in fires or explosions. The indicator $M[t_1]$ is quantified by the following relations:

$$M[t_1] = \int_0^{t_1} M[t]dt; \quad M[t] = |\,\mathbf{u[t]}\,|\,\rho[t]A_h \qquad (2)$$

where,

$|\mathbf{u[t]}|$ - the magnitude of the velocity through the hole at the time t - [m/s];

$\rho[t]$ – the density of the liquid fuel leaving the hole at the time point t – [kg/m$^3$];

$A_h$ – [m$^2$] the cross-section of the wall's rupture, specified by a circular hole with the same face.

For this study, $R_1$ identifies the location on the wall surface in which the tank fails and $R_2$ is the diameter of a circular hole with cross-section of $A_h$. One of the approach's tasks is to specify the joint distribution of these two random variables.

Let us suppose that the tank of study is put on the Earth surface and there is no thermal isolation over its metal wall. The tank height is 3 [m] and its diameter is 1 [m]. Neither chemical reactions nor other sources generate or sink heat into the tank but heat fluxes from the outside make the pressure, the temperature and the fuel properties to fluctuate. The tank has no connection with other vessels or pumps also the fuel inside is under stable static pressure and its temperature is almost the same as the ambient one. Thus, when a rupture arises the static pressure is the force pushing the liquid fuel outside the tank. Later on due to the loss of fuel the pressure and the density of fuel inside the tank decrease and the mass flow rate through the hole reduces continuously in the time. (The pressure inside cannot change suddenly due to other vessels or active components like pumps and valves). After the tank fails the pressure and the density inside will change very slowly as only small holes are assumed possible to occur unexpectedly. When the failure of the tank's wall induces a too mild transient the Bernoulli equation is a suffieciently correct deterministinc law for prediciting the quasi-static change in the pressure of fuel inside. Due to the assumpions listed above, for a short time step the average velocity over the hole's cross-section $u_h[t]$ is assessed as:

$u_h[t] = (h[t]g)^{0.5}$; (3)

where,

g – acceleration of gravity [$m/s^2$];

h[t] – the distance between the free fuel surface in the tank and the center of hole at the time t [m].

*Identifying the ranges in the hyperspaces of parameters*

To estimate uniquely the fuel mass flow rate through the hole at any given time $t_1$ we need the initial values of two deterministic parameters - the temperature behind the hole $T_h[0]$ and the distance h[0]. The initial temperature in the whole tank can be supposed almost the same and equal to $T_h[0]$ but its exact value is uncertain because the varying ambient conditions influence on the state of the fuel inside. For this study we assume that $T_h[0]$ varies in the range [5$^o$, 45$^o$] degrees Celsius. Due to the uncertainty about exact value of $T_h[0]$ it falls into a larger range than the range in which the $T_h[t]$ varies during the progress of release scenarios. Thus, for the period $t \le t_1$ $T_h[t]$ is considered a constant equal to $T_h[0]$. The h[0] is a function of the random parameter $R_1$, which is discussed later on, as 0<h(0)<3.

The following sequential steps are applicable in the inner cycle of the iteration scheme, given the random factors $|^K R_1, {}^L R_2|$ are identified to the accuracy of a small region within their space:

1 The values ${}^b u_h(t_i)=f(h[t_{i-1}])$, $\rho[t_{i-1}]=\rho(p_h[t_{i-1}],T_h[0])$, $p_h[t_i]=p_0+g\,{}^b h[t_{i-1}]\rho[t_{i-1}]$, for $p_0$ the atmospheric pressure, and $\Delta^b M[t_i]={}^b u_h[t_i]\rho[t_{i-1}](t_i-t_{i-1})A_h$ are assessed at each time step i first ;

2 After correcting the fuel mass in the tank by the lost mass of $\Delta^b M[t_i]$ the new value of ${}^c h[t_i]$ is estimated. Then ${}^c u_h[t_i]$, $\rho[t_i]$, $T_h[t_i]$ and $\Delta^c M[t_i]$ are calculated. The time step is reduced if the difference between $\Delta^b M[t_i]$ and $\Delta^c M[t_i]$ is too large. When the error of lost mass at current time step is acceptable then $\Delta M[t_i]=\Delta^c M[t_i]$ and the calculation process goes on;

3 Since the conjugate space of the deterministic variables for the case study is two dimensional the indicator should be predicted by combining their initial values at least in four couples. The biggest among the calculated values is used as conservative estimate for the fuel mass lost through a particular area over the wall surface. The maximal value of the indicator can be obtained as:

$\Delta^m M[t_i]=\max(\Delta^{d,d}M[t_i], \Delta^{d,u}M[t_i], \Delta^{u,d}M[t_i], , \Delta^{u,u}M[t_i])$

The meaning of the above listed symbols is as follows:

$T_h(0) \in [{}^J T^d, {}^J T^u]; h(0) \in [{}^N h^d, {}^N h^u]; {}^L R_2 \in [{}^L R_2^d, {}^L R_2^u]$ ;

${}^K \mathbf{R_1}$ is radius vector of a space surface;

$\Delta^{d,d}M = f({}^J T^d, {}^N h^d, {}^K \mathbf{R_1}, {}^L R_2)$; $\Delta^{d,u}M = f({}^J T^d, {}^N h^u, {}^K \mathbf{R_1}, {}^L R_2)$ ;

$\Delta^{u,d}M = f({}^J T^u, {}^N h^d, {}^K \mathbf{R_1}, {}^L R_2)$; $\Delta^{u,u}M = f({}^J T^u, {}^N h^u, {}^K \mathbf{R_1}, {}^L R_2)$

The range of the initial temperature of fuel in the tank can be divided on two sub-ranges [5$^o$, 25$^o$) and [25$^o$, 45$^o$]. The sub-ranges of the initial distance h[0] depend on the sub-regions on which the random parameter $\mathbf{R_1}$ is divided on.

The outer cycle of the iteration scheme includes sequential visiting of all sub-regions on which the entire region of random parameters' space is separated for the case of study.

1 The parameter $\mathbf{R_1}$ should identify so small areas on the entire surface of the tank's wall within which the minimal and the maximal value of the indicator differ not too much. For the case of study a cylindrical coordinate system is suitable to define the radius vector of any part of the wall surface in which the rupture can arise. Also, the point at which the tank axis crosses the land surface is a good origin of this coordinate system. In order to identify, the radius vector accepting the set of values ${}^K \mathbf{R_1}$, that correspond to the area ${}^K \mathbf{A_w}$ of the wall surface, two parameter are used - height Y and azimuth, the angle θ:

$Y \in (0,3)$; ${}^1 Y \in (0, 0.6]$; ${}^2 Y \in (0.6, 1.3]$; ${}^3 Y \in (1.3, 2.1]$; ${}^4 Y \in (2.1, 3)$

$\theta \in [0^o, 360^o]$; ${}^1\theta \in [0^o, 60^o]$; ${}^2\theta \in [60^o, 120^o]$; ${}^3\theta \in [120^o, 180^o]$

${}^4\theta \in [180^o, 240^o]$; ${}^5\theta \in [240^o, 300^o]$; ${}^6\theta \in [300^o, 360^o]$

By using the listed notations it is easy to find that the couple ${}^{3,5}\mathbf{R}_1 \equiv |{}^3 Y, {}^5\theta|$ corresponds to that part of the wall surface for which the Y and the θ falls into the ranges (1.3, 2.1] and [240$^o$, 300$^o$], respectively.

2. The other random parameter $R_2$, the diameter of the hole, is needed to specify uniquely the cross-section of the crack location as $A_h = \pi R_2^2$. A suitable inferential model is required to quantify the distribution of this random variable.

Because of the above listed, for the case of interest the outer cycle of the iteration scheme consists of visiting of 4x6 sub-regions within the conjugate space of the random parameters. For each one of those 24 regions the initial values of deterministic parameters are altered at least 4 times and by means of the deterministic laws the values of the indicator should be found and ranked. The maximal among the indicator values, obtained in the inter cycle of the iteration scheme, is the conservative assessment of the potential of each one of the so specified 24 parts of the wall surface to generate release scenarios. The mass of fuel left the tank for the time $t_1$ shows how likely is given release scenarios to progress later on into huge fires and explosions. The discussion so far focuses on identifying significance of release scenarios in terms of deterministic arguments. In the author's opinion the more important question is what is the fraction of release scenarios that for the period $t_1$ can push out of the tank a fuel mass bigger than given threshold value?

*Quantifying the probabilities of the major release scenarios*

As it was discussed in section 2 the approach here presented estimates the chance that the possible failures of the tank of study can grow to major releases of hazardous substances. The approach introduces the conditional probabilities $P(D_x[t]|F_J, R_x)$ and $P(R_x|F_J)$. The term $P(D_x[t]|F_J, R_x)$ identifies how probably is after the rupture has occurred the deterministic variables to fall initially into a certain region of their hyper-space and then they to change in a particular way, given the random parameters are restricted within a small region of their hyperspace.

For the tank of investigation we should assess probability of the following complex events:

$$E_{1,1,[1,K2],L} \equiv [{}^1T_h[0] \in [5^o, 25^o]) \cap ({}^1h[0] \in (2.4,3])] | ([{}^1Y, {}^{K2}\theta], {}^LR_2]$$

$$E_{2,1,[1,K2],L} \equiv [{}^2T_h[0] \in [25^o, 45^o]) \cap ({}^1h[0] \in (2.4,3])] | ([{}^1Y, {}^{K2}\theta], {}^LR_2]$$

……………………………………………………………

$$E_{1,4,[4,K2],L} \equiv [{}^1T_h[0] \in [5^o, 25^o]) \cap ({}^4h[0] \in (0,0.9])] | ([{}^4Y, {}^{K2}\theta], {}^LR_2]$$

$$E_{2,4,[4,K2],L} \equiv [{}^2T_h[0] \in [25^o, 45^o]) \cap ({}^4h[0] \in (0,0.9])] | ([{}^4Y, {}^{K2}\theta], {}^LR_2]$$

for $K_2$ fixed in 1 to 6, L fixed in 1 or 2

We can define the following probabilities:

$$P({}^1T_h[0]) = 0.5; \;\; P({}^2T_h[0]) = 0.5$$

In the case of study the other term that the methodology introduces $P(\mathbf{R_x}|F_J)$ should specify the rupture location with respect to the defensive barrier – the tank's wall for this study.

To addresses the uncertainty about random parameters their joint probability distribution is specified. Supposing that the parameters $\mathbf{R_1}$ and $R_2$ are independent the following is true:

$$P(R_1 \cap R_2) = P(\mathbf{R_1})P(R_2); \;\; P(\mathbf{R_1}) = P(\bigcup_{K=1}^{24} {}^K\mathbf{R_1}); \;\; P(R_2) = P({}^1R_2 \cup {}^2R_2)$$

The symbol ${}^1R_2$ indicates that value of the hole diameter at which the cumulative distribution is equal to some value $c_1$ or $P(0<R_2 \leq {}^1R_2)=c_1$. The symbol ${}^uR_2$ shows the 97.5% quintile of this distribution or $P({}^1R_2<R_2 \leq {}^uR_2)=0.975-c_1$.

Having no reliable observations about those areas on the tank surface within which the wall's integrity is more often lost the assumption that rupture is equally likely in each one of the specified 24 parts of the wall surface is reasonable one or:

$$P({}^1\mathbf{R_1}) = .... = P({}^{10}\mathbf{R_1}) = .... = P({}^{20}\mathbf{R_1}) = .... = P({}^{24}\mathbf{R_1}) = 0.04167$$

In order to find the values ${}^1R_2$ and ${}^2R_2$ the distribution about the hole's diameter should be identified first. When there is not enough specific data, as usually the situation is, the Bayesian statistic can help. It is capable to combine suitably generic information with the limited data coming from identical units.

*Identifying the distribution about the hole's diameter*

There in no discussion here on the Bayesian concept on probability since many excellent works as [9] etc. are dedicated on it. A parametric Bayesian model is used to specify how the entity $R_2$ is distributed. The aim of the inferential model is to obtain the posterior density function about the rupture diameter relating it with both its prior distribution and the likelihood function about the available observations.

$$\pi(\varphi \mid \mathbf{O}) = \frac{\lambda(\varphi \mid \mathbf{O})\pi(\varphi)}{\Lambda}, \;\; \text{where } \Lambda = \int \lambda(\varphi \mid \mathbf{O})\pi(\varphi)d\varphi \quad (4)$$

$p(\mathbf{o} \mid \varphi) = \lambda(\varphi \mid \mathbf{o})$ - likelihood function about the evidence $\mathbf{O}$

$\pi(\varphi)$, $\pi(\varphi \mid O)$ - prior and postrior density functions

$\Lambda$ – normalizing constant

$\mathbf{O} \equiv [\mathbf{O_G}, \mathbf{O_I}]$ – a set of more or less relevant observations about the entity $R_2$;

The set of observations includes generic data, $\mathbf{O_G}$, and more relevant data about ruptures of identical tanks - $\mathbf{O_I}$. The source of generic information for the study is the (HSE, 2000). The appendix includes the generic data used. Due to the lack of reliable data for the size of cracks on identical tanks the set $\mathbf{O_I}$ ≡[2, 5, 10] in [mm] is applied in order to show how the inferential model works.



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The Bayesian theorem is use two times. On the first stage the evidence $\mathbf{O_G}$ is used to obtain the generic posterior distribution. On the second stage the generic posterior distribution is updated by means of the set $\mathbf{O_I}$ coming from identical units. Hierarchical Bayesian models are applied on every one of these stages. A huge number of references are dedicated as on the theoretical aspects of Bayesian models with hierarchical structure, like (Robert, 2004), (Browne&Draper, 2000), (Gelman&Pardoe, 2006) and many others, so to the application of such inferential models, for example (Esner et al., 2004), (Argirov, 2006) etc., so none of these issues are here discussed.

The multilevel model used has the following structure:

$$\beta \sim \text{gamma}(\alpha_1, \mu_1); \text{ where } \alpha_1, \mu_1 \text{ are constants}$$

$$\sigma \sim \text{uniform}(\alpha_2, \mu_2); \text{ where } \alpha_2, \mu_2 \text{ are constants}$$

$$\pi(\varphi) \equiv \pi(\beta, \sigma)$$

$$\lambda(\varphi \mid \mathbf{O_L}) \sim \text{Normal}(\beta, \sigma \mid \mathbf{O_L}); \text{ for } L = G, I \qquad (5)$$

The constants $\alpha_1$, $\alpha_2$ , $\mu_1$, $\mu_2$ are chosen in such a manner that the distributed parameters β, σ to identify our prior believe for the variability of the hole diameter. Then, under assumption that the likelihood functions for all separate observations belong to the normal family, the parameters β, σ are updated by using first the evidence $\mathbf{O_G}$ and then the $\mathbf{O_I}$. Although, certainly better hierarchical model than the presented one can be specified it demonstrates a reasonable way for addressing the uncertainty about the entity $R_2$.

The computer code WinBUGS (Spiegelhalter et al., 2003), (Woodward, 2005) is used to solve this multilevel inferential model. The generic prior, the generic posterior and the tank specific posterior density functions are presented on figures 1, 2 and 3 respectively. Some characteristics of these distributions are listed in table 1. Table 1 shows that as far as the evidence O is relevant to our case we can be 97.5% sure that the hole's diameter is smaller than 14.5 mm.

Therefore, we can specify that $P(0<R_2\leq 8.44)=0.75$, $P(8.44<R_2\leq 14.5)=0.225$ and $P(R_2>14.5)=0.025$.

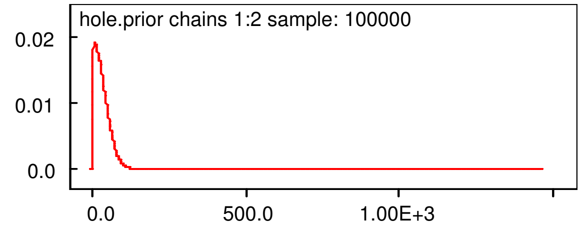


Figure 1: Generic prior distribution.

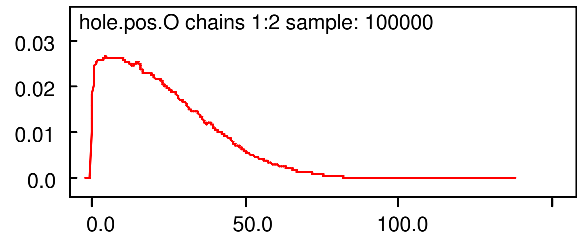


Figure 2: Generic posterior (specific prior) distribution.

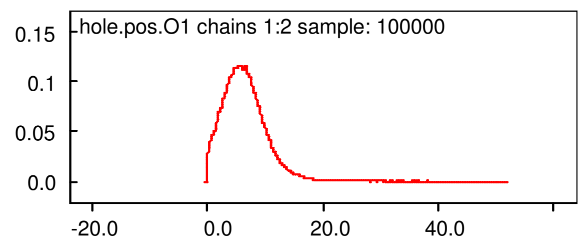


Figure 3: Specific posterior distribution.

Table 1: Distributions about the diameter of the hole.

| Distribution about the hole diameter in [mm] | 2.5 % | 50% | 75% | 97.5 % |
|---|---|---|---|---|
| Generic prior (hole.prior) | 1.29 | 27.4 | 46.6 | 104.3 |
| Specific prior (hole.pos.O) | 0.95 | 19.8 | 33.2 | 63.2 |
| Specific posterior (hole.pos.O1) | 0.66 | 6.04 | 8.44 | 14.5 |

*Quantitative characteristics of the release scenarios*

For the tank of study it is easy to figure out that the bigger accidental release rates are associated with a sub-area of its wall that is closest to the earth surface. These parts of the wall surface are analyzed by the following events:

$$E_{1,1,[1,K2],L} \equiv ({}^{1}T_h[0] \in [5^o, 25^o]) \cap ({}^{1}h[0] \in (2.4, 3]) \mid ([{}^{1}Y, {}^{K2}\theta], {}^{L}R_2)$$

$$E_{2,1,[1,K2],L} \equiv ({}^{2}T_h[0] \in [25^o, 45^o]) \cap ({}^{2}h[0] \in (2.4, 3]) \mid ([{}^{2}Y, {}^{K2}\theta], {}^{L}R_2])$$

$$\text{for } K_2 \text{ fixed in 1 to 6, L fixed in 1 or 2}$$

About all of these events, or when the parameter h[0] varies into the range [2.4073, 2.9927] in [m], the velocity through the hole $u_h[0]$ falls in the rage [4.86, 5.42] in [m/s].

The events $E_{1,1[1,K2],1}$ and $E_{2,1[1,K2],1}$ represent the holes for which the $P(0<R_2<8.44)=0.75$ as their maximal value of $A_h$ is $2.24\times10^{-4}$ [$m^2$]. For the events $E_{1,1[1,K2],2}$ and $E_{2,1[1,K2],2}$ whose value of $A_h$ is in the range [$2.24\times10^{-4}$, $6.61\times10^{-4}$] the following is true $P(8.44<R_2<14.5)=0.225$.

Let assume that the tank contains flammable methanol whose density at pressure of 1.3 [bar] and the boundary temperatures are $\rho[5^o]=805.1$ [kg/s], $\rho[25^o]=786.4$ [kg/s] and $\rho[45^o]=767.4$ [kg/s], respectively. Having in mind all listed figures we can conclude that the maximal mass flow rate from the tank at the t=0 is 2.88 [kg/s]. Thus, for the case study the following is true:

$$P(E_{1,1[1,K2],2} \cup E_{2,1[1,K2],2}) = P(\bigcup_{K2=1}^{6} E_{1,1[1,K2],2}) + P(\bigcup_{K2=1}^{6} E_{2,1[1,K2],2}) = 0.0563$$

$$P(\bigcup_{K2=1}^{6} E_{1,1[1,K2],2}) = P(5^o < T_h[0]) < 25^o) P(\bigcup_{1}^{6} {}^{1,K2} R_1) P(8.44 < R_2 < 14.5)$$

$$P(\bigcup_{K2=1}^{6} E_{2,1[1,K2],2}) = P(25^o < T_h[0]) < 45^o) P(\bigcup_{1}^{6} {}^{1,K2} R_1) P(8.44 < R_2 < 14.5)$$

$$P(T_h[0]) < 25^o) = P(25 < T_h[0]) < 45^o) = 0,5;$$

$$P(\bigcup_{1}^{6} {}^{1,K2} R_1) = 0.25; \quad P(8.44 < R_2 < 14.5) = 0.225$$

Thus, a fraction of 5.63% of all scenarios, emerging from the tank, is associated with an initial mass release rate varying in the range [0.835, 2.88] [kg/s]. For the rest parts of the wall surface as the upper so the down values of the ranges within which the mass flow rate varies are smaller.

## 4. Conclusions

An easy for implementing in practice approach capable to “measure” the potential of release scenarios to progress further to major accidents, is presented. This methodology allows the fraction of those scenarios which can affect badly certain target land areas, situated in particular directions from a hazardous unit, to be identified. The part of the approach presented in this work is applicable to search for those regions over a defensive barrier, separating hazardous substances from the surrounding, within which risk significant release scenarios can emerge. The information, that even the first stage of the approach here presented finds, can help in ranking of dangerous zones in the surroundings of a hazardous unit by using quantitative criteria. By predicting conservatively the most likely amounts of dangerous substance entering the spatial zones around the failed unit the uncertainty about the magnitude of accidents and their consequences for the human beings and the environment can be reduced.

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## Appendix

Generic evidence, $\mathbf{O_G}$ based on HSE, 2000, for failures of units with liquids

| No (year) | System | Equivalent hole [mm] |
|---|---|---|
| 1 (92-93) | Utilities Oil; Heat transfer Oil | 3 |
| 2 (93-94) | Gas Compressor lubricating Oil | 25 |
| 3 (93-94) | Gas Compressor lubricating Oil | 1 |
| 4 (92-94) | Gas Compressor lubricating Oil | 1 |
| 5 (93-94) | Condensate methanol | 50.8 |
| 6 (93-94) | Processing Methanol | 20.4 |
| 7 (93-94) | Dehydration of Glycol | 10 |
| 8 (93-94) | Dehydration of Glycol | 12.7 |
| 9 (93-94) | Power gen. turbine, Diesel released | 6.7 |
| 10 (93-94) | Utilities, Oil, diesel | 25.4 |
| 11 (93-94) | Utilities, Heat transfer oil | 9.53 |
| 12 (93-94) | Power gen. turbine, Oil released | 1.0 |
| 13 (93-94) | Separation, Oil test | 12.7 |
| 14 (93-94) | Flare, Condensate released | 76.2 |
| 15 (93-94) | Processing, LPG released | 12.7 |
| 16 (94-95) | Export, Oil released | 1.0 |
| 17 (94-95) | Gas Compression, Lub. Oil released | 12.7 |
| 18 (94-95) | Gas Compression, Lub. Oil released | 1.0 |
| 19 (94-95) | Gas Compression, Lub. Oil released | 1.0 |
| 20 (94-95) | Gas Compression, Lub. Oil released | 1.0 |
| 21 (94-95) | Processing, Glycol released | 2.0 |
| 22 (94-95) | Dehydration of Glycol | 1.0 |
| 23 (94-95) | Dehydration of Glycol | 1.0 |
| 24 (94-95) | Dehydration of Glycol | 1.0 |
| 25 (94-95) | Power Gen. turbine, Diesel released | 5.0 |
| 26 (94-95) | Utilities Oil, Heat transfer Oil | 1.0 |
| 27 (94-95) | Utilities Oil, Heat transfer Oil | 1.8 |
| 28 (94-95) | Utilities Oil, jet fuel | 1.0 |
| 29 (94-95) | Power Gen. turbine, Diesel released | 11.8 |
| 30 (94-95) | Power Gen. turbine, Diesel released | 11.8 |
| 31 (94-95) | Power Gen. turbine, Oil released | 25.4 |
| 32 (94-95) | Treatment of ($H_2S/CO_2$), Condensate | 25.4 |
| 33 (95-96) | Gas Compression, Lub. Oil released | 1.0 |
| 34 (95-96) | Gas Compression, Lub. Oil released | 2.7 |

| No (year) | System | Equivalent hole [mm] |
|---|---|---|
| 35 (95-96) | Dehydration of Glycol | 1.0 |
| 36 (95-96) | Power Gen. turbine, Diesel released | 1.0 |
| 37 (95-96) | Utilities, Diesel released | 2.3 |
| 38 (95-96) | Heat transfer Lub. Oil released | 1.0 |
| 39 (95-96) | Heat transfer Lub. Oil released | 38.1 |
| 40 (96-97) | Export Lubrication Oil | 1.0 |
| 41 (96-97) | Power Gen. turbine Lub. Oil released | 5.4 |
| 42 (96-97) | Power Gen. turbine, Diesel released | 1.0 |
| 43 (96-97) | Utilities, Diesel released | 1.0 |
| 44 (96-97) | Utilities, Diesel released | 1.0 |
| 45 (96-97) | Utilities, Diesel released | 12.7 |
| 46 (96-97) | Utilities, Diesel released | 12.7 |
| 47 (96-97) | Utilities, Diesel released | 12.7 |
| 48 (96-97) | Utilities, Diesel released | 1.0 |
| 49 (96-97) | Utilities, Diesel released | 1.0 |
| 50 (96-97) | Utilities, Diesel released | 1.0 |
| 51 (96-97) | Import, Condensate released | 1.0 |
| 52 (97-98) | Utilities, Diesel released | 1.0 |
| 53 (97-98) | Utilities, Diesel released | 3.0 |
| 54 (97-98) | Utilities, Diesel released | 1.0 |
| 55 (98-99) | Gas Compression, Lub. Oil released | 5.0 |
| 56 (98-99) | Dehydration of Glycol | 1.0 |
| 57 (98-99) | Power Gen. turbine, Lub Oil released | 1.0 |
| 58 (98-99) | Power Gen. turbine, Lub Oil released | 1.0 |
| 59 (98-99) | Power Gen. turbine, Lub Oil released | 5.0 |
| 60 (98-99) | Power Gen. turbine, Oil released | 3.2 |
| 61 (98-99) | Power Gen. turbine, Lub Oil released | 1.0 |
| 62 (98-99) | Utilities, Diesel released | 1.0 |
| 63 (98-99) | Utilities, Diesel released | 1.0 |
| 64 (98-99) | Utilities, Diesel released | 1.0 |
| 65 (99-00) | Utilities, Diesel released | 1.4 |
| 66 (99-00) | Utilities, Diesel released | 1.0 |
| 67 (99-00) | Utilities, Diesel released | 1.4 |
| 68 (99-00) | Power Gen. turbine, Lub Oil released | 1.9 |

# Energy and environmental impacts from extensive use of VSDs in Uzbek industry

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**Abstract**

A new design of controller for asynchronous motor drive systems has been proposed and from the very early tests it was evident that the controller had a great prospect for wide use applications in industry, where reducing electricity consumption is important. A selection of industrial results obtained from tests (over a period of five years) on the new controllers in various motor-drive systems in Uzbek industry is presented, analyzed and discussed. Taking into account the above mentioned industrial results, a scenario based approach is used to allow evaluation of energy savings potential in Uzbekistan from the use of controllers in industry. The results of this study could help to better understand the costs and benefits of various policies and to accelerate energy efficient technologies in Uzbekistan.

**Key words –** Controller, asynchronous motor, energy policies, energy savings, $CO_2$ emissions.

## 1. Introduction

A new design of controller for asynchronous motor drive systems (VSD) has been proposed. This controller constantly adjusts the voltage to the motor terminals in such a way as to provide just sufficient magnetizing forces to meet the driven load demand. Thus a corresponding reduction in the iron losses is obtained and the efficiency and power factor of the motor are improved (Khashimov, 1995; Khashimov, 1996). Initially, this controller was used for the training and research needs of the students at Tashkent State Technical University (TSTU) and the research work was conducted at the laboratories of the Chair of the Energy Faculty of TSTU. From the very early tests it was evident that the controller had a great prospect for wide use applications in industry, agriculture and other sectors where reducing energy consumption costs of electric motor driven systems is important (Khashimov, 1999). In order to investigate the behaviour and the potential for electricity savings of a motor with and without the new controller several tests for more than five years were performed on various sizes of induction motors in different applications in industry in Uzbekistan. A selection of industrial results obtained from tests on the controllers in various motor-drive systems is presented, analyzed and discussed.

Taking into account the above mentioned industrial results, a scenario based approach is used to allow evaluation of electricity savings potential in Uzbekistan from the use of controllers in industrial application. The results of this study could help to better understand the costs and benefits of various policies to accelerate energy efficient technologies.

The analysis focuses on two scenarios:

- Business-As-Usual (BAU)
- Moderate

The BAU forecast describes a future in which policies and the use of controllers are not greatly different from today. In contrast, the Moderate Scenario is defined by policies that are consistent with an increasing level of public commitment and political resolve to solving the nation's energy and related environmental challenges. The Moderate Scenario requires larger expenditures on public and private R&D, incentives in industry, and government investment in programmes that promote the energy efficient technologies and environmental protection schemes. It must be emphasized that none of the two scenarios is a prediction of the future, and they only attempt to characterise the results of different assumptions about the future on the energy system and the economy in Uzbekistan.

In Table 1.1 there is a list which simply illustrates and summarises the policies and programmes that define the Moderate Scenario for the introduction of energy saving controllers in motor drive-systems in industry.

| MODERATE SCENARIO |
| --- |
| ♦ Expand the efficiency standards and implement new efficiency standards for industrial equipment, beyond those already planed. |
| ♦ Increase enforcement and adoption of energy saving and environmental protection schemes in industry. |
| ♦ Expand cost shared government R&D expenditures on energy saving new technologies to increase the penetration of energy efficient equipment in industry. |

Table 1.1. Illustrative Polices for the penetration of energy efficient technologies in industry.

## 2. Energy Savings Potential in Metallurgical Sector in Uzbekistan

The scenarios address and assess the impact of controllers for asynchronous motor (VSDs) on electricity savings in the Metallurgical Sector in Uzbekistan up to the year 2018. Both scenarios are based on measurements over a period of five years on selected electric motor-drive systems in the industrial site of the “Uzbek Metallurgical Plant” in Tashkent Province. The selected electric motor-drive systems are the following:

- a 75 kW compressor unit,
- a 7.5 kW pump unit, and
- an 11 kW ventilation unit.

Extensive measurement programmes on the above selected electric motor-drive systems have shown annual electricity savings of 19%, 23.5% and 20.5% respectively through the use of controllers. Additionally, the results of industrial tests upon the above mentioned selected equipment have clearly shown a reduction in the starting currents of the motors by 1.8 to 4.0 times and a considerable reduction in the operating temperatures of the motors through the use of controllers. Both these results improve the lifetime and the reliability of the motors, but this will be analyzed and presented in another article which is under preparation.

In the Metallurgical Sector there are 520 compressor, 2599 pump and 1561 ventilation units with installed capacities 290811 kW, 227400 kW and 52110 kW respectively. Their annual electricity consumption in the year 2008 was estimated to be $25.13\times10^8$ kWh, $19.65\times10^8$ kWh and $19.65\times10^8$ kWh respectively. In order to project energy consumption and thus to evaluate potential energy savings from the use of VSDs over time, it was necessary to combine the present annual electricity consumption figures (with and without the use of controllers) on the selected systems and the statistical data of the 2008 of the Metallurgical Sector in Uzbekistan with projections of future consumption taking into account the deterioration of the existing systems due to aging.

Figure 2.1 displays the annual electricity consumption projections from the total number of the selected electric motor-drive systems in the Metallurgical Sector in Uzbekistan produced by the BAU and Moderate Scenarios. The assessment of scenarios was restricted up to the year 2018 due to the large number of motor-drive systems and the associated additional uncertainties.

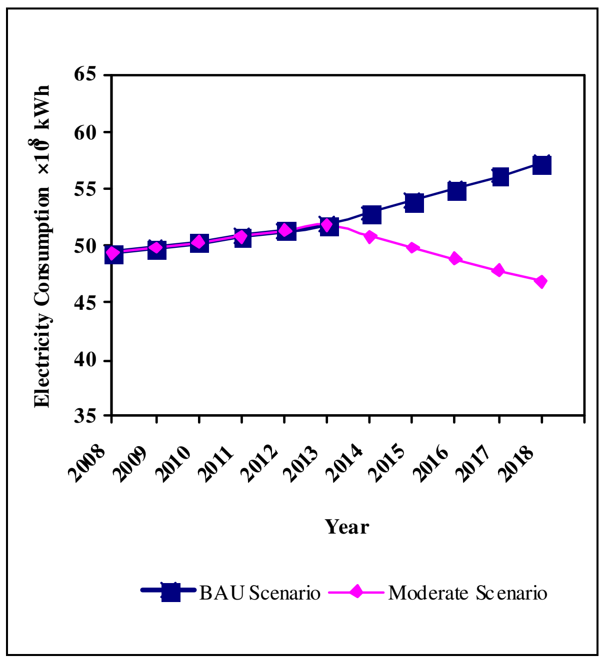


Figure 2.1. Total annual electricity consumption by compressors, pumps and ventilators in the Metallurgical Sector in Uzbekistan.

In the BAU Scenario for the Metallurgical Sector, annual electricity consumption from the total number of the selected electric motor-drive systems grows at an annual rate of 1% between the base year 2008 and 2013 and in the following five years period the consumption grows at an annual rate of 2% mainly due to the aging of the systems. Electricity consumption in 2018 reaches $57.19 \times 10^8$ kWh, 16.05% higher than in 2008.

In the Moderate Scenario annual electricity consumption from the total number of the selected electric motors and drive systems grows at an annual rate of 1% between the base year 2008 and 2013, reaching $51.79 \times 10^8$ kWh in 2013. During the following five years the introduction of energy efficiency policies and the accelerated penetration of controllers in industry at an annual rate 20% (five times the average growth of the country) reverse the energy consumption growth trend. Energy consumption in 2018 instead of reaching $57.19 \times 10^8$ kWh decreases to $46.87 \times 10^8$ kWh, 4.89% below the $49.28 \times 10^8$ kWh consumed in the base year 2008.

Figure 2.2 summarises the overall electricity savings potential in the Metallurgical Sector in Uzbekistan from the Moderate Scenario which includes a portfolio of energy polices and programmes for the introduction of controllers in the particular asynchronous motor- drive systems. The energy policy measures will result to cumulative energy savings of the order of $30.96 \times 10^8$ kWh.

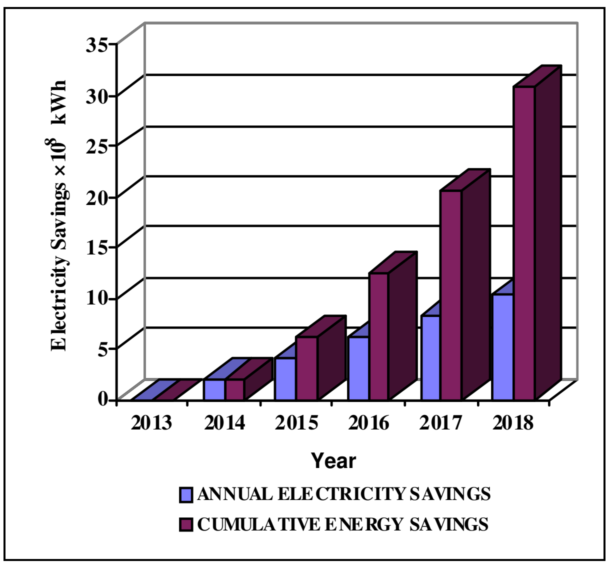


Figure 2.2. Annual and cumulative electricity savings from the Moderate Scenario from all compressors, pumps and ventilators in the Metallurgical Sector in Uzbekistan.

In 2002 fuel-energy sector enterprises in Uzbekistan emitted about 452 thousands tones of pollutants into the atmosphere amounting to 62% of all industrial atmospheric pollution (UNDP, Goskompriroda, 2004). Air water and soil pollution caused by energy sector activities have in some areas reached levels high enough to disturb the ecological balance to the detriment of people's health and biodiversity (UNDP, 2007). Electricity savings from the Moderate Scenario in the Metallurgical Sector of the order of $30.96 \times 10^8$ kWh within five years, will have an important impact on the reduction of atmospheric pollution caused by energy sector. Using the conversion factor of 0.68 kg of carbon dioxide emissions per kWh of electricity produced by power plants in Uzbekistan (UNDP, 2007) the cumulative avoided $CO_2$ emissions by the year 2018 will be 2.1 million metric tons of $CO_2$, as shown in Table 2.1.

| **Metallurgical Sector** | |
|---|---|
| Cumulative Electricity Savings by the year 2018 | Cumulative Avoided $CO_2$ Emissions by the year 2018 |
| 3.1 billion kWh | 2.1 million metric tons of $CO_2$ |

Table 2.1. Avoided $CO_2$ Emissions from the Moderate Scenario for the Metallurgical Sector in Uzbekistan.

### 3. Conclusions

This approximate analysis documents the important role that policies can play in stimulating the development and market penetration of modern controllers in Uzbek industry. These energy efficient technologies, in turn, could help Uzbekistan meet a wide array of challenges, including reduction in air pollution and improvement in economic competitiveness. Our assessment suggests that the technology and policy costs required to implement these technologies and policies would be less than the energy cost savings from the more efficient use of electricity in the Metallurgical sector.

It is clear that a baseline build on current approaches to energy policy in industry will result in a considerable increase in electricity consumption in the Metallurgical Sector and a subsequent increase in emissions of carbon dioxide and other pollutants in the period 2013-2018. The BAU case shows increase in energy consumption of approximately 16.05% above 2008 levels in 2018.

The Moderate Scenario demonstrates a range of policies that are conceivable with a modest shift in the present context. One view of the Moderate Scenario, which shows a reduction in electricity consumption in the sector of 18.11% from the corresponding value of the BAU Scenario for the year 2018, is that it is a modest effort to curb demand growth.

The Moderate Scenario also shows that the effort to expand the use of controllers in all motor-drive systems in Metallurgical Sector could achieve a substantial reduction of atmospheric pollution caused by energy sector by the year 2018.

In this analysis two scenarios have been developed. None of them is a prediction of the future. They attempt to characterise the results of different assumptions about the future on the energy system and the economy. In the Moderate Scenario there are two areas of uncertainty. In many cases, technology is not presently fully developed in Uzbekistan in order to achieve the Moderate Scenario results. If the Government and private sector invest in the R&D, the technology improvements required are possible. The second area concerns the effectiveness of the policies. There are uncertainties about the efficacy of policies in the industrial sector. It may be possible that the market barriers to energy efficiency are more stubborn than expected and/or the costs of implementing energy efficiency to be high. This is tied closely with the success in technology R&D. If the R&D is successful, and the technologies are well developed, available and cost effective, then the policies need less aggressive push and the cost of their implementation is lower.

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# Assessing the impact of traffic regulations on the waiting queues of maritime straits; the Bosporus example

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**Abstract**

*Straits consist a key component of international maritime traffic while, the combination of limited capacity and heavy traffic load poses a challenge for combining safe and efficient navigation. In the current article, a general and fully parameterizable queueing model is proposed in order to evaluate the impact of physical characteristics, queueing schemes, applied regulations and transit traffic attributes to the efficiency of the straits system. Bosporus (Istanbul, Turkey) demonstrates a unique combination of, on one hand, navigation difficulties and heavy traffic load and, on the other hand, comprehensive and detailed regulations that govern its operations, thus, comprising a suitable testbench for the proposed model. Variations of five applied regulations and traffic scheduling policies are modelled and their impact on the average waiting time and the average queue length is assessed and discussed.*

**Keywords:** Simulation; Queueing model; Traffic regulations; Maritime straits; Bosporus;

## 1. Introduction

Chokepoints are a common concept in transport geography and they refer to locations that limit the capacity of traffic and cannot be easily bypassed. Considering the characteristics of maritime transportation, chokepoints (straits, canals, channels, etc) are particularly prevalent. Many of them are the result of the constraints of physical geography while others, are artificial creations. Three concepts define a chokepoint as a resource:

- *Physical characteristics*: A chokepoint is a location forcing the convergence of traffic and limiting its capacity through its physical characteristics, whether by depth, width or overall navigability.
- *Usage*: The value of a chokepoint is proportional to its usage level, with regard to its physical limit of service, and the availability of alternatives.
- *Access*: A level of control must be established to insure safe and efficient access to the chokepoint. This involves agreements regulating its usage, tolls or other means of compensation for the usage and the needed access infrastructures [Rodrigue].

Although the physical characteristics of most chokepoints are very stable, implying a fixed capacity, their use and value is subject to significant variations. With the growth of maritime traffic and world trade, many have become extremely valuable resources accounting for the most important strategic locations in the world. However, like all fixed supply resources, there is a limit to which they can be used. The closer they are to being "exhausted", the more unstable their usage is and the more efforts to be spend on securing their access.

Regarding straits used for international navigation, their special status was recognized, for the first time in a codified international instrument, in the Third United Nations Law of the Sea Convention 1982 (UNCLOS III). Part III of the Convention sets out the defining criteria, the right of transit passage and the rights and obligations of users and coastal states [UN].

UNCLOS, COLREG (Collision Regulations) and International Maritime Organization (IMO) traffic separation schemes (TSS), in conjunction with long-standing international agreements comprise a set of regulations that apply in navigation through most straits.

## 2. Objective of the article

Whether due to unilateral or multilateral international agreements or due to UN and IMO recommendations, applied regulations for navigation in straits imply an effort to compromise the rights and demands of the coastal states and their economical, social and environmental concerns, the clients of international maritime trade and the shipping industry.

On initiating a set of regulations, practical rules and scientific results are evaluated in order to formulate a set that will allow for *efficient* and *safe* navigation. In cases of highly utilized straits there is a trade-off between safety and efficiency since stricter safety rules result in an unavoidable degradation of the straits throughput. However, since safe navigation is a priority, rules and measures that have been proved to be sufficient when applied single, are assembled in a set of entangled regulations, whose actual effect on the throughput of maritime traffic cannot be assessed beforehand.

For the same reason, altering or improvement, in terms of efficiency, of the applied regulations, in cases of time-evolving traffic patterns, special traffic events or changes in the straits' physical characteristics, need a considerable amount of historical traffic data and experimentation in order to bring results.

The objective of this article is to propose a universal simulation model for the vessels traffic in maritime straits, in order to provide a practical platform to evaluate transit traffic behaviour, relying on the physical characteristics of the strait, the applied set of measures and regulations and the traffic statistics. The proposed approach can offer valuable insight in determining how applied measures and regulations interact with each other in the definition and utilization of the straits' throughput.

Following, a case study on the Bosporus will exhibit the impact of a changeable regulations and traffic environment to the Straits waiting queues. An approach that has produced many interesting results related to maritime traffic in the Bosporus Straits and its consequences and can be used in determining safety rules is the analytical solution of a set of differential equations [K. Sariöz et al, 1999, H. Ors et al, 2003, E. Otay et al, 2003, B. Tan et al, 1999]. In [E. Kose et al, 2003], a discrete-event model of the Straits has been developed that relates the average waiting time in the Straits entrances to the mean arrival rate of vessels. Finally, in [Ozbas et al, 2007], a detailed functional simulation model of the Bosporus has been presented in which factors that affect maritime traffic are being identified.

## 3. A universal model of maritime straits

A queueing model of maritime straits can help at the assessment of the traffic bottlenecks that develop due to random (e.g. weather conditions) or systematic (e.g. applied regulations or traffic patterns) components of the system. Parameterized modeling of this system can serve as a testbench for benchmarking different regulation sets or varying traffic distributions that can emerge in the future. The proposed methodology focuses at the efficiency of the system and its traffic flow variables, namely, the average queue length $\hat{q}(n) = \dfrac{\int_0^{T(n)} Q(t)dt}{T(n)}$, where *T(n)* the time required to observe *n* waiting vessels in the system and *Q(t)* the number of vessels in queue at time *t*, for $0 \le t \le T(n)$ and the average waiting time $\hat{d}(n) = \dfrac{\sum_{i=1}^{n} D_i}{n}$, where *n* transiting vessels wait for $D_1, D_2, \ldots, D_n$ time until they enter the straits. To this end, vessels are considered as moving points, with no dimensions, navigating without deviations in a predefined route with constant speed. Moreover, the set of maritime traffic regulations is considered as being well-defined and applicable, with no exceptions and invariably to all arriving and transiting vessels.

Since the model aims in studying traffic flow characteristics, accidents can be represented as time-delaying events that do not affect the quality of service of the operating straits. Thus, the probability of an accident for a transiting vessel is considered to be zero and the historical average accident delays are added in the average delays due to maintenances or bad weather conditions.

A universal and fully parameterizable model of maritime straits has been developed in ANSI C [Law et al., 2000] and is presented in Figure 1 [Mavrakis et al., 2007]. The model consists of four main components: the physical description of the waterway, the waiting queues at its entrances, the applied transit regulations and the description of the traffic that uses the waterway.

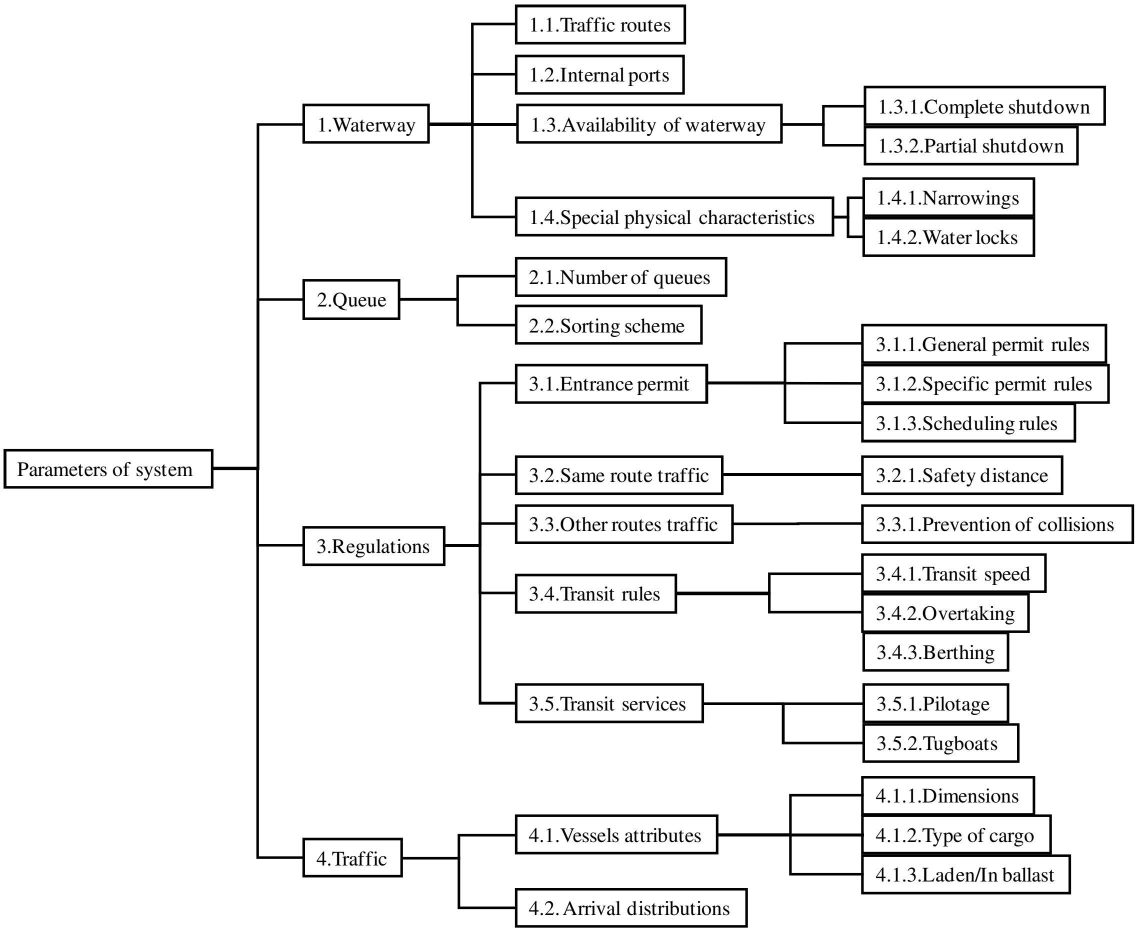


Figure 1: Parameterized straits model.

Physical description of the waterway includes the definition of the traffic routes that it permits, existence and description of any internal ports, since they function as additional entrance or exit traffic points, definition of any special characteristics like water locks or narrowings that affect navigation and the description and quantitative evaluation of factors that limit the waterway's availability, partially or as a whole, e.g. weather conditions, accident probability or maintenance periods.

The queues' component reflects the number and type of queues used in each entrance of the waterway, where first come - first serve as well as sorted queues can be implemented.

Applied transit regulations include, apart from rules regarding the conduct of transit (transit speed and overtaking), the necessary conditions to permit entrance to a vessel, transit rules that ensure safe navigation and are dependent on the same or different route traffic and description of the transit services that can affect aspects of transit maritime traffic like the provision of pilots and availability of tugboats.

Finally, the model is parameterized with regard to the transiting vessels attributes (namely, size, type of vessel and whether it transits laden or in ballast) as well as the time distribution of vessels arrivals, in terms of their attributes and direction of transit.

## 4. Typical model flow

A typical model configuration regards a waterway with two opposite, identical routes. Arriving vessels are placed in the respective waiting queue, which is then sorted. In the first occasion, the first vessel in the queue enters the straits and the queue is refreshed. After a predefined amount of time that is determined by its speed, the vessel exits the straits and, thus, the simulation system (Figure 2). A sequencer module determines, whether a vessel in the waiting queue can enter in the desired direction.

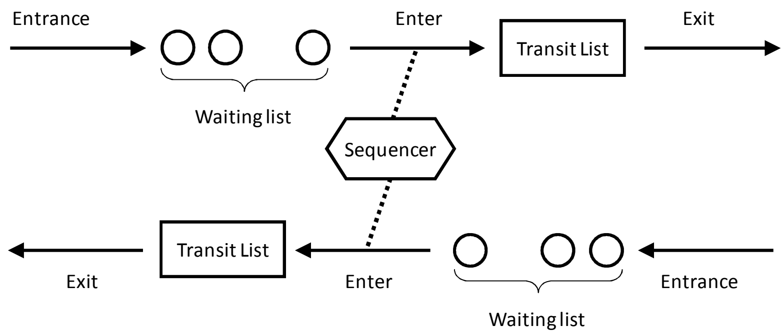


Figure 2: Bosporus model.

Upon a vessel's arrival, the sequencer checks the waterway conditions with regard to the traffic regulations and if every constraint is met, the vessel enters the waterway. Otherwise, vessel is added to the waiting queue and the entrance is postponed for a time instance that is calculated with respect to the current conditions. Upon a vessel's entrance, the sequencer variables are updated and new potential entrance times for both directions are calculated. A transit list that maintains all currently transiting vessels is updated. When a vessel exits the straits and the simulation system, the transit list is updated. A separate event for closing of the waterway due to severe weather conditions is provided. This event is also used to model delays due to accidents, mechanical problems of the transiting vessels or other occurrences (e.g. maintenance works). A second separate event is provided to demark the daytime and nighttime periods of every simulation day based on a set of sunrise/sunset data.

## 5. Bosporus model

The Bosporus lies between the Black Sea to the North, and the Sea of Marmara to the South. It is approximately 31 km long (Figure 3), with an average width of 1500 meters and only 700 metres at its narrowest point, has many sharp turns, some of them more than 45 degrees and a constant surface current directed from the Black Sea to the Sea of Marmara and a deep water counter current. Bosporus traverses through the city of Istanbul, an urban area of over 12 million people and an average of 50000 vessels transit it annually, along with hundreds of passenger, fishing, and leisure crafts, which daily cross it from one side to the other [Republic of Turkey, TMFA and TUMPA].

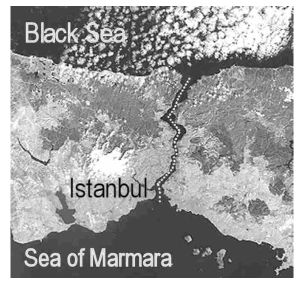


Figure 3: Bosporus straits geography.

Navigation in Bosporus is regulated by the 1936 Montreux Convention which is considered as the most detailed international convention regulating navigation in straits. According to it all merchant vessels enjoy, in principle, complete freedom of passage and navigation by day and night, without being subject to any 'formalities' except for sanitary controls and optional towage and pilotage services [Jia, 1998, Plant , 1996, Plant, 2000, Republic of Turkey, TMFA and WVTS].

Bosporus, apart from its importance for international maritime trade, has faced a number of changes in the recent years that underpin the need for a modelling approach like the one proposed in the current article; A set of maritime regulations that were introduced in 1994 and amended in 1998 and 2002 that transformed traffic management in Bosporus; a novel Vessel Traffic Service (VTS) system that is gradually coming online and that will eventually offer new capabilities; the increased crude oil production in Russia and NIS countries as well as the economic development of Black Sea littoral states that will alter the traffic patterns; evolution of maritime vessels safety and navigation procedures and subsystems;

## 6. Constraints and input data description

Following the proposed parameterization, the simulation model is configured according to the actual physical characteristics of the Bosporus, the transit rules, regulations and policies, as applied by the Turkish maritime authorities and the historical traffic data [Brito, 2000, GMCSSA, 2003, Kose et al., 2003, Nitzov, 1998, Ors et al., 2003, Otay et al., 2003, Tan et al. 1999, TUMPA and TSA]. An event graph for this model is shown in Figure 4 [Law et al., 2000]:

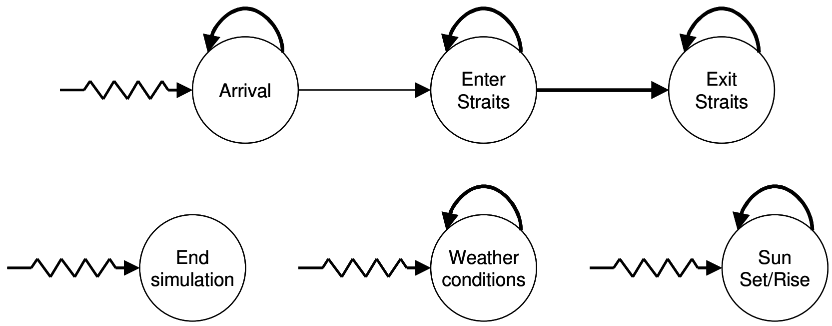


Figure 4: Event graph for the Bosporus model.

1. *Waterway*
   a. *Traffic routes*. Two directions of traffic, northbound (Marmara Sea to Black Sea) and southbound (Black Sea to Marmara Sea), each 31 km long.
   b. *Internal ports*. In this paper, internal ports of Bosporus are not modeled.
   c. *Weather conditions*. An independent event for weather conditions is triggered every 4 hours of simulation time. Using a Poisson distribution, a decision is made of whether the Straits are suitable for navigation due to severe weather or not for the next 4 hours. The model is adjusted so that the Straits are closed, on average, for 480 hours every year. Shutdowns due to weather conditions apply to the whole waterway.
   d. *Accident probability*. On average, 30 hours every year are added to the severe weather period to count in for the closing of the Straits due to accidents or mechanical problems of the transiting vessels. Shutdowns due to accidents apply to the whole waterway.
   e. *Special physical characteristics*. A special set of rules apply for the Straits narrowing between Vanikoy and Kanlica. There are no water locks or other physical obstacles in Bosporus.
2. *Queues*
   a. *Number of queues*. One queue per direction for all vessels.
   b. *Sorting scheme*. According to the applied regulations, passenger vessels are scheduled to enter the Straits with top priority over all other vessels. Dangerous cargo vessels are scheduled to enter the Straits with minimum priority over the remaining types of cargo. A first-in-first-serve scheme (FIFS) is implemented; however, the whole queue is scanned in order to find the first vessel that can transit without violating any regulation.
3. *Regulations.* Detailed regulations, as applied by the Turkish authorities, can be found in [GMCSSA, 2003]. In brief:
   a. *Entrance permit*. Vessels longer than 200 m, carrying dangerous cargo can navigate through the Straits only during daytime. During severe weather conditions or accident occurrences, no vessel can enter the Straits. Once every day, during daytime and for a predetermined period of time, two-way traffic is suspended and a batch of large or dangerous cargo vessels is forwarded in one-way traffic mode. Afterwards, traffic is inverted and a batch of large or dangerous cargo vessels is forwarded in the opposite direction.
   b. *Same route traffic*. The minimum safety distance between two consecutive vessels that enter the Straits in the same direction is defined to 8 cables (~1.5 km). The safety distance is considerably longer between two large dangerous cargo vessels; nearly 29 km for northbound vessels and 23 km for southbound vessels.
   c. *Other routes traffic*. Virtually no dangerous cargo vessels can enter on the opposite direction of an already transiting dangerous cargo vessel. Moreover, two-

d. way traffic is suspended, when a large or dangerous cargo vessel transits the Straits. Special attention is paid to schedule transits so as to avoid meetings of almost all types of vessels between Vanikoy and Kanlica.

e. *Transit rules*. A constant transit speed of 10 knots relative to land is used for all vessels and overtaking is not allowed. Overtaking is not allowed within Bosporus. All vessels transit the whole length of the Straits; a vessel does not depart from or arrive in a port within Bosporus.

| Type of cargo \ LOA (m) | 50-100 | 100-150 | 150-200 | 200-250 | 250-300 |
|---|---|---|---|---|---|
| Passenger Cargo | 0.15 | 0.47 | 0.24 | 0.04 | 0.10 |
| General Cargo | 42.56 | 32.02 | 12.09 | 1.83 | 0.39 |
| Dangerous Cargo | 0.84 | 1.14 | 4.31 | 2.40 | 1.42 |

Table 1: Arriving vessels' attributes distributions (%).

| | | Passenger Cargo | General Cargo | Dangerous Cargo |
|---|---|---|---|---|
| Southbound | Laden | 100% | 75% | 90% |
| | In Ballast | 0% | 25% | 10% |
| Northbound | Laden | 100% | 75% | 20% |
| | In Ballast | 0% | 25% | 80% |

Table 2: Vessels laden/in ballast (%).

4. *Traffic*. The simulation system uses as its input historical data that have been processed to match the conventions of the model. A uniform distribution is used to generate all possible events for the discrete-event model. Interarrival time is defined to be the same at both entrances (~21.45 minutes). According to the data, arriving vessels can be represented by a matrix consisted of all possible length and cargo categories (Table 1). Since, for safety reasons, the applied transit regulations discriminate laden from in ballast vessels, a distribution for the cargo state of arriving vessels is needed (Table 2). Following a series of interviews with maritime agents, passenger vessels (passenger, RO-RO, etc) are assumed to be always laden, while general cargo vessels (bulk carriers, container carriers, general cargo ships, etc) are assumed to be 75% laden during transit for both directions. On the other hand, dangerous cargo vessels (which according to the IMO and, subsequently, the Turkish authorities include all oil tankers, chemical tankers, LPG/LNG carriers, etc) are assumed to heavily depend on the direction of transit: for southbound transits 90% of the vessels are considered laden a ratio that for northbound transits falls to only 20%. This bias can be justified by the general pattern of the Black Sea oil industry which mainly exports large amounts of Caspian Sea and Russian oil using the ports of Novorossiysk, Supsa and Tuapse through the Straits and imports smaller quantities of oil for refining in Bulgaria and Romania as well as oil products. Indicatively, for the period 1997-1998, the quantity of oil and oil products that was transited southbound through the Straits was 6-fold the quantity that was transited the opposite way.

Vessels under 50 m are not included in the input data since they transit the Straits essentially unconditionally, while transits for vessels over 300 m are rare incidents. Also, use of tugboats, pilotage services, maneuvering to and from the actual designated waiting vessels areas and their subsequent time losses are not modeled in this article.

## 7. Assessing the impact of traffic regulations

Apart from the codified maritime regulations, there are a number of implementation policies that the Turkish maritime authorities exercise in order to manipulate incoming traffic. In this paper, three maritime regulations and two implementation policies have been selected to be studied:

- Length of the Bosporus Straits waterway that is regulated;
- Minimum safety distance between two consecutive transiting vessels;
- Forwarding of the first vessel that can enter the Straits without violating the regulations, regardless of its position in the waiting queue.
- Alternately suspension, during daytime, of two-way traffic, and transit of a batch of large or dangerous cargo vessels in each one-way traffic period;
- Partial suspension of navigation through the Straits during night time;

In all cases, the regulation or policy under consideration is treated as a free variable and the simulation results are compared against those of the base scenario that consists of: i) The actual, currently applied maritime regulations and policies; ii) Vessels' distribution with regard to their length and cargo rates according to the data of Table 1 and Table 2 and iii) A mean annual arrival rate of 55000 vessels for both directions. Each scenario is run for a simulation time of one year and repeated three times.

### *7.1 Scenario 1*

Definition of the total (regulated) length of Bosporus as well as of the minimum safety distance following a laden dangerous cargo vessel is studied in this scenario. The boundaries are defined by the line Turkeli light traffic control station – Yam Burnu in the north and the Ahirkapi traffic control station location in the south (a total navigation length of approximately 31 km). After a southbound dangerous cargo vessel passes the Bosporus bridge (23.5 km distance from the northern boundary) or a northbound dangerous cargo vessel passes the Hamsi Burnu – Fil Burnu line (29 km distance from the southern boundary), another similar vessel may enter Bosporus on the same direction.

Scenario 1 examines the possibility of reducing the regulated length of the Straits or the minimum safety distance between two consecutive dangerous cargo vessels. For this purpose, waypoints (Figure 5) are combined to generate 5 new combinations of distances (Table 3). Combination #1 corresponds to the base scenario (SB stands for southbound traffic and NB for northbound traffic).


Figure 5: Bosporus Straits waypoints.

| Combination / Distance (km) | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Total Bosporus length | 31.0 | 29.0 | 29.0 | 27.0 | 25.0 | 23.0 |
| Northbound safety distance | 29.0 | 29.0 | 27.0 | 27.0 | 25.0 | 23.0 |
| Southbound safety distance | 23.5 | 21.5 | 23.5 | 21.5 | 19.5 | 19.5 |

Table 3: Distances combinations.

Average waiting time and queue length (Figure 6 and Figure 7) for all vessels, and specifically for dangerous cargo vessels, decrease as the total length and minimum safety distance following dangerous cargo vessels decrease. However, simulation shows that reducing the regulated length of the Straits or the minimum safety distance between two consecutive dangerous cargo vessels would not result in significant benefits, while, in the meantime, substantially increase the exposure of inhabited areas of Bosporus near its entrances to unregulated traffic.

Results are slightly different for each direction of travel (SB and NB) due to the different rules that apply on laden or in ballast large and dangerous cargo vessels. Specifically, southbound dangerous cargo vessels are more often laden (Table 2), thus, more strict regulations apply to them and any following vessel [GMCSSA, 2003].

### *7.2 Scenario 2*

The minimum safety distance between two consecutive vessels transiting the Straits is studied in this scenario which, according to the applied maritime regulations, is defined to 8 cables (1482 m). Scenario 2 studies the span from 5 to 11 cables

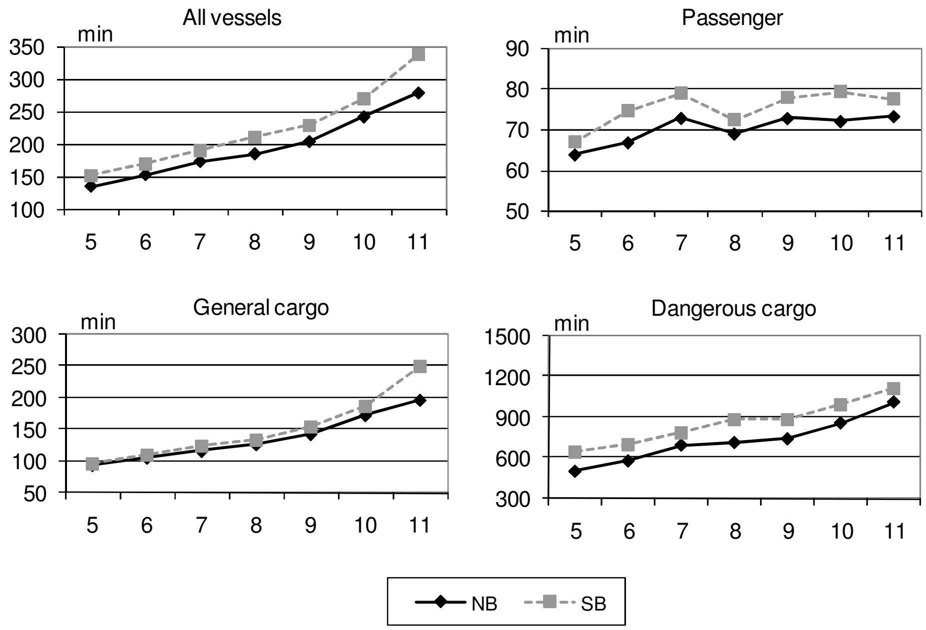


Figure 8: Scenario 2 - Average waiting time.

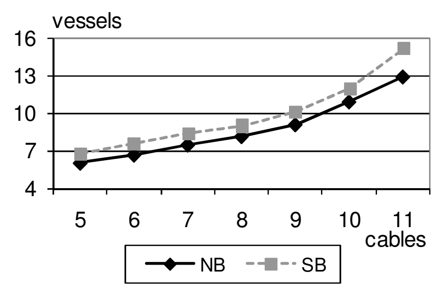


Figure 9: Scenario 2 - Average queue length.

Passenger traffic, having top priority, is essentially unaffected by the altering of the minimum safety distance. As the latter moves from 5 to 11 cables, general cargo and dangerous cargo vessels suffer from a two-fold increase in their average waiting time, which also affects the average waiting time for all categories of vessels (Figure 8). Dangerous cargo vessels contribute most in the increase of the average queue length (Figure 9). In the area of 8 cables, changes in average waiting time and queue length can be considered as linearly proportional to changes in the minimum safety distance. Again, results are slightly different for each direction of travel (SB and NB) due to the different rules that apply on laden or in ballast large and dangerous cargo vessels.

Simulation results for the first two scenarios show that a tradeoff between safety distances and level of navigation safety is anticipated, although, in the presence of a modern VTS system like the one currently implemented, less strict regulation could be studied.

### *7.3 Scenario 3*

An implementation policy is studied in this scenario, namely the forwarding of the first vessel that can enter the Straits without violating the regulations, regardless of its position in the waiting queue. After taking into account that passenger vessels are scheduled on top of the waiting queue, and large or dangerous cargo vessels on the bottom, applied regulations imply a FIFS scheme for the scheduling of each cargo category [GMCSSA, 2003]. This practice would downgrade the service capacity of the Straits since, e.g. a 75-meter tanker could wait for days behind a 200-meter tanker that arrived earlier. To ease the problem, we assume that every time a vessel can enter Bosporus, the traffic supervisor scans the whole waiting queue (passenger then general cargo then dangerous cargo vessels in a FIFS fashion) to locate a vessel that can enter without violating any regulation.

Scenario 3 studies the benefit of such a policy. For this purpose, 3 variations have been created: i) The FIFS scheme is strictly followed and vessels must wait for their turn to enter the Straits (policy #1), ii) FIFS scheme is strictly followed for passenger and general cargo vessels while dangerous cargo waiting queue is scanned each time so that small vessels can get past and enter on first occasion (policy #2) and iii) The base scenario policy where all three waiting queues are scanned (policy #3).

Average waiting time is reduced to even the 1/30 of the original time (southbound traffic) after applying the studied policy (Figure 10). The improvement must be wholly attributed to the dangerous cargo vessels category, where, especially for the southbound traffic, average waiting time is reduced two orders of magnitude. This is due to the better optimization of the time slots that are available for this kind of traffic; short and medium length, in ballast, dangerous cargo vessels can transit mixed with general traffic all day long leaving the regulated, one-way traffic periods to large and laden dangerous cargo vessels.

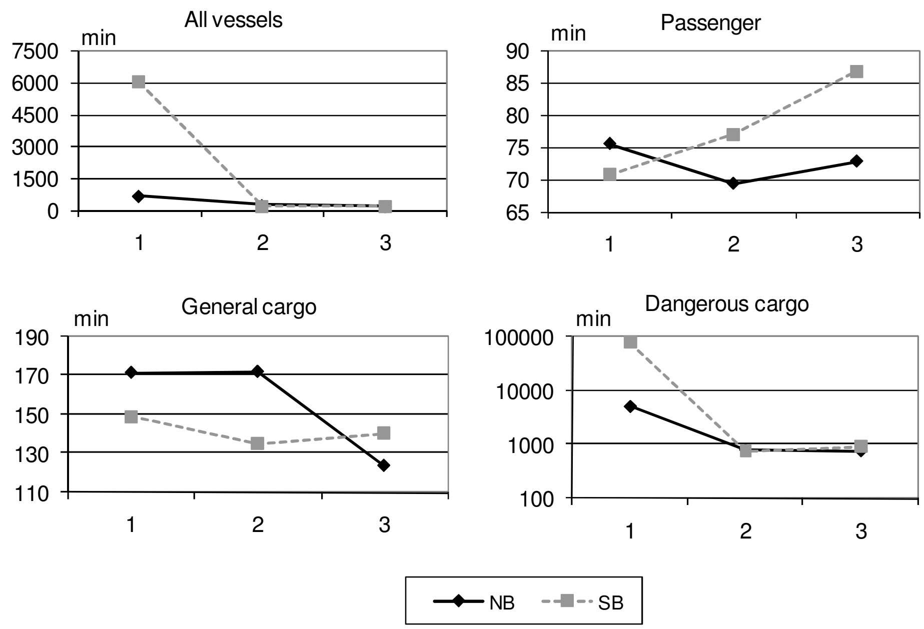


Figure 10: Scenario 3 - Average waiting time.

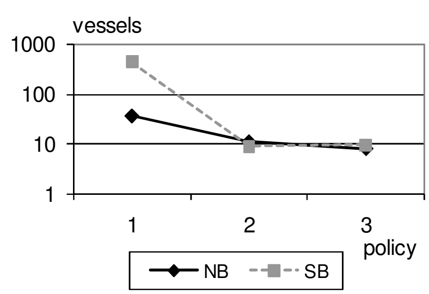


Figure 11: Scenario 3 - Average queue length.

Times for passenger and general cargo vessels stay, for all policy implementations, steady or slightly increased, since the increased possibility that a medium dangerous cargo vessel will transit the Straits reduces, on the average, the available time slots for passenger and general cargo traffic.

Average queue length (Figure 11) follows the trend of average waiting time due to the better scheduling of large and dangerous cargo vessels.

### *7.4 Scenario 4*

An implementation policy is studied in this scenario, namely the alternate suspension of two-way traffic, during daytime. Usually, large or dangerous cargo vessels suffer from large delays due to the longer safety distance that their transit requires as well as the fact that they cannot transit Bosporus during nighttime. To ease the problem, maritime authorities suspend traffic for a predefined amount of time during daytime, e.g. first to southbound traffic, allow the transit of a batch of northbound, large or dangerous cargo vessels and then apply the same policy to the opposite direction.

| Time (hr) \ Combination | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Northbound one-way time period | 0.0 | 1.0 | 2.0 | 2.0 | 2.0 | 3.0 | 3.0 | 3.0 |
| In between two-way time period | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 |
| Southbound one-way time period | 0.0 | 2.0 | 2.0 | 3.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| Total one-way time period | 0.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 | 8.0 | 8.0 |

Table 4: Time periods combinations.

Scenario 4 examines how different time periods of two-way traffic suspension times affect traffic variables. For this purpose, 8 combinations have been created (Table 4); combination #1 assumes no suspension time while combination #7 assumes that, in total, 8 hours/day are reserved for daytime, one-way, large or dangerous cargo vessels transit. Combination #6 corresponds to the base scenario that is applied in all other scenarios of this article. Finally, combination #8 is an extra experiment that uses the same time windows as combination #7 but allows for two-way, passenger and general cargo traffic (1 hour) in between the one-way, large or dangerous cargo vessels traffic periods.

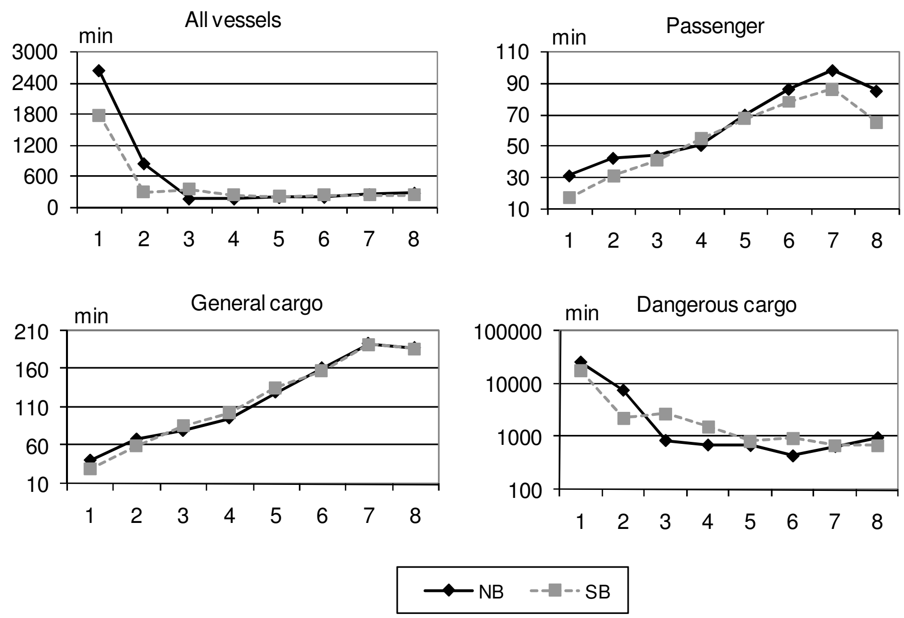


Figure 12: Scenario 4 - Average waiting time.

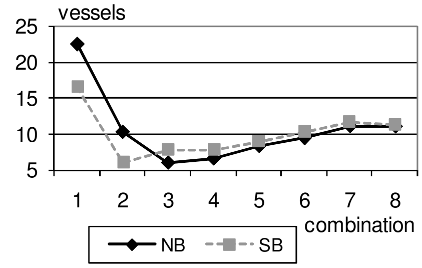


Figure 13: Scenario 4 - Average queue length.

Average waiting time for all vessels substantially decreases when the studied policy is applied. Though, after combination #3, the average waiting time seems unaffected by the increase in the suspension periods, this is not the case for each cargo category and maritime authorities are called to balance an increase in the passenger and general cargo waiting times for the benefit of large and dangerous cargo vessels and vice versa, depending on the actual day to day demand for transits (Figure 12). The trade-off between these two categories of traffic is well justified, since an increase in the two-way traffic suspension periods (up to 8 hours or one third of the day) reduces the available time slots for passenger and general cargo vessels. Moreover, it is evident that average waiting time for dangerous cargo vessels is reduced only when an increase in the respective two-way suspension time period is implemented (e.g. for northbound traffic in combinations #2, #3 and #6).

Average queue length (Figure 13) is steeply reduced in the first two cases and then slightly increasing in proportion to the total suspension time for both directions which results from the fact that for an ever increasing time (4 to 8 hours from combination #3 to combination #7) Bosporus is closed to passenger and general cargo traffic that account for almost 90% of the total traffic (Table 1).

Combination #8 might propose an alternative that achieves better results. Between the two suspension periods, there a small period of 1 hour that passenger and general cargo traffic (that has been accumulated during the first suspension period) is served, thus resulting in a better performance than in combination #7.

In general, implementation of the studied policy can substantially decrease average waiting times for large or dangerous cargo vessels (in one case, up to 98% or from ~20 days down to ~7.5 hours) in the expense of larger, but tolerable, average waiting times for passenger and general cargo vessels (in one case, six-fold increase or from ~0.5 hour up to ~3 hours)

### *7.5 Scenario 5*

Suspension of large dangerous cargo vessels traffic during nighttime is studied in this scenario. According to the applied regulations [GMCSSA, 2003], laden, dangerous cargo vessels longer than 200 m and laden or in ballast, dangerous cargo vessels longer than 250 m cannot transit Bosporus during nighttime.

Scenario 5 examines three policy variations: i) The base scenario, where current regulations are applied, ii) All vessels can transit during nighttime but with the use of a double minimum safety distance (16 cables), along with the special safety distance that is used after the transit of a dangerous cargo vessel (23 or 29 km depending on the direction of transit); iii) All vessels can transit during nighttime using the 8 cables minimum safety distance.

Average waiting time and average queue length evolve similarly in the three policy variations. They both increase from policy #1 to policy #2 and stay almost unaltered from policy #1 to policy #3. Applying a double minimum safety distance during nighttime effectively cuts in half the respective transit slots, a cut that accounts for 18.4% – 30.6% of all slots during a single day (the exact figure depends on the time of year), offsetting any benefit that might come from allowing large dangerous cargo vessels transit during nighttime and resulting in a significant increase from policy #1 to policy #2 (Figure 14 and Figure 15).

In any case, the regulation large dangerous cargo vessels account for less than 4% of the total maritime traffic in Bosporus (Table 1) but require larger safety distances around them and this combination is reflected in the second comparison (policy #1 to policy #3), where although average waiting time for large dangerous cargo vessels traffic has been reduced (18% for northbound and 32% for southbound traffic) passenger and general cargo waiting times and queue lengths increase offset this improvement.

Moreover, apart from not improving the general traffic characteristics, transit of large dangerous cargo vessels during nighttime would increase the probability of an accident within Bosporus.

## *8. Conclusions*

Bosporus can be considered a finite resource consisting of time slots that are distributed so that arriving maritime traffic is efficiently serviced. Moreover, the marine environment of the straits and the urban environment of Istanbul have to be secured from accidents that can inflict serious damages in case a large dangerous cargo vessel is involved. In this context, applied regulations recognize three types of traffic which contest for the available limited resources: passenger, general cargo and dangerous cargo.

Passenger and general cargo vessels oppose to dangerous cargo vessels and as a general trend increase in the availability of slots for the one group decreases available slots for the other. In all five scenarios, passenger traffic, having top priority over all other traffic was less affected by any modeled regulation variation. On the contrary, dangerous cargo traffic is very sensitive to any change, a trend that is intensified by the fact that dangerous cargo vessels consume more time slots due to increased safety distances during their transit.

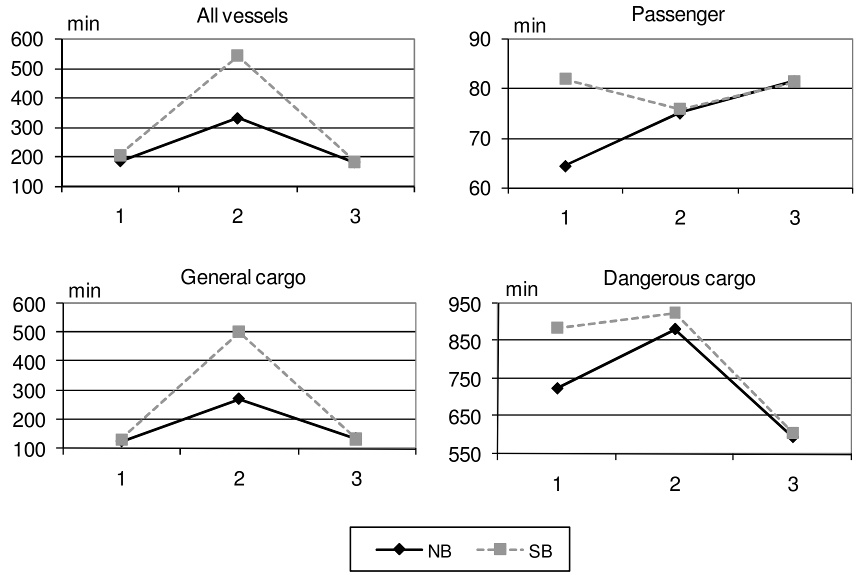


Figure 14: Scenario 5 - Average waiting time.

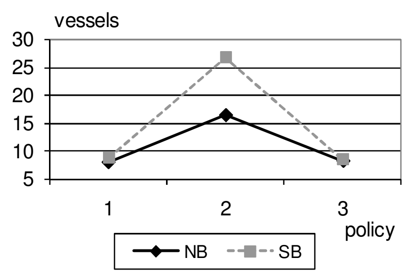


Figure 15: Scenario 5 - Average queue length.

The presented model shows that different regulations and policies have a varying effect on the average waiting time and average queue length for the three different cargo categories. In addition, the applied variations have not been proved equally effective: e.g. scenario #1 exhibits an improvement in traffic variables on the expense of leaving large areas of Bosporus (and Istanbul) unregulated and so rather unprotected. Also, some variations may have a result opposite than the desired one: scenario #5 indicates that permitting dangerous cargo vessels transit during nighttime (a change in regulations that could be discussed since the Turkish authorities have implemented a modern VTS system) would not have the expected result: neither average waiting time nor average queue length are improved (policy #1 → policy #3). Moreover, the Bosporus system safety would be compromised, since, in case of an accident, SAR operations are greatly hindered during nighttime.

In any case, scenarios #3 and #4 indicate that clever scheduling policies can substantially improve traffic variables in Bosporus, while keeping safety at the desired level. Even more, and provided the suitable tools, experimenting with these policies (e.g. combination #8 in scenario #4) shows that there is room for more improvement. The proposed parameterized model can add to this direction by allowing for the modelling and quantitative analysis of almost any possible combination of straits physical characteristics, traffic regulations and arriving traffic distributions in maritime straits in general and in Bosporus in particular.

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# Problems of repair and renewal operations in oil and gas industry

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At the present stage of development of the oil and gas industry the main directions of increase of oil and gas production are the introduction of effective technological processes of augment of oil recovery from layers, as well as the expanding of operating well stock due to an intensification of works on major repair and commissioning of new and staying idle wells. Problems of speeding up and depreciation of cost for the repair and renewal operations of oil and gas wells are particularly actual [1].

Annually the volume of operations on liquidation of failures in drilling and exploitation of wells increases. According to statistics, regularity of failures per thousand metres equals 0,3. If single isolation performance in a well with depth of 2000 m takes 30-40 hours on the average, so for liquidation of one failure it takes about 800 hours [2, 3].

In this connection the first priorities are the drastic reduction of duration of repair and renewal operations (RRO) in wells, introduction of modern technologies in the manufacture processes and advanced designs of repair machinery promoting a decrease of round-trip operations number, taking into account the peculiarities of conditions of oil and gas wells exploitation.

Problems with wells of the liquidated stock requires the application of consistent and complex approach to their decision and to this purpose the programme system for selection of effective variant/way of carrying out of repair and renewal operations has been offered and elaborated (fig. 1.).

The system is open for the further modifications and consists of blocks which can be grouped onto three levels:

I level – blocks of gathering and data processing, database, the analysis of condition of system “well - breakdown facility”;

II level – blocks of decision-making to which concern: the block of classification of failures by code variants, selection of the most comprehensible variant for realization of repair and renewal operations under indistinct condition of system and alternatives utility;

III level – blocks of delivery of results and registration of the documentation for the repair and renewal operations to which concerns - the block of "recommendation" on selection of an effective method of repair and restoration of well. Below is provided the general algorithm of programme system work:

1. Information collected about the wells of liquidated stock through the block of gathering and data processing should be entered into database.
2. The block for the analysis of condition of system "well – breakdown facility" which examines a failure situation is launching.
3. On the basis of analyzed information the classification of oil-field failure situation by code variants is carried by means of the block of classification of failure situations.
4. On this step according to the results of the block of classification the selection of the most comprehensible variant of repair and renewal operations should be realized, taking into account illegibility and uncertainty of condition of system and alternatives utility.
5. The documentation and the program of effective repair and renewal operations are to be prepared.

The development of oil-field conditions classifier for further usage of intrawell machinery during repair and renewal operations is required for realization of competitive by purposes, range of application, operation and cost indicators, serviceability and reliability of intrawell machinery for work with wells of the liquidated stock, as well as servicing in directions: a) disassembling of wellbores of the low perspective liquidated wells for the reuse of retrieved pipes of oil assortment; b) renewal and further exploitation of the oil and gas wells liquidated earlier for technical reasons. For this purpose it is necessary to select a mathematical device and to elaborate a method of classification of programs for repair and renewal operations.

The success of repair and renewal operations basically is predetermined by information support and validity of selection of realized strategy in the given situation. The basis of this support is provided by up-to-date oil-field experience on repair and renewal operations. The oil-field and statistical data of repair and renewal operations experience is the basis for formalization and automation of technology of decision-making for the selection of strategy of failure liquidation in the given oil-field situation. It is known, that depending on technological operation hold in the well there might be the various failures classified by the methodology, generally accepted in the oil-field practice. Various technologies and corresponding complex of the equipment might be utilised for their liquidation, which is shown on fig. 1. where there are provided the developed by us the classifier of repair and renewal operations and the corresponding codes of these operations.

The identification of an effective method of repair and renewal operations is implemented by results of comparison from the point of view of the economic feasibility, the code variants with positive action according to the simple logic scheme shown below (fig. 2.).

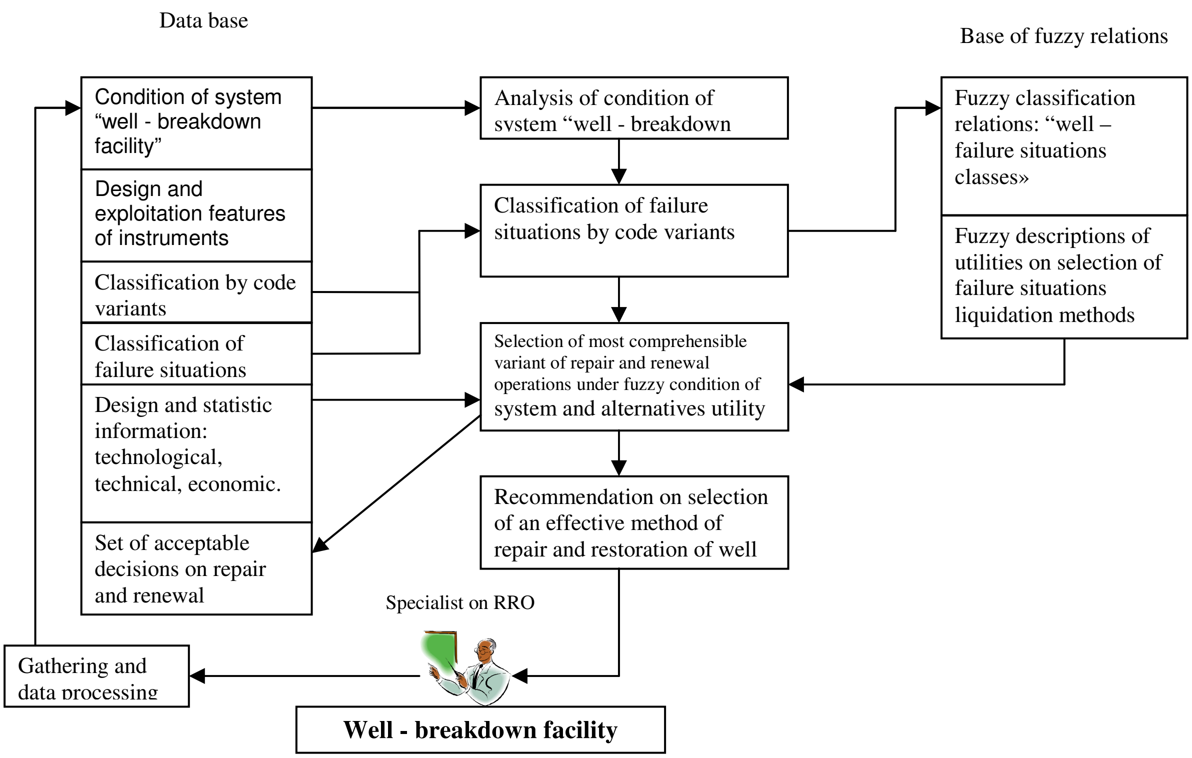


Figure 1: General architecture of programme system for the selection of effective variant/way of repair and renewal operations in wells.

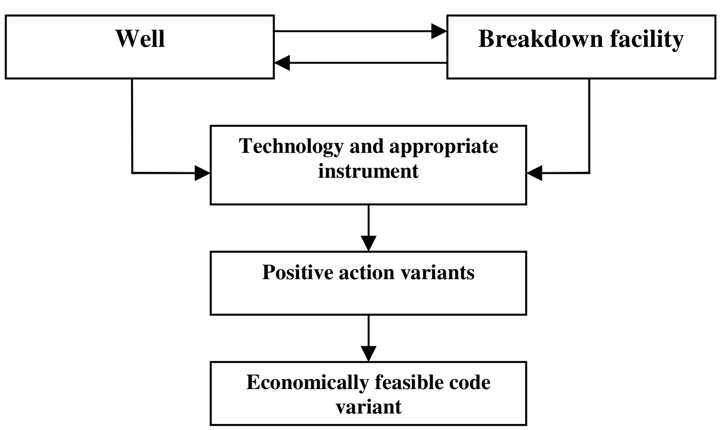


Figure 2: The logic scheme for selection of economically feasible code variant of repair and renewal operation.

As follows from this logic scheme of decision making the efficiency of implemented action is defined by condition of the system "well – breakdown facility", design and operational features of the equipment exploited for liquidation of failure.

Classification of failure situations is carried out with view of condition of the system "well – breakdown facility", design and operational features of the equipment exploited for liquidation of failure (A): diameter of well ($a_1$), condition of borehole wall (cased, a borehole is open) ($a_2$), depth of well ($a_3$), position of object in well, location of breakdown facility in the borehole ($a_4$), degree of stuck of breakdown facility ($a_5$), danger of oil ingress ($a_6$), geometrical fractures of breakdown facility ($a_7$), end form of breakdown facility ($a_8$), physical and mechanical features of material of breakdown facility ($a_9$), parameters describing the design and operational characteristics of tool ($a_{10}$ – $a_{23}$) and etc.

The analysis of existing publishing has allowed to reveal that for various classes of failures it is impossible to define and accept precisely the prescription of failure liquidation, as well as the utility of use of different liquidation methods. Nevertheless, proceeding from existing experience of repair and renewal operations and basing on the language of theory of fuzzy sets it is possible to formulate verbally-linguistically the utility ($\tilde{P}$) of exploitation of different liquidation methods for the certain classes of failures:

$$\tilde{P} = \begin{array}{c|cccc} & e_1 & e_2 & e_3 & e_4 \\ \hline t_1 & H & M & M & L \\ t_2 & M & H & M & VL \\ t_3 & H & VL & M & L \\ t_4 & H & M & H & L \end{array} \qquad (1)$$

where T={$t_1$, $t_2$, $t_3$, $t_4$} – set of existing types of failures ($t_1$ – failures with pipes, $t_2$ – failures with engines, $t_3$ – failures with cables, $t_4$ – other failures), E={$e_1$, $e_2$, $e_3$, $e_4$} – sets of possible ways of failure liquidation. VL – very low, L – low, M – medium, H – high – are values of matrix of utilities, where the utilities are put by linguistically fuzzy sets.

The correlations between the ways of failure liquidation (E) and the failure situations (G) hold also fuzzy character and are expressed linguistically [4].

According to the analysis of oil-field and statistical material of repair and renewal operations experience in the state oil company of the Republic of Azerbaijan in the article there are indicated four groups - classes of failure situations by consumed resources on failure liquidation: G={$g_1$, $g_2$, $g_3$, $g_4$}.

The measures of similarities between these failures are of probabilistic – fuzzy character and shown below:

$$\tilde{G} = \begin{array}{c|cccc} & g_1 & g_2 & g_3 & g_4 \\ \hline g_1 & 1 & 0.39 & 0.23 & 0.44 \\ g_2 & 0.39 & 1 & 0.43 & 0.22 \\ g_3 & 0.23 & 0.43 & 1 & 0.45 \\ g_4 & 0.44 & 0.22 & 0.45 & 1 \end{array} \qquad (2)$$

Due to impossibility of precise definition of breakdown facility conditions, the degree of affiliation of each new breakdown facility taken into consideration for the selection of ways of failure liquidation has fuzzy character and is defined as follows [5]:

$$\tilde{G} = \bigcup_i \mu_{\tilde{G}_i}(g_i) \big/ g_i\,, \quad g_i \in G \qquad (3)$$

where $\mu_{\tilde{G}_i}(g_i)\ /g_i \in [0,1]$ - the degree of affiliation $g_i \in G$ to the set $\tilde{G}$ and is defined by the following equation:

$$\mathrm{E}(x_i, x_j) = \frac{\sum_{p=1}^{n} a_{ip} a_{jp}}{\sqrt{\sum_{p=1}^{n} a_{ip}^2 \sum_{p=1}^{n} a_{ip}}}, i, j = 1, \ldots m \qquad (4)$$

where $a_{ip}$, $a_{jp}$ (parameters characterizing the conditions of failure situation) – coordinates of vectors $x_i$, $x_p$ (parameters describing the conditions of groups-classes of failure situation).

The elaborated classification procedure by economic indicators and the offered variants of repair and renewal operations allow defining the comprehensible of them by the estimation of complexity of failure situation and likeness to their similar classes.

## Conclusion

Has been developed the project on realization of production programs for the work with temporarily shut-in and liquidated stock of wells and indicated the manufacture of competitive by purposes, range of application, operation and cost parameters, serviceability and reliability of intrawell machinery for work with wells of the liquidated stock;

The opportunity of development of intrawell machinery manufacture corresponding to the western standards with the purpose of export on international markets of oil an gas field equipment is provided;

1. It is recommended to provide the service in following directions: a) disassembling of wellbores of the low perspective liquidated wells for the reuse of retrieved pipes of oil assortment; b) renewal and further exploitation of the oil and gas wells liquidated earlier for technical reasons.

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# The introduction of new reagents, jobs, raising to efficiency, at production and transportation of high paraffin oils

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**Abstract**

*The analysis of the condition of the control of the complications in asphalt–resin– paraffin oils extraction and transporting shows that the main problematic question is the deposit of solid hydrocarbon phases hoisting pipes hole bottom reservoir also in the equipment of discharge system, oil transporting and storage. We have carried out certain works in this direction, and as a result new highly effective reagents, conditionally named MORE–R, PG–R have been developed. These reagents are also good solvents and reducers of viscosity and solidification of paraffin oils. Developed new compositions are multicomponent. There are there are patents of the Azerbaijan republic and technical conditions for these reagents. Reagents industrial tests have passed out successfully and are let out by factories and applied in the concentrations 50 – 500 q/t depending on oil type and paraffin content. The reagents are added into the flow before the beginning of paraffin deposit. The industrial test was carried out reagent MORE in a chink № 2576 in NQEE «Neft Dashlar» is skilled. Results rather positive. So, the number of heat treatment of chinks with hot petroleum was reduced. Besides, if before introduction reagent each month was replaced 50-60 pieces of pipes by new, however after introduction reagent MORE within 6 months the education of paraffin in pipes lift did not occur. It was established after rise of a pipe from a chink. It is a very good parameter. As, clearing of pipes lift from paraffin adjournment rather labour-consuming job. Besides the environment becomes soiled. Other positive factor is the reduction middle of the daily charge of gas. So, if before introduction he made about 5000 м3/day, after introduction of reagent has made - 3420 м3/day. Reagent PG was applied too in a chink 2358 NQEE «Neft Dashlar» in struggle against paraffin of adjournment in pipes lift. The results have appeared rather effective.*

Oils exploitated in perspective areas of Azerbaijan Republic as Azeri-Chirag-Guneshli and others concern the category of asphalt resin paraffin oils. Solidification temperature of the most oils ranges in +20÷30°C.

Loss of mobility - solidification of paraffin oils at the temperature considerably exceeding the temperature of environment creates very complex problem in transporting along the pipeline. That's why we carried out complex research works in the sphere of regulation of solidification temperature and structural-rheological properties of high viscous and high solidificated oils.

It has been determined that the oils from abovementioned deposits contain various length hydrocarbon chain paraffines with their various content share. Behavior of these oils as complex dispersion system considerably depends on the temperature of environment and content of asphaltens and resins. That's why in the development of reagents of regulating of solidification temperature and structural-rheological properties of oils it is necessary to consider each deposit individually. The experiments showed that if one reagents are effective for regulating of solidification temperature or structural-rheological data of paraffin oils, then they are not suitable for asphalten resin paraffin oils. Multicomponents MORE-1 and MORE-2 reagents were developed for regulating of the data of these oils. Composition contents of shown present mixture of various aromatic hydrocarbons with PAB substitute additives, dispersants and modificators considering definite coorelations in the oils of initial components characterized for each definite deposit. Due to synergetic efficiency a new reagent with new qualities is obtained. They are usually used in 0,01 - 0,03 % concentrations of oil masses, depending on type and content of paraffin. Experiments showed, that by the treatment of paraffin oil from Sanqachal-deniz, it is possible to reduce solidification temperature from +20°C to 0°C.

One of the ways confirming the influence of depressor additives on phase structure of oils in transition stages is investigation of its rheological data. Experiments were carried out on rotation viscousymeter «Reo-2» allowing to determine dependence «stress - shift speed» in the deformation speed in 1,8-437,4 $c^{-1}$ interval. According to the measuring results for each speed gradient $\dot{\gamma}$ shift stress was considered τ and for effective viscosity - $\eta_{ef}$.

Carried out experiments showed, that all investigated oil samples relate to rheologically complex systems of elastic - viscous plastic ones, for which strength and viscousity properties are characteric. Injection of new MORE-1, MORE-2 reagents into paraffin oil in 0,01-0,05 mass % quantity considerably reduces both maximum strength limit $\tau_{nr}$ in transition of which great destruction of the structure takes place and the least shift stress $\tau_{\infty}$ in the determined regime of the flow. It evidently shows that injection MORE complex reagents into resin and paraffin oil changes surface structures of the oil, as a result shift stress of uniform flow regime (figure 1) is considerably reduced. It will bring to the reduce of stationary working pressure in the pipeline, and also power expenses spent on oil pumping.

It is significant to mention by increasing the temperature from 15,5 to 24,5°C in unchangeable shift speeds $\dot{\gamma}$ value $\tau_{\infty}$ for pure oil as a rule reduces, and character of the development of the flow curves doesn't change (fig. 2a, b, c).

The main characteristic of structural rheological properties of investigated system is viscousity. In figure 3a, b dependence of flow curves on shift speed $\dot{\gamma}$ and shift stress $\tau_{\infty}$ for the oil of Alyat-deniz and Sanqachal-deniz in the absence and presence of MORE-1 and MORE-2 is shown.

Given dependence curves $\ell g\eta_o = \ell g(\dot{\gamma})$ ; $\ell g\eta_{ef} = \ell g(\dot{\gamma})$ (fig. 3a, b) also indicate studied samples of the oils relating to non-Newton oils as they show the reduce of viscousity with the increase of shift speed $\dot{\gamma}$ and working shift stress τ in the system.

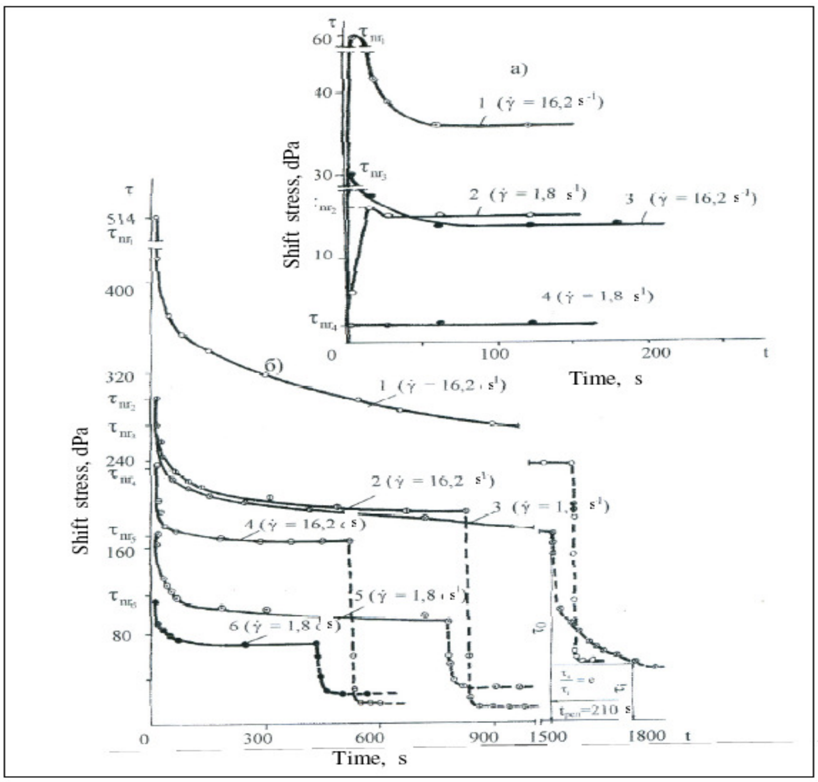


Figure 1. Kinetics of development of tangent stresses of shift τ for oils Alyati-deniz (a) and Sanqachal- deniz (b) containing reagent MORE in % (in mass) in various shift speeds: a)Sanqachal-deniz oil: 1,2 – 0; 3,4 – 0,07 (MORE – 2); shift speed $\dot{\gamma}$: 2,4 – 1,8 $s^{-1}$; 1,3 – 16,2 $s^{-1}$, temperature – 16,2°C; б) Alyati-deniz oil:1,3 –0; 2,5 –0,07 (MORE – 1); 4,6 –0,07 (MORE – 2); shift speed $\dot{\gamma}$: 3, 5, 6 – 1,8 $s^{-1}$; 1, 2, 4 – 16,2 $s^{-1}$, temperature – 15,5°C.

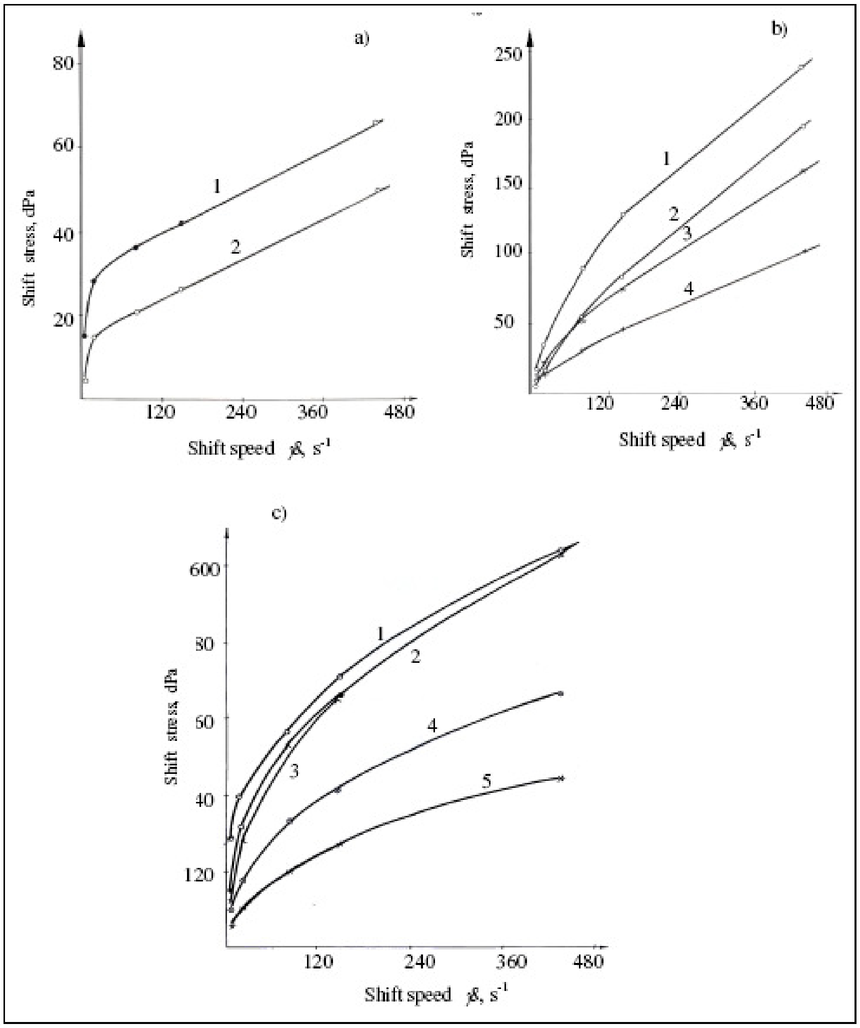


Figure 2: Dependence of shift stress $\tau_\infty$ on shift speed $\dot{\gamma}$ for oils Neft-Dashlari (a), Sanqachal-deniz (b), Alyati-deniz (c), containing MORE-1 and MORE-2: a): temperature – 1 – 17,5$^0$C; 2 – 20$^0$C; b): 1, 3, 4 – 0; 2 – 0,07% (mass.) – MORE-2; temperature – 1,2 – 16,2$^0$C; 2 – 20$^0$C; 4 – 24,2$^0$C.c): 1, 3, 4 – 0; 2 – 0,07% (mass.) – MORE-1; 3 – 0,07% (mass.) – MORE-2; temperature 1, 2, 3; 4; 5 – 15,5$^0$C; 20$^0$C; 24,5$^0$C.

From the graphic materials it is evident that in the absence of MORE-1 and MORE-2 reagents reduce of both maximum viscousity $\eta_o$ (fig. 3b, curves 1; 2; 3) corresponding to strength limit $\tau_{st}$, and final effective viscousity $\eta_{ef}$ in the equal flow regime in comparison with pure oil is observed. The greatest difference effective viscousity mainly in MORE-1 and MORE-2 masses is equal correspondingly to 5001 and 4012 MPa·sec (fig. 2b curves 2, 3) that is than 48 and 58 %. In the shift speed $\dot{\gamma}$ =16,2 sec$^{-1}$ if effective viscousity in the absence of reagent in the oil is $\eta_{ef}$ = 1976 MPa·sec, then in the presence of 0,07 mass MORE-1 and MORE-2 reagents it is 1179 and 1031 MPa·sec, that is correspondingly less 41 and 48 %. As it is shown from figure 3a paraffin oil of Sanqachal-deniz also relates to non-Newton oils with considerable dependence on shift stress and shift speed. Type of dependence $\ell g_{\eta_{ef}} = \ell g(\dot{\gamma})$ considerably differs from pure oil and the oil containing MORE-2 (fig. 3a, curves 1, 2).

Thus they differ by the availability of the areas of some value increase of maximum viscousity $\eta_o$ (corresponding $\tau_{st}$) in the sphere of low speeds of the shift with the following reduce of maximum viscousity $\eta_o$ with the increase of shift tension $\tau$ and shift speed $\dot{\gamma}$ (fig. 3a, curves 1′, 2′).

The most reduce of effective viscousity $\eta_{ef}$ of paraffin oil containing MORE-2 reagent as in resin oil is observed mainly in the low values $\dot{\gamma}$. If in the shift speed equal 1,8 sec$^{-1}$ effective viscousity $\eta_{ef}$ for initial oil from Sanqachal-deniz is equal 834 MPa·sec (fig. 3a, curves 1), then the additive of MORE-2 mass reagent sharply reduces effective viscousity $\eta_{ef}$ and it is 111 MPa·sec, that is nearly less than 8 times. With the increase of deformation speed $\dot{\gamma}$ and shift stress $\tau_{\infty}$, intensity of reduce of effective viscousity $\eta_{ef}$ decreases. For example, in invariable deformation speed is 16,2 sec$^{-1}$, then additive 0,07 % (mass) MORE-2 to the oil reduces $\eta_{ef}$ to 86 MPa·sec, that is nearly 2,6 times less.

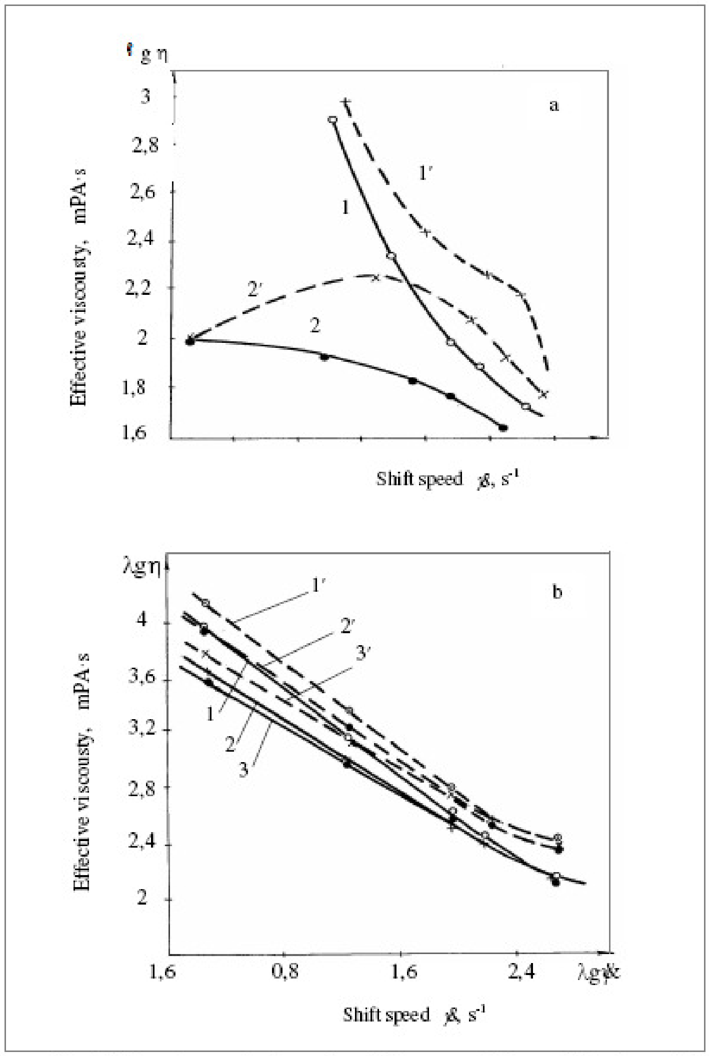


Fig. 3. Dependence of viscousity efficiency on shift speed for Sanqachal-deniz (a) and Alyati-deniz (b): a): 1 – 0; 2 – 0,07% (mass.) – MORE-2; entire lines – minimum values $\eta_{\infty}(\tau)$; point – maximum values $\eta_0(\tau_{nr})$; temperature – 15,5$^0$C b): 1 – 0; 2 – 0,07% (mass.) MORE-1; 3 – 0 07% (mass.) MORE-2; entire lines – minimum values $\eta_{эф}(\dot{\gamma})$; point – maximum values $\eta_0(\dot{\gamma})$; temperature –15,5$^0$C.

Obtained regularities can be connected by the considerable influence of mechanical shift efforts on the structure and consequently oil properties. For paraffin oil of Sangachal-deniz containing reagent MORE-2, influence of mechanical pole on the structure in the area of shift speeds from 1,8 till 16,2 sec$^{-1}$, change of initial system of intermolecular interactions and forming in the pole of new above mentioned molecular formation are possible. By raising maximum viscousity $\eta_o$ of the oil such processes take place in the lower shift speeds, and about 16,2 $sec^{-1}$ shift speed plastic flow area connected with the orientation of paraffin macromolecule units is observed. For investigated oils it was evident from the results of the experiments shown in graphic materials (fig. 1-3). Thus thixotrophic structure of Alyati-deniz oil is the consequence of availability of associates in the resin asphalten system. Structural-mechanical properties of Sangachal-deniz oil - from paraffin phases on which asphaltens and resins are adsorbed.

Structure forming processes in these oils in dynamic conditions are conditioned by their physico-chemical state, that is individual for each thixotrophic system. For paraffin oil Sanqachal-deniz dynamic structure remains stable in high shift speed 145,8 $sec^{-1}$, as the dependence from $\dot{\gamma}$ is linear, stationary flow of thixotrophic system is achieved, and for each shift speed determined balance between destruction and restoring processes of the structure is correspondent.

Breakdown of linearity is always connected with one or other rearrangement of the structure. Arrangement of the dynamic structure can indicate various hidden mechanisms of the process - discrete phase orientation, their destruction or strengthening, confirmation of components and etc. The main cause is the change of disperse phase configuration under the shift influence (and also disperse medium). Disperse paraffin phase and asfalten-resin components are oriented along flow line created under the influence of shift effort and provides reduce of viscousity. Injection of composition reagent MORE at the temperature lower the solidification temperature of the oil exerts modifying influence and reduces viscousity individually for each oil more. That's why in determining of thixotrophic oils flow it is necessary to take into account shift history. For example, in comparison of flow characteristics of various oil systems the last must be undergone to preliminary shift before the balance state in standard speed. When rheological parameters are supposed to be used for calculation of pressure overfall in the system, it is important to create tangent stress corresponding to shift speed prevailing in the pumping interval.

For projecting oil transporting regime it is very important to make right choice of rheological equalities for describing these oil flows. Carried out calculation data show that the use of three parameter model of Gershel-Balkly $\tau = \tau_o + k(\dot{\gamma})^{n-1} \cdot$ in the calculation is more acceptable. Advantage of Gershel-Balkly model is its study and possibility to determine changes taking place in highviscous asfalten-resin-paraffin oils according to the change of rheological coefficients with the purpose of taking corresponding decisions.

Table 1: Efficiency of PG-R reagent against paraffin sedimentation Alyati-deniz area, well № 71

| № | Oil composition | Reagent consumption, гр/тон | Quantity of sediment in cold stick, гр ($\tau_{гат.су}$=+10°C, $\tau_{хар.нефт}$=35°C) | Реаэентин еффектлийи, % |
|---|---|---|---|---|
| 1 | Oil | - | 87,70 | - |
| 2 | Oil + 0,01 % PG-R | 100 | 19,50 | 77, 65 |
| 3 | Oil + 0,05 % PG-R | 500 | 16,95 | 80,67 |
| 4 | Oil + 0,1 % PG-R | $1\cdot10^3$ | 15,80 | 81,98 |
| 5 | Oil + 0,3 % PG-R | $3\cdot10^3$ | 17 | 80,62 |

Table 2: Efficiency of PG-R reagent against paraffin sedimentation - Sangachal-deniz area, well № 456

| № | Oil composition | Reagent consumption, гр/тон | Quantity of sediment in cold stick, гр ($\tau_{ins.w.}$ =+10°C, $\tau_{outs.\ w}$=35°C) | Efficiency of reagent, % |
|---|---|---|---|---|
| 1 | Oil | - | 65,40 | - |
| 2 | Oil + 0,01 % PG-R | 100 | 13,40 | 79,50 |
| 3 | Oil + 0,05 % PG-R | 500 | 10,80 | 83,50 |
| 4 | Oil + 0,1 % PG-R | $1\cdot10^3$ | 9,10 | 86 |
| 5 | Oil + 0,3 % PG-R | $3\cdot10^3$ | 11 | 83,20 |

Laboratory researches have also been carried out to reveal efficiency of developed reagents against the paraffin sediments. As an initial oil Sangachal area paraffin oil was used, as paraffin asfalten-resin oil Alyati-deniz area oil was taken. The results of the experiments are shown in tables 1 and 2. As it is shown from the table efficiency of reagent occurs in its lower values - 50-100 q/ton.
Efficiency of the reagent is kept in their increase in the oil too. Considering that the reagent PG-R is also good solvent for hard paraffin sediments, and efficiency against paraffin sedimentation is 80 - 86 %, then we can suppose with confidence that the reagents MORE-R and PG-R will be also effective in real conditions. The experience of implementation of reagents MORE and PG-R on the area of «Neft Dashlari» proved it.
The industrial test on reagent MORE in well №2576 in NQEE «Neft Dashlari» was carried out. The results were positive. The number of chinks treated with hot oil was reduced. If before the reagent injection 50-60 pieces of pipes were replaced each month, however after reagent MORE injection paraffin sedimentation didn't occur within 6 months. It was evident when the pipe was lifted out of the chink. It is a very good parameter. Clearing of lifted pipes from paraffin sedimentation is rather labour-consuming job. Besides, it the environment becomes polluted. Other positive factor is the reduction of used gas. Before the injection it was about 5000 $m^3$/day, after the injection of the reagent it was 3420 $m^3$/day.
The reagent PG was also applied in well № 2358 NQEE «Neft Dashlari» in the struggle against paraffin sedimentation in pipes. The results were rather effective.
Rheological data of oils have been also studied and positive results have been obtained. Reagent MORE had industrially tested in NQEE «Neft Dashlari» in 6 inch pipelines with the efficiency 320 t/day. The results were quite positive.

# New composition of high inhibited drilling mud for use of unstable clay deposits

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**Abstract**
*The main condition for raising of technique–economical data of drilling is the improve-ment of the drilling mud recipes. Drilling of the intervals, consisting from montmorillonite clay or from their layers has great difficulty. Mass share of the montmorillonite in various section is approximately 40 – 50 %. These clay are characterized by high hydration energy and easily swell and in ingress into the solution are dispersed. Control of these or other complications in the drilling of unstable clay deposits by the mud waterless control is not successful. It is connected with that the pressure of water diffusion suction into the clay is approximately in 34.5 – 69 MPa diapason. That's why the significance of mud waterless doesn't play any role: it will suck the necessary moisture for clay. After clay plates adsorb water, suction pressure reduces till the balance condition. From the other hand as soon as clays water, tension increases to fail. The value of this strength is so high, that in hermetic environment it can deform not only casing columns not depending on their thickness, but also earth crust. For solving of this task and also for reducing collector data of productive reservoir foreign companies use synthetic and other drilling muds. But these muds are not available for local enterprises. On the instruction of SOCAR a new composition of high inhibited drilling mud has been developed. The new composition (patented, conditionally named PAK – f) is at the same time is a filter reducer of drilling mud. For example after adding 0,5; 0,75; 0,88; 1 % dry product to the drilling mud made in sea water and having initial filtration 35 $sm^3$/30 min (on BM –6) the filtration reduces greatly, than in mud treatment by known filtration reducers – polysacharide polyanions. The example of preparing of drilling mud is shown in the report.*

The main condition for raising of technique-economical data of drilling is the improvement of the drilling mud recipes. Drilling of the intervals, consisting from montmorillonite clay or from their layers has great difficulty. Mass share of the montmorillonite in various section is approximately 40-50%. These clay are characterized by high hydration energy and easily swell and in ingress into the solution are dispersed.

Control of these or other complications in the drilling of unstable clay deposits by the mud waterless control is not successful. It is connected with that the pressure of water diffusion suction into the clay is approximately 34.5-69 MPa diapason.

That's why the significance of mud waterless doesn't play any role: it will suck the necessary moisture for clay. After clay plates adsorb water, suction pressure reduces till the balance condition. From the other hand as soon as clays water, tension increases to fail. The value of this strength is so high, that in hermetic environment it can deform not only casing columns not depending on their thickness, but also earth crust.

For solving of this task and also for reducing collector data of productive reservoir foreign companies use synthetic and other drilling muds. But these muds are not available for local enterprises.

For carrying out qualitive completion of the wells it is necessary to solve all complex questions just beginning with the drilling process. For example, well shaft becomes unstable in due course because of clay hydration. As a result real conditions for chute formation are created, in its turn it causes increase of rotary moment, and also resistance forces in displacement of column along the wellshaft. Besides it collapse and scree of the rocks arouses necessity of additional treatment of wellshaft, bulge formation instrument breakdown, drilling mud clogging, unqualitive on its cleaning and preparing wellshaft to the column descent.

It should be mentioned that processes of swelling and collapsing of well walls are repeated continuously, consequently expansion of the cavity lasts with the movement of fluid into the depth of the layer from the well centre. Hydration clays are dissolved in the mud at the expense of their dispersion, increasing content of hard phase in the drilling mud, which makes worse work of the pumps and turbodrill and reduces mechanical speed of drilling as a main indicator.

Besides it high hydrated clay on the wellshaft can't provide good carrier surface for bottom assembly and it makes difficult regulation of trajectory of controlled directional well, especially with high zenith angle value.

Complications of the such character and their other types, on liquidation of which a lot of unproductive time, material resources and etc. are spent, negatively influence on main technico – economical data of drilling.

Potassium drilling muds are used for their prevention which gave good results. However high qualitive chemical reagents are required for regulation of structural – reological data of these muds. That's why as a rule cost of multicomponent potassium drilling mud is always higher than the muds not containing potassium chloride. We developed and realized mass implemention of high-inhibited drilling mud made on the basis of polyglycol.

Equally with the other properties of polyglycerol based drilling mud, its inhibition ability by the determination of moistening capability of the clay has been investigated.

If moistening ability of 0.3% acryl stiffener water solution equals 9,3 . $10^2$, then in 5% polyglycerol content it is – 3.8 . $10^2$ and in 40% it is – 0,45. $10^2$ m/h, that is 20 times less (table).

| Content of the solution % | | Moistening ability data $10^2$ m/h |
|---|---|---|
| Acryl stiffener (0,3% solution) | PG 300 | |
| 100 | - | 9,3 |
| 95 | 5 | 3,8 |
| 90 | 10 | 2,0 |
| 85 | 15 | 1,8 |
| 80 | 20 | 1,13 |
| 75 | 25 | 0,8 |
| 70 | 30 | 0,6 |
| 65 | 40 | 0,45 |

If to consider that approximate time of stable state of clay rocks depending on moistening ability value of drilling mud determined on the drilled clay samples are modeled on PD 39 – 0,14-7009-6.032-86

$$T_1 = \frac{833 - R_1 p}{\Pi O P_1}$$

Where R1 - well radius, m; p-drilling mud density, kg/m³; P1- porous pressure in clay rocks in equivalent with solution density, kg/m³; Po- data of moistening ability, %/h; it is evident that the less Po, the more probability of safe well shaft leave in open-hole condition. Condition of well shaft drilled with the help of drilling mud on the basis of polyglycerol, according to caliper data taken before column descent is shown in figure 1.

Labour condition on the rig has been considerably improved with the implemention of polyglycerol. As polyglycerol in comparison with other known reagents is not toxic with respect to sea fauna and flora then its implemention will exert positive influence in the struggle against environment pollution by drilling waste. Progressive companies of the world consider principal the influence of drilling muds on natural data of productive layers and directly final oil extraction as the most important requirements in preparing of drilling muds [4]. It is impossible to achive maximum oil extraction from productive layers opened by water based drilling muds. Thus if small particles in the mud (powder, clay, hard rock and so on) are bigger than layer pores they flow easily with the flow, but if they are smaller they enter pores and cause serious obstacles on oil production. One of the obstacles is swelling of clay fractions as a result of passing of water based drilling mud filtrate into oil layers and layer depths of the process. One of the factors influencing intensification of complications is the getting into reaction of alkali component in the mud formation of unsolubale sediments. Later on it is impossible to clean these sediments and as a result natural data (permeability, porosity and etc.) of productive layers are getting worse for ever.

At present demand on the reagent preventing clay collapsing in well drilling and at the same time reducing drilling mud filtration is one of the most difficult problems for drilling sphere.

As a result of number of investigations reagent PAK-f (polyglycol –aluminate potassium based) regulating drilling mud filtration, at the same time having high inhibitor data in drilling of quickly swelling, collapsing and undergoing dispersion unstable clay layers ahs been developed and prepared.

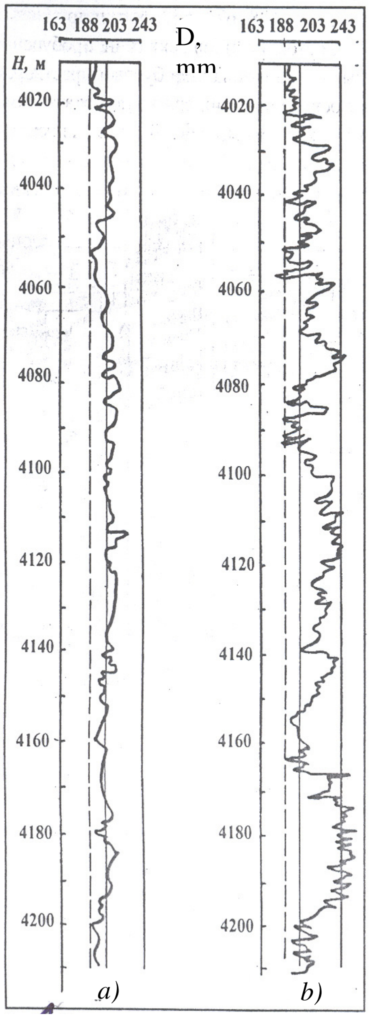


Figure1: Calipers of the wells, drilled by 188-mm bit with PG-300 (*a*) and (*b*) CAR muds washing.

The reagent consists of various components. At the same time the content having high inhibitor ability against the clays. In the experiments mud samples taken from the drilling wells and not treated by chemical reagent have been used. When analyzing influence of PAK-f reagent on technological data known CMC (carboxyl methyl cellulose) and at present applied CAR (coal alkali reagent) have been used for comparison. As CMC product of Perm plant (Russia), PAK-f CAR have been used. Coorelation of PAK-f, CMC and CAR to soda is 1:0,2. The results of carried out investigations are given in the table.

The experiments show that new PAK-f reagent exerts good influence on the mud filtration used in drilling offshore and onshore wells. If the initial filtration of sea water based mud is 30 $sm^3$/30 min., (see table, mud № 1) when adding it 0,5; 0,75; 0.88; 1% PAK-f reagent (according to dry mass and active component) its filtration descent accordingly to 20; 1; 6,5; 6$sm^3$/30 min.

These results are close to the of the mud treated with CVC (N13-16).

These data are better in ordinary water based muds.

# Session 3: Electricity – Renewable Energy Sources

# Sustainable Energy Planning for Autonomous Power System of Crete


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**Abstract**

*The autonomous power system of Crete has been selected as a representative model for long term energy planning estimation in case of significant high share in power and energy balance from renewable energy sources. A generation capacity expansion model selects from conventional electricity generation technologies such as thermal power units, combined cycle units, combustion turbines, and renewable energy technologies such as wind parks, photovoltaics and hybrid systems in order to supply the projected demand of the future years. At the same time, power system operation and control, special restrictions, performance projections, as well as generation expansion costs, should be comprehensively investigated. More precisely, this study analyses current system operation and demonstrates benefits and obstacles of a substantial share of Crete's projected load demand from renewable energy sources and hybrid systems by the end of 2020. The potential of high share is technically feasible, not cost-prohibitive, and provides advantages in the forms of carbon emission reductions, energy adequacy and dependency.*



**Key-words:** Autonomous Power Systems, Energy Planning, Renewable Energy Sources


## 1. Short Overview

Renewable energy sources (RES) for electricity generation have several advantages over conventional generation technologies. Reduction of greenhouse gases (GHG) that contribute to global climate change and to local air quality is one of the major advantages of RES utilization. Additionally, they reduce the risk of fossil-fuel price fluctuations, spread the energy-mixture, and decrease the electricity-sector dependency.

At the other side, by their geographical and natural position, European Islands represent a key actor with specific characteristics into the implementation framework of a sustainable energy policy. More precisely, three main dimensions have been identified by the European Commission for a successful energy planning, which are security of supply, sustainability and competitiveness. Furthermore, several obstacles and technical restrictions are evident in island's the energy sector, such as higher total costs, fluctuations in the price and insecurity of supply. However, these disadvantages can be outweighed by inherent advantages, especially by utilization of renewable energy technologies, thanks to their relative high wind and sun exposure [Papadopoulos et al., 2008]. This potential should be better exploited in order to investigate the operation and planning limitations and estimate the possible solutions [Boulaxis et al., 2005].

The autonomous power system of Crete has been selected as a representative model for long term energy planning estimation in case of significant high share in power and energy balance from renewable sources [Zografakis, 2005]. Crete possesses ample wind [Katsaprakis, Christakis, 2004] and solar resources, technically more than 1.2 GW that could be harnessed to produce electricity at reasonable cost, if control and management restrictions are excluded. The dispersion of RES installations and the variability of electricity production must be successfully managed by electricity grid. Generally, the dispersed generation changes distribution networks from passive networks, with power flows from higher to lower voltage levels, into active networks with multi-directional power flows, [Strbac, 2002]. Furthermore, transmission and distribution infrastructures require specific economic regulations, [Stoft, 2002]. Although wind reduces fossil-fuel usage, the total cost of RES projects must be careful investigated.

This paper analyses the feasibility, and benefits of high percentage electricity supply from RES technologies till 2020 in Crete. Operation and statistical data of Crete's power system is used as a baseline input to this study that assess electricity generation capacity expansion for a cost-optimal generation mixture over a long-term planning horizon up to 2020, taking into consideration previous studies as [Tsioliaridou, et al. 2006], [Katsaprakakis, et al. 2008], [Tsoutsos, et al. 2009], [Kaldellis et al., 2009], and [Giatrakos, G.P., 2009].

## 2. Autonomous Power Systems

Autonomous or isolated power systems are all the small and medium size power systems where no interconnection exists with conterminous and/or continental systems. These power systems, like the ones operating in large islands, face increased problems related to their operation and control, [Smith, et al. 2006]. In most of these systems, dynamic performance is a major concern, since mismatches in generation and load and/or unstable system frequency control might lead to system failures, easier than in interconnected systems.

Renewable sources and especially wind power exploitation appear particularly attractive, [Doherty, O'Malley, 2006]. However, the integration of a substantial amount of wind power in isolated systems needs careful consideration, so as to maintain a high degree of reliability and security of the system operation, [Hatziargyriou, et al. 1998]. The main problems identified concern operational scheduling (mainly unit commitment) due to high production forecasting uncertainties, as well as steady state and dynamic operating problems [Thalassinakis, Dialynas, 2007]. These problems may considerably limit the amount of wind generation that can be connected to the island systems, increasing the complexity of their operation [Dialynas, Hatziargyriou, 2007]. Thus, next to the more common angle and voltage stability concerns, frequency stability [Karapidakis, Thalassinakis, 2006] must be ensured. This depends on the ability of the system to restore balance between generation and load following a severe system upset with minimum loss of load.

## 3. Power System of Crete

Grete is the largest Greek island with approximately 8,500 $km^2$ and one of the largest in Mediterranean region. Its population is more than 600,000 inhabitants that triple in summer period. As well, it features a considerable annual increase of electricity demand approaching the 7% during the last decade, as it is clearly shown in Fig.1. As a result, the annual energy consumption during 2008 surpassed the 3TWh in comparison with the modest 280 GWh of year 1975.

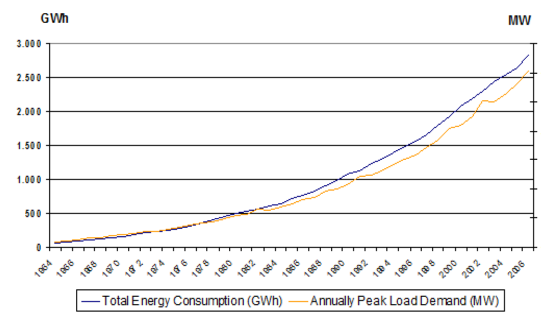


Figure1: Load and Energy Consumption Time Evolution.

Additionally, comparing the mean hourly load demand variation all year round, there is a considerable electricity generation diversification between months and seasons, as it is shown in Fig. 2.

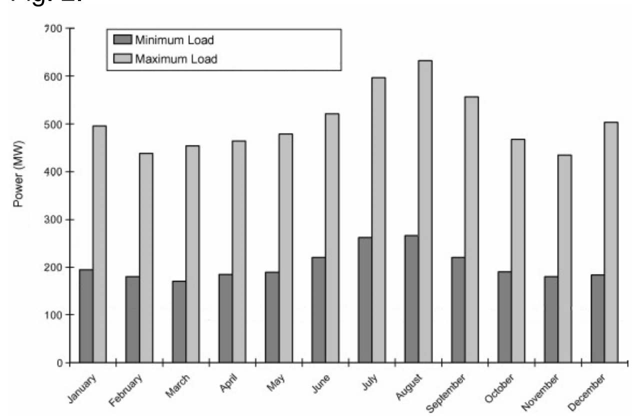


Figure 2: Monthly variation of min and max load demand.

However, even during the low consumption periods, minimum load demand is greater than current system technical minimum (approximately 120 MW). Island's electricity generation system is based mainly on three (3) oil-fired thermal power units, located as it is shown in Fig. 3. The nominal capacity of the local power plants is 742 MW in total, although the actual power is considered to be 721 MW for winter and 674 MW for summer operation, as it is described in the following Table 1.

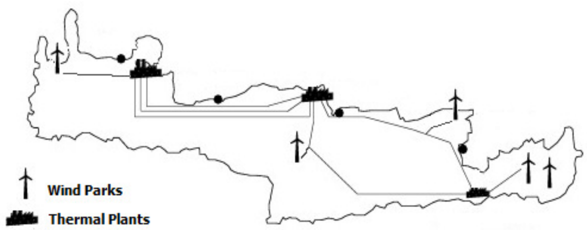


Figure 3: Power plants and wind parks locations.

The annual peak load demand occurs on a summer day, usually within August. Furthermore, the overnight loads can be assumed to be approximately equal to 25% of the corresponding daily peak loads. More precisely, Fig. 4 depicts the 24-hours load demand variation range.

Table 1: Conventional Installed Capacity.

| | Nominal Power | Actual Power (Winter) | Actual Power (Summer) |
|---|---|---|---|
| **Power Plant 1** | | | |
| STM 1 | 5,9 | 5,9 | 5,7 |
| STM 2 | 14,3 | 14,3 | 13,2 |
| STM 3 | 14,3 | 14,3 | 13,2 |
| STM 4 | 23,5 | 23,5 | 23,0 |
| STM 5 | 23,5 | 23,5 | 23,0 |
| STM 6 | 23,5 | 23,5 | 23,0 |
| DIESEL 1 | 11,0 | 11,0 | 10,8 |
| DIESEL 2 | 11,0 | 11,0 | 10,8 |
| DIESEL 3 | 11,0 | 11,0 | 10,8 |
| DIESEL 4 | 11,0 | 11,0 | 10,8 |
| GAS 1 | 15,0 | 15,0 | 12,8 |
| GAS 2 | 15,0 | 15,0 | 12,8 |
| GAS 3 | 42,7 | 42,7 | 41,0 |
| GAS 4 | 13,5 | 13,5 | 12,8 |
| GAS 5 | 27,6 | 27,6 | 25,0 |
| **Power Plant 2** | | | |
| GAS 1 | 16,2 | 14,0 | 11,0 |
| GAS 1 | 28,0 | 27,6 | 25,0 |
| GAS 4 | 24,0 | 20,0 | 18,8 |
| GAS 5 | 30,0 | 28,0 | 26,5 |
| GAS 11 | 59,4 | 58,0 | 54,0 |
| GAS 12 | 59,4 | 58,0 | 54,0 |
| GAS 13 | 27,6 | 27,6 | 25,0 |
| CC Unit | 132,3 | 126,0 | 112,0 |
| **Power Plant 2** | | | |
| DIESEL 1 | 51,1 | 49,7 | 49,5 |
| DIESEL 2 | 51,1 | 49,7 | 49,5 |
| | **741,8** | **721,2** | **674,0** |

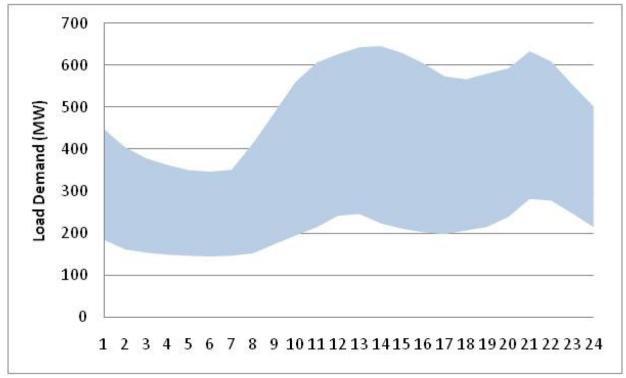


Figure 4: Crete's 24-hours load demand variation range.

The steam and diesel units mainly supply the base-load demand. The Gas turbines normally supply the daily peak load or the load that cannot be supplied by the other units in outage conditions. These units have a high running cost that increases significantly the average cost of the electricity being supplied. The annual duration curve is composed by each generation unit share, as it is presented in following Fig.5.

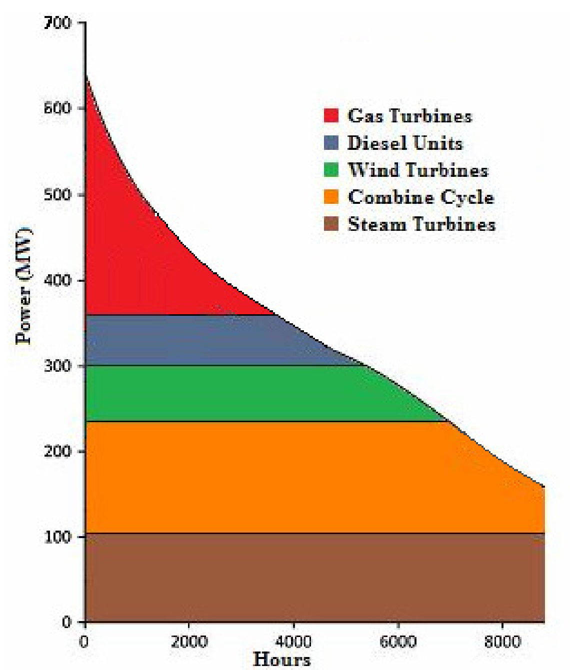


Figure 5: Crete's annual load duration curve.

## 4. Current Status of RES in Crete

Currently, there are 30 wind parks installed with nominal power of 160.45MW in appropriate regions of the island. These WPs are connected to the grid through MV/HV substations of 20kV/150kV. The following Tables 2 and 3 present all the wind parks that are already installed and are planned to be installed in the near future respectively at the four prefectures of Crete island (Lasithi. Iraklio, Rethimno and Hania).

Table 2: Installed Wind Parks.

| | Prefecture | Plants | Percentage | Installed Power | Percentage |
|---|---|---|---|---|---|
| 1 | Lasithi | 21 | 70% | 98,90 | 62% |
| 2 | Iraklio | 6 | 20% | 41,40 | 26% |
| 3 | Rethimno | 0 | 0% | 0,00 | 0% |
| 4 | Hania | 3 | 10% | 20,15 | 13% |
| | **Total** | **30** | **100%** | **160,45** | **100%** |

Table 3: Wind Parks that will be installed shortly.

| | Prefecture | Plants | Percentage | Installed Power | Percentage |
|---|---|---|---|---|---|
| 1 | Lasithi | 4 | 24% | 8,22 | 15% |
| 2 | Iraklio | 2 | 12% | 4,00 | 7% |
| 3 | Rethimno | 5 | 29% | 24,30 | 44% |
| 4 | Hania | 6 | 35% | 18,15 | 33% |
| | **Total** | **17** | **100%** | **54,67** | **100%** |

The previously mentioned wind parks will be located almost all over Crete as it is depicted in Fig. 6, fact that wasn't met in previous years, where most of them were located in the eastern part of the island.

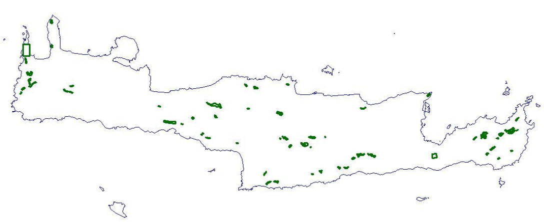

Figure 6: Geographical allocation of Wind parks in Crete.

Collecting and analyzing all the relevant recorded data of the load demand and the corresponding wind production of the year 2008 few interesting figures are emerged. First, in Fig.7 the wind power production as a share of the overall power generation in a specific day (29/07/08) within 2008 is presented. In that day the daily energy supplied by wind parks was the annually highest and equal to 2,641.2 MWh. As well as the energy share of wind energy was 24% that is considered as a quite significant high share. Additionally, in that specific day the wind power penetration varied between 19% and 36% of the total power supply.

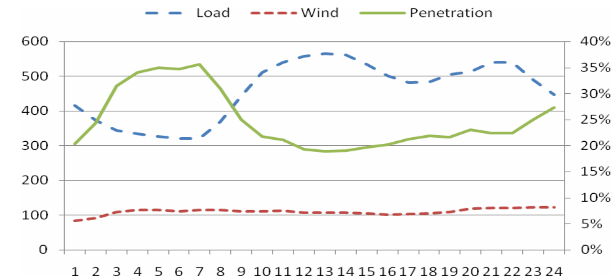


Figure 7: Wind power penetration in power system of Crete.

Furthermore, the day (25/10/08) with the highest share of wind energy in a daily base is depicted in Fig.8 where the wind energy production share was 32.6%. More precisely, that day the daily energy supplied by wind parks was equal to 2,359.1 MWh, while the wind power penetration varied between 29% and 38% of the total power supply without any significant operation difficulty. Consequently, these are considered as significant high RES penetration values, especially for an autonomous system such as Crete's network.

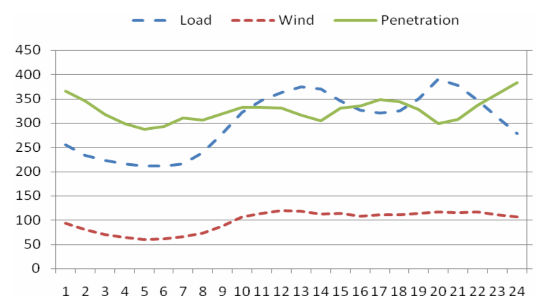


Figure 8: Wind power penetration in power system of Crete.

In the next Fig. 9 the hourly average values in daily base of the wind power and the corresponding penetration of the year 2008 are presented.

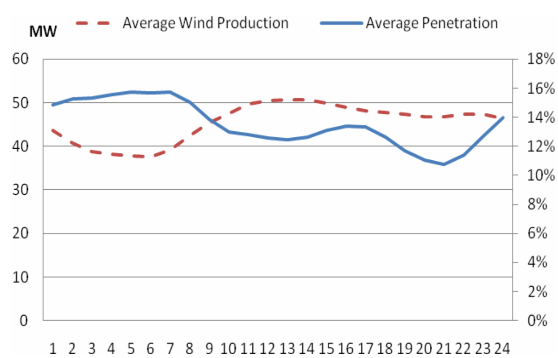


Figure 9: Hourly average production of wind power.

Another interesting parameter of Crete's power system operation for the year 2008 is that combining the highest recorded wind power production with the lowest recorded load demands, the possible maximum penetrations could be emerged. Of course in these cases, system operator should eliminate the wind power production to secure penetration values regarding the actual conditions, [Kaldellis, 2004]. However, this figure may give a nice picture of the corresponding upper limits of the current status.

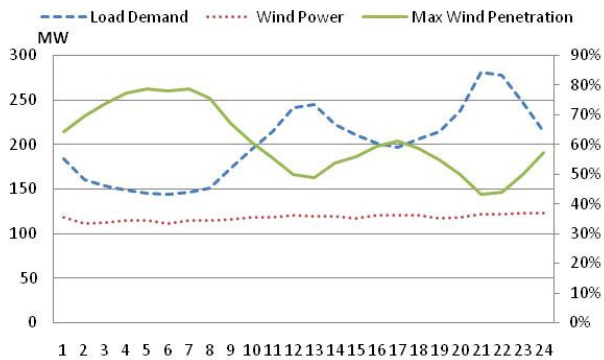


Figure 10: Max recorded penetration in a 24-hours profile.

Thus, according to the previous presentation of the current condition of wind parks and their operation for the year 2008, Crete deals even now with a significant dispersed generation and high RES penetration. This could be a fine baseline scenario for an even higher share of RES, taking into consideration the future prospects and the potential opportunities.

## 5. Future Prospects

The annual energy consumption in Crete for 2008 was 3.01 TWh. During the previous years the annual increase of electricity consumption was significant high, varying between 4% and 6%. In this study, two cases of the annual electricity demand evolution up to year 2020 have been considered, as they are depicted in Fig.11. These cases combine differently annual increase rates between 2% and 4%. The second and most moderate scenario of load demand augment, takes into account both the slight population growth, the financial crisis and the energy saving that might be achieved (EU directive 2006/32) at Crete till 2020.

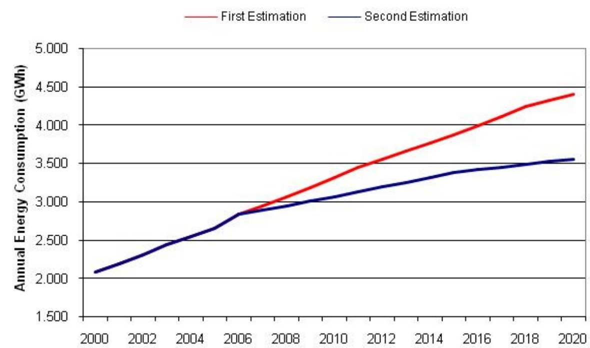


Figure 11: Load demand evolution estimations.

In addition to previous mentioned wind parks that are already installed or planned to, there are currently two more cases for extra 43.65 MW under license approval. This fact will lead shortly to even higher wind power equal to 258MW in the near future (Table 4). In this study two basic scenarios were investigated concerning wind power capacity till 2020. The first scenario follows the current trend that will lead to 258 MW wind power capacity till 2012 and estimates a capacity of 320 MW till 2020. The second scenario assumes a possible installation of pump storage systems [Kaldellis, et al. 2007] in Crete that will allow the expansion of wind power to 900 MW till 2020.

Table 4: Estimated wind power till 2012.

| | Prefecture | Plants | Percentage | Installed Power | Percentage |
|---|---|---|---|---|---|
| 1 | Lasithi | 25 | 51% | 107,12 | 41% |
| 2 | Iraklio | 10 | 20% | 89,05 | 34% |
| 3 | Rethimno | 5 | 10% | 24,30 | 9% |
| 4 | Hania | 9 | 18% | 38,30 | 15% |
| | **Total** | **49** | **100%** | **258,77** | **100%** |

Furthermore, the Greek Legislation (L.3468/2006) that promotes electricity production from RES and especially from PV introduces a program for a total installed capacity of at least 500MW in the interconnected system and at least 200MW in autonomous island systems till the end of 2020. As a result, a great interest for PV plants integration of 88.82 MW in Crete power system has been recorded. In the following Table 5 the share of each Crete's prefecture is presented, while in Fig.12 the geographical diversion of the corresponding PV plants are depicted. This fact will lead shortly to even higher RES generation and wider power dispersal.
Additionally, in this study two basic cases were investigated concerning PV power capacity till 2020. The first case assumes a moderate two steps increment, 88.2MW till 2012 and 120MW till

2020. The second case assumes final PV capacity of the second increment step up to 200MW till 2020.

Table 5: PV planned to be installed.

| | Prefecture | Plants | Percentage | Installed Power | Percentage |
|---|---|---|---|---|---|
| 1 | Lasithi | 262 | 22% | 19,90 | 22% |
| 2 | Iraklio | 501 | 42% | 35,91 | 40% |
| 3 | Rethimno | 241 | 20% | 18,26 | 21% |
| 4 | Hania | 200 | 17% | 14,75 | 17% |
| | **Total** | **1204** | **100%** | **88,82** | **100%** |

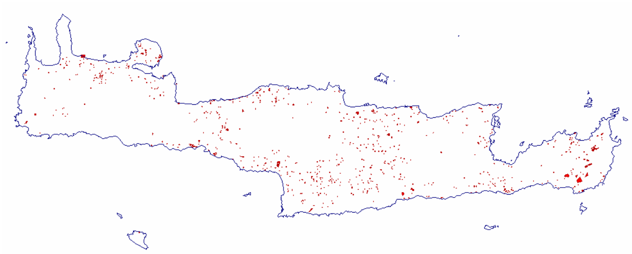

Fig. 12 Geographical dispersal of PV plants.

Concluding, Cretan power system presents all the typical characteristics of an autonomous network and has been selected as a representative model for long term energy planning estimation, due to significant high share of RES and its expected future prospects.

## 5. Long-term Energy Planning

This paper uses a scenario-based energy-environment modeling platform called Long-range Energy Alternatives Planning [Heaps, 2002] system to estimate the impacts of different scenarios in Cretan Power System operation. Hence several scenario on future energy demand and environment development by designing different schemes have been investigated. LEAP emphasizes the detailed evaluation of specific energy problems within the context of integrated energy and environmental planning for each 'what if' scenario or combinations of scenarios. Constructed model incorporates a full range of energy demand, conversion, transmission, distribution, and end-use. The model can simulate over existing as well as advanced technologies that may be deployed in the future. The final platform not only includes the Technology and Environmental Database (TED) that provides extensive information of the current technical characteristics, costs and environmental impacts of energy technologies, but also enables the user to make projections of energy supply and demand over a long-term planning horizon.

Four of the Energy Scenario programs address the main components of an integrated energy analysis relevant to mitigation analyses: energy demand analysis (Demand), energy conversion and resource assessment (Transformation), emission estimation (Environment), and the comparison of scenarios in terms of costs and physical impacts (Evaluation).

In order to evaluate the effect of alternative approaches that are related to high penetration of renewable energy technologies (WTs and PVs) in the autonomous power system of Crete for the period 2009-2020, two basic scenarios have been developed:

1. In the first scenario, the energy penetration of RES technologies will be increased linearly from 12% of total energy demand in year 2008 to 20% in year 2020. Considering approximately 3% annual energy growth, this penetration can be achieved by setting a target for WTs installed capacity of 258MW till 2012 and capacity of 320 MW till 2020, which will produce the 16% of annual energy. Concerning PVs this scenario assumes capacity of 88.8 till 2012 and capacity of 120 till 2012, which will produce the 4% of the annual energy.
2. In the second scenario, where hydro pumped storage (HPS) systems are constructed and used, the energy penetration of RES technologies will be increased linearly from 12% of total energy demand in year 2008 to 50% in year 2020. Using HPS systems, the conventional power units' generation will be frequently limited to their technical minima, while RES penetration may reaches 90%. Considering once again approximately 3% annual energy growth, this penetration can be achieved by setting a target for installed capacity in 2020 to 900 MW for WTs (which will produce the 42% of annual energy), and to 200 MW for PVs (which will produce the 8% of the annual energy).

In Fig. 13, the installed capacity evolution of the power generation technologies for the first scenario is depicted. The steam units that consume heavy oil are considered to be closed till 2017, while two 250 MW liquid natural gas (LNG) units are added in the years 2014 and 2017 respectively [Kapros, 2006]. Moreover, the simulation of Cretan power system showed that the installation of an additional 50 MW diesel generator in year 2011 is crucial for the reliable operation of the system.

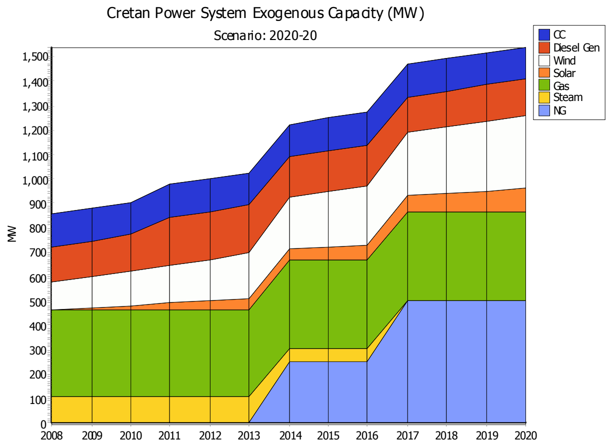


Figure 13: Installed capacity evolution.

For each one of the examined scenarios and for each year of the examined period, the annual energy production from each type of electricity generation technology is calculated, as well as the corresponding annual $CO_2$ eq. emissions. Moreover, a sensitivity analysis of $CO_2$ eq. emissions considering different rates of annual energy growth (2% and 4%, respectively) is implemented.

## 5.1 First Scenario Results

Fig. 14 shows the annual energy contribution of each power generation technology, while Fig. 15 shows the annual $CO_2$ eq. emissions of conventional generators. Although the annual energy consumption is increased with a growth rate of 3%, the high RES technologies penetration, combined with the installation of the NG units after year 2014, results almost constant $CO_2$ eq. emissions. The new NG units are used as base-load, while the penetration of peak-load gas units is slightly decreased.

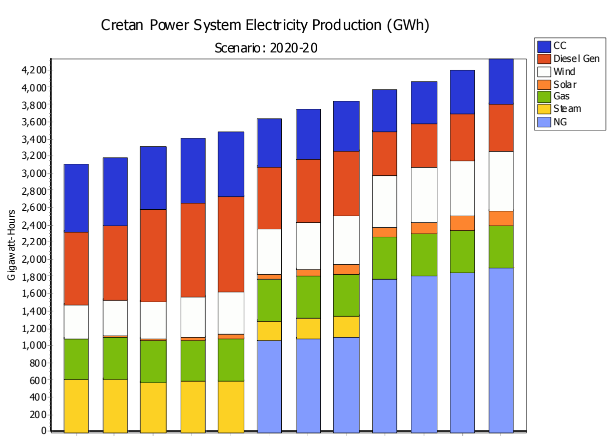


Figure 14: Annual electricity production.

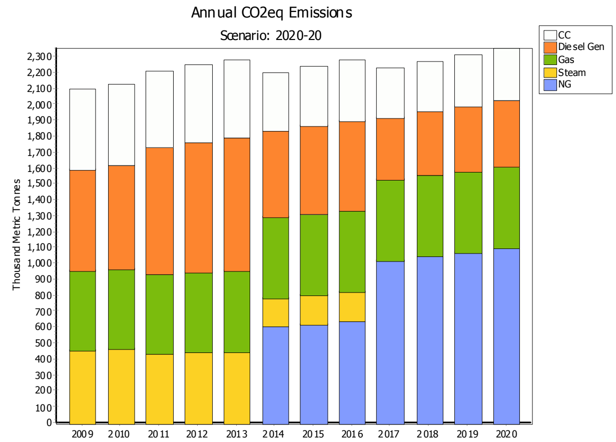


Figure 15: Annual $CO_2$ eq. emissions.

## 5.2 Second Scenario Results

The annual energy contribution of each power generation technology, as well as the annual $CO_2$ eq. emissions of conventional generators for the second scenario, are presented in Fig. 16 and Fig. 17, respectively. The large penetration of RES technologies, which achieves 50% in year 2020, results significant decrease of $CO_2$ eq. emissions, especially after the installation of the NG units. The energy production of the combined cycle and the gas units that consume expensive diesel fuel is also decreased, while the NG units are used for base-load requirements.

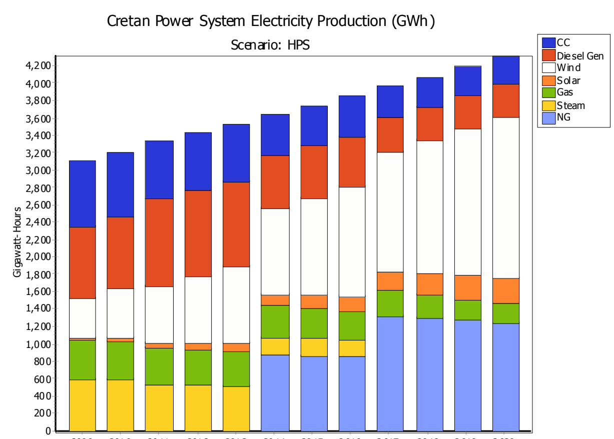


Figure 16: Annual electricity production.

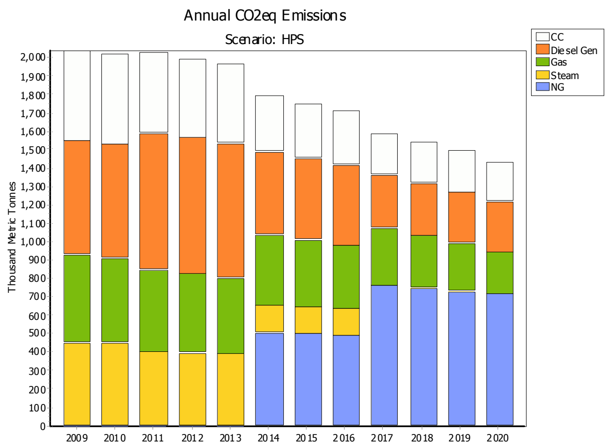


Figure 17: Annual $CO_2$ eq. emissions.

### 5.3 Sensitivity Analysis

The sensitivity analysis examines the effect of two different annual growth energy consumption rates (2% and 4%) in $CO_2$ eq. emissions at the last year of the examined period. The results are presented in Table 5. It can be concluded that the decrease of annual energy growth by 1% decreases 11% the final $CO_2$ eq. emissions for both scenarios, while the increase of annual energy growth by 1% increases 12% the final $CO_2$ eq. emissions for both scenarios. Moreover, the reduction of $CO_2$ eq. emissions in year 2020 in the HPS scenario is almost 40%, compared to the first scenario.

Table 6: Effect of different annual growth energy consumption rates in $CO_2$ eq. emissions at year 2020.

| Annual Energy increment | Final $CO_2$ eq. Emissions (first scenario) | Final $CO_2$ eq. Emissions (second scenario) |
|---|---|---|
| 3% (base case) | $2355 \cdot 10^3$ tn | $1434 \cdot 10^3$ tn |
| 2% | $2095 \cdot 10^3$ tn | $1275 \cdot 10^3$ tn |
| 4% | $2644 \cdot 10^3$ tn | $1610 \cdot 10^3$ tn |

### 7. Conclusions

This paper examined the effect of two different high RES penetration scenarios in the electricity production and the total $CO_2$ eq. emissions of the Cretan isolated power system. The examined period was twelve years (from 2009 to 2020), and the analysis was implemented with the help of LEAP software. The first scenario assumes 20% RES penetration in year 2020, while in the second scenario the final RES penetration is increased to 50%, and it is achieved with the installation of hydro pumped storage systems.

The obtained results showed that in the first considered scenario and in case of higher load demand annually increment, the improvement by renewable energy sources cannot overcome the presumed annual energy demand, resulting almost constant $CO_2$ eq. emissions for the whole examined period. On the other hand, in the second considered scenario, the high penetration of renewable energy technologies overcomes the increase in annual energy demand, so the final $CO_2$ eq. emissions almost 40% lower, compared to the first scenario.

In this study, the utilization of other renewable energy technologies and sources except wind turbines and photovoltaics didn't considered. This was due to low energy potential of them (geothermal energy, biomass, etc) in Cretan terrain and to lack of interest by investors. Therefore this study focused only to the wind parks and PV power plants evolution with or without the parallel construction of pump storage systems.

Additionally, this study didn't examine the possibility of Cretan power system interconnection with the continental power system of Greece. The implementation of such an interconnection will offer the opportunity for further wind and solar power exploitation, overcoming current technical and operational limitations, such as system stability that is clearly defined in [Kundur, et al. 2004].

Concluding, comprehensive studies for sustainable energy planning, which combines grid enhancement, advance operation control [Karapidakis, Hatziargyriou, 2002], wind and solar further exploitation in collaboration with pump storage systems [Bagen, 2005], in parallel with successful energy and power saving, could lead to a realistic high RES share implementation scenario.

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# Potential of floating wind turbines in Aegean Sea

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**Abstract**

*In our days there is an urgent search for new renewable sources to cover earth's energy demand. Although sea is covering 75% of the planet and easily absorbs huge amount of solar and wind energy which is converted in other energy sources such as waves and currents, has been recently used as main source of energy. In offshore wind velocity is 20% higher and steadier than in land. In the paper the design of autonomous floating desalination unit is described. Stress and fatigue analysis of the platform using finite elements analysis is detailed presented following with some results and discussion for future designs.*

## 1. Introduction

Wind energy is the fastest growing energy source worldwide at about 20 to 30% per year. The worldwide installed capacity of onshore grid-connected wind power is about 40 GW. Turbine sizes have increased over the past two decades. The first offshore wind facilities were installed in the early 1990s in Europe where there was limited land available for onshore wind energy production. Since then, the trend has been to move wind turbines offshore to take advantage of higher wind speeds; smoother, less turbulent airflows; larger amounts of open space; and the ability to build larger, more cost-effective turbines.

Offshore turbines have technical needs not required of onshore turbines because of their exposure to the more demanding climates that exist in offshore locations. Offshore turbines look similar to those onshore, with several design modifications. These include strengthening the tower to cope with wind-wave interactions, protecting the nacelle components from the corrosive nature of sea air, and adding brightly colored access platforms for navigation and maintenance. Offshore turbines are typically equipped with corrosion protection, internal climate control, high-grade exterior paint, and built-in service cranes. To minimize expensive servicing, offshore turbines may have automatic greasing systems to lubricate bearings and blades, and preheating and cooling systems to maintain gear oil temperature within a narrow temperature range. Lightning protection systems minimize the risk of damage from lightning strikes that occur frequently in some locations offshore. There are also navigation and aerial warning lights. Turbines and towers are typically painted light blue or grey to help them blend into the sky. The lower section of the support towers may be painted bright colors (e.g., yellow) to aid in navigation and to highlight the structures for passing vessels.

Offshore wind turbines are also bigger than onshore turbines (to take advantage of the steadier and higher velocity offshore winds and economies of scale). A typical onshore turbine installed today has a tower height of about 60 to 80 m, and blades about 30 to 40 m long; most offshore wind turbines are at the top end of this range. Offshore turbines installed today have power generating capacities of between 2 and 4 MW (Figure 2), with tower heights greater than 61 m and rotor diameters of 76 to 107 m. Turbines of up to 5 MW are being tested.

In the paper the designing of a floating wind turbine powering a desalination unit is presented. In section 2 a brief presentation of the water scarcity is given followed in section by a detailed description of the design of the platform and the respective tests using finite elements analysis.

Finally in section 4 the concludes our design and discusses future development

## 2. Floating windturbine platform

In many small Aegean Islands water shortage is a major problem. Their water supply needs are mostly covered by transporting water from other regions. However in most cases this is not enough and additionally the cost is high. On the other hand all these islands are windy, sunny and surrounded by clear sea water. Therefore sea water desalination can be a good solution. However, the cost of producing electrical energy in these islands is also increased due to the fact that those islands are not connected to the central national grid and generator sets are powered from diesel fuel. Wind turbines have been installed in many areas and in islands. Since wind generators are placed on ridges, the cost of installation and power transmission to the desalination unit is considerably high, because they are installed far from each other. Second, desalination units exist in floating structures (e.g. ships, barges), which operate with power produced from energy sources not friendly to the environment. Thus we have worked on coupling a desalination unit with wind turbine, placed on a floating structure. In this way we achieve: (a) Reduced cost of connection between the units, since we don't require long network transmission, (b) Possibility of placement of unit far from villages, so that it doesn't bother the residents, (c) Possibility of transporting the unit if required.

The floating desalination platform has been modeled with finite element analysis in order to ascertain the resulted stresses and strains during static and dynamic loading. An analytical fatigue analysis also took place as far as the loads on the welded nodes (joints) are concerned. All five floating tubes have been modeled with Shell Elements while the other supporting pipes have been modeled with beam elements. Mild steel non linear material properties have been utilized along with non linear geometry. The structure has been analyzed in Sagging, Hogging condition and during dynamic motion in which non linear boundary conditions have been incorporated. The derived loads from the erected forces of the Wind turbine have also taken into account. The calculated results reveal the maximum buckling loads developed on the beams as well as the stresses on the floating members. Presented results are compared with maximum allowable stresses for the adopted material."

## 3. Development

### 3.1 Requirements and solution concept

System's design and development combined research from several scientific domains. The most important requisites we had to satisfy were that the system is friendly to the environment and autonomous. Environment friendly means that it does not have any side effects and autonomous means that the floating platform operates unmanned and that energy comes from renewable sources. The solution focused on the development of the required subsystems, their integration on a suitable floating structure and operation under the supervision of intelligent control system. In this way components that are in general installed far apart can come together and operate in remote islands, which lack the required facilities for land installations.

From an operational point of view potable water is produced from the sea water desalination unit, which requires energy. This is provided by the wind generator and the photovoltaic system. Management system controls the operations and also handles safety issues. The main energy source is a wind generator. The reason is that the Aegean Islands are windy in general and second PV energy is more expensive per kilowatt. Therefore PV modules provide smaller power contribution and mainly operate as an auxiliary source. Energy management is crucial and has three main targets: (a) System survival in case where there is prolonged period without significant energy input. This means that the system will always be able to perform crucial operations and never leave the system without energy. (b) Extract as much energy as possible from wind and maximize water production. (c) Reduce maintenance cost and problems, mainly for batteries and desalination unit components such as pumps, filters, membranes.

Research has been conducted on: (a) Optimizing energy efficiency of desalination unit over a wide range of water output according to available power, (b) Environmental friendly operation without any chemical additives [1] [2]. (c) Design of the floating structure so that it is stable, not affected by waves and provides safe operation of all components. (d) Suitable modification of Wind turbine components for standalone operation. (e) Design of the electrical interconnection. (f) Design of control and teleoperation system. (g) Suitable adjustments of subsystems and Integration.

### 3.2 Design of Floating Platform

The development of the floating structure in order to fulfill controversial requirements went over the following phases: (a) Survey of studies world wide for floating wind turbines and state of the art [3][4][5]. (b) Design of a feasible solution that can fulfill the requirements. (c) Optimization of design characteristics to improve performance and reduce cost. (d) Final stability study and load analysis of optimized design. The optimization goals were to minimize movements and loads from waves, improve the operation conditions for the wind turbine, and withstand extreme weather conditions.

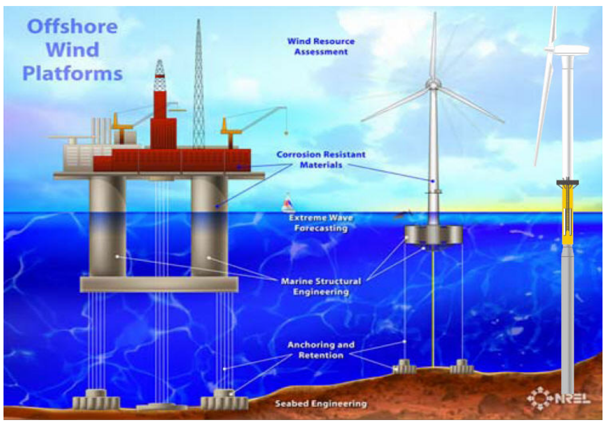


Figure 1: Offshore Floating Concepts.

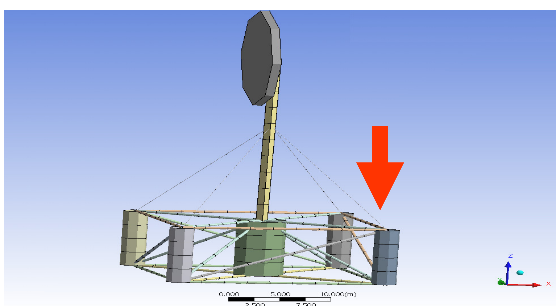

Figure 2: Excitation of floating structure.

Simulation programs like Sesam, Wamit, Ansys, Abaqus have been examined. First optimization step was to examine the shape of the structure and then modify critical dimensions. We examined which is the appropriate number of peripheral floaters around the central floating structure. Four peripheral floaters were selected, because this design provides better stability and has construction advantages. Then we examined the influence of several characteristic dimensions of the floating structure to the natural periods of the structure.

The design of one central floater and four peripheral was examined further. Then study was conducted using finite element analysis to study the effects of waves to the floating structure.

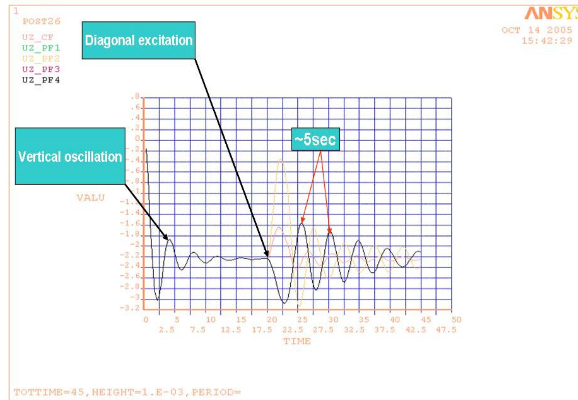


Figure 3: Motion response under above conditions.

Pipe elements were used and computations were based on Stokes Fifth Order Wave Theory. In this way motion and loads induced by waves were studied for several possible conditions. Optimization results and final design study conclude to the following dimensions of the platform: platform radius 14.5 m, central floater diameter 4m, peripheral floater diameter 2m, height 8m. Furthermore, water is stored in peripheral floaters in order to modify dynamic characteristics.

### 3.3 Constructive Description of the structure

As mentioned earlier the floating platform is comprised from 4 peripheral floating cylinders with total height of 8 m and diameter 2 m each, and a central floating cylinder the diameter of which is 4 m and height 8 m as well as shown in figure 4.

The connection of all cylinders takes place with a tubular mesh with pipe diameter of 273 mm and wall thickness of 8,8 mm. There are peripheral and central mesh connections as shown in figures 5 and 6.

Inside the peripheral cylinders there are vertical structural pipe elements which are connected on the tubular mesh as shown on figure 7 thus preventing the cylinder shell to bear the axial compressive or tensile developed forces during normal operation at sea.

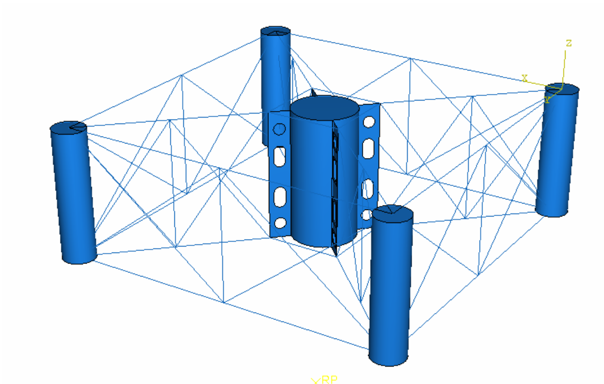

Figure 4: The tubular mesh and cylinders.

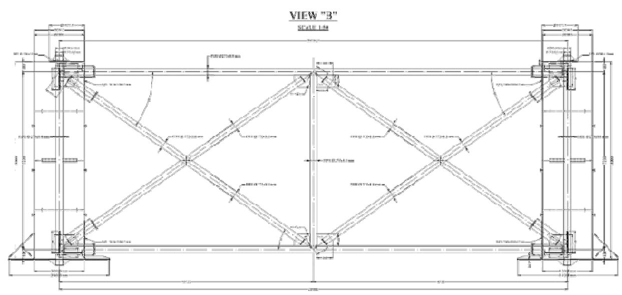


Figure 5: The side tubular mesh.

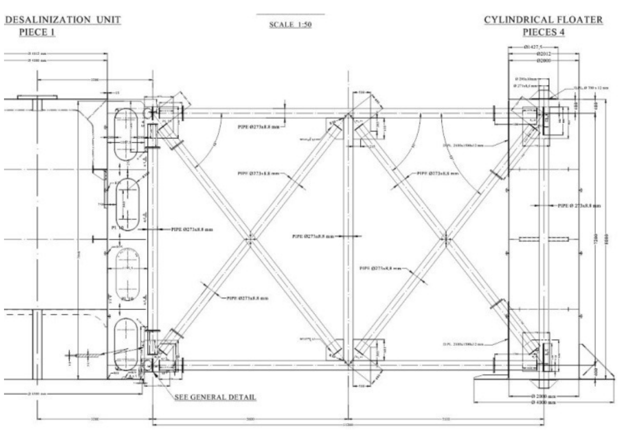


Figure 6: The inner connection between the peripheral and central cylinders.

The constructed nodes are separated from the tubular mesh by joining flanges. The nodes are welded, however they are connected with the rest mesh via flanged links as shown on figure 7.

The peripheral cylinders are joined with the inner vertical pipe on 3 different locations with respect to the perpendicular. The tubular mesh in the central cylinder forms an external rectangular box shape since any internal cylinder connection would restrict the space in the machinery room located in the central cylinder. The rectangular pipe mesh restrains any major force application on the main cylindrical shell.

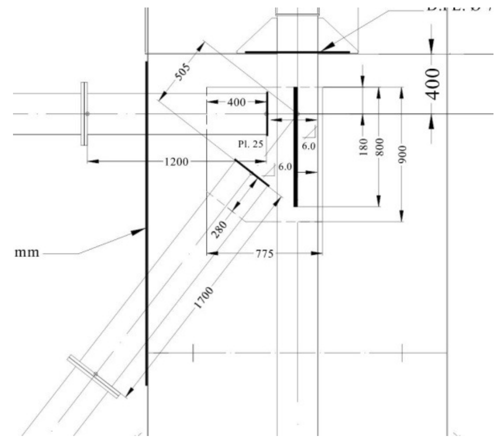


Figure 7: The upper node construction and vertical pipe inside the peripheral cylinders.

### 3.4 Stress analysis calculations

The developed stresses are calculated with the use of finite element analysis. The scope of the analysis is to derive the maximum operating axial loads exerted on the mesh piping and compare them with those theoretically calculated with Euler as in [10]. Also the Misses yield stress is calculated and compared with the material yield stress.

Four different loading cases are examined:

1. Static loading under sagging condition.
2. Static loading under hogging condition.
3. Dynamic motion with respect to external excitation with direction parallel to the side of the platform and
3. Dynamic motion with respect to external excitation with direction parallel to the diagonal of the platform.

The selection of dimensions of pipe segments was made after considering not only the structural strength but also the market availability, cost and corrosion factor. Uncertain parameters related to the place of installation of the platform, method of deployment at sea such us the use of drydocking or carnage facilities were still unknown during the static analysis. It was therefore necessary to assume loading scenarios which would provide results for any case. The structural analysis was performed in conjunction with the accreditation and certification classification society.

The mass distributive loads of the platform have been calculated from the constructive drawings and are shown below:

| | |
|---|---|
| Each peripheral cylinder | 7325,5 kg |
| Central cylinder | 18426,0 kg |
| Mesh | 44910,0 kg |
| Engine room apparatus | 25000,0 kg |
| Wind turbine | 2140,0 kg |
| Wind turbine suspension | 3000,0 kg |
| Grid plating on the access way | 5000,0 kg |
| **Total mass** | **127778,0 kg** |

The total weight of the platform is equalized from the exerted buoyancy.

The wind turbine is suspended on the main cylinder and is also rigged with 4 stays along the diagonal upper tubular members as shown on figure 8. When the wind turbine is operating, the maximum horizontal force due to wind resistance is provided by the manufacturer and corresponds to gale conditions.

The forces exerted on the structure because of the wind turbine operation are taken into account in the analysis with respect to the angle of heal of the structure.

The elastic buckling load are calculated via Eulers Theory for beams with fully clamped ends. The formula is shown below:

$$Pe = \frac{4 \cdot \pi \cdot E \cdot I}{L^2} \quad (1)$$

Where E is the elastic modulus
I moment of inertia
L length of Pipe segment.

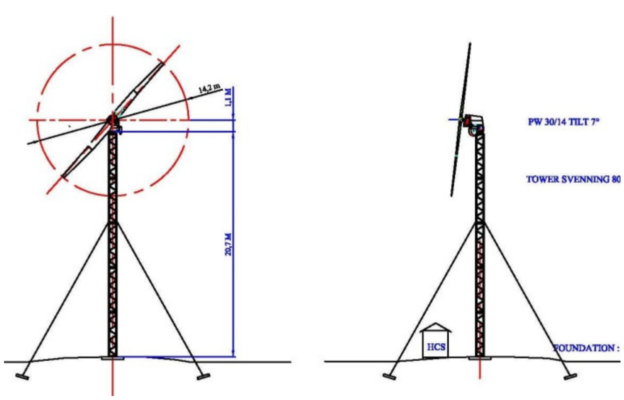


Figure 8: The wind turbine suspension arrangement.

The following table shows the theoretically calculated buckling loads for the pipe segments used in the mesh:

Table 1. Buckling loads for the Pipe segments utilized in the mesh.

| | |
|---|---|
| Pipe Diameter | D = 0,273m |
| Cross Sectional Area | A = 0,007304077 $m^2$ |
| Second Moment of Area | I =0,0000638 $m^4$ |
| Pipe segment weight | W = 57,1 kg/m |

| α/α | Segment Length [m] | Segment Weight [kg] | Buckling Force [MN] | Buckling Stress [MPa] |
|---|---|---|---|---|
| 1 | 4,560 | 260,4 | 25,56 | 3499,19 |
| 2 | 5,600 | 319,8 | 16,95 | 2320,18 |
| 3 | 6,264 | 357,7 | 13,54 | 1854,36 |
| 4 | 7,200 | 411,1 | 10,25 | 1403,56 |
| 5 | 10,253 | 585,4 | 5,06 | 692,14 |

### 3.5. The finite element Analysis and Case studies examined

The FEA analysis is non linear. Pipe segments have been modeled as 3 node non linear beam elements and shell and internal stiffeners of the floating cylinders have been modeled as shell elements.

Meshing and element dimensions have been selected after careful consideration and validation with analytical models.

The material properties used were those for mild steel as shown below:

| | |
|---|---|
| Youngs' Modulus: | E=211 $10^3$ MPa. |
| Yield Stress: | $\sigma_y$= 235 MPa. |
| Gravity acceleration: | g = 9,81 $m/s^2$. |
| Material Density: | p= 7850 $kg/m^3$. |

#### 3.5.1 Sagging Condition

During this loading condition the structure is supported on the 4 peripheral cylinders while the central cylinder is free to move in the vertical direction as shown on figure 9a

Furthermore the structure is also supported on two diagonal cylinders in order to examine stress development and vertical displacement of the middle cylinder as shown on figure 9b. Results are shown in paragraph 2.6.

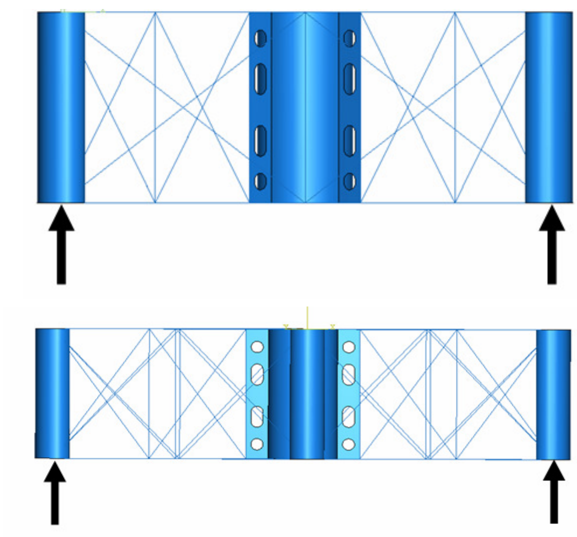

Figure 9a and 9b: The Sagging condition supports.

### 3.5.2. Hogging Condition

During this loading condition the structure is supported on the central cylinder while the peripheral cylinders are free to move in the vertical direction as shown on figure 10. Results are shown in paragraph 3.6.

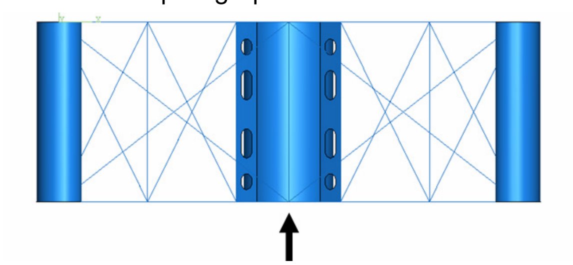

Figure 10: The Hogging condition support.

### 3.5.3. Dynamic Motion

In this case the Platform is supported from springs. The spring coefficient is calculated from the buoyancy characteristics of the cylinders with respect to their draft. Maximum buoyancy is achieved when the draft of the platform equals to the height of cylinders.

The springs for the peripheral cylinders are identical while the central cylinder is supported onto the 4 adjoining vertical pipe segments as shown in figure 11. The vertical pipes located inside the peripheral cylinders and those adjacent to the central cylinder transmit onto the tubular mesh the exerted loads from the buoyant cylinders. Therefore the supporting spring elements are linked to the bottom of the relevant vertical pipe segments as shown on figure 11.

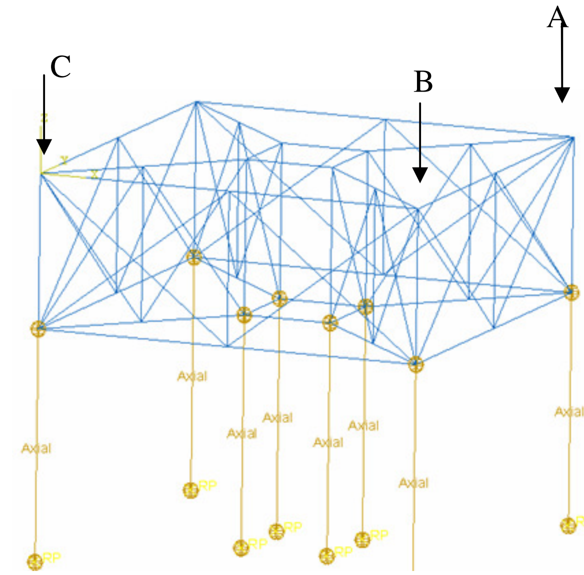


Figure 11: The spring supporting arrangement.

The scope of the Dynamic Motion analysis is to examine the mass inertia effect on the structure and the nodes. No dumping coefficient has been introduced, therefore upon excitation, the structure performs a harmonic periodic oscillation with period equal to T=7,8sec. as shown on figure 12.

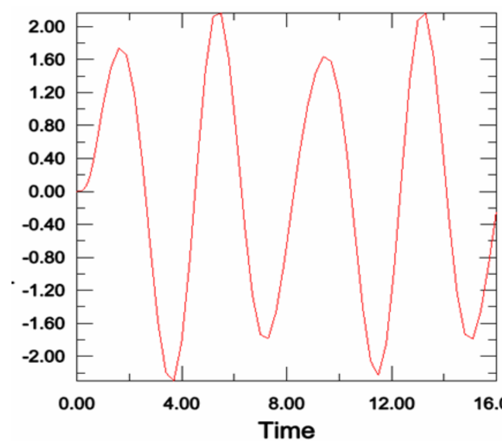


Figure 12. Vertical displacement of node C as shown on Figure 11.

The construction is excited in the following 2 ways:

1. The structure is vertically displaced simultaneously on points A and B downwards until freeboard equals zero on cylinders A and B. Thereafter it is left free to perform harmonic oscillation and
2. The structure is vertically displaced only on point C until freeboard equals zero on cylinder C. Thereafter it is left free to perform harmonic oscillation.

Results are presented in paragraph 2.6.

### 3.6 Simulations and Results

In all cases the structural has shown to be very strong.

The calculated vertical displacement as extracted from the FEA results have been experimentally compared and evaluated after the construction of the floating platform.

Maximum vertical displacement in the sagging condition as shown on figure 9a is calculated from the FEA $U_3$=2,75 mm and for same condition as shown on figure 9b max $U_3$=7,16 mm.

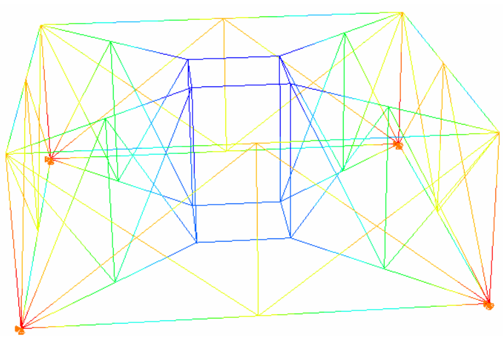

Figure 13: Vertical displacement distribution on the sagging support condition as per figure 9a.

The above calculated vertical displacement was validated upon completion of the construction of the floating platform and found to have a difference of about 2%.

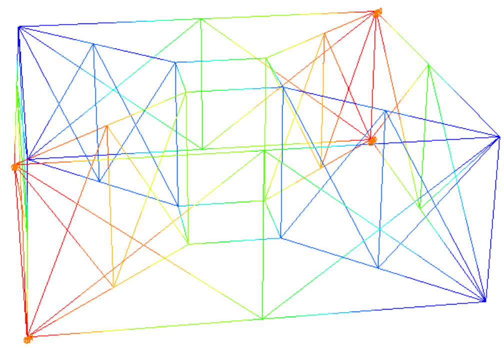

Figure 14: Vertical displacement distribution on the sagging support condition as per figure 9b.

Vertical Displacement in the second supporting scenario results in higher displacements since the horizontal distance between the supports is larger, thus stresses in some internal piping segments.

Maximum observed axial stress in the pipe segments are 28,24 MPa about 2-5% of the maximum allowable in the red rods as shown on Figure 15.

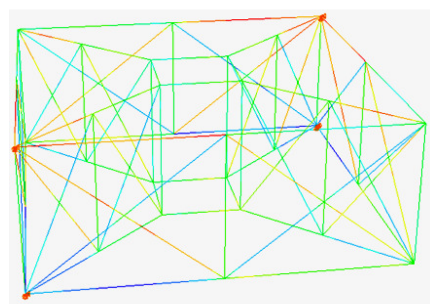

Figure 15. Axial stress distribution

Maximum Calculated Stresses according to the Misses Criterion is about 32MPa. This stress distribution is shown on Figure 16.

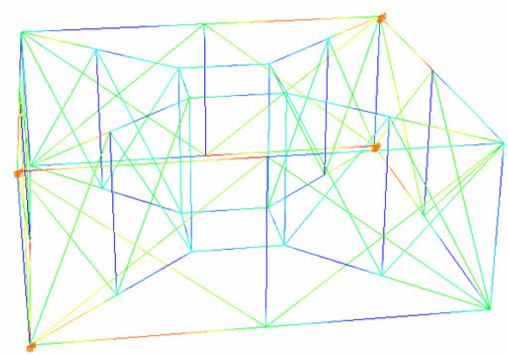

Figure 16: Von Misses stress distribution.

In Case of the Hogging condition, the maximum vertical displacement is about 4 mm revealed in the peripheral vertical rods as shown on Figure 17.

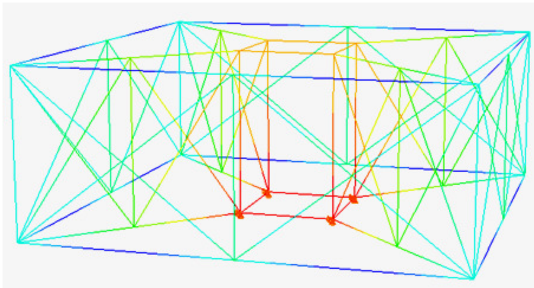

Figure 17: Vertical displacement distribution on the hogging support condition.

Maximum axial stresses shown in this condition are 26,22 MPa which is about the 2% of the maximum allowable. Such a stress distribution is shown on Figure 18.

For the Dynamic Motion model a stress analysis takes place on selected pipe regions and nodes where increased stresses appeared during the simulation. The examined areas consist amongst 40 regions. Some of those regions denote constructive nodes while some denote part of the piping mesh.

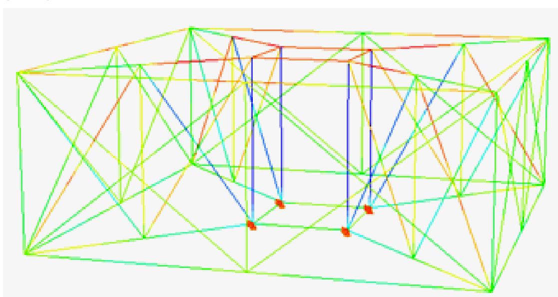

Figure 18: Axial stresses in the Hogging Condition.

Results were extracted with respect to the axial and von-misses stress variation some of which are presented herewith

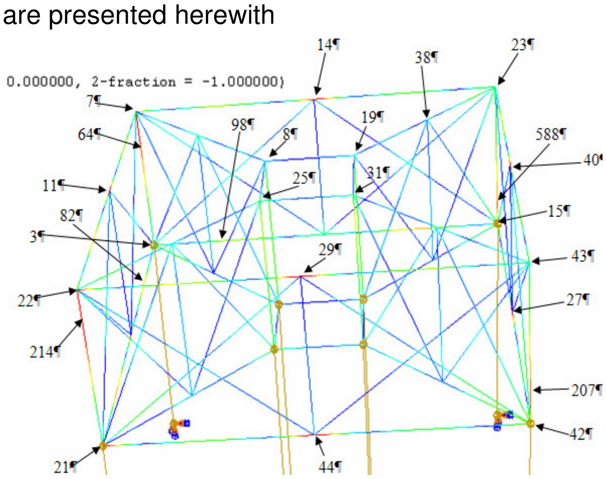


Figure 19: Examination areas during the dynamic motion analysis.

Developed stresses were presented with respect to time for all above nodes. As an example, the Misses stress calculation is shown below for Node 31.

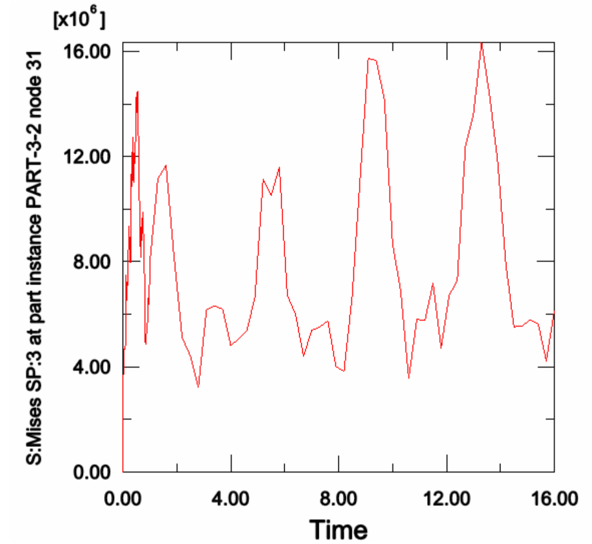


Figure 20: Misses stress calculation for the Dynamic Motion case.

Similarly the Axial stress for the horizontal beam element next to node 8 is shown below.

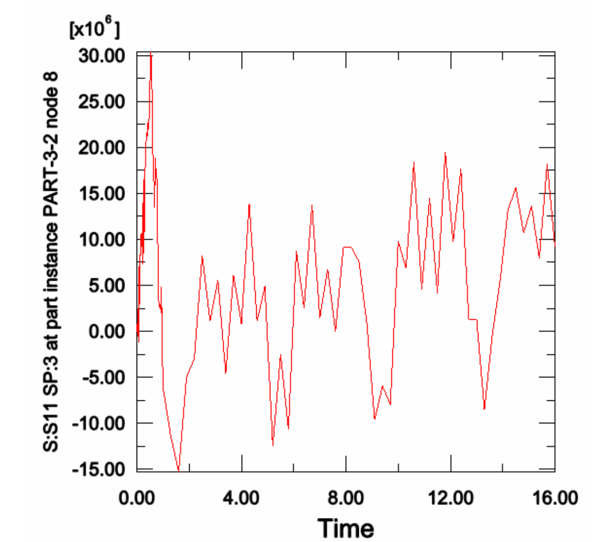


Figure 21: Axial stress calculation for the Dynamic Motion case for a beam element.

As may be seen the above values are within safe limits in comparison with the values shown on table 1.

Developed stresses were less than the 10% of the maximum allowable. The next smaller available pipe diameter produced stresses close to 60% of the maximum allowable, thus it was agreed to proceed with the size shown in table 1.

### 3.7 Construction Nodes Fatigue Analysis

The traditional method for fatigue analysis requires the link of the nominal stress, far away from the location of interest with the peak stress via a stress concentration factor. An appropriate S-N curve was used to estimate the fatigue life, taking into account other parameters such as corrosive environment, detail geometry and load direction. However, for complicated details the S-N curve selection is not always obvious and it depends greatly on experience and engineering judgment.

For complicated local structural details for which fatigue performance is critical, the finite element analysis is widely used. It is possible to determine exactly the peak stress at the location of interest, using a very fine mesh, until the solution converges. There are several ways to estimate the peak stress from this model.

For locations where stress singularities are expected, eg. weld toes, an extrapolation method was used. The finite element size in the fine mesh region is taken as the plate thickness. The stresses perpendicular to the assumed crack direction, i.e. the principal stresses within ± 60%, at the centre of the last two elements, are linearly extrapolated to the weld toe. At locations where a stress gradient could not be developed, the stress at the centre of the adjacent element was used.

At locations which did not form a stress singularity, eg. openings and cut outs with rounded corners, a bar element with very small stiffness can be used, at the edge of the cut outs. The peak stress was directly given by the axial stress in this element.

A very fine local model was required, with a very fine mesh close to the location of interest, with element size equal to the thickness of the plating. The elements utilized were 4 nodded shell elements, and more specifically second order shell elements. The displacements of a global model were transferred at the boundaries of the local model.

Only dynamic loading should be considered in the global model, with the stress range being the difference between two load cases, for example between a hogging and a sagging condition. The load should represent the normal daily load, usually taken as the load with a probability of exceed $10^{-4}$, from a long term stress distribution, such as a Weibull two parameter distribution, typical for ship and offshore structures.

### *3.8 Discussion*

The advantages of such floating units are the following:

(a) Reduced cost of connection between the units, since we don't require long network transmission,

(b) Possibility of placement of unit far from villages, so that it doesn't bother the residents,

(c) Possibility of transporting the unit, so that is possible to achieve better utilization in different regions depending on the conditions.

The construction could have achieved with smaller diameter and weight of cylinders, hence the cost could have been reduced. However availability in the market of pipes which would support a more efficient solution is not always feasible and special orders are delaying and are expensive.

Furthermore, should the idea would be adopted in a larger scale, it could be possible to attach self anchoring and propulsion devises in order to make the platform more autonomous and cost efficient in a long term.

Because of the unique construction and application of the constructed unmanned platform, certification from an accredited body such as a classification society and a flag administration was a new concern and certain issues had to be introduced and encountered.

### 4. Conclusions

The development of the floating, environmental friendly desalination unit for producing potable water is considered a prominent technological solution for addressing water shortage problems in isolated, insular regions. At the same time the platform is an actual floating research laboratory, carrying several sensors, data measurements and logging units that will provide significant research data. Collecting information on wind, sea condition and operation related parameters; it will provide the research community with data that will encourage the use of renewable energy sources by developing economically efficient offshore applications. Experience gained so far shows that local communities are in favor of the proposed floating environmental desalination approach in comparison to land-based systems, because we avoid permanent installations and reduce environmental impact.

**Acknowledgements**

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# Solar recharging stations: Selling hours of solar lighting

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**Abstract**

*This paper is a concept note on Sunlabob's latest innovation to tackle the challenge of rural electrification using renewable energy sources in developing countries. A technical and operational description is given of a rechargeable battery lantern and solar charging station rental scheme, which at the time of writing was at a pilot implementation stage. Two key principles drive the innovation. Firstly it is necessary to go beyond improving living conditions through electrification and work towards increasing income in local communities, with the involvement of villagers, and cooperation between the public and private sectors. Secondly service-oriented solutions offer a more sustainable approach than hardware interventions for rural electrification in developing countries. The system was designed as a competitive alternative to the conventional use of kerosene for lighting purposes found in many rural households. End-users pay for a service (i.e. number of hours of lighting) rather than the hardware, in a manner qualitatively similar to the purchase of kerosene. Technical assistance and training is provided by Sunlabob, but the operation and management is undertaken by villagers, in order to empower communities and develop a sense of ownership, and hence ensure sustainability. The battery lantern rental scheme is the product of Sunlabob's many years of experience in providing electricity using renewable energy sources to rural communities in Laos. A brief market analysis is provided in context of the rechargeable lantern system, and risks and opportunities are considered for investment.*

**Keywords:** rural electrification, solar lantern, fee-for-service

## 1. Introduction

Rural electrification remains a global challenge, particularly in poorer nations. Sunlabob has developed an innovative solution that has been successfully piloted in Laos, one of the poorest nations in the world. Village entrepreneurs rent solar charging stations that are set up at a central location in the village to recharge portable and exchangeable lanterns and other equipment (mobile phones, radios, laptops, etc). The village households pay a charging fee that covers all operational costs. This configuration allows to take advantage of economies of scale on the charging and control equipment. The resulting recharging fee for the lanterns is comparable to typical household expenditures for lighting with kerosene. Each lantern has an integrated microprocessor, which gives it a unique identity and monitors and safeguards its battery. Every time a lantern is recharged, the charging station collects data on the use and status of the lantern. These data are used to ensure the equipment's efficient operation, whilst enabling accurate accounting of carbon credits. Financing of the systems is achieved through private channels for the charging stations, and public grants (as revolving funds) for the first batch of lanterns required to launch the village entrepreneurs' businesses. This results in a public-private partnership (PPP) providing electric lighting to poor households in remote rural villages.

## 2. Challenge

Various solar lantern technologies are now being widely propagated as a solution for lighting in remote off-grid villages. Evidence suggests that these lanterns often fail much earlier than expected considering the lifetime of solar equipment (Varadi et al. 2005). The common use of low quality components in many products is largely responsible for this occurrence, and is itself caused by the need to minimise costs and make the lanterns affordable for rural households. Premature failure of battery is another common issue, due to irregular charging, and product abuse (such as the 'hot-wiring' of batteries to operate other equipment). As a result, solar lanterns rarely offer a long-term, economically-viable alternative to conventional lighting practices, and thus have made only a minor impact in poor rural areas. Beyond the electricity grids, kerosene still dominates the lighting market.

The challenge therefore is to find an operational scheme for solar lanterns that can:

1. use state-of-the-art charging equipment and tamper-proof units to exploit the full life expectancy of the components;
2. tightly control the use and charge status of the lanterns, and monitor the life cycle of their components, thereby increasing their real on-site efficiency;
3. reduce costs per hour of light to be commercially competitive with kerosene lanterns on a household level.

**With such innovations, solar lighting can make a significant impact in thousands of low-income rural households.**

## 3. Sunlabob's response

Sunlabob has responded to these challenges by developing a package based upon a village entrepreneur operating a large solar charging station rented from Sunlabob. The entrepreneur charges portable lanterns, and circulates them among the village households in return for a fee collected for each recharge. The revenue covers the costs of operating the whole system on a commercial basis. For households the recharging fee is a regular small expense, qualitatively comparable to buying kerosene at the village outlet.

As illustrated in Fig. 1, a fully operational system comprises:

- one large solar array
- one battery charging station
- 50 lanterns
- an electronic system control unit

The system is entirely modular and additional charging stations can be operated if required.

To date, 5 systems have been piloted and are in operation in Laos, 14 in Uganda and 1 in Afghanistan.

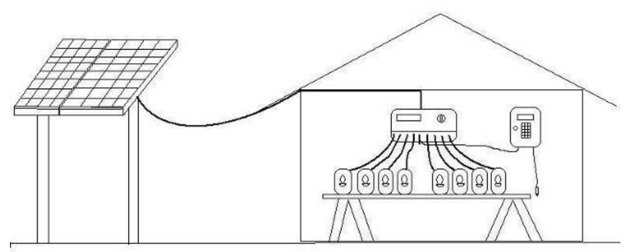

Figure 1: Sketch of operational setup.

### *3.1 Technical details*

Sunlabob's Solar Lanter Rental System (SLRS) is made up of the charging station and the lanterns units. The charging station itself includes the system control unit, management software, the battery charging unit and the solar photovoltaic ("PV") modules.

#### *3.1.1 Design Principles*

The conceptual design of the SLRS is based on the idea of keeping its construction as simple as possible, while still providing versatility, robustness and ease of use. This is achieved by reducing the number of technical components in the LU to a bare minimum, placing most of the system's "intelligence" in the external SCU.

The electronic circuits designed for both the lanterns and the SCU are highly energy efficient. The use of carefully selected components ensures a long product life. All plugs, receptacles and switches are mechanically robust, easy to clean and designed for frequent use. The LU and the SCU are both driven by fully programmable microprocessors that come with custom-built software.

The most unique feature of the SLRS is the update feature that makes it possible to modify or completely replace the internal software or "firmware" of the and the SCU with the help of the management software. Upon every contact with a Lantern Unit, the SCU transfers the updated software to the internal controller. With this update feature, it is easy to modify virtually any parameter of the system without the need for hardware modifications.

A schematic representation of the whole system is shown in Fig. 2 and a detailed description of each component is provided below.

**Figure 2:** Schematic representation of a complete system.

*3.1.2 The Lantern Unit*

The Lantern Unit comprises an energy efficient lamp, battery, and control electronics. As shown in Fig. 3, they are designed to be portable. Sunlabob lantern units can be taken home, hung up, stood on a surface, or carried whilst illuminated. A robust tamper-proof casing protects the internal components.

Figure 3: Photograph of the lantern unit.

Controlled use is ensured by an integral microprocessor, which can be configured to capture various data including the number of hours the lantern has been in use. The functional status of lanterns is limited according to discrete modes, through which it is cycled as it passes from user to technician and from discharging to recharging.

The battery is a sealed lead-acid battery, rated at 12V, 7.5Ah. It is leak-proof, provides good deep cycle resistance and requires virtually no maintenance. The system is designed for flexibility, and virtually any rechargeable battery with suitable voltage and capacity rating can be used with the LU, including gel-cell lead-acid batteries and NiMH batteries.

The Lantern Unit can be used as an regulated 12V power supply for small electronic devices, including cell phone charging or powering portable radios. An integrated low voltage disconnect circuit protects the battery when the LU is used as a power supply for other devices.

The use of lanterns is carefully constrained whilst rented to a user. After 9 hours of lighting operation have elapsed, a slow-flashing LED warning light indicates to the user that one hour of operation remains. After another 30 minutes, the LED starts flashing at a higher frequency to warn of the upcoming shutdown. The Lantern Units are disabled after 10 hours and cannot be turned on again by the customer. If used as a power supply, e.g. to charge a cell phone, and a low voltage condition is detected (flat battery), the integrated low voltage protection feature also results in the disconnection of the power outlet and the lamp is switched off.

During the entire period between charges, the Lantern Unit's power output receptacle cannot be used to charge the unit's battery. This ensures that no unauthorized charging can occur. In order to prepare for charging, the Lantern Unit is connected to the System Control Unit (SCU). Once it is connected to the SCU, the Lantern Unit can be unlocked by choosing the corresponding option on the SCU's display. At the same time, the SCU reads the number of hours the Lantern Unit has been used since the last charging and writes it to the charging log, along with the Lantern Unit's unique ID and the current date and time. The Lantern Unit can now be connected to the Battery Charging Unit until its battery is fully charged.

While in charging mode, the Lantern Unit's internal controller prevents switching on the lamp, and also interferes with any attempt of power extraction through the receptacle that exceeds a certain period of time. This approach ensures that only fully charged Lantern Units are handed out, but does not interfere with the operation of modern charge regulators that may probe the battery by discharging it for short periods of time.

Once the battery is fully charged, a Lantern Unit can be prepared for handing out to the next household, ordinarily in exchange for a spent one. Before the Lantern Unit can be given to a household, it must be reconnected to the SCU, which is used to activate the Lantern Unit for lighting operation. At the same time, the SCU records the Lantern Unit's unique ID and writes it to the activation log, along with the current date and time.

*3.1.3 The System Control Unit (SCU)*

The SCU is located at the charging station. It is used to activate the Lantern Units for either charging or lighting mode. The SCU is also used to collect any data acquired since the last recharging. A photograph of the SCU is shown in Fig. 4 below.

**Figure 4:** Photograph of the System Control Unit.

The SCU currently uses an integrated SD storage module to store the log files and firmware updates of the associated Lantern Units. It is also used to store the SCU's firmware updates and configuration data. The size of this storage module can be increased to accommodate the needs of system setups with large numbers of Lantern Units per SCU. The maximum number of LUs per SCU depends on various factors, such as how often data is transferred from the SCU to a microprocessor-controlled system recognises the connection sequence of the batteries. The battery PC or the size of the SCU's storage memory module.

*3.1.4 Management Software*

To facilitate the handling of data collected by many System Control Units (SCU) in many villages, the Sunlabob Lantern Recharging System comes with a Management Software complete with a graphical user interface for ease of use. The software can be installed on a PC or notebook computer running either Linux or Microsoft Windows (Windows 2000, XP, Vista or compatible) operating systems. System Control Units installed in each village may be interfaced with a computer via a USB Port.

The management software can collect data from a large number of lamps distributed over a wide area. This data can be analyzed in many different ways, i.e. number of charges and their fluctuations in time, distribution of lamps, diverse intensity of usage in various areas, frequency of switching on and off, average time of switched on light.

In order to facilitate data processing and analysis, the rental and activation log files can be visually displayed, copied to a clipboard cache or saved as text files, which can later be imported to spreadsheet or accounting software.

The Management Software also enables firmware updates intended for Lantern Units and the SCUs to be transferred from a computer to the SCUs. The software is also used to modify configuration settings of the System Control Units. The scenarios can be adapted according to the specific requirements of a given system implementation. Operating times can be modified to allow for changes to the battery or lamp, and warning modes can be adjusted or the protection scheme may be altered to accommodate different power supply regimes. All this can be done by simply uploading a new lantern firmware with the aid of the SCU.

*3.1.5 Battery Charging Unit ("BCU")*

Charge regulators are a major contributor to the costs of a traditional-style PV lantern. These internal regulators are also often poorly designed, resulting in a significantly reduced battery lifetime. Sunlabob's lantern unit design does not provide for an internal charge regulator, but uses a high-quality, external regulator selected specifically for the type of battery used. This increase the battery lifetime and also significantly lowers the lantern cost.

The SLRS uses the Steca PL2085 to charges up to 8 lead-acid batteries simultaneously. The which is connected first is charged first and as soon as the first battery is full, it switches over to

the second battery etc.
The charging terminals are protected against wrong polarity, short circuit, no load operation and overload. Battery charging starts even from run down batteries at voltages higher than 5V. At night the charging station works in an energy saving mode and no battery data is lost.

*3.1.6 PV Modules*

Currently the main power source of the charging station is a solar PV system, although Sunlabob may explore alternative renewable sources where practical in the future.
Sunlabob designs and installs the PV array in the village, after determining the best location and requirements such as the solar irradiation and number of clients expected. The standard configuration is a 240 Wp system consisting of 2 PV modules in series (with a maximum power voltage of 34V). Alternative configurations can be arranged as needed.
The current SLRS uses poly-crystalline modules with a conversion efficiency of 13.7%. However, Sunlabob works with a range of solar PV module suppliers and the system here has the flexibility to work with many brands and technology.

*3.2 Operational details*

The village entrepreneurs and Sunlabob enter a franchise agreement, which encompasses:

1. The installation of the charging station, including the SCU
2. The regular servicing of the charging station
3. The sale of Lantern Units, and of spare parts
4. Regular training to maintain quality and introduce technical upgrades
5. Operational and business advice
6. Assistance in local marketing: PR materials, demonstrations, campaigns
7. Assistance in accessing soft loans and financing opportunities

The rental income usually pays for these services, although various programmes funded by public agencies may pick up some of the costs, e.g. training.
An overview of the flows of equipment, money, advice and information is presented in Fig. 5 below.

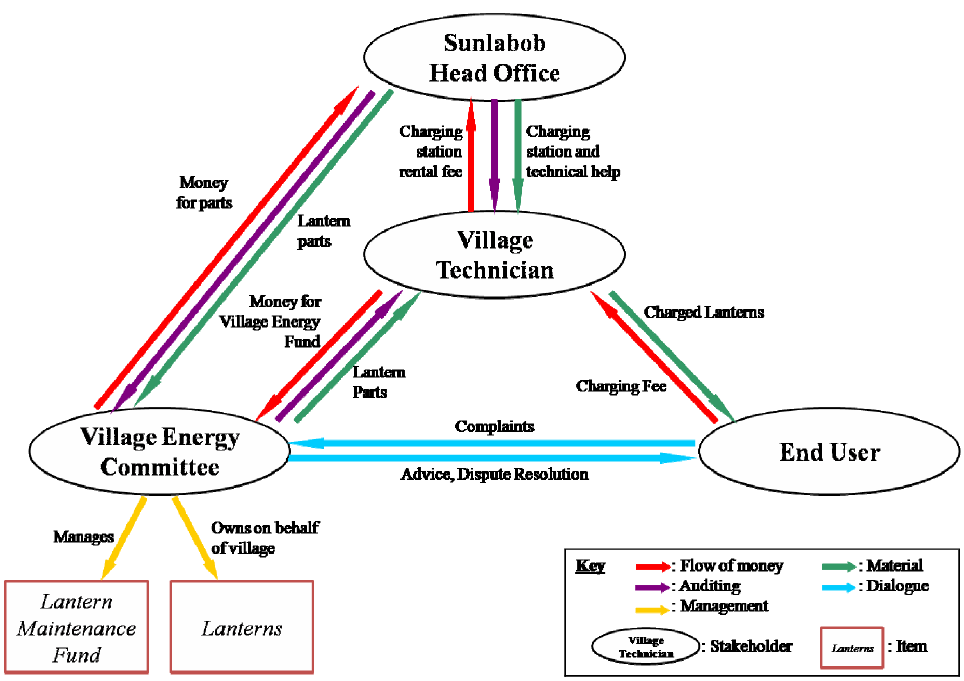


**Figure 5:** Overview of flows.

## 4. Market and investment opportunities

*4.1 Benefits for Households*

Village households are the end-users of this product and its services. They will most likely compare solar lanterns with the kerosene lanterns that they conventionally use. The small but regular payments for kerosene add up over a year to one of the main forms of expenditure for households. Other disadvantages cited by households include the smoke and odour associated with kerosene, and the fire hazard. The solar lanterns should achieve a reduction of expenses for lighting for a typical poor household. In effect, the operations result in the sale of hours of light, as opposed to the sale of equipment, emulating the service provided by grid connection. The routine payment of recharging fees is also similar to the established behaviour of regularly buying small amounts of kerosene from the village shop. The routine cycle of household expenditure thus remains unchanged. Combined, these features allow for easy adoption of this new service. Direct competition with kerosene-based lighting is the challenge that solar lanterns are tackling.

*4.2 Benefits for Village Entrepreneurs*

Renting and operating a recharging station is a sustainable village-based enterprise, technically and operationally safeguarded by a franchise arrangement with Sunlabob. Although the village entrepreneur may not make a living just from operating a single charging station, it provides a regular and steady revenue that can supplement other income sources. The village entrepreneur is connected to the Sunlabob franchise network and through that gains awareness of other technologies and services that he/she may wish to develop in the village, e.g. TV/Video or even projector with screen, coolers, a laptop with GPRS internet connection, or UV-sterilised bottled drinking water.

*4.3 Carbon*

The software enables the unambiguous conversion of each single solar recharge to a quantified replacement of kerosene. This is a breakthrough for such a highly dispersed usage of kerosene. The accumulation of all these saved equivalent uses of kerosene into packages for carbon trading thereby further reduces the charging fees and allows households to benefit directly from the carbon savings they achieve.

*4.4 Risks*

The most serious risk are programs and projects that subsidize solar lighting or provide it free of charge to communities. Experience shows that, after the implementing organisation leaves, the equipment sooner or later begins to fail, with villagers losing confidence in solar technology.

A particular challenge for earlier Sunlabob endeavours has been the need to convince such villagers to subscribe on a rental basis or for a fee. Another threat is that kerosene vendors who will lose business may retaliate. This has not been experienced to date, as the shopkeepers who sell kerosene often become the local entrepreneur to rent the charging station.

A further risk is that a village could gain access to the national electricity grid, at which time households might choose to switch. This risk is mitigated by the fact that:

a) installation fees for a household connection are often too high for the poorest households who are those targeted by this service, and
b) the whole equipment from Sunlabob can be dismantled and set up in another village.

*4.5 Global potential*

The presented operational procedures and technical solutions are replicable worldwide in all areas where:

- there is adequate sunlight
- populations are organised into villages or, if dispersed throughout the landscape, regularly gather at particular locations, such as schools or markets
- kerosene is expensive at the household doorstep (i.e. ≥ US$1.5 per litre)

The potential market in rural areas worldwide is therefore correspondingly immense.

*4.6 Investment Opportunities*

When exploring the opportunities to finance ventures with charging stations and solar lanterns, one must take into account the strong public interest in rural electrification, particularly in remote areas and for poor households. While the primary objectives are always to launch and sustain both commercially-viable village enterprises and the private franchisers providing support services, there is also a strong case to be made for public involvement in launching such ventures.

However, public financial involvement must be designed to encourage private investments into commercial operations. Subsidies, if badly designed, can be counterproductive.

Public and private investments can offer mutual leverage, in circumstances where one alone may not achieve the intended effect. As illustrated in Fig. 6 below, it is suggested that private investors (e.g. social investment funds, eco-investment funds, carbon investment funds, etc.) can invest in the charging stations to be rented out, whereas publicly launched revolving funds can provide the first batch of lanterns to start up the businesses of the village entrepreneurs.

Note that after the initial investment by the public, the launched village enterprises are expected to generate sufficient income to expand and continue their operations through the revolving fund without any further investments by the public.

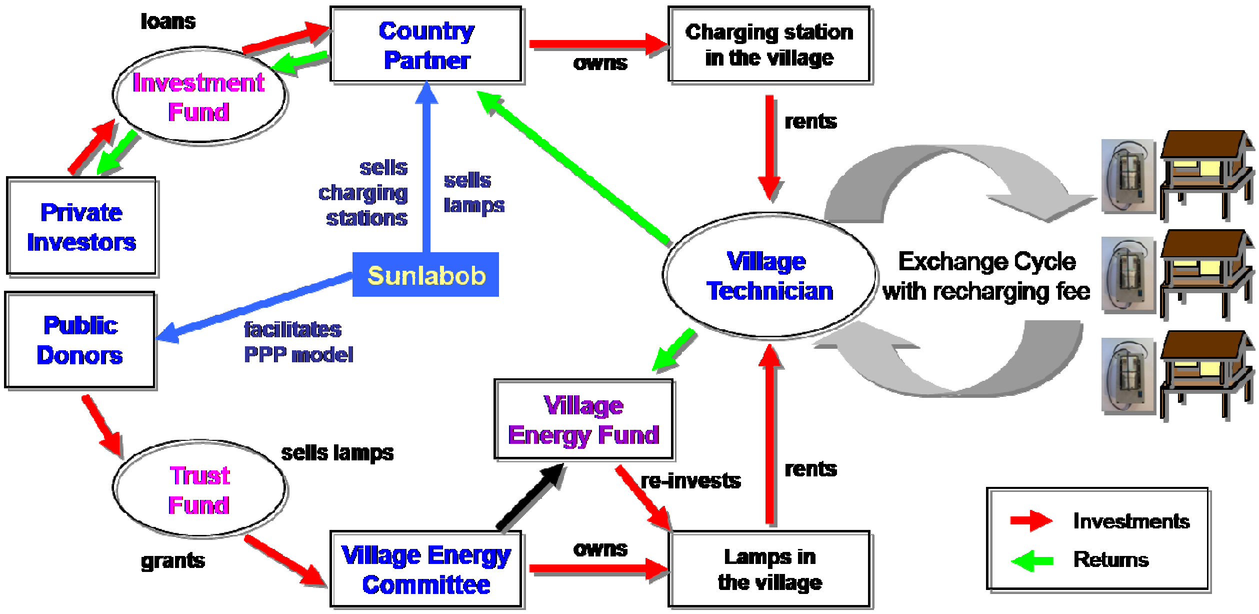


**Fig. 6** Involvement of partners and financial transactions

Of course, conversely, private investment funds could contribute to lantern purchases and the public can also invest in charging stations. In some instances this may be required to balance out the investments of each party (to be later evened out again). Through this mechanism, a Public-Private Partnership can be achieved on the basis of providing solar lighting to poor households in remote villages.

### 5. Conclusion

Sunlabob's experience has shown that technical expertise is essential but needs to be combined with a robust operational and financial model offering economic sustainability, in order for rural electrification programmes to be successful and have long-lasting benefits for populations in developing countries. Involvement of local populations is also decisive, both for a smooth transition and for good management and maintenance of the renewable energy solutions proposed. Sunlabob's pilot programmes with the solar battery lantern have so far proved very successful, both in terms of technical performance and end-user behaviour, predicting a very promising future for this innovation in off-grid areas of the developing world.

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# Barriers on the propagation of renewable energy sources in Greece

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**Abstract**

Renewable Energy Sources (RES), excluding big hydroelectric plants, currently cover 4,21% of total electricity production in Greece. Even when considering the additional production from big hydroelectric plants, which accounts for some 7,8%, the distance to be covered towards the objective of 20% electricity produced from RES by 2010 and respectively towards 20% of total energy production by 2020 is discouraging. The potential, though, does exist; unfortunately so does a series of barriers. National legislation is trying to help the development of a "green" electricity market, by means of supply-side policies like subsidies for renewable electricity production and attractive feed-in tariff rates. However, socio-economic and public awareness problems are still met in the planning and implementation of RES projects, together with the lack of a complete national cadastre and a spatial development master plan, specifying areas eligible for RES development. Specific barriers occur for individual RES and the on-going inclusion of waste-derived RE in the examined palette is further increasing the complexity of the entire issue. The consolidated study of this broad set of barriers was a main task of the work carried out within the frame of a Hellenic-Canadian research project; the main results will be discussed in this paper.

**Keywords:** Renewable energy sources; energy policies; barriers; legislation

## 1. Introduction

Since the '90s the demand for a change in energy policies became a major issue of discussion around the world, driven by economic, environmental, security and social concerns. Political and legislative changes occurred, having a profound influence on the development of Renewable Energy Systems (RES) directly or indirectly. On a European level changes were expressed i.a. by a series of Directives dealing with renewable energy matters, including the Directive on the promotion of electricity from renewable energy sources (EC, 2001b) and the Directive on the promotion of biofuels (EC, 2003b) which aimed at the elimination of existing barriers. Within this process, new policies are being elaborated after the adoption of the climate change and energy package proposed by the Commission in January 2008. That is a far-reaching package of proposals that falls within the line of the European Union's ambitious commitment to fight climate change and promote renewable energy up to 2020 and beyond. The new proposed EU policy on the promotion of renewable energy, therefore, leaves it to up to the Member States to decide how to split their national target between the heat and the electricity sector.

The share of renewable energy sources in primary energy consumption in the EU-27 increased from 4.4 % in 1990 to 6.7 % in 2005, this development lead to a respective reduction in $CO_2$ emissions. However, rising overall energy consumption in absolute terms has counteracted some of the environmental benefits from the increased use of renewables. The strongest increase came from wind and solar energy, with biomass playing a significant role lately. Still, and despite the progress made, significant growth is needed if the indicative target of 12% for the EU, referring to primary energy consumption is to be met by 2010. Given the current technology the penetration levels in 2009 towards the 2010 targets on renewable in final energy consumption are given in the following Table 1.

Table 1: Electricity from renewable energy sources: progress towards the 2010 target.

| Member State | Share in the reference year[84] | Share in 2004 (%) | Share in 2006 (%) | Change in percentage points in shares 2004-2006 | Progress made towards target from reference year in 2006 (%) | 2010 target (%) |
|---|---|---|---|---|---|---|
| **Austria** | 69.00 | 60.94 | 61.62 | 0.7 | 0 | 78.1 |
| **Belgium** | 1.06 | 2.15 | 3.89 | 1.7 | 57.29 | 6 |
| **Bulgaria** | 6.37 | 6.43 | 6.82 | 0.4 | 9.72 | 11 |
| **Cyprus** | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 6 |
| **Czech Rep** | 3.47 | 3.68 | 4.11 | 0.4 | 14.13 | 8 |
| **Denmark** | 8.87 | 27.08 | 25.93 | -1.2 | 84.75 | 29 |
| **Estonia** | 0.26 | 0.59 | 1.45 | 0.9 | 24.59 | 5.1 |
| **Finland** | 26.29 | 26.79 | 26.47 | -0.3 | 3.45 | 31.5 |
| **France** | 15.62 | 14.01 | 14.29 | 0.3 | 0 | 21 |
| **Germany** | 6.33 | 10.58 | 12.59 | 2.0 | +100 | 12.5 |
| **Greece** | 7.70 | 7.59 | 8.79 | 1.2 | 8.79 | 20.1 |
| **Hungary** | 0.48 | 2.28 | 3.68 | 1.4 | +100 | 3.6 |
| **Ireland** | 4.25 | 5.65 | 8.57 | 2.9 | 48.27 | 13.2 |
| **Italy** | 15.52 | 15.78 | 18.32 | 2.5 | 40.11 | 22.55 |
| **Latvia** | 47.48 | 46.01 | 40.40 | -5.6 | 0 | 49.3 |
| **Lithuania** | 3.56 | 3.43 | 3.87 | 0.4 | 9.01 | 7 |
| **Luxembourg** | 1.21 | 3.33 | 3.67 | 0.3 | 54.79 | 5.7 |
| **Malta** | 0.00 | 0.00 | 0.00 | 0.0 | 0 | 5 |
| **Netherlands** | 3.51 | 5.71 | 7.93 | 2.2 | 80.51 | 9 |
| **Poland** | 1.63 | 2.19 | 3.05 | 0.9 | 24.19 | 7.5 |
| **Portugal** | 32.56 | 28.56 | 31.16 | 2.6 | 0 | 39 |
| **Romania** | 30.66 | 29.15 | 28.05 | -1.1 | 0 | 33 |
| **Slovak Rep** | 14.49 | 13.55 | 16.00 | 2.5 | 9.15 | 31 |
| **Slovenia** | 29.66 | 29.37 | 28.26 | -1.1 | 0 | 33.6 |
| **Spain** | 16.45 | 18.58 | 19.11 | 0.5 | 20.54 | 29.4 |
| **Sweden** | 47.99 | 51.52 | 52.28 | 0.8 | 35.72 | 60.0 |
| **UK** | 2.12 | 3.64 | 4.63 | 1.0 | 31.85 | 10 |
| **EU27** | **12.85** | **14.35** | **15.72** | **1.4** | **35.21** | **21** |

Source: Eurostat (with normalised hydro)

[84] Reference year for EU-15 is 1997. Reference year for EU-12, BG and RO is 2000.

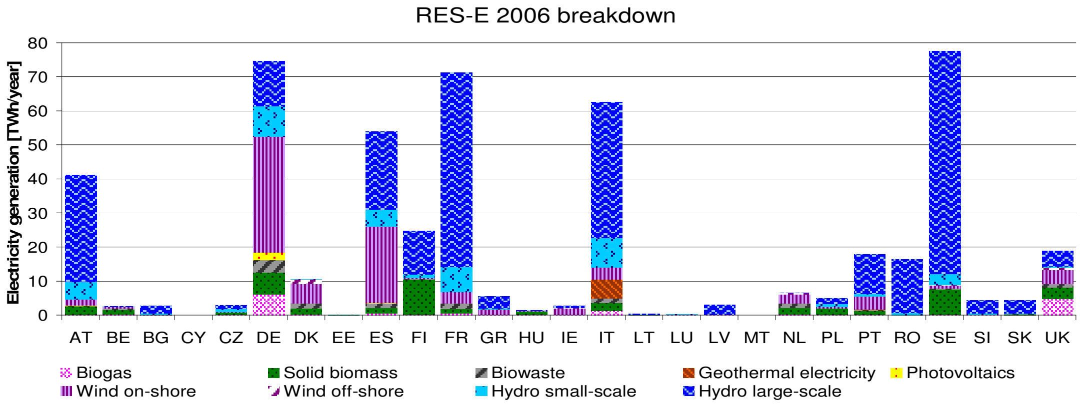


Figure 1: Renewable electricity generation in European Union in 2006.
Source: Eurostat/Fraunhofer ISI: Electricity from renewable energy sources 2006 breakdown of normalised renewable electricity in 2006.

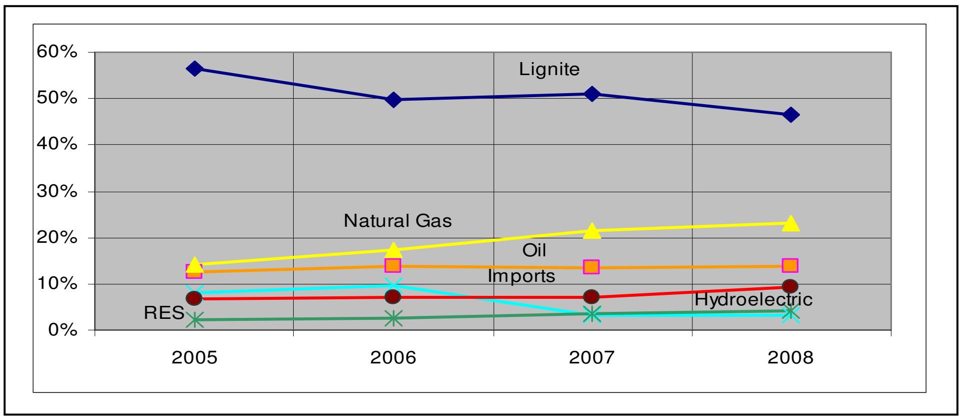


Figure 2: Greek Electric Energy Balance for Continental & non- interconnected islands (The energy produced percentage for the non-interconnected islands is about the 9% of the whole year (3.9 TMh oil and 447 GWh RES). The total power of PV is around 23.278.)
Source: Data by RAE, 30/09/08, processed by the authors.

In order to reach the target set for 2010, an increase in the share of electricity from renewable energy sources from 13% to 21% would be needed. Given the fact that in 2006 we were at a level of 15.7%, a further relative increase of 35.2% (2.87/8.15) is needed to achieve the 2010 target. (Eurostat, 2006).

## 2. The Greek situation

Even though a great part of the Greek mainland and also many Greek islands have a high RES potential and despite the significant technological advances of the last decade, which in theory do allow even up to 100% RES supply in isolated areas, the actual use of RES is still rather limited. Between 2004 and 2008 electricity generation from renewable energy sources increased by 21.1% whilst electricity consumption as such grew by 4.21% (RAE, 2008). In line with earlier estimates, Greece predicts that electricity from renewable energy sources will grow, but with less than 10% of the effort made towards the target, it is unlikely that the initial target for 2010 will be reached. A series of European Directives were integrated in the national legislation, in order to create a framework that will guarantee a rapid progress in the development of RES. These include (a) the Directive 2001/77/EC, which requires that electricity from renewable energy sources has guaranteed access to the grid and requires Member States to set rules for sharing and bearing the cost of various grid investments necessary to integrate it. (b) COM(2006)848[85]

[85] http://eur-lex.europa.eu/LexUriServ/site/en/com/2006/com2006_0848en01.pdf, Communication from the Commission to the Council and the European Parliament: renewable energy roadmap: renewable energies in the 21st century: building a more sustainable future.

which noted that grid connections and extensions needed to be simplified and stated. (c) SEC(2008)57 86 which noted that despite the requirements of Directive 2001/77/EC, project developers still faced different grid-related barriers, which were mainly related to insufficient grid capacity, non-transparent procedures for grid connection, high connection costs and long lead times to obtain authorisation for grid connection. The Communication noted that high priority should be given to removing administrative barriers and improving grid connection for renewable energy producers.

Greek legislation incorporated the afore mentioned directives in a series of successive laws, the last one being Law 3468/2006 on "Production of Electrical Energy form RES and combined heat and power in the gross electricity production and other". The law simplifies licensing procedures, whilst it provides a feed-in tariff guarantee for 10 years, which can be extended by 10 years following a producer's unilateral declaration towards the Transmission System Operator. That was made in order to expanse the electrical power market and to provide long term stability. The 20 years period is one element of best practice for national support schemes because it provides stability and support of long term mechanisms.

Furthermore, a series of supplementary laws and ministerial decisions were legislated to create the framework for an efficient implementation of the system. In some instances they were used in conjunction with green certificate/obligations support schemes. In most cases they are used by electricity suppliers to show their consumers that they have purchased "green electricity" but the barriers in promoting RES still remains.

Still, and despite the effort, one of the major barriers is the overall authorisation procedure and grid connection. As it depicted in Figure 3, Greece ranks in the last third of the average lead time for overall licensing procedure in Europe.

## 3. The RES Barriers in Greece

Greece is considering its morphology, climate and development a very clustered country, as it incorporates mountainous areas and islands, high income touristic places and low income rural areas as well as highly urbanized cities and sparsely populated remote areas.

Despite this fact, a series of studies have proven that there are several drivers and barriers common in the whole country. Administrative and procedural decoupling of conflicting interests characterizes most of the barriers. Eurostat (2007) used socioeconomic indicators in order to categorize the RES barriers in Greece. The five major types are:

(1) technological barriers;
(2) environmental barriers;
(3) social/public opinion barriers;
(4) economic barriers;
(5) regulatory, administrative and legislative barriers.

The present study, which was based on a consolidated Hellenic – Canadian research project which major part had to broad the set of barriers, adopts that approach and attempts to identify the existing barriers.

### 3.1. Technological barriers

There are different needs for continental use of RES and for their use to the islands. It is obvious that when it comes to the continental needs the infrastructure network is much more proper to absorb the electrical energy produced by RES in areas with increased potential. The insular electrical communication connections are rather weak and incompetent to absorb or to store the whole some of the power produced by wind parks (Oikonomou, 2009).

Concerning the wind energy Papadopoulos (2007) presented the limited capabilities of absorbing RES-generated power. The need of upgrading existing grids, a time consuming and expensive procedure, especially in the case of high-voltage nets. These problems occur mainly in the regions of Thrace, Evoia and Lakonia, where there is a high investing interest due to the very favourable wind potential. The seasonal fluctuation of the energy demand, especially on Greek islands, underlines the weakness of the network's infrastructure. There is an absence of balance between the demand and the offer of energy. Especially when referring to the use of RES, usually PV, at a building the lack of knowledge not only to the know-how but also experience in placing such kind of systems it's characteristic.

[86] http://ec.europa.eu/energy/climate_actions/doc/2008_res_working_document_en.pdf
Commission Staff Working Document: the support of electricity from renewable energy sources. Accompanying document to the proposal for a Directive to the European Parliament and to the Council on the promotion of the use of electricity from renewable energy sources (COM (2008) 19)

Table 3: Drivers and barriers for RES and projects in Greece.

| | | **Renewable Energy Systems** |
|---|---|---|
| **Barriers** | Technological barriers | · Participation in EU funding projects in public-private partnerships<br>· Incorporation costs for RES<br>· High cost of grid connection<br>· Delays to overall procedure<br>· Lack of funds<br>· Lack of special spatial design for RES<br>· Ineffective control mechanisms and administrative structures<br>· Lack of trained human resources<br>· The is no maturity to the recognition and realistic assessment of the RES potential and performance |
| | Environmental barriers | |
| | Social/public opinion barriers | |
| | Economic barriers | |
| | Regulatory, administrative and legislative barriers | |

Source: DEPOIR, 2007

### 3.2. Environmental barriers

The problem with the Greek energy market, at least in its current shape, is that environmental costs are not adequately internalised. While the production of fossil energy is combined with the greenhouse gas emissions, and consequently with global warming, costs of these external factors are poorly reflected in the price market for energy. Thankfully external environmental costs are only to a small extent reflecting to the eco-system (Stangeland, 2007).
According to Oikonomou et al (2009) the effects on environmental barriers can be recognised on the ecosystems, on the landscape and on the change of land use. More analytically, fauna and flora can change until a RES work completion. Especially, minimal interventions should be made in order for the side to return to its original environmental state as close as possible upon completion of all works.

### 3.3. Social / public barriers

This is the most important factor because it refers to the public acceptance of the RES. There are an important number of complaints published to the local press and to the internet. Insufficient sources of information are used in order to inform and guide the public. There is a failure in the market to estimate the RES and especially the wind park financial and also the social benefits for the local community e.g. create new jobs. In island wind parks can also be used as tourism attractions.
Construction and design standards do not include PV installations or use of geothermal energy which will help to the explosion of RES systems to the local market and to the conscience of the consumer. Around the world and in Greece there is a variety of construction and operation related standards that include RES applications. Those do not work properly and are not focused to ensure that contractors will have the necessary experience and knowledge in RES.

### 3.4. Economic barriers

There is an absence of economic advantages and motivations for implementing RES systems at buildings. Moreover the initial cost is still high both for commercial and domestic use. Only a small effort has been made the last semester from the Greek market to reduce the price of PV but the investment remain expensive and with a 7 year, which is a long-term amortization.
The currently valid Law 3468/06, which was introduced in June 2006, aimed at simplifying and speed up the whole procedure but without a result. Even though quite many investors expressed their interest in RES projects, the result remained meagre (DEPOIR, 2007). Even where feed-in tariffs were almost too attractive, as in the case of photovoltaics, progress is slow and tedious (Papadopoulos and Karteris et al, 2009)

### 3.5. Regulatory, administrative and legislative barriers

Government procurement policies aim to promote sustained commercial development of renewable energy but bureaucracy creates obstacles.

There is a rather complicated licensing procedure for RES. Ten 10 essential documents are needed in order to start the apposition of a PV system to a building and much more in a field (Figure 4). Concerning the construction of a wind park the duration of the entire procedure is more extended (Figure 5). The whole duration for a PV park is about 2 years and for a wind park can reach the 4 years.

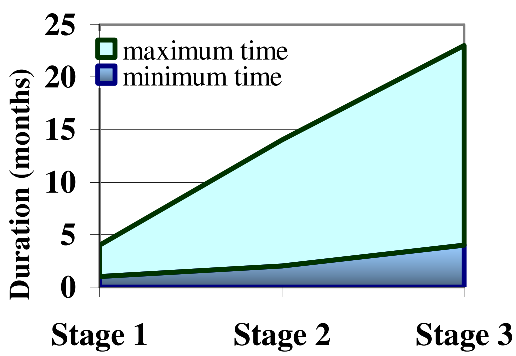


Figure 4. Stages of development and operation of a PV park. Source: DEPOIR 2007

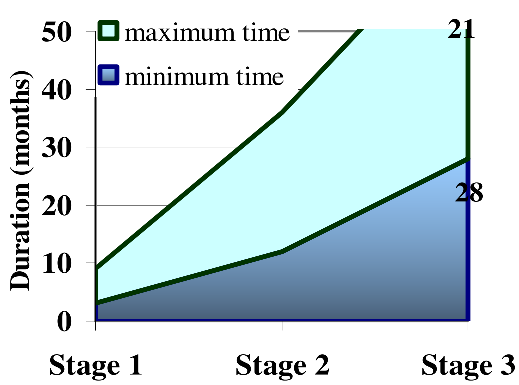


Figure 5. Stages of development and operation of a wind park, Source: DEPOIR 2007

The lack of a national spatial master plan for RES is another barrier. In 2007 was published the spatial plan specifically for RES, but its implementation has shown that there are many question to be answered before it actually helps speeding up the whole procedure.

Finally, a problem that cannot remain unaddressed concerns the fact that the same projects are monitored concerning their operation and performance by different authorities simultaneously. The turn-key cost of wind parks is monitored by the Ministry of Development, which is granting the production licences and is also responsible for managing the European Union funds of the in the energy sector. The monthly and annual energy output is monitored by the Hellenic Transmission System Operator (HTSO) which is responsible for the payment of energy producers. The Regulatory Authority of Energy is monitoring the producers' compliance with the terms of the production licences, as well as the evolution of the electricity market as a whole. Although both HTSO and RAE are supervised by the Ministry of Development, this fragmentation does not enable a rundown of the data needed for the evaluation of the wind parks' energy performance and economic efficiency (Papadopoulos, 2007).Finally, the Ministry for Finance is monitoring the cash flows from national funding sources

## 4. Conclusions

Price-setting policies in order to reduce cost and pricing related barriers will give a boost to the development of RES. Also, proper education to the local communities will help in overcoming the social reaction.

Government should purchase the RES in early market stages with a view to overcome the institutional barriers to commercialization, to encourage the development of appropriate infrastructure and provide the local markets paths for technologies that require intergraded technical, infrastructure and regulatory changes.

Even though public support for renewable energy expanded rapidly in the late decade, a wide variety of policies are designed to explicitly to promote renewable energy and a rise is to the MW produced from RES is obvious Greece need more efectove measures to achieve the 20-20-20 target.


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# Biogas a secure and sustainable energy source: Obstacles and perspectives of biogas projects in Hellas

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**Abstract**

*The paper will give an overview about the biogas status in Hellas and will attempt to illustrate the main non technological barriers that a biogas project may face during the design, development and implementation phase. The aim is to assist all the involved parties in understandings which are today the most important barriers and how they can affect the whole lifetime of a biogas project. In parallel this work can become a useful tool and help the policy makers and biogas market actors on coordinated initiatives in order to reduce, eliminate or even remove at least the most crucial of these barriers. Although the new legislative and financial framework has been improved in parallel with renewable development which is positively affected by country's very good resource potential, state policy and social conditions, there are still barriers toward wider biogas exploitation and especially for small farm scale biogas plants implementation. Such barriers are the stakeholders and public perception, awareness and experience in such schemes, the investment costs and the revenues (eg. lack of price for heat or "gate fees", externalities, development of compost market), the time consuming licensing procedure and broader institutional and regulatory issues.*

**Keywords:** biogas barriers, socio-economic aspects, sustainability

## 1. Introduction

In Greece like in the most OECD countries, energy represents one of the most important and dynamic sectors of the economy. In the year 2006, gross electricity generation was about 60 TWh, of which 60% was from lignite (domestically extracted low-calorific value lignite of about 70 million tons), 16% from petroleum products (oil, mainly used by the power plants on the islands not connected to the mainland's system), 18.7% from natural gas (imported from Russia by pipeline and Algeria in the form of LNG), 14% from hydroelectric power and 2.1% from wind power [1].

Renewable Energy Sources contributed 5.0% (1.68MToe) of the Greek Total Primary Energy Supply (33.5MToe) in 2007. Biomass accounted 67% and covers mainly thermal needs [2]. In 2007 about 5.9Mtoe of biogas were produced for energy uses in the European Union, nevertheless, the potential is estimated at more than 20 Mtoe. In Hellas at the same year the Primary Energy Production of Biogas was 47.8Ktoe (the landfill gas represents 38Ktoe and sewage sludge covers 9.8Ktoe). In terms of final Energy the electricity production had a total of 175.3GWh [3]. In 2008 the installed capacity of electricity generation from biogas-biomass was 39.4MW (40.8MW during August 2009). At the same year (2008) the gross electricity generation from biogas-biomass was 176.7GWh [4].

## 2. Biogas status in Greece

The term "Biogas" hides a wide range not only in the ways in which it is valorised but also the technologies in which it is produced. Biogas can be produced of nearly all kinds of organic material. Nowadays in Europe there are quite a few biogas process volumes at the current wastewater treatment plants, landfill gas installations, and industrial biowaste processing facilities. However, the largest volume of produced biogas will be, by

2020, originate form farm biogas and from large co-digestion biogas plants, integrated into the farming – and food – processing structures [5].

In Hellas the picture is different as the produced biogas derives mainly from landfills, wastewater treatment plants and a couple of industrial applications. During 80's some efforts were carried out, which were abandoned after the initial operational phase. In 2007 fifteen biogas plants were in operation[87]. The collection of the required data was done through a country wide field survey at biogas plants covered by CRES every year. The utilisation of biogas in most of these cases mainly covers heat demands of the plants. Nevertheless, the installed capacity of electricity generation from biogas was 37.4 MW and the gross electricity generation reached to 155.9 GWh [4]. The most energy was produced in the area of Athens due to the operation of the Municipal Wastewater Treatment Plant (MWTP) of Psytallia and the Sanitary landfill (SL) of Ano Liosia, which treat liquid and solid wastes respectively.

Feedstock for Anaerobic Digestion plants can be derived mainly from three major categories (sources of wastes):

- Municipal waste (eg. landfill gas and wastewater treatment plants)
- Industrial waste (eg. dairy industries, food/beverage industries, slaughterhouses)
- Agricultural waste & energy crops (eg. cattle-pig-poultry manure, energy crops, agricultural residues).

According to the Agricultural - Livestock Survey of 2006:

- The livestock was dominated by sheeps and goats (119,355 holdings with 9,031,645 heads and 123,348 holdings with 4,986,423 heads respectively). There were also 23,437 holdings with 684,057 heads of Cattle and 34,721 holdings with 1,055,057 heads of Pigs.
- There were 1,273 holdings in Central Macedonia with more than 50 Cattle and in Thessaly there were 735 holdings with more than 50 Cattle. At the same time there were 238 holdings and 127 holdings with more than 100 pigs in Thessaly and in Western Hellas respectively.

Generally, promising areas of biogas exploitation in Hellas can be considered the following:

- Crete island,
- Lakonia,
- Evia island,
- Aitoloakarnania,
- Preveza,
- Thessaly
- Central Macedonia.

According to estimates made by CRES, and based on a conservative scenario, it is estimated that the AD of manure and organic wastes from the slaughter houses and milk factories could feed CHP plants of total installed capacity of 350 MW and a mean annual electricity production equal to 1.121.389 MWhe [6]. It is worth mentioning that taking into account only the breeding animals in Hellas (cattle and pigs) and based on different assumptions, several authors have estimated that the theoretical annual manure production comes up to 10-17 million tones[88].

## 3. Biogas Policy

There is no specific biogas policy in Hellas. The development of biogas projects and biogas exploitation falls mainly under the provisions of the general RES legislation and fiscal measurements and the country environmental and agricultural policy for waste management.

In November 1997, the European Commission published a White Paper entitled «Energy for the future: renewable sources of energy». The paper sets an ambitious goal of doubling from 6 to 12% the share of renewable energies in the total energy demand (20.1% for Hellas). Biomass should produce more than 80% of the total RES additional contribution by 2010. Agriculture is expected to produce more than 50% of the additional Renewable Energies to be implemented by 2010, through energy crops and use of residues and the Biogas (livestock, sewage treatment, landfills) target for 2010 is 15Mtoe. Thus, important efforts particularly concentrated on farmers have to be undertaken in order to realise this objective because the farmers'

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decision to become involved in biomass is essential.
According to the Greek Ministry of Development estimations reflected to its national reports regarding the penetration level of RES the installed capacity required for 2010 in order for the target to be achieved, is presented in Table 1 [7]. For biomass, the installation requirements to meet these targets are 103 MW (0.81TWh or 1.13% of RES share in 2010).

Table1: RES installation requirements to meet the 2010 target.

| | Requirements in installed capacity by 2010, in MW | Energy generated in 2010 in Twh | Percentage share of every renewable energy source in 2010 |
|---|---|---|---|
| Wind parks | 3,648 | 7.67 | 10.67 |
| Small-scale hydro | 364 | 1.09 | 1.52 |
| Large-scale hydro | 3,325 | 4.58 | 6.37 |
| Biomass | 103 | 0.81 | 1.13 |
| Geothermal | 12 | 0.10 | 0.14 |
| Photovoltaics | 200 | 0.20 | 0.28 |
| **Total** | 7,652 | **14.45** | **20.10** |

Source: Ministry of Development

According to article 1 of the Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport «This Directive aims at promoting the use of biofuels or other renewable fuels to replace diesel or petrol for transport purposes in each Member State, with a view to contributing to objectives such as meeting climate change commitments, environmentally friendly security of supply and promoting renewable energy sources». The Directive sets indicative targets for biofuels and other renewable fuels share of 2% until 31-12-2005 and 5.75% until 2010. These targets are based on the basis of energy content, of all petrol and diesel for transport purposes. The Directive was adopted in the Greek legislation by the Law 3423/2005. It is estimated that the biodiesel and bioethanol required satisfying the needs of Hellas according to the principles set in Directive 2003/30/EC, for the year 2010 is approximately 148,000t and 390,000t respectively [8].

The EU's climate and energy policy sets the following ambitious targets for 2020:

- greenhouse gas emissions reduction from developed countries by 30% and it has already committed to cut its own emissions by at least 20% compared to 1990 level.
- a mandatory target of a 20% share of energy from renewable sources in overall Community energy consumption by 2020 and a mandatory 10% minimum target to be achieved by all Member States for the share of biofuels in transport petrol and diesel consumption by 2020, to be introduced in a cost-effective way.
- cutting energy consumption by 20% by improving energy efficiency.

The national overall target for the share of energy from renewable sources in gross final consumption of energy in 2020 has been set to 18% (Annex 1 of Directive 2009/28/EC).

In parallel, The 2nd National Programme for Climate Change was developed and adopted in 2003 (Ministerial Council Act 5/27-2-2003) with an aim to establish a set of policies and measures to reduce greenhouse gas emissions. The aim of the Programme was for Hellas to fulfill its national obligations under the Kyoto Protocol during the commitment period 2008-2012 (that is to limit the increase of greenhouse gas emissions to 25% during that period compared to base year emissions).

The main actions foreseen by the 2nd National Programme were:

- Further penetration of Natural Gas (NG) in all energy demand sectors and electricity generation, including combined heat and power generation (CHP).
- Promotion of Renewable Energy Sources for electricity and heat production
- Energy saving in industry and the residential – tertiary sector.

Policies used to promote renewable energy development are described also in the revised Greek National Programme for Climate Change, which estimates realistic $CO_2$ savings of 4.5 Mt $CO_2$-eq from the increased use of Renewables [9]. Based on the Law 2741/1999 the Special Spatial Plan for RES was prepared by the Ministry of Environment not only to stress the priority of RES but also to show the priority for sustainable development (JMD 49828/2008, OG2464/B/08). The Plan establishes guidelines and rules for the sitting of RES plants and gives directions to the other planning levels such as regional or local level. Furthermore, it has special provisions and references to the RES categories like wind parks or hydropower plants. For biogas plants the most suitable sites are considered those located near to the «feedstock» production and availability. The Plan excludes some areas and land uses and gives some general criteria but doesn't recommend specific sites for biogas exploitation (eg. like in wind parks).

Currently, among others, there are two main state financial-support instruments that provide substantial public subsidies to RES investment projects:

- The so-called «National Development Law» (Law 3299/2004 as was modified by law 3522/2006, Article 37, Official Gazette 276 A', December 22, 2006)
- The Greek Operational Programme for Competitiveness, one of the eleven (11) National and the thirteen (13) Regional Operational Programmes, in which the Third Community Support Framework (CSF III; 2000-2006) for Hellas is divided (the Operational Programme "Competitiveness & Entrepreneurship" is scheduled to continue for the period 2007-2013).

The new law for RES (Law 3468/2006, «Generation of Electricity using Renewable Energy Sources and high-Efficiency Cogeneration of Electricity and Heat and Miscellaneous Provisions», OG 129/A/06 as it was modified by Law 3734/2009 «Promotion of cogeneration of two or more useful forms of energy and miscellaneous other provisions», OG 8/A/09) is dedicated to the promotion of RES and in order to speed up the licensing procedures and to reform the electric energy production from renewable energy sources. The law sets the new environment in the electricity generation, the guaranteed market price is increased and the market time expands from 10 to 20 years. Furthermore, the licensing deadlines are being reduced. The new pricing tariff system for electricity production from RES and CHP systems set a tariff of 73€/MWh (€80.14/MWh for the year 2008) for the most of RES.
The impact and effects of the implementation of these policies are not yet visible especially in biogas project implementation.

## 4. Barriers to biogas projects

Renewable Energy Sources (RES) seems to have an essential and important contribution to the Greek Energy System the years to come. In parallel the last decade a favorable climate has been created for the substitution of the conventional energy sources (fossil fuels) as they contribute to the greenhouse effect and their use is associated with a series of environmental problems. Thus, RES becomes more and more important in the State Energy agenda.

The implementation of biogas projects demands careful planning, taking into consideration technical, social (information of all involved parties) environmental and financial factors. Some times is difficult to develop a biogas project due to the variation of the sites characteristics and feedstock availability. But in most of the cases the non technological barriers are referred as the most crucial for the project development.
Although social pressure, economic conditions and legislation improved the framework for biogas production, there are still barriers to overcome in Hellas, especially for the materialization of small scale biogas plants. Among the main barriers one can identify the stakeholders and public perception, awareness and experience in such schemes, the investment costs and the revenues (eg. lack of price for heat or "gate fees", externalities, development of compost market), the time consuming licensing procedure and broader institutional and regulatory issues.

- **Awareness:** Nowadays there is still lack of knowledge and adequate information not only to the farmers but also to the industries (owners) and the general public about the possible energy exploitation of wastes, their final uses (eg. electricity, heat, injection to the natural gas grid, transport fuel) and benefits.
- **Costs and revenues**: Biogas projects still need high investment costs. Taking into consideration that project financing remains a major concern and the revenue comes mainly from the new pricing tariff system for electricity production for RES these type of projects have high payback period.
- **Market issues**: Although there is a mature "Energy Market" in Hellas the development of a full liberalized electricity market suffered a delay.
- **Institutional & Regulatory issues**: The new RES law (law 3648/2006) sets a new reality in the electricity generation, and among others, simplifies the licensing procedures. Despite this, the regulatory and institutional framework for the promotion of biogas must further be improved taking into consideration the needs for environmental protection and the promotion of energy exploitation and efficiency (eg. Kyoto Protocol, EU Directives like 2001/77/EC, 2009/28/EC, 2003/87/EC, 96/61/EC).

## 5. Initiatives to support Biogas

### *5.1 Market roadmap*

Besides the technical or other form of barriers it is even more important to identify barriers related to market and dealing among others with financial and administrative issues. The proposed actions to overcome such barriers comprising the market roadmap for the promotion of biogas projects are described in the following paragraphs:

- **Feedstock availability:** Agricultural and animal wastes are a matter of special concerns due to the high potential and their spatial distribution almost allover the country. In some cases there is still lack of knowledge about the technical potential of wastes in a certain area and their biogas exploitation alternative. Parameters like stable supply of raw material and feedstock composition are fundamental for the biological process and biogas production. The seasonal production of some wastes like agro-industrial residues (eg. citrus processing industries, or olive oil mill residues) is crucial for the successful implementation of a biogas scheme and needs very careful examination. In such cases long-term contracts between biogas plant operators and feedstock suppliers must be guaranteed and the use of different wastes (eg. agro-industrial waste with animal manure) is necessary (Co-fermentation with other raw material).
- **Energy Market issues:** Apart to the need of Full Liberalization of the Electricity Market, elimination of end users barriers is needed (eg. development of heat market, biogas use as a transportation fuel, injection to the natural gas grid, compost etc).
- **Costs and revenues**: Biogas projects still need high investment costs. Taking also into consideration that a) project financing remains a major concern, b) the revenue comes mainly from the new pricing tariff system for electricity production for RES, c) externalities are not assessed and monetized, d) there in no "gate fees" in Hellas, e) the «polluter pays» principle is not efficiently applied, further improvement of the financial and economical instruments for the support of RES and especially biogas project are needed (eg. examination of differentiation of public funds, introduction of tradable green certificates, higher electricity price according to the form of Biomass). This will attract new biogas projects.

***<u>5.2 Policy roadmap</u>***

- **Commitment:** in political level a stronger commitment concerning the exploitation of biogas as a sustainable energy and environmental choice is needed. This commitment will affect the other levels too (eg. regulatory, institutional, administrative, financing etc).
- **Awareness, Public acceptance and participation:** Public Awareness in all levels is needed accompanying by stakeholders training and support. Furthermore, a biogas plant must be adapted to the particular regions and must be accepted from neighbors and the general public. Thus apart from its economical and technological viability a biogas plant must have also "environmental and social compatibility" based on thorough examination of the project and public awareness and participation.
- **Legislative framework for biogas:** Although the new RES law (law 3648/2006) sets a new reality in the electricity generation, and among others, simplifies the licensing procedures, the regulatory and institutional framework for the promotion of biogas must further be improved (eg. further administrative simplification and coherence, specific legislation concerning biogas, one-stop-shop process).
- **Energy price:** Although the new pricing tariff system for electricity production from RES and CHP systems set a tariff of 73€/MWh (€80.14/MWh for the year 2008) for biogas plants the electricity prices are rather low. A higher electricity price must be examined based on the form of Biomass (there is no differentiation according to biomass form).
- **Strategic Biogas Plan:** The penetration of Anaerobic Digestion schemes in Hellas concerning farm scale applications (biogas exploitation from animal manure and agricultural residues) is not still mature. A Strategic biogas Plan must be incorporated within the National and Regional Energy and Environmental Policy. The Agricultural Policy (Ministry of Agricultural Development and Food), Environmental Protection (Ministry of Environment) and Energy Investments (Ministry of Competitiveness) concerning biogas exploitation should be further coordinated.

## 6. Conclusions

Lignite, the domestic fossil fuel country resource seems that will dominate in the future fuel mix, but further RES penetration is a necessity and a milestone. Biogas is an energy carrier which can be used for several energy applications (eg. electricity generation, heat production, combine heat and power production, transport fuel, injection to the natural gas grid). Biogas exploitation can contribute to the energy, agricultural and environmental policy.

Apart from its energy content Anaerobic Digestion can play an effective waste management method, providing a natural high quality fertilizer and environmental protection (reduces emissions of particulate matter and NOx & contributes to GHG mitigation).

The use of agricultural material such as manure, slurry and other animal and organic waste for biogas production has, in view of the high greenhouse gas emission saving potential, significant environmental advantages in terms of heat and power production and its use as biofuel. Biogas installations can, as a result of their decentralised nature and the regional investment structure, contribute significantly to sustainable development in rural areas and offer farmers new income opportunities [10].

The European Parliament resolution of 12 March 2008 on sustainable agriculture and biogas: a need for review of EU legislation (2007/2107(INI)) stresses among others that producing agrofuels from waste should not become a goal in itself; reducing waste should continue to be a priority in the environmental policy of the European Union and in that of Member States and Emphasises that biogas production based on animal manure, sludge and animal and organic waste should be prioritised as the sustainability and environmental benefits of these methods are unequivocal.

In Hellas it is estimated that Anaerobic Digestion of pig manure (35% of the total breeding animals in 2010 and 50% of the total breeding animals in 2015 respectively) can reduce greenhouse gas emissions by 60,000t $CO_2$-eq in 2010 and 83,000t $CO_2$-eq in 2015 [9].

It is worth mentioning that in the framework of the calls for permits to generate electricity by Independent Power Producers (IPPs) by the Hellenic Regulation Authority for Energy (RAE), five applications for such permits (biogas plants) were submitted during 2008-09 for agricultural and industrial biogas projects (installed capacity of appox. 9.5MW).

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# Session 4: Climate Change

# A model for describing the concentration field of gases instantaneously released in the atmosphere

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**Abstract**

*The concentration signal of repeated instantaneous releases of hazardous gases into the atmosphere is decomposed into its principal components by means of the Proper Orthogonal Decomposition (POD) with the dual purpose of reconstructing it from its first (most energetic) components and predicting it in cases sharing common features with the cases from which those features were extracted by applying the POD. The analysis showed that the first eigenfunctions (principal components) obtained by the POD collapsed to a common shape in all cases of neutrally buoyant gases and those representing the threshold from neutrally buoyant to heavy gases with respect to downwind distance, thus providing evidence that a model can be constructed by interpolation in the range of varied parameters. The important issue of the uncertainty associated with the proposed POD model is discussed and a measure of uncertainty is provided.*

**Keywords:** concentration, dispersion, turbulence, prediction, proper orthogonal decomposition

## 1. Introduction

In cases where a polluting substance is released into the environment, the need for assessing the consequences of its release arises. The question of the extent of the impact caused may be posed by government agencies or private operations administrations, relating the extent of the impact to regulatory directives or legal actions or both. In particular, referring to the case of hazardous (toxic or flammable) gases being released into the atmosphere, in order to quantify the environmental impact of such releases, mathematical models are constructed and employed that describe the physical process of dispersion of the released substances in the atmosphere, as well as the chemical processes involved. Such models have been introduced decades ago and since then are being continuously improved as research carries on. The aim is to improve the accuracy of the model performance by taking into account the factors that affect it. Such factors include the fundamental physics and chemistry associated with the phenomenon of the dispersion of the released substance, as well as the mathematical and statistical techniques applied to describe the phenomenon.

### 1.1. Physical and mathematical - statistical background.

In this present study no chemical reactions will be considered, so the concentration of the pollutant in question will be treated as a passive scalar. In such a case, the concentration Γ(***x***,*t*) at position ***x*** and time *t* is determined by two processes: advection by a turbulent flow with velocity field **Y**(***x***,*t*), and molecular diffusion with constant diffusivity *k*. The equation Γ obeys is

$$\frac{\partial \Gamma}{\partial t} + \mathbf{Y}.\nabla\Gamma = k\nabla^2\Gamma \qquad (1)$$

where **Y** satisfies the Navier-Stokes equations with the incompressibility condition
$\nabla$ .**Y** = 0 (Monin & Yaglom vol.1, 1971).
At this point, some properties, often taken for granted, concerning the nature of the above quantities must be carefully discussed and clarified for the sake of precision and, consequently, the validity of the arguments about to follow, based on which the proposed methodology will be developed.
Since all the flows encountered in the real world are turbulent, **Y** and hence Γ, are random (or *stochastic*) fields. That means that their values at a given location ***x*** and at a given time instant *t* cannot be predicted and vary from realisation to realisation, in antithesis to predictable quantities like time or space averages or *rms* concentration

values often considered in practical applications. Hence, a probabilistic approach should be followed so as to describe these random fields.

The probability density function (PDF) of the concentration field $\Gamma(\boldsymbol{x},t)$, denoted by $p(\theta;\boldsymbol{x},t)$, is defined by

$$p(\theta;\boldsymbol{x},t) = \frac{d}{d\theta}\{P[\Gamma(\boldsymbol{x},t) \leq \theta]\}$$

for all $\theta \geq 0$. The variable $\theta$ ranges over all the possible values $\Gamma(\boldsymbol{x},t)$ can take.

$P[\Gamma(\boldsymbol{x},t) \leq \theta]$, the probability that $\Gamma(\boldsymbol{x},t) \leq \theta$ is the proportion of realisations forming the *ensemble* of realisations for which $\Gamma(\boldsymbol{x},t) \leq \theta$.

Being a probability measure, $p(\theta;\boldsymbol{x},t)$ satisfies

$$\int_0^\infty p(\theta;\boldsymbol{x},t)d\theta = 1.$$

Then, the expected value (or ensemble mean or 1st moment) and the variance (2nd central moment) of $\Gamma(\boldsymbol{x},t)$ are defined in the usual way moments of a PDF are defined, by

$$\mu(\boldsymbol{x},t)=E[\Gamma(\boldsymbol{x},t)]= \int_0^\infty \theta p(\theta;\boldsymbol{x},t)d\theta \quad (2)$$

and

$$\sigma^2(\boldsymbol{x},t) = \mathrm{var}[\Gamma(\boldsymbol{x},t)] = \int_0^\infty [\theta - \mu(\boldsymbol{x},t)]^2 p(\theta;\boldsymbol{x},t)d\theta = \int_0^\infty \theta^2 p(\theta;\boldsymbol{x},t)d\theta - [\mu(\boldsymbol{x},t)]^2 \quad (3)$$

respectively. The square root of the variance denoted by $\sigma(\boldsymbol{x},t)$ is the standard deviation of the concentration, otherwise known as the *rms concentration fluctuation.* Higher central moments are defined in analogy to eq.(3) with a suitable choice of the exponent. Usually, the first four moments suffice for describing theoretically the dispersion of an atmospheric pollutant via a PDF method.

The time evolution equations of the PDF, mean and variance of concentration are given in Chatwin (1990).

At this point, it is desirable to include some comments regarding the above *ensemble* parameters (2) and (3). The true values of these parameters are unknown, therefore in practice, in order to estimate them, one must draw a random sample from the *ensemble* of realisations and compute statistics to be used as estimators of the aforementioned parameters.

**1.1.1. The mean concentration.**

$$\overline{\Gamma}_n(\boldsymbol{x},t) = \frac{1}{n}\sum_{i=1}^{n}\Gamma_i(\boldsymbol{x},t) \quad (4)$$

In particular, regarding the mean, from a sample of $n$ realisations $\Gamma_i(\boldsymbol{x},t)$ one may compute the sample mean,

defined as the arithmetic mean of the data (the subscript $n$ is often omitted). This is itself a random variable (it varies as the sample is varied with respect to its size as well as with respect to the experimenter's choice of values of the varied parameters). Therefore, it possesses its own statistical properties:

$E[\overline{\Gamma}(\boldsymbol{x},t)] = \mu(\boldsymbol{x},t)$ and $\mathrm{var}[\overline{\Gamma}(\boldsymbol{x},t)] = \sigma^2(\boldsymbol{x},t)/n$ (Arnold, 1990; p.179).

Furthermore, when used as an estimator of $\mu(\boldsymbol{x},t)$, it possesses the property of *unbiasedness,* since $\mathrm{bias}[\overline{\Gamma}(\boldsymbol{x},t)] = E[\overline{\Gamma}(\boldsymbol{x},t)] - \mu(\boldsymbol{x},t) = 0$, as well as that of *least variance,* hence being referred to as the *best unbiased estimator* of the mean (Arnold, 1990; p.264). Notably, in the limit as $n \to \infty$, (1.1) provides

$\mu(\boldsymbol{x},t) = \lim_{n\to\infty} \overline{\Gamma}_n(\boldsymbol{x},t)$ .

Often, when data are not available, the mean concentration is modelled with a Gaussian, which provides a reasonably good approximation some time after release (Hanna and Drivas, 1987).

However, although the mean (eq.(4)) suggests itself as an important measure in estimating concentrations of harmful substances dispersing in the atmosphere under realistic conditions, it does not *per se* establish a panacea in that regard. The reason is that a predictive concentration model should also incorporate concentration fluctuations, measured by the concentration *rms* as defined above, since in many cases the standard deviation of concentration is as large as its mean or even larger (Chatwin, 1982).

**1.1.2. The variance of concentration.**

The sample variance of the concentration field, defined by

$$s_n^2 = \frac{1}{n-1}\sum_{i=1}^{n}[\Gamma_i(\boldsymbol{x},t) - \overline{\Gamma}_n(\boldsymbol{x},t)]^2$$

is an *unbiased* estimator of the ensemble concentration variance, not possessing though the property of least variance (Arnold, 1990; p. 266).

Further, the statistical noise it contains (being a random variable) is likely to be greater than that of the sample mean. (In fact, statistical noise is likely to increase as *n* decreases and as the order of the moments of concentration estimated becomes higher, e.g. the estimator of the $3^{rd}$ moment is likely to contain more statistical noise than $s^2$ and that of the $4^{th}$ moment even more.)

A very important contribution in the direction of modelling the concentration variance in the context of turbulent diffusion was the introduction of the Chatwin – Sullivan collapse theory (Chatwin and Sullivan, 1990), which states that a simple quadratic relationship between the mean and the variance exists, namely

$$\sigma^2=\beta^2\mu(\alpha\mu_0-\mu)$$

where $\beta$ and $\alpha$ are scalar non-dimensional parameters and $\mu_0$ is a scale for $\mu$ (e.g. its maximum).

The above equation has been shown to fit well data taken from steady continuous sources for which the statistical properties of the concentration field are stationary. In these cases $\alpha$ and $\beta$ must both be constants satisfying $1<\alpha$ and $0<\beta<1$. For instantaneous releases though, for which the statistical properties of the concentration field are non-stationary, $\alpha$, $\beta$ and $\mu_0$ must be functions of downwind receptor position and time. More on mathematical models for $\alpha$ and $\beta$ can be found in Sullivan (1990), Moseley (1991), Mole (1995) , Mole *et al*. (1997) as well as in Mole *et al.* (2007).

### Stochastic concentration models – motivation for use of Principal Components Analysis

The development of mathematical models predicting, ideally the PDF, or less ambitiously, the mean and variance of the concentration field has been and carries on being a major area of research as already pointed out by Chatwin and Sullivan (1994).

The main reason is that such models are much less costly than most deterministic ones, exhibiting at the same time a very good performance, often superior to that of deterministic ones that need vast computing power (unavailable in the reasonably near future) for the large number of direct numerical simulations required. They also tend to replace Gaussian models which due to the many unrealistic assumptions they include are becoming obsolete. Mole, Chatwin and Sullivan (1993) provide a detailed account on different modelling approaches, as well as methods for assessing model performance.

Hanna and Drivas (1987) also declare emphatically the need for development of concentration fluctuation models in their detailed synopsis, adding the imperative requirement of inclusion of the uncertainty assessment that should accompany the model, without which use of the model should be avoided.

Here, the less ambitious direction will be followed, i.e. the proposed model will restrict itself to describing the variance of the concentration field, with the mean being estimated by (1.3). The methodology proposed is based on the decomposition of the variance – covariance matrix of the concentration field into its principal components. It has been used to identify and describe the coherent structures of turbulent flows by analysing the velocity field **Y** into a series of orthogonal functions (principal components) possessing the property of *optimal convergence* with success (Berkooz *et al*., 1994; Kevlahan *et al.,* 1994; Holmes *et al.,* 1996). The term "optimal" means that only a few of these functions suffice in order to reproduce the original signal, thus playing a key role in the identification of coherent structures. Following an analogous way of thinking, the method is applied here with the hope of extracting from data sets common features characterising the process of turbulent dispersion of a passive scalar, in particular the concentration field. In such a case it would be possible to reconstruct the concentration field or make predictions based only on a few orthogonal functions whose shape would bear the common features mentioned above.

## 2. The problem and the proposed methodology

The problem addressed here is stated as follows:

Given as input

(a) the dimensions of a gaseous pollutant source with finite dimensions e.g. the cylinder radius $R_0$ and the cylinder height L (which is taken to be the length scale of the problem), in the case of a cylindrical source;

(b) the initial gas density $\rho_{gas} \Rightarrow g'=g\Delta\rho/\rho=g(\rho_{gas}-\rho_{air})/\rho_{air}$;

(c) the mean wind speed U at source height,

so that the (initial) Richardson number is calculated as $Ri=g'L/U^2$,

describe and predict the temporal evolution of the concentration of the instantaneously released gas in the atmosphere, at some position downwind of the source.

The proposed methodology is the Proper Orthogonal Decomposition (POD), or Principal Components Analysis, presented in Holmes *et al.* (1996), the basis of the analysis of the concentration field into its principal components that provides an optimal, low-dimensional model for the description of the concentration field, as carried out in the following chapters.

### 2.1. POD of concentration field

Consider an ensemble $\{\Gamma_i(t)\}$ of concentration fields, each being defined in the domain $0 \le t \le T$ and thought of as a point in an infinite dimensional Hilbert space $L^2([0,T])$ with inner product

$$(f,g)=\int_0^T f(t)g(t)dt \qquad (5)$$

The evolution in time of such a concentration field is, as already mentioned,
governed by eq. (1).

When the Reynolds number Re=UL/ν >> 1 (U is the mean wind velocity, L is the characteristic length scale and *v* the molecular viscosity), the flow is turbulent (Monin & Yaglom vol. 1, 1971), so **Y** and, consequently, $\Gamma_i$ are random variables.
Hence, a statistical description of the physical phenomenon of turbulent diffusion is necessary, as discussed in the introduction.

To that end, define the non-dimensional *concentration fluctuation*

$$F_i(t)=\frac{\Gamma_i(t)}{\Gamma_0}-\mathrm{E}\left[\frac{\Gamma_i(t)}{\Gamma_0}\right]=C_i(t)-\mathrm{E}[C_i(t)] \quad (6)$$

where $\Gamma_0$ is a typical concentration scale so that the value of *C(t)* is a non-dimensional concentration representing the data set, and $\mathrm{E}[.]$ denotes an "ensemble"
average.

Thus *F(t)* is non-dimensional with E[*F(t)*]=0. The purpose here is "to find a basis $\{\varphi_j(t)\}_{j=1}^{\infty}$ for $L^2$ that is optimal for the data set in the sense that finite-dimensional representations of the form

$$F^{(N)}(t)=\sum_{j=1}^{N}a_j\varphi_j(t) \qquad (7)$$

describe typical members of the ensemble better than representations of the same dimension in any other basis" (Holmes *et al.*, 1996).
In this context, the optimality problem is stated as:

$$find \max E[|(F(t),\varphi(t))|^2]$$

*subject to* $\|\varphi\|^2=1$

where $\|.\|$ is the standard norm in $L^2$,

$\|f\|=(f,f)^{\frac{1}{2}}=[\int_0^T f^2(t)dt]^{\frac{1}{2}}$ from eq. (5).

Introducing a Lagrange multiplier λ, construct the functional

$$J[\varphi]=E[|(F,\varphi)|^2]-\lambda(\|\varphi\|^2-1)$$

and impose the extremum condition

$$\frac{d}{d\delta}J[\varphi+\delta\psi]\Big|_{\delta=0}=0\ ,$$

where $\varphi+\delta\psi\in L^2([0,T]),\delta\in R$,
is a variation of $\varphi$.

Solving the extremisation problem it is found that the optimal basis is given by the eigenfunctions $\{\varphi_i\}$ of the covariance of concentration (Holmes *et al.,* 1996).

In the finite dimensional case, where the observations $\{C_i\}$ are m-vectors (where m is the number of sampled time points), the eigenvectors $\{\varphi_i\}$ are the principal components of the mxm concentration covariance matrix.
Furthermore, the eigenfunctions $\varphi_j$ are mutually orthogonal in $L^2$ being basis vectors:

$$\int_0^T \varphi_i(t)\varphi_j(t)dt=0, i\neq j$$

Assuming no degeneracy of the eigenvalues, that is:
(i) $\lambda=0$ is not an eigenvalue;
(ii) no multiple eigenfunctions for a given eigenvalue;
and from $\lambda_j\ge 0$, we may order the eigenvalues:

$$\lambda_j>\lambda_{j+1}. \qquad (8)$$

Then, *F*(t) may be reproduced by a modal decomposition based on the eigenfunctions $\{\varphi_j(t)\}_{j=1}^{\infty}$:

$$F(t)=\sum_{j=1}^{\infty}a_j\varphi_j(t) \qquad (9)$$

where

$$a_j=\int_0^T F(t)\varphi_j(t)dt\,. \qquad (10)$$

Equation (9) is called the POD, {$\varphi_l(t)$} are the empirical orthogonal functions (EOF), {$\lambda_j$} are the empirical eigenvalues and the (random) constants $a_j$ (eq.(10)) are the expansion coefficients with the following statistical properties:

$$E[a_j] = \int_0^T E[F(t)]\varphi_j(t)dt = 0 \quad (11)$$

and

$$\mathrm{cov}[a_i, a_j] = E[a_i a_j] = \lambda_i \delta_{ij} \quad (12)$$

Thus, the expansion coefficients $a_j$ are uncorrelated and $\mathrm{var}[a_j] = \lambda_j$.

Also,

$$\mathrm{var}[F(t)] = \frac{1}{\Gamma_0^2}\mathrm{var}[\Gamma(t)] = \sum_{i=1}^{\infty} \lambda_i \varphi_i^2(t) \quad (13)$$

If ineq. (8) can in practice be strengthened to $\lambda_j >> \lambda_{j+1}$, in which case only a few modes will suffice to reproduce the original signal accurately, so that eq. (9) can be replaced by eq (7), the model will be of great value for describing the data and possibly for making predictions.

Finally, when the domain of {$\Gamma_i(t)$} is not bounded, as in the case of open flows considered here, it will be assumed that $\Gamma_i(t)$ decays rapidly to zero outside some bounded domain [0,*T*], when no measurements exist for *t>T,* where *T* is the length of the record of the experiment, so that the above analysis is still valid.

**3. The experiments and the data**

The data used here to carry out the POD were collected in the course of the experiments of Hall *et al.* (1991) which modelled the Thorney Island (UK) trials at 1/100 scale. The experiment corresponds to the sudden release of a heavy gas in the neutrally buoyant atmospheric boundary layer over a flat terrain. The apparatus used consisted of a cylinder of height *L*=13cm and diameter 14cm that collapsed upon release of its content, a dense contaminant gas, in a wind tunnel. The Richardson number*, Ri,* characterising the gas, is defined by $Ri = g\Delta\rho L/\rho U^2$, where $\Delta\rho/\rho$ is the relative to air gas density and *U* the mean air velocity at the top of the cylinder. The values of *Ri* were 0, 0.5, 1, 2, 5, 10. Values of *Ri* close to zero indicate a neutrally buoyant gas, while higher values characterise heavier (denser-than-air) gases. 50 releases were made with the two highest values of *Ri* and 100 with the rest. Four sensors were used to record the gas concentration signal, located at 70 and 200cm along the centre-line, at heights of 0.4 and 2.4cm above the ground. In this paper, the four measuring positions are denoted by **X1**(70,0,0.4), **X2**(70,0,2.4), **X3**(200,0,0.4), **X4**(200,0,2.4). The near-field sensors at positions **X1** and **X2** monitored gravitational effects dominating close to the source, while the far-field sensors located at positions **X3** and **X4** captured atmospheric turbulence effects at a further downwind location where the gas concentration was 2% of the initial concentration upon release. Typical release plots with Ri=0 are provided in **(Figure 1)**

The POD is applied here to the time series obtained from the experiments of Hall *et al.* described above, with the purpose of investigating the possibility of obtaining a universal model for the description of the data, as well as a predictive tool with varying parameters *Ri*, downwind distance from the source and height from the ground.

**4. Results**

**4.1. Comments on eigenfunctions**

The sequence of resulting eigenvalues $\lambda_i$ (shown in **Table 1**) of the concentration variance-covariance matrix appears to satisfy $\lambda_i >> \lambda_{i+1}$ in agreement with the discussion in section **2.1.**

The first eigenfunction, corresponding to the largest eigenvalue, resembles a typical replication (see **Figure 4**) since it carries the largest variance proportion because

$$\mathrm{var}[F(t)] = \sum_{i=1}^{\infty} \lambda_i \varphi_i^2(t) \approx \lambda_1 \varphi_1^2(t)$$

from eqs (7) & (13), and since the plot of concentration standard deviation against time resembles that of mean concentration (**Figure 2** and **3**).

Also, the fact that the plot of concentration standard deviation against time resembles that of mean concentration more with decreasing Richardson number, and particularly so for Ri=0 (Robinson, 1996), suggests that it may be possible to obtain a universal POD model for neutrally buoyant gases.

The first eigenfunction tends to zero as time tends to infinity, while the long right tails observed in some cases and dealt with in section **4.2** not only do not represent actual concentration measurements (they should be attributed to instrument noise) but may potentially distort the

true shape of the eigenfunction, contributing unwanted fluctuations to consequent calculations.
The first eigenfunction's smoothness decreases with Richardson number at the higher measuring stations consistent with the larger degree of intermittency in those cases.
The initial peak characterising measurements of concentration at the three highest Richardson numbers, 2, 5 and 10, at the measuring stations close to the source is exhibited by the first eigenfunction, displaying the existence of a gravity current head at the edge of these gas clouds.
The first eigenfunction's shape widens as the Richardson number increases closer to the ground, indicating that heavier gases spend a larger proportion of time near the ground, again consistent with the gravity current motion induced by these gases.

The shape of the eigenfunction is not affected when reducing the length of record down to 2/3 of the original length. The eigenvalues are almost the same, with small differences in the 3rd decimal. When the record length was reduced to 1/2 the original length, in one case (Ri=10, **X**3), the first eigenfunction changed slightly and in another case (Ri=.5, **X**4) even less. In these cases, eigenvalues differ to the second decimal. In all cases, eigenvalues are not affected by truncation of record length, when rounded to one decimal. All of the above provides evidence that the shape of eigenfunctions is invariant under record length truncation when the main part of the cloud has passed, so that further measurements do not contribute. Record length appears to have an effect only when the cloud is truncated.

**Table 3.1.:** Normalised concentration eigenvalues (relative variance proportion) corresponding to the first four eigenfunctions (modes).

| Ri | Station | Normalised Eigenvalues | | | |
|---|---|---|---|---|---|
| 0 | **X**1 | 0.438 | 0.142 | 0.090 | 0.066 |
| | **X**2 | 0.220 | 0.150 | 0.130 | 0.080 |
| | **X**3 | 0.397 | 0.205 | 0.074 | 0.057 |
| | **X**4 | 0.213 | 0.148 | 0.080 | 0.070 |
| 0.5 | **X**1 | 0.458 | 0.159 | 0.089 | 0.059 |
| | **X**2 | 0.198 | 0.127 | 0.085 | 0.059 |
| | **X**3 | 0.481 | 0.195 | 0.079 | 0.043 |
| | **X**4 | 0.289 | 0.129 | 0.065 | 0.051 |
| 1 | **X**1 | 0.389 | 0.152 | 0.072 | 0.044 |
| | **X**2 | 0.146 | 0.103 | 0.079 | 0.063 |
| | **X**3 | 0.516 | 0.172 | 0.080 | 0.044 |
| | **X**4 | 0.257 | 0.121 | 0.078 | 0.054 |
| 2 | **X**1 | 0.475 | 0.171 | 0.093 | 0.045 |
| | **X**2 | 0.207 | 0.156 | 0.083 | 0.054 |
| | **X**3 | 0.609 | 0.126 | 0.057 | 0.027 |
| | **X**4 | 0.202 | 0.076 | 0.056 | 0.040 |
| 5 | **X**1 | 0.322 | 0.178 | 0.120 | 0.070 |
| | **X**2 | 0.463 | 0.131 | 0.082 | 0.048 |
| | **X**3 | 0.504 | 0.249 | 0.076 | 0.033 |
| | **X**4 | 0.091 | 0.074 | 0.059 | 0.056 |
| 10 | **X**1 | 0.325 | 0.149 | 0.099 | 0.080 |
| | **X**2 | 0.117 | 0.090 | 0.067 | 0.062 |
| | **X**3 | 0.550 | 0.290 | 0.039 | 0.025 |
| | **X**4 | 0.140 | 0.066 | 0.056 | 0.048 |

### 4.2 Normalisation and scaling.

In order to be able to transfer results to another scale, so that a universal model can be obtained, the problem of normalisation and scaling of the first eigenfunctions of concentration covariance is addressed:

By applying an appropriate transformation to the eigenfunctions defined in section **2.1**, it is hoped that their shapes will collapse to a common universal shape, thus removing the dependence on varied parameters. Then, by inverting the transformation, it would be possible to reproduce an eigenfunction based on the universal shape obtained, thus enabling one to transfer to another scale. That would lead to a simple model for describing the data and for making predictions.
The eigenvectors $\varphi_i$ ,i=1,…,N of the concentration covariance matrix defined in section **2.1** are normalised as

$$\int_0^T \varphi_i^2 \, dt = 1 \qquad (14)$$

To obtain a common universal shape produced by the first (most energetic) eigenfunctions $\varphi_1(t)$, start by defining

$$\mu_t = \int_0^T t\varphi_1^2(t)dt \Big/ \int_0^T \varphi_1^2(t)dt = \int_0^T t\varphi_1^2(t)dt \qquad (15)$$

$$\sigma_t^2 = \int_0^T (t-\mu_t)^2\varphi_1^2(t)dt \Big/ \int_0^T \varphi_1^2(t)dt = \int_0^T (t-\mu_t)^2\varphi_1^2(t)dt \qquad (16)$$

where the last equality in both eqs. (15) and (16) is obtained by virtue of eq. (14).

Then, apply the scale transformations

$$\psi_1(s) = \sigma_t \varphi_1(t)/A \qquad (17)$$

$$s = \frac{t-\mu_t}{\sigma_t} \qquad (18)$$

$$A = \int_0^T \varphi_1 dt, \qquad (19)$$

under which all scaled eigenfunctions have area equal to 1:

where dt=$\sigma_t$ds from eq. (18) .

The reason for the unusual definition of $\mu_t$ and $\sigma_t^2$

$$\int_{t=0}^{t=T} \psi_1(s)ds = \int_0^T \phi_1(t)dt/A = 1 \qquad (20)\ ,$$

in eqs. (15) and (16) is that choosing $\varphi_1^2(t)$ as the weight in the definition of $\mu_t$ and $\sigma_t^2$ , effectively removes the small fluctuations about zero in the long right tail of $\varphi_1(t)$ in experiments which measured much further into the tails, thus resulting in obtaining comparable functions as desired (see **Figure 5**, bottom plots).

The statistics $\mu_t$ and $\sigma_t$ can be interpreted as estimators of the mean signal time and its standard deviation (rms), respectively. In particular, $\sigma_t$ may be regarded as a measure of the cloud width. Below is provided a physical description of the variation of $\mu_t$ and $\sigma_t$ with Richardson number and spatial position.

*a. The variation of $\mu_t$*

$\mu_t$ gives a central time for the cloud at the measurement position. Therefore this time is the sum of the time the cloud takes to arrive at that point and roughly half the time it takes to pass over that point. The latter contribution will be roughly proportional to $\sigma_t$ , which measures the spread of the cloud.
Regarding the former contribution, it can be pointed out that comparing values of $\mu_t$ with 90%iles of cloud arriving time reported by Hall *et al.* (1991), in principle there is a direct analogy in variation. As Ri increases though, there is a disproportionate decrease of $\mu_t$ from the low near to the high near station. Also, for the three heavier gases (Ri=2,5,10) a similar decrease of $\mu_t$ is observed from low far to the high far station, which for Ri=5 and 10 is reported for the 90%ile of cloud arriving time too, suggesting that the variation pattern reported is not greatly altered.
Regarding the latter contribution now, as far as variation of $\mu_t$ with respect to height is concerned, for the three higher values of Ri (Ri=2,5,10), the cloud spends more time at the lower stations than at the higher ones due to the gravity current-like motion being more pronounced in these cases (heavier gases) and causing velocity shear stress layers between the cloud and the surrounding air (Hunt *et al.,* 1983).
As Ri decreases, this effect is attenuated and particularly for Ri=0, $\mu_t$ is almost the same at the lower and higher stations, because a neutrally buoyant gas will diffuse faster than a heavier one

that will settle on the ground due to negative buoyancy.

Concerning now the variation of $\mu_t$ with respect to downwind distance, for the three lower values of Ri (Ri=0,0.5,1), the cloud spends about twice as much time at the far stations than at the near stations as a result of the larger travel time to the downwind stations. For the three higher values of Ri (Ri=2,5,10), the time the cloud spends at the lower stations is almost tripled going from near to far stations for the same reason as above, the effect being more pronounced for heavier gases though. Also, for all values of Ri>0, one may explain the larger times spent at the downwind stations as a result of the decoupling of the cloud from the ambient flow and its motion downwind at a rate slower than the ambient wind speed.

At the higher stations now, as the cloud moves from the position close to the source (near field) to that away from the source (far field) the amount of time spent is about four times as much because upward diffusive flux dominates over downward flux produced by the mean sinking motion of the cloud (Hunt *et al.,* 1983).

*b. The variation of $\sigma_t$*

In the case of a neutrally buoyant gas (Ri of 0), from near to far stations $\sigma_t$ increases (more than double) because spreading from turbulent dispersion as well as gravity current spreading has occurred as it moves downstream. As Ri increases, $\sigma_t$ increases at the stations near the source, which, acting as near-field monitors, record fluctuations occurring during the gravity slumping phase. Thus, heavier gas clouds exhibit a wider profile in time. At the far stations, $\sigma_t$ is also increasing with increasing Ri.

A general (all stations), but not striking, exception in the increasing trend of $\sigma_t$ with Ri is observed when Ri changes from 0.5 to 1. Referring to the Appendix of Hall *et al.* (1991) though, it is seen that plots of typical repetitions also possess this feature. A possible physical explanation is that these values of Ri represent the threshold of the transition from neutrally buoyant to heavier gas behaviour. A notable exception is the decrease of $\sigma_t$ at position **X**2 when Ri is changed from 1 to 2. It should also be pointed out that in that case (Ri=2, **X**2), the first principal component was swapped with the second principal component (its shape resembled the shape of the second principal components produced by the POD).

### 4.3. Towards a universal model

Application of the normalisation procedure described above gave the normalised first eigenfunctions, which were then matched. The results are summarised in the following plot in **Figure 6**, which depicts clearly the most successfully matched first eigenfunctions.

Inspection of the collapse of the shape of the first normalised eigenfunctions in **Figure 6** suggests that it might be possible to describe the first eigenfunction for Ri=0 at all measuring positions and Ri=0.5 at the two lower positions by a common universal shape, so that one would be able to transfer to another downwind distance or height or Richardson number by inverting the

$$\varphi_1'(\sigma_t s+\mu_t)=\frac{A}{\sigma_t}\psi_1(s) \qquad (21)$$

transformations (17) and (18):

where the left hand side is a predicted first eigenfunction from a given scaled eigenfunction $\psi_1$.

### 3.5. Reconstructing the signal.

The first eigenfunction (principal component or mode) carries the more coarse features of the signal, since it resembles a typical repetition, the finer details being carried by the next (higher) eigenfunctions.

More specifically, the first eigenfunction carrying most of the variability represents the largest scale of the fluctuations caused by the biggest eddies. The next eigenfunctions with less and less energy content represent smaller scale fluctuations due to smaller size eddies. According to the "energy cascade" theory (Batchelor, 1953; Tennekes and Lumley, 1972), bigger eddies supply energy to smaller ones in a hierarchical order, until in the final stage of the dispersion process all the energy will have dissipated to heat.

As provided by the theory in section **2.1**, the signal can be reconstructed using only a few principal components (eq. (7)) when the sequence of the eigenvalues converges sufficiently rapidly, a condition that is generally satisfied here.

Next, a measure of the accuracy of reconstruction (and prediction – see section **4.6.2**) of the concentration signal is proposed.

Since the data are conceptualised as vectors in an $L^2$ space (section **2**), it would seem natural to choose an error formula that incorporates the $L^2$ norm:

The relative error (RE) in the $L^2$ space is defined as

$$RE_i = \frac{(\sum (C_t - Cr_t)^2)^{1/2}}{(\sum C_t^2)^{1/2}}, i=1,\ldots,n, \quad (22)$$

where $C_i$ is the observed concentration signal and $Cr_i$ the reconstructed concentration signal from the principal components of the covariance matrix at sampling time *i*.

The mean relative error (MRE) is the sample mean value of RE over all *n* replications:

$$MRE = \frac{1}{n}\sum_{i=1}^{n} RE_i \quad (23)$$

The reason for choosing RE as the appropriate measure of accuracy of reconstruction of a concentration signal is that from the point of view of the ultimate user of the model, knowing that the MRE is 10 percent means a great deal more than knowing that the mean absolute error is 123 for example (Makridakis *et al.*, 1983, p.47).

Now, from the concentration eigenvalue sequence (see **Table 1**) is provided an indication that initially the MRE converges relatively fast. This was verified by computing MRE, shown in **Table 2**, with 2 and 4 modes. When more modes (5 to 12) were included in the reconstruction of the concentration signal, differences in the MRE occurred only in the 3rd decimal place or above, indicating that the rate of convergence of the MRE is much slower beyond the 4th mode.

In the cases where the MRE is small and almost the same (or the same within 1 decimal place) when 2 or 4 modes are used, it is clear that the signal can be reconstructed using the first 2 modes only as discussed also by Kevlahan *et al.* (1994). In those cases the contribution of small scale fluctuations is negligible in the sense that the amount of energy contained in the first 2 eigenfunctions representing the larger scales of motion is sufficient to reproduce the signal fairly well.
The mean relative error (MRE) computed over all replications, between observed and reconstructed signal is shown in **Table 3.4** below.

**Table 2:** Mean relative error between observed and reconstructed signal using 2 and 4 modes.

| Ri | Station | No of modes | MRE |
|---|---|---|---|
| **0** | **X1** | **2** | **.41** |
| | | **4** | **.34** |
| | **X2** | **2** | **.50** |
| | | **4** | **.42** |
| | **X3** | **2** | **.32** |
| | | **4** | **.26** |
| | **X4** | **2** | **.48** |
| | | **4** | **.43** |
| **0.5** | **X1** | **2** | **.33** |
| | | **4** | **.27** |
| | **X3** | **2** | **.60** |
| | | **4** | **.50** |

In **Figure 7**, the reconstructed signal from the first four modes is plotted together with the original signal, portraying the good approximation expected from the theory.

### 4.5. The distribution of the expansion coefficients

It is also of interest to discuss the distribution of the coefficients (eq.(10))in the expansion (9) of the concentration field, and particularly the distribution of □□□used in the prediction model developed in section **4.6**.

In **Figure 8**, histograms of the first expansion coefficients are shown in all cases with Ri=0 and for the lower stations with Ri=0.5 (i.e the cases for which the first eigenfunctions of concentration collapse - see section **4.3**). The sample means are almost zero and the sample variances are almost equal to the respective eigenvalues. The small differences observed between these statistics and the theoretical values of the respective parameters provided by the theory should be attributed to the fact that a finite sample of gas releases was used to produce these results.

Next, the hypothesis that the expansion coefficients come from a normal distribution is tested. The reason behind this particular choice is that normality might be a desirable property related to the practical application of the model, although no such property is prescribed by the theory.

The setting is:

Null hypothesis

$H_0$:True PDF of coefficients is normal

vs.

Alternative hypothesis

$H_1$:True PDF of coefficients is not normal.

To carry out this test, an appropriate test statistic and a test criterion must be chosen. As far as the test criterion is concerned, the null hypothesis will be rejected whenever the p-value (i.e. the computed level of significance or probability of a Type I error – rejecting the null hypothesis when it is true – associated with the chosen test statistic) is less than 0.01 (the fixed level of significance).
So, it remains to see which test statistic is more appropriate.
Kolmogorov and Smirnov have developed a normality test in which estimates of the parameters of the normal distribution from the data are used. This test is rather conservative though, in the sense that lower p-values than those computed by the Kolmogorov-Smirnov test can be achieved (Lilliefors, 1967). A more powerful normality test has been proposed by Shapiro and Wilk (Shapiro and Wilk, 1965), based on a variance ratio, that will reject the null hypothesis more often than the more conservative Kolmogorov-Smirnov test.
Carrying out both tests it was found that the more powerful Shapiro-Wilk (S-W) test rejected the null hypothesis concerning the first expansion coefficient $\alpha_1$ in the following cases:Ri=0, station **X**3 (p-value=0.0094); and Ri=0.5, station **X**1 (p-value=0.0082), while the Kolmogorov-Smirnov (K-S) test never did.
Further, regarding the question of independence of the first expansion coefficient $\alpha_1$, Pearson's $\chi^2$ -criterion was employed in order to carry out two hypothesis tests according to the following setting:

(a) Null hypothesis

$H_0$: $\alpha_1$ independent with respect to measuring position vs.

Alternative hypothesis $H_1$: $\alpha_1$ not independent with respect to measuring position;

(b) Null hypothesis

$H_0$: $\alpha_1$ independent with respect to Richardson number vs.

Alternative hypothesis $H_1$: $\alpha_1$ not independent of Richardson number.

In all cases the tests rejected the null hypotheses of independence, thus providing evidence that the first expansion coefficients are not independent with respect to measuring position or Richardson number.
Here, it is worth mentioning that according to Holmes *et al.* (1996), in the event where "the expansion coefficients are both normally distributed and independent, linear stochastic estimation can be applied for predicting the conditional PDF of a field *u(x)* given observations *u(x')* at other points, or possibly a vector of events at several points", an event far from what the above analysis has shown.

**4.6. The POD–based prediction model**

In this section, a predictive model for the concentration dose field is proposed, based on the results found in the previous sections.
The model is built based on the assumption that the true mean-corrected concentration curve is closely approximated by the first eigenfunction of concentration, given that the first eigenfunction carries most of the variability.
Furthermore, the universal shape of the first eigenfunction obtained in section **4.3** suggests the feasibility of constructing a POD–based prediction model for the case of neutrally buoyant gases (Ri=0 and Ri=0.5).

**4.6.1. Predictive methodology.**

The proposed model is

$$F(t)=a_1'\varphi_1'(t) \qquad (24)$$

or, from the definition (eq.(6)) of the concentration fluctuation *F(t),*

$$C(t) = \mu(t) + a_1\varphi_1(t) + \varepsilon(t)$$

where dashes denote predictors and

*C(t)* is the concentration field,

*μ(t)*= E[*C(t)*] is the mean concentration field,

$\varphi_1(t)$ is the normalised first (most energetic) eigenfunction of concentration,

$a_1$ is the first expansion coefficient chosen from the PDF of coefficients given and discussed in section **4.5**, and

*ε(t)* is the error to be discussed in section **4.6.2**.

Now, since *C(t)* is a random variable, because of the nature of the phenomenon of turbulent dispersion, any prediction of it would be a prediction of one member of the ensemble of realisations considered. It is more sensible therefore to predict the mean and standard deviation of the ensemble instead, as discussed in the introduction of this work, where the standard deviation is approximated by the square root of $\lambda_1\varphi_1^2(t)$.

Given that the collapse of the first concentration eigenfunction occurred at all measuring stations for Ri=0, and at **X**1 and **X**2 for Ri=0.5, predictions for the mean concentration (and dose) field can be obtained by means of linear interpolation between values of the varied parameters.

As discussed in the introduction (section **1.1**), the sample mean curve is the *best unbiased* estimator of the true mean concentration curve.

The sample mean concentration defined by eq. (4) at a measuring position is computed as

$$\overline{C}(t) = \frac{1}{n}\sum_{i=1}^{n} C_i(t).$$

where *n* is the number of repetitions of the experiment.

To assess convergence of the statistic, the data sets were split in half and the sample mean was recalculated with *n/2* observations. The resulting mean curves were indistinguishable from the ones found using all *n* observations in agreement with Schopflocher and Sullivan (1997), thus providing evidence that convergence of the statistic was attained.

Furthermore, the proposed model predicts the mean concentration when the *best* estimator of the coefficient $a_1$ is chosen to be the expected value of the distribution of coefficients - which is found to be zero in agreement with the theory (see section **2.2**).

To predict the variance of concentration now, the first eigenvalues and squared first eigenfunctions of concentration must be predicted, so as to form their product as the concentration variance predictor. The method of linear interpolation can be used again as discussed above.

Regarding the question of estimation of the first eigenfunction from the data, though, it must be pointed out that the eigenfunctions derived from *n*/2 observations differed significantly (not in the statistical sense) from those derived from all the observations. This suggests that the sample size plays an important role in the estimation of the first eigenfunction, which could possibly be better approximated with larger samples.

#### 4.6.2. Model evaluation and uncertainty.

As far as the predictive uncertainty is concerned, this is due to three factors:

One is the data input and observations factor, which is not dealt with in this work; the second factor is the mean estimation error and the third one is stochastic or random atmospheric (turbulent) fluctuations characterising the natural phenomenon of dispersion of a pollutant substance (Mole et al, 1993).

It is mandatory that any predictive model claiming reliability and completeness must incorporate its uncertainty in the output so as to assist end users in the decision making process.

Since the second and third uncertainty components are uncorrelated by virtue of eq. (11), the total uncertainty of the model is given by the following equation (*mean squared error*: Papoulis,

$$E\{[C(t)-C'(t)]^2\} = E\{[\mu(t)-\mu'(t)]^2\} + E\{[C(t)-\mu(t)]^2\}$$
$$= E\{[\mu(t)-\mu'(t)]^2\} + E\{[a_1\phi_1(t)]^2\} + E\{[\varepsilon(t)]^2\}$$
$$= [l(t)/2]^2 + \lambda_1\phi_1^2(t) + Var\{\varepsilon(t)\}$$

1965), when data input and observations errors are ignored (Hanna and Drivas, 1987):
where

*l(t)* is the expected length of the confidence interval for the mean, $\lambda_1$ the first eigenvalue,
$\phi_1(t)$ the first normalised concentration eigenfunction and
*ε(t)* the POD model error.

The total model uncertainty is reduced when

(a) the expected length of the confidence interval for the mean is minimised;
(b) the first (normalised) eigenvalue approaches 1 so that $\varepsilon(t)$ approaches 0 (see section **4.4**).

Regarding (a), the classical approach of the construction of a large sample confidence interval (see for example Arnold, 1990; Roussas, 1973), gives large expected lengths. However, a non-parametric approach that makes no assumptions about prescribed form distributions of the concentration mean, described by Frangos and Antypas (2001), leads to a dramatic reduction of the confidence interval expected lengths.

Regarding the POD model error now, $\varepsilon(t)$, using the definition of the relative error (RE) in the $L^2$ space introduced in section **4.4** (eq. (22)), where $C_t$ is the observed concentration signal and $Cr_t$ the predicted concentration signal now from the POD model at sampling time *t*, it is possible to obtain a measure of $\mathrm{var}\{\varepsilon(t)\}$ by computing the variance of *RE* when $Cr_t$ is "predicted" by eq. (24) for values of the parameters for which $C_t$ has been observed:

$$VRE = \frac{1}{n-1}\sum_{i=1}^{n}(RE_i - MRE)^2 ,$$

where *MRE* is given by eq. (23).

Here, of course, the model employs only the first (most energetic) principal component.

The following table (**Table** 3) summarises the results concerning the model predictors variance in all cases exhibiting common features, that is, the cases with corresponding collapsing first eigenfunctions (Ri=0, all stations and Ri=0.5, low-height stations – see section **4.3**).

Table 3: Variance of POD model predictors $a_1'$ and $F'(t)=a_1'\varphi_1'(t)$.

| Ri | Station | Variance of $a_1'$ | *VRE* of $F'(t)=a_1'\varphi_1'(t)$ |
|---|---|---|---|
| **0** | X1 | **0.438** | **0.037** |
| | X2 | **0.220** | **0.014** |
| | X3 | **0.397** | **0.033** |
| | X4 | **0.213** | **0.013** |
| **0.5** | X1 | **0.458** | **0.031** |
| | X3 | **0.481** | **0.039** |

**5. Discussion of results and conclusions**

In this paper is provided a model for the description and prediction of the concentration field of gases dispersing in the atmosphere. A basic property of the model is the incorporation of turbulence fluctuations that charactrerise the physical phenomenon of dispersion of contaminants in the atmosphere (Chatwin, 1981, 1982). Initially it was hoped that by applying the POD method of analysis, a model unifying the common features of neutrally buoyant and heavy gases would be obtained. The research provided in the previous sections did not prove to be all that fruitful, nevertheless:

The proposed model claims *universality* only for neutrally buoyant gases with respect to downwind distance and height, as well as for gases close to the threshold between neutral buoyancy and heaviness, with respect to downwind distance.

For these gases predictions can be made, that is, the end user of the model is in position predict the mean concentration with the associated POD model uncertainty will be at a fixed time instant, downwind location, height and Richardson number, the varied parameters taken into account by the model. As far as heavier gases are concerned, physical modelling (box models, as discussed by Andronopoulos (1992)) can be employed so as to provide predictive results extending thus the proposed model for the neutrally buoyant gases case.

An important advantage of the model is its *simplicity* in the sense that only a few modes (sometimes only one) suffice so as to describe and predict the concentration field. This is in agreement with the findings of Kevlahan *et al.* (1994).

Among the limitations of the model, except for its inability to incorporate heavier gases, one notes the absence of the parameter of atmospheric stability. Also, it should be noted that predictions are limited within the range of the values of the varied parameters because of their small sample sizes, extrapolation beyond these values being thus performed via physical modelling as mentioned above.

Regarding now the estimation of population parameters in the model, the sample mean lends itself as a reliable estimator of the true mean being *unbiased*, while the analysis showed that the first eigenfunction would possibly be better estimated with larger samples (as would the concentration PDF). Rice and Silverman (1991) propose smoothing the first eigenfunction via the choice of a smoothing constant by the method of cross-validation, thus counteracting its tendency to track high frequency components not present in the population eigenfunction. This may result in a predictor with smaller expected mean squared error. No attempt was made in this work to apply the smoothing method, for it could be argued that smoothing the first concentration eigenfunction might lead to loss of valuable information concerning turbulence phenomena.

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# Energy efficiency in Apartment Buildings. The comparison between Degree Day Calculation and Simulations

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**Abstract**

*In the past 15 years energy consumption for heating in apartment buildings has decreased essentially in Estonia. Article first presents the two different calculation methodologies the degree-day method and the energy demand calculation with the dynamic simulation tools. Secondly, heating energy consumption results for residential buildings for both calculation methods before and after reconstructions are presented. Finally these two calculation methods: the degree-day method and the dynamic simulation have been compared. The results show that in residential buildings the heat energy requirements can be determined by the degree-day calculation method with good sufficient accuracy. In office buildings, however, for the analysis of the heat energy consumption the dynamic simulation software is necessary.*

**Key words:** energy performance, degree-day methods, dynamic simulations.

## 1. Introduction

Global warming and its after-effects have become to a major environmental impact matters to be paid attention, therefore energy conservation potential is tried to ascertain. In most European Union (EU) Member States maximum allowed Energy Performance (EP) values are applied by Energy Performance of Buildings Directive (EPBD Directive 2002) – calculated whether by degree day methods or dynamic simulations. Some countries among those are using the effectiveness of primary energy production applied by special coefficients for different fuels. For example: energy produced by electricity has the multiplier 1,5 or renewable energy as a fuel has it 0,7. It varies a lot in different EU Member States, but this shows better the real energy conservation situation of the country.

In Estonia EP minimum requirements became into affect in year 2009. Special care to research the energy conservation potential and environmental matters has been paid since the Soviet Union collapse. In cooperation with mostly Scandinavian countries a good results and fast self-assurance have been acquainted in building sector energy efficiency design and maintenance. Nevertheless some differences have been noticed during the implementation process. Most Scandinavian countries have sufficient thermal conductivity values for building envelope and no special recommendations are proposed as the conservation measures. Conservation measures are mostly referred to building services adjustments and alteration of people's habits. In Eastern Europe building envelopes are in worse condition. It is widely known that the buildings energy demand does not rely only on envelope thermal conductivity – also ventilation air, hot water, etc. consumes heating energy. In addition to that lighting, electrical devices and utilizable free energy are the part of EP calculation process.

Residential buildings heating energy consumption (envelope, air exchange and hot water heating included) has been studied in Estonia in 1995, (J.Kurnitski.) [1]. Averagely in Tallinn heat energy consumption for the buildings constructed between 1960 and 1980 was 300 kWh/($m^2$ year).

In 1998, (T.A. Kõiv) [2] study of 172 apartment buildings was carried out. The results show heating energy consumptions between 249 and 322 kWh/($m^2$ year). Averagely 280 kWh/($m^2$ year). The lower heating energy consumption compare to 1995 results refers to hot water consumption decrease.

Following heat energy consumption distribution was proposed:

- Outdoor walls 22%;
- Hot tap water 34%;
- Windows 18%;
- Air exchange 13%;
- Roof 9%;
- Ground floor 4 %.

In 1999 average specific heating energy consumption was investigated 113 residential buildings. The conclusion for the study was heat energy consumption of 231 kWh/m$^2$ per normal year. In the different buildings the specific heat consumption was within 180-320 kWh/m$^2$ per year, on basis of consumption data in 1999, (Kõiv and Toode, 2001) [3] see Figure 1. In there results firstly degree-day calculation was used, therefore the climate variation between different years has been neutralized.

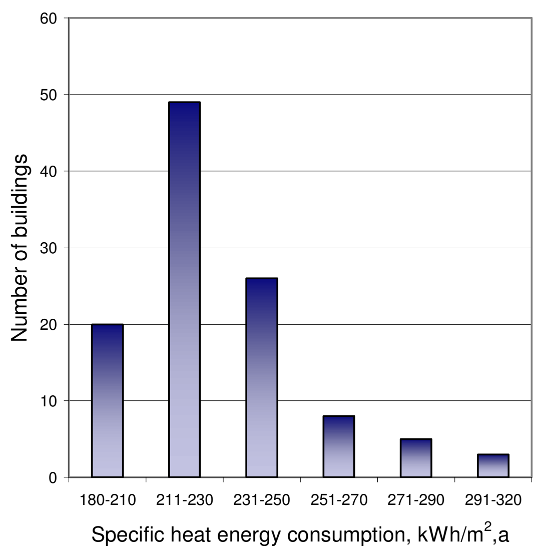


Figure 1.Dispersion of annual specific heating energy consumption in Estonian multi-storey apartment buildings connected to district heating networks.

In 2006 Test Reference Year [4] with Estonian climate was created to support the dynamic simulation tools calculations. Since then building steady-state (degree- day) methods and dynamic energy calculations have been compared in Estonia.

## 2. Energy conservation measures adopted by the domestic sector

Energy conservation directions for the buildings can be divided into two major groups in Estonia:

- Existing building stock renovation measures;
- Requirements for new constructions.

For existing apartment buildings energy labelling and energy auditing is widely used in Estonia. Energy auditing is a basis for economically efficient renovation measures selection and is required for apartment buildings bank loans applications.

Energy labels EP-value$_{real}$ consists of buildings average last three year energy consumption divided by heated area (kWh/m$^2_{heated\ area}$ year). Heating energy, electrical energy and primary energy production effectiveness are included in this calculation. The scale is highly challenging for Nordic climate and existing Estonian apartment buildings – see Table 1.

| Energy consumption kWh/(m$^2_{heated\ area}$ year) | Energy Labelling |
|---|---|
| EP-value$_{real}$ ≤100 | A |
| 101≤EP-value$_{real}$≤120 | B |
| 121≤EP-value$_{real}$≤150 | C |
| 151≤EP-value$_{real}$≤200 | D |
| 201≤EP-value$_{real}$≤250 | E |
| 251≤EP-value$_{real}$≤300 | F |
| EP-value$_{real}$≥301 | G |

Table 1. Energy labelling according to real consumption based EP-values.

The regulation on minimum energy performance (EP) requirements of buildings came into effect in Estonia in 2007 (EGo no. 258, 2007). It is applied to new constructions and significantly renovated buildings. For apartment buildings at the moment dynamic simulations are required, but the demand has been researched and steady state (degree-day) methods can be applied with sufficient accuracy. Further study should be done for utilized free heat used in degree-day calculations. Minimum EP requirements consist also heating, electrical energy and primary energy production effectiveness. EP-values$_{calculated}$ Energy Labelling has the same scale as indicated in Table 1. Nevertheless, EP minimum requirements define maximum allowable apartment building energy consumption kWh $_{calculated}$/(m$^2$ year) for buildings permit application:

- Existing buildings renovation max 200 kWh/(m$^2_{heated\ area}$ year);
- New buildings max 150 kWh/(m$^2_{heated\ area}$ year).

Presented requirements can be achieved in different ways. For example using the fuel with high primary energy production factor, the heat recovery and thermal conductivity have to be in high level. Other case is to use for energy production heat pumps, renewable energy sources – then it is possible to acquire discount from envelope insulation and air handling heat recovery. The principle is simple, but exact calculations have to be carried out using steady-state or dynamic simulation tools.

As in the Estonian Government level requirements are defined, the buildings energy conservation will be obtained. Only problematic matter is the time schedule – it can take quite long period. Therefore the EP minimum requirements will be revised at least in every five years. Motivation to energy efficiency has got into economical level – real estate prices will vary in energy performance of buildings.

### 3. Degree-day and dynamic simulation comparison for typical Estonian apartment buildings.

In 2009 an energy consumption research has been done for apartment buildings in major cities of Estonia. Energy consumptions real measuring has been compared with calculation methods. For calculation methods degree-day and dynamic simulation with $BV^2$ software was carried out. Totally 12 buildings in Tallinn, Tartu and Narva cities were among the study.

Energy balances between real measurements and dynamic simulations were compared. Results can be seen in Table 2.

| Address | Calculated energy consumption kWh/m²a | Measured energy consumption kWh/m²a |
|---|---|---|
| B1 | 179 | 178 |
| B2 | 214 | 213 |
| B3 | 214 | 213 |
| B4 | 199 | 199 |
| B5 | 192 | 191 |
| B6 | 144 | 142 |
| B7 | 166 | 165 |
| B8 | 176 | 175 |
| B9 | 173 | 172 |
| B10 | 170 | 170 |
| B11 | 183 | 183 |
| B12 | 199 | 199 |

Table 2. Calculated and measured heating energy consumptions.

Calculation accuracy is rather good and therefore simulated heating energy balances can be presented.

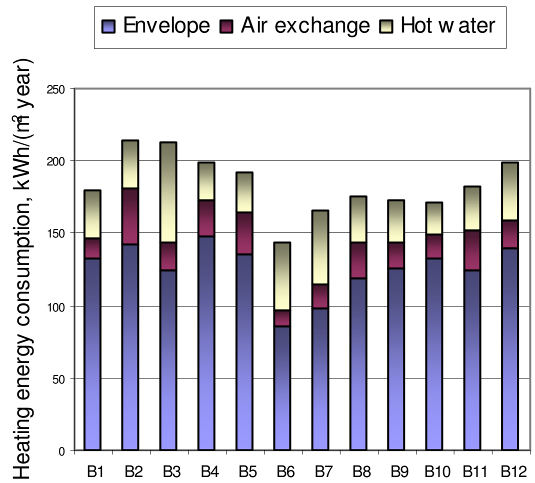


Figure 2. Heating consumption of studied buildings.

Average heating energy consumption is 185 $kWh/m^2_{heated\ area}$ year.

Comparison of two energy consumption calculation methods: degree-day and dynamic simulation was done for those apartment buildings. Results do not include domestic hot water heating energy consumption. Typical original condition and two renovation packages were calculated with both calculation methods. Dynamic simulations were carried out by software $BV^2$.

- Package 0 consists of original typical Soviet Union time apartment building. Envelope thermal conductivities are in original condition. Air exchange rate is 0,45 1/h.
- Package A consists following renovations – heating system is replaced and equipped with thermostatic valves. Buildings side walls and roof have additional thermal insulated. Windows-doors have been replaced with modern ones. Air exchange rate is calculated 0,6 1/h.
- Package B includes all package A renovations. Additionally front walls have added thermal insulation.

The comparison results can be seen in Figures 3,4,5. First bar indicates the degree-day calculation result for certain building and second bar $BV^2$ simulation result:

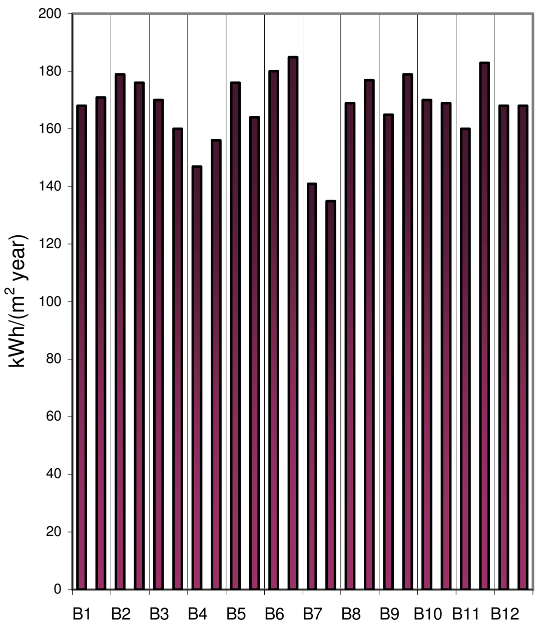


Figure 3. Package 0 in studied apartment buildings.

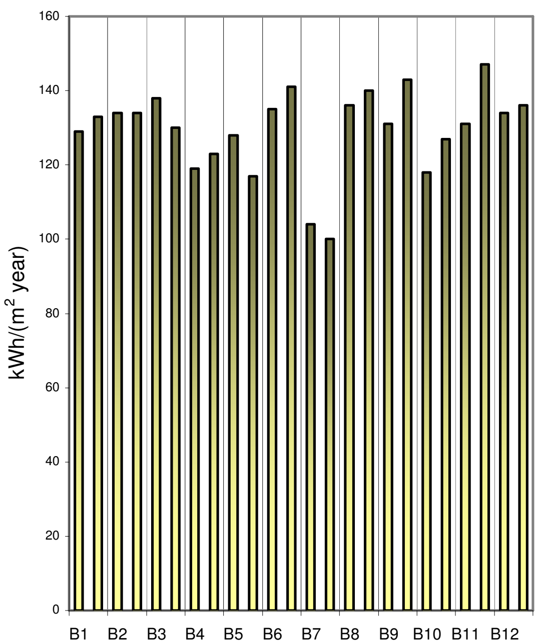


Figure 4. Package A in studied apartment buildings.

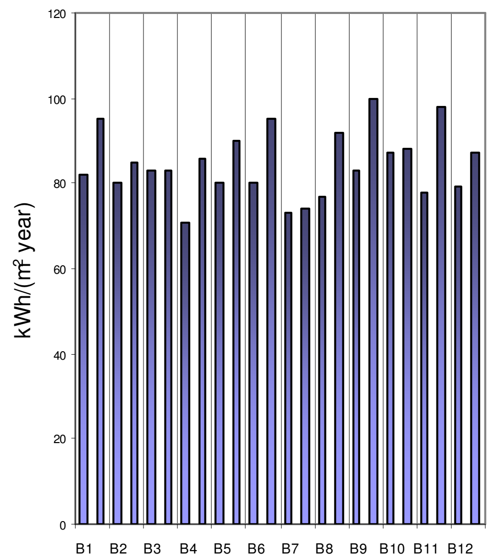


Figure 5. Package B in studied apartment buildings.

Results show that simple degree-days method can be used for heating energy calculations with sufficient accuracy.

## 4. Conclusions

Heating energy consumption has decreased noticeably during the last 15 years. See Figure 6. Main reasons for the decrease are high fuel prices, lower hot water consumption, heating system renovations, envelope insulation improvements etc.

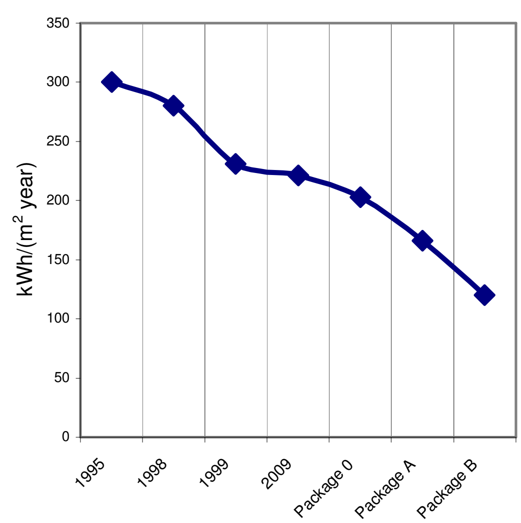


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Figure 6. Average heating energy consumption in apartment buildings.

The results in Figures 3, 4, 5 indicate heating energy consumption without domestic hot water heating. For that reason in Figure 6 for year 2009 and packages 0, A and B has been added 36 kWh/($m^2$ year) average domestic hot water heating energy consumption. With the improvement packages it is possible to receive quite good results. At the moment payback times for the packages are estimated averagely between 7 – 10 years. Excellent energy conservation would be received by using air handling units with heat recovery. At the moment there is some savings potential used, but with constant renovations the overall picture will look better. The existing buildings renovations and new buildings have to be followed by the regulation on minimum energy performance (EP) requirements – the energy savings will be gained more quickly.

Also is important fact that simple degree-day methods can be applied for energy consumption calculations in apartment buildings with good accuracy. Therefore the calculation tools will be cheaper and not much computing time needed. In addition it is rather difficult for beginners to use dynamic software and get adequate results. Degree-day calculation methods should be preferred in apartment building calculations.

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# National projections of GHG emissions by sources and their removal for the years 2010, 2015 and 2020

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**Abstract**
*Romania's current political outlook regarding environmental protection presents a proactive approach that is mainly shaped by the approximation of national policy to EU standards. Chapter 19 of Romania's Governmental Programme 2009 - 2012 (adopted in December 2008) stipulates specific priorities for climate change mitigation and adoption of specific policies and measures in order to stabilize GHG emissions (promote the decrease of energy consumption through the use of efficient energy technologies, thermal insulation of residences and through sustaining the use of less polluting vehicles; promoting the cheap and clean energy production from renewable sources; identifying and implementing of feasible measures on carbon capture and storage). Important parts of these commitments are already being implemented, such as the elaboration of the National Strategy on Climate Change (NSCC) and the National Action Plan on Climate Change (NAPCC), as well as the development of institutional capacity at the national level. Other provisions of the government's programme concerning climate change were also developed, like the establishment of the legal procedure for the national system of assessing GHG emissions, the national registry and the adaptation measures.*
**Key words:** climate change, GHG inventory, GHG projections, GHG emissions mitigation.

## 1. Introduction

The general objective of this paper is to achieve the green house gases ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$) projections for the years 2010, 2015 and 2020. The projections are made for different socio-economical evolution scenarios and of technological evolution for achieving the environmental commitments of Romania.

## 2. Description of methodologies, models, underlying assumptions and key input and output parameters

The methodology for GHG projections calculation is similar to the one used for establishing the National Allocation Plan under the EU ETS. It relies both on historical data provided by the national GHG Inventory, for the period 1989 - 2006, and on macroeconomic indicators forecasts, indicators considered in the Romanian Government's relevant strategies and for the socio- economic policies taking into consideration EU acquis communautaire.

The energy GHG projections were established considering the energy demand subsector (industry, transport, agriculture, household and commercial consumption) and the supplying sub-sector (primary energy resources extraction, their conversion in refineries, thermo-electric power plants, thermal power plants, transport and distribution of energy products to consumers).

The projections are based on calculations carried out using the ENPEP (Energy and Power Evaluation Program) programs package, developed by Argonne National laboratory of US Department of Energy (DOE) and distributed to Romania by the International Atomic Energy Agency (IAEA).

In order to allow the use of the modules package, a national energy balance has been prepared considering the available or imported primary energy resources. The main elements of the energy balance are:

- primary energy resources;
- primary energy resources conversion technologies;
- energy products transport and distribution;
- energy consumers classified according to the IPCC Guidelines.

Every sector is modeled in detail considering the technological processes and the IPCC emission factors; based on that modeling, the GHG emissions are determined using the IMPACTS module.

The analyzed non-energy sectors comprise:

- the forestry – for evaluating the C sequestration options;
- the agriculture – for evaluating the $CH_4$ and $N_2O$ emissions from livestock management and the $N_2O$ emissions from the nitrous fertilizers use;
- industry – for evaluating the industrial processes emissions;
- solvents and other products use;
- waste management.

The GHG emissions projections were prepared for three different scenarios:

- a reference scenario, "business as usual" (BAU), possible to be realized in the future, which does not include distinct activities for GHG emissions mitigation;
- a "with measures" scenario similar to the BAU scenario considering the evolution of the economic-social indicators, which comprises GHG emissions mitigation policies and programmes;
- a "with additional measures" scenario similar to the "with measures" scenario, which comprises additional GHG emissions mitigation policies and programmes.

Technological source processes and their mitigation options were identified for every GHG Inventory sector.

The prioritization of options within each sector is realized based on a detailed analysis considering different criteria:

- mitigation potential of the GHG emissions;
- cost-benefit balance related to the GHG mitigation options;
- indirect economic impact (creation of new jobs, import decrease);
- easy implementing options;
- mitigation option long-term sustainability

Romania's macroeconomic structure is still different from the other EU countries. Over the past decades, Romania has undergone a long process of restructuring, consisting of decreased activity of primary and secondary processing sectors and increased activity of the services sector.

Over the next period new industrial activities with high added value and reduced material consumption are expected to enhance as well as a reduced share of agriculture in the gross added value.

## 3. Hypothesis on macroeconomic indicators and on Energy activities

The main macroeconomic indicators trend for the period 2008 - 2020 is presented in table 1.

The macroeconomic policies envisaged in Romania are:

- selective restructuring of the economy;
- development of the industries with a competitive potential;
- modernization and development of the infrastructure;
- modernization of agriculture in line with the natural, human and economic potential of the country;
- implementation of supporting information technology based activities;
- development of tourism;
- diversification of activities in the services sector.

Industry adjustment and restructuring policies are aiming to increase the productivity, efficiency and quality of products and services. They also seek to assure compatibility between Romanian inter-sectorial structures with the existing and future EU structures, to progressively reach the same level of competitiveness with the EU Member States, including the promotion of better access for the Romanian products on the EU markets.

## 4. Analysis of the options for the development of the electricity production sector

The Romanian Power System (RPS) registered an installed power capacity of 20293 MW in 2007 (**table 2**). A reduction of installed capacity of 7% can be noted from the evolution of installed power during 2000 - 2007 due to the fact that only the group no. 2 of the Cernavoda nuclear power plant (NPP Cernavoda) and hydropower groups totaling an installed capacity of about 240 MW were put into operation while some thermal power groups have been withdrawn at the end of normal life.

Table 1. Evolution of macroeconomic and energy indicators

| Year | Meas. Unit (MU) | Realized | | | | | | | | | | Forecast | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1990 | 1995 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| Population | $10^6$inhabitant | 23.2 | 22.5 | 21.9 | 21.84 | 21.79 | 21.73 | 21.67 | 21.62 | 21.55 | 21.47 | 21.38 | 21.32 | 21.26 | 21.20 | 21.14 | 21.08 | 21.02 | 20.96 | 20.3 |
| Gross Domestic Product | $10^9$Euro 2005 | 71.40 | 64.00 | 59.13 | 62.70 | 66.00 | 69.77 | 76.09 | 79.26 | 84.25 | 89.30 | 96.10 | 101.00 | 104.90 | 111.20 | 117.90 | 125.00 | 132.50 | 141.10 | 185.10 |
| GDP / inhabitant | Euro 2005/inhabitant. | 3078 | 2845 | 2700 | 2871 | 3029 | 3211 | 3512 | 3666 | 3910 | 4160 | 4495 | 4738 | 4935 | 5300 | 5578 | 5930 | 6304 | 6732 | 9119 |
| GDP growth | % | - | - | - | 6.1 | 5.3 | 5.8 | 9.1 | 4.2 | 6.3 | 6.0 | 7.7 | 5.1 | 3.9 | 6.0 | 6.1 | 6.1 | 6.0 | 6.5 | 5.7 |
| Primary energy intensity | toe/$10^3$Euro2005 | 0.86 | 0.74 | 0.63 | 0.60 | 0.55 | 0.56 | 0.51 | 0.48 | 0.47 | 0.44 | 0.42 | 0.40 | 0.39 | 0.36 | 0.35 | 0.34 | 0.33 | 0.32 | 0.26 |
| Final energy intensity | toe/$10^3$Euro2005 | 0.51 | 0.41 | 0.38 | 0.36 | 0.35 | 0.36 | 0.36 | 0.32 | 0.31 | 0.29 | 0.28 | 0.26 | 0.25 | 0.24 | 0.23 | 0.22 | 0.21 | 0.21 | 0.17 |
| Primary energy consumption | $10^6$toe | 61.49 | 47.10 | 37.07 | 37.97 | 36.48 | 39.03 | 39.02 | 37.93 | 39.57 | 39.3 | 40.4 | 40.4 | 40.9 | 41.1 | 41.2 | 42.5 | 43.7 | 45.2 | 48.1 |
| Primary energy consumption per inhabitant | toe/inhabitant | 2.65 | 2.09 | 1.72 | 1.74 | 1.67 | 1.79 | 1.80 | 1.75 | 1.84 | 1.83 | 1.89 | 1.89 | 1.92 | 1.94 | 1.95 | 2.02 | 2.08 | 2.16 | 2.37 |
| Gross electricity consumption | TWh | 63.40 | 59.26 | 51.94 | 53.86 | 54.94 | 56.65 | 56.48 | 59.41 | 62.69 | 62.7 | 65.5 | 67.7 | 70.6 | 72.2 | 74.5 | 79.5 | 84.5 | 89.5 | 100.0 |
| Gross electricity consumption per inhabitant | kWh/inhabitant | 2732 | 2634 | 2370 | 2466 | 2521 | 2606 | 2606 | 2748 | 2905 | 2920 | 3064 | 3175 | 3320 | 3405 | 3524 | 3771 | 4120 | 4270 | 4926 |

**Table 2. Evolution of installed power capacity in the period 2000 – 2007**

[MW]

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|
| Total installed capacity, of which: | 21905 | 20863 | 19659 | 19368 | 19626 | 19042 | 18835 | 20293 |
| - nuclear power plant | 706 | 706 | 706 | 706 | 706 | 706 | 706 | 1411 |
| - hydro power plants | 6120 | 6122 | 6242 | 6248 | 6279 | 6289 | 6363 | 6334 |
| - thermal power plants | 15079 | 14035 | 12529 | 12414 | 12641 | 12047 | 11766 | 12548 |

**Source**: National Institute for Statistics – Romanian Statistical Yearbook 2008

The trends in the electricity consumption and heat cogeneration were forecasted in order to establish a program for the development of electricity power plants sector in the period 2009 - 2020. The diversification of primary energy resources, the necessity to improve and modernize the sector, modern technologies for the production of electricity and heat and the environmental requirements were also considered in the programme.

*Scenario A - reference* takes into account that all plants of all types (nuclear, thermal, hydro, and wind) are in free competition, without restrictions, the order of selection being the economic order allowing the consideration of the loading curve.

Alternative scenarios considering the required hydropower, wind and thermal power programs for an efficient use of lignite in the country are being considered. These alternative scenarios are:

- Scenario B is considering the use of new hydroelectric power groups in 2010 - 2020 totalizing an installed power of 217 MW, 472 MW, 1472 MW, the other candidate groups being in a free competition;
- Scenario C is considering an imposed thermal power programme during 2010 - 2013 by installing groups with a power of 3100 MW (1200 MW gas-fired, 700 MW on lignite, 1200 MW on coal), the other candidate groups being in a free competition;
- Scenario D takes into account new wind power plants with an installed power of 4000 MW in 2010 - 2017, the other groups being in a free competition;
- Scenario E takes into account new installed thermal power groups to use domestic coal and lignite correlated with forecasted productions presented and hydro power groups of 472 MW during 2010 - 2020;
- Scenario F takes into account in addition to the scenario E new installed wind

power plants with an installed power of 4000 MW.

## 5. Hypothesis on non-energy activities in industrial processes

The assumptions in the industry sector are related to the evolution of the main industrial processes. Thus, the production parameters for cast-iron, steel, aluminum, other nonferrous metals, chemical fertilizers, other chemical products and cement represent essential elements that were analyzed for the establishment of GHG emissions projections.
Evolution of the main industrial processes is determined in accordance with the economic development of Romania. Levels of production for various industrial products for 2010 - 2020 are established in line with the period 2000 - 2006 and taking into account the various industries development prognosis.
**Table 3** shows the evolution of different product industries envisaged for calculation of the reference scenario emissions. The same production levels are considered for the alternative scenarios, but the focus is on improving the industry technology and replacing the inefficient technologies with modern ones.
It should be mentioned that the old technology is not expected to be replaced in the period 2009 - 2015. Thus, the production will be generated with the improved old technology. New capacities with modern technology are expected to be put into operation after 2015. Emissions from Solvents and Other Products Use have been determined in correlation with the economic and technological evolution

Table 3. Industrial production trend.

| No. | Production (th. tonne) | Realized | | | | Forecast | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2015 | 2020 |
| 1. | Steel | 5578 | 5920 | 6175 | 6300 | 7960 | 8600 | 8800 | 9000 | 9000 | 9000 | 9300 | 9500 |
| 2. | Coke | 1550 | 1573 | 1777 | 1900 | 2150 | 2250 | 2320 | 2360 | 2360 | 2360 | 2500 | 2800 |
| 3. | Iron | 4101 | 4244 | 4098 | 4500 | 5800 | 6230 | 6400 | 6510 | 6510 | 6510 | 6700 | 6900 |
| 4. | Cement | 5002 | 5624 | 6021 | 7280 | 8600 | 10000 | 11400 | 12900 | 14400 | 16000 | 16000 | 18000 |
| 5. | Lime | 1936 | 1978 | 1978 | 2000 | 2100 | 2250 | 2400 | 2560 | 2730 | 2900 | 3000 | 3500 |
| 6. | Glass | 314 | 315 | 320 | 350 | 480 | 500 | 520 | 540 | 570 | 600 | 620 | 700 |
| 7. | Ceramics | 1503 | 1787 | 2112 | 2300 | 2400 | 2600 | 2750 | 2900 | 3000 | 3100 | 3300 | 4000 |
| 8. | Paper | 444 | 454 | 371 | 435 | 552 | 640 | 670 | 680 | 795 | 800 | 850 | 950 |

**Source**: National Allocation Plan, January 2008

## 6. Hypothesis on non-energy activities in Agriculture

Romania has an agricultural area of about 14800 thou. ha out of which approximately 9400 thou. ha are arable area, cultivated with cereals and green crops (**table 4**). Table 4 presents the agricultural area trend for the "BAU" (reference) scenario, by land use, for the period 2001 - 2020. During the period 2000 - 2006, approximately 40 kg of chemical fertilizers per hectare were used as an average in Romania (**table 5**). This amount does not compensate the amount of the nutrient substances removed from soils and does not ensure a production level comparable to those in the European Community. The nitrous fertilizers are the source of $N_2O$ emissions. The $N_2O$ emissions vary considering the application mode and the administration periods. Therefore, the improvement of the fertilizers use technologies is envisaged in order to reduce the $N_2O$ emissions. Rice cultivation generates methane emissions due to the anaerobic fermentation of the organic matter in the flooding or irrigation period. Rice cultivation is performed on small areas. These areas have been continuously decreasing from 1989 (49.3 thou. ha) to 2003 (0.1 thou. ha); the areas increased in 2006 to 5.6 thou. ha. Due to the small proportion of these emissions in the total level (0.1% in total methane emissions in 2006), mitigation measures are not envisaged. Livestock methane emissions are generated by the enteric fermentation and manure management. **Table 6** presents the livestock trend during 2000 - 2020. It can be noted that the livestock and the animal production are increasing together with the private property consolidation in agriculture. The improvement of nutrition quality and the recovery and use of methane from manure management are envisaged in order to reduce the methane emissions.

Table 4: Agricultural area trend - 2001 – 2020.

| Year | Agricultural area (thou. ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Historic | | | | | | Forecast | | |
| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2010 | 2015 | 2020 |
| Total agricultural area, of which: | 14852.3 | 14836.6 | 14717.4 | 14711.6 | 14741.2 | 14731.0 | 14900.0 | 15100.0 | 15400.0 |
| - arable | 9401.5 | 9398.5 | 9414.3 | 9421.9 | 9420.2 | 9434.6 | 9480.0 | 9610.0 | 9800.0 |
| - pastures | 3421.4 | 3424.0 | 3355.0 | 3346.9 | 3364.0 | 3334.4 | 3430.0 | 3470.0 | 3540.0 |
| - hayfields | 1510.0 | 1513.6 | 1490.4 | 1498.4 | 1514.7 | 1524.9 | 1540.0 | 1560.0 | 1590.0 |
| - vineyards and vine nurseries | 267.4 | 259.6 | 230.5 | 223.3 | 224.1 | 223.7 | 240.0 | 245.0 | 250.0 |
| - orchards and tree nurseries | 252.0 | 240.9 | 227.2 | 221.1 | 218.2 | 213.4 | 210.0 | 215.0 | 220.0 |

Table 5: Chemical and natural fertilizers amounts used in Agriculture trend – 2001 – 2020.

| Year | Fertilizers (thou. tonnes) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Used | | | | | Forecast | | | |
| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2010 | 2015 | 2020 |
| Chemical fertilizers, of which: | 369 | 326 | 362 | 380 | 461 | 363 | 460 | 492 | 525 |
| - nitrogenous | 268 | 239 | 252 | 270 | 299 | 252 | 300 | 320 | 340 |
| - phosphatic | 87 | 73 | 65 | 94 | 138 | 94 | 140 | 150 | 160 |
| - pottasic | 14 | 14 | 15 | 16 | 24 | 17 | 20 | 22 | 25 |
| Natural fertilizers | 15327 | 15746 | 15762 | 17749 | 16510 | 14900 | 16000 | 16500 | 17000 |

Table 6: Livestock trend – 2000-2020.

| Year | Livestock (thou. head) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Historic | | | | | | | Forecast | | |
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2010 | 2015 | 2020 |
| Livestock, of which: | 86803 | 87296 | 94139 | 93680 | 105243 | 105168 | 103949 | 109400 | 116405 | 124665 |
| - bovines | 2870 | 2800 | 2878 | 2897 | 2808 | 2862 | 2934 | 3060 | 3230 | 3400 |
| - swine | 4797 | 4447 | 5058 | 5145 | 6495 | 6622 | 6815 | 7675 | 8900 | 10325 |
| - sheep | 7657 | 7251 | 7312 | 7447 | 7425 | 7611 | 7678 | 7965 | 8340 | 8730 |
| - goats | 538 | 525 | 633 | 678 | 661 | 687 | 727 | 850 | 1035 | 1260 |
| - horses | 865 | 860 | 879 | 897 | 840 | 834 | 805 | 850 | 900 | 950 |
| - poultry | 70076 | 71413 | 77379 | 76616 | 87014 | 86552 | 84990 | 89000 | 94000 | 100000 |

Table 7: Evolution of the $CO_2$ emissions for the “BAU” scenario, 2000 – 2020.

| No | Source of emissions | $CO_2$ emissions (Gg CO2) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Historical | Estimated | | Forecasted | | | | | | | |
| | | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1. | Energy | 92,817.00 | 104,100.00 | 112,400.00 | 121,200.00 | 125,400.00 | 130,100.00 | 134,200.00 | 139,200.00 | 144,000.00 | 149,400.00 | 168,700.00 |
| | A. Fuel combustion | 92,817.00 | 104,100.00 | 112,400.00 | 121,200.00 | 125,400.00 | 130,100.00 | 134,200.00 | 139,200.00 | 144,000.00 | 149,400.00 | 168,700.00 |
| | 1. Energy industries | 48,788.00 | 53,700.00 | 59,100.00 | 64,700.00 | 66,800.00 | 68,500.00 | 70,300.00 | 73,100.00 | 76,000.00 | 79,100.00 | 89,600.00 |
| | of which: | | | | | | | | | | | |
| | under ETS | 48,788.00 | 53,700.00 | 59,100.00 | 64,700.00 | 66,800.00 | 68,500.00 | 70,300.00 | 73,100.00 | 76,000.00 | 79,100.00 | 89,600.00 |
| | 2. Manufacturing Industries and Construction | 19,303.00 | 21,800.00 | 22,500.00 | 23,900.00 | 24,400.00 | 25,900.00 | 26,500.00 | 27,100.00 | 27,700.00 | 28,300.00 | 31,900.00 |
| | of which: | | | | | | | | | | | |
| | under ETS | 5,550.00 | 6,200.00 | 6,600.00 | 6,700.00 | 6,900.00 | 7,400.00 | 7,900.00 | 8,200.00 | 8,400.00 | 8,800.00 | 9,700.00 |
| | 3. Transport | 12,282.00 | 14,700.00 | 15,900.00 | 16,800.00 | 17,600.00 | 18,500.00 | 19,500.00 | 20,600.00 | 21,400.00 | 22,600.00 | 25,300.00 |
| | 4. Other Sources | 12,444.00 | 13,900.00 | 14,900.00 | 15,800.00 | 16,600.00 | 17,200.00 | 17,900.00 | 18,400.00 | 18,900.00 | 19,400.00 | 21,900.00 |
| | of which: | | | | | | | | | | | |
| | under ETS | 4,120.00 | 4,600.00 | 5,100.00 | 5,700.00 | 6,200.00 | 6,700.00 | 7,100.00 | 7,300.00 | 7,700.00 | 8,400.00 | 8,700.00 |
| 2. | Industrial processes | 17,646.00 | 18,900.00 | 20,100.00 | 21,800.00 | 23,600.00 | 24,400.00 | 25,300.00 | 26,200.00 | 27,100.00 | 28,000.00 | 31,100.00 |
| | of which: | | | | | | | | | | | |
| | under ETS | 11,440.00 | 12,900.00 | 15,700.00 | 16,700.00 | 17,800.00 | 18,600.00 | 19,400.00 | 20,100.00 | 20,900.00 | 21,300.00 | 24,100.00 |
| 3. | Solvent and Other Product use | 210.00 | 250.00 | 270.00 | 280.00 | 290.00 | 290.00 | 300.00 | 300.00 | 310.00 | 310.00 | 350.00 |
| 4 | Land Use, Land Use Change and Forestry | -37,495.00 | -37,600.00 | -37,700.00 | -37,735.00 | -37,770.00 | -37,805.00 | -37,840.00 | -37,875.00 | -37,905.00 | -37,940.00 | -38,115.00 |
| 5 | Waste | 338.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 400.00 | 500.00 |
| | Total $CO_2$ emissions without LULUCF | 111,011.00 | 123,650.00 | 133,170.00 | 143,680.00 | 149,690.00 | 155,190.00 | 160,200.00 | 166,100.00 | 171,810.00 | 178,110.00 | 200,650.00 |
| | Total $CO_2$ emissions including LULUCF | 73,516.00 | 86,050.00 | 95,470.00 | 105,945.00 | 111,920.00 | 117,385.00 | 122,360.00 | 128,225.00 | 133,905.00 | 140,170.00 | 162,535.00 |
| | Total $CO_2$ under ETS | 69,898.00 | 77,400.00 | 86,500.00 | 93,800.00 | 97,700.00 | 101,200.00 | 104,700.00 | 108,700.00 | 113,000.00 | 117,600.00 | 132,100.00 |

## 7. Projections of the GHG emissions

The overall GHG projections are presented below considering the IPCC categories and also the ETS relevance.

### 7.1. Projections of $CO_2$ emissions

**Table 7** presents the $CO_2$ emissions trend in 2000 - 2020 for the "BAU" scenario. The fuel burning is responsible for approximately 84% from total $CO_2$ emissions, the industrial processes are contributing with approximately 15%; meanwhile, 65% from total $CO_2$ emissions are generated in ETS installations.

The $CO_2$ emissions trend in 2006-2020 for the "with measures" and "with additional measures" scenarios are presented in **tables 8** and **9**. The $CO_2$ emissions in 2020 are larger than those in the base year only for the "BAU" scenario. For the alternative scenarios, these emissions are approximately 6%, respectively 12%, lower than those in 1989.

### 7.2. Projections of $CH_4$ emissions

The 2006 - 2020 $CH_4$ emissions trend is shown in **tables 10, 11** and **12**. In 2010 the Energy is generating 42% from total $CH_4$ emissions, the Waste Management 31.1% and the Agriculture 26.5%; these proportions are almost constant during 2010-2020. Therefore, these sectors are subject to $CH_4$ mitigation measures.

### 7.3. Projections of $N_2O$ emissions

The 2006 - 2020 $N_2O$ emissions evolution is shown in **tables 13, 14** and **15**. The Agriculture is the main source of $N_2O$ emissions (with approximately 70% of total $N_2O$ emissions) followed by the Industrial Processes (with approximately 20%).

Table 8: Evolution of the $CO_2$ emissions for "with measures" scenario, 2006 – 2020.

| No | Source of emissions | $CO_2$ emissions (Gg CO2equiv) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1. | Energy | 92,817.00 | 116,900.00 | 120,400.00 | 123,800.00 | 127,400.00 | 130,700.00 | 134,100.00 | 151,000.00 |
| | A. Fuel combustion | 92,817.00 | 116,900.00 | 120,400.00 | 123,800.00 | 127,400.00 | 130,700.00 | 134,100.00 | 151,000.00 |
| | 1. Energy industries | 48,788.00 | 62,800.00 | 64,300.00 | 65,900.00 | 67,400.00 | 68,900.00 | 70,500.00 | 80,000.00 |
| | 2. Manufacturing Industries and Construction | 19,303.00 | 23,500.00 | 24,300.00 | 25,000.00 | 25,800.00 | 26,500.00 | 27,200.00 | 29,800.00 |
| | 3. Transport | 12,282.00 | 16,500.00 | 17,300.00 | 18,000.00 | 18,800.00 | 19,500.00 | 20,200.00 | 22,900.00 |
| | 4. Other Sources | 12,444.00 | 14,100.00 | 14,500.00 | 14,900.00 | 15,400.00 | 15,800.00 | 16,200.00 | 18,300.00 |
| 2. | Industrial processes | 17,646.00 | 22,200.00 | 23,100.00 | 23,900.00 | 24,700.00 | 25,600.00 | 26,500.00 | 29,900.00 |
| 3. | Solvent and Other Product use | 210.00 | 270.00 | 280.00 | 280.00 | 290.00 | 290.00 | 300.00 | 340.00 |
| 4 | Land Use, Land Use Change and Forestry | -37,495.00 | -37,780.00 | -37,820.00 | -37,860.00 | -37,890.00 | -37,940.00 | -37,980.00 | -38,180.00 |
| 5 | Waste | 338.00 | 380.00 | 380.00 | 380.00 | 380.00 | 380.00 | 390.00 | 480.00 |
| **Total $CO_2$ emisiions without LULUCF** | | **111,011.00** | **139,750.00** | **144,160.00** | **148,360.00** | **152,770.00** | **156,970.00** | **161,290.00** | **181,720.00** |
| **Total $CO_2$ emisiions including LULUCF** | | **73,516.00** | **101,970.00** | **106,340.00** | **110,500.00** | **114,880.00** | **119,030.00** | **123,310.00** | **143,540.00** |
| **Total $CO_2$ under ETS** | | **69,898.00** | **91,500.00** | **94,500.00** | **97,610.00** | **100,260.00** | **103,130.00** | **106,150.00** | **119,530.00** |

Table 9: Evolution of the $CO_2$ emissions for "with additional measures" scenario, 2006 – 2020.

| No | Source of emissions | CO2 emissions (Gg CO2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1. | Energy | 92,817.00 | 112,300.00 | 115,300.00 | 118,450.00 | 121,550.00 | 124,500.00 | 127,500.00 | 141,900.00 |
| | A. Fuel combustion | 92,817.00 | 112,300.00 | 115,300.00 | 118,450.00 | 121,550.00 | 124,500.00 | 127,500.00 | 141,900.00 |
| | 1. Energy industries | 48,788.00 | 60,800.00 | 61,900.00 | 63,100.00 | 64,200.00 | 65,400.00 | 66,500.00 | 75,000.00 |
| | 2. Manufacturing Industries and Construction | 19,303.00 | 22,500.00 | 23,200.00 | 23,900.00 | 24,600.00 | 25,300.00 | 26,000.00 | 28,000.00 |
| | 3. Transport | 12,282.00 | 15,500.00 | 16,250.00 | 17,000.00 | 17,750.00 | 18,400.00 | 19,200.00 | 21,900.00 |
| | 4. Other Sources | 12,444.00 | 13,500.00 | 13,950.00 | 14,450.00 | 15,000.00 | 15,400.00 | 15,800.00 | 17,000.00 |
| 2. | Industrial processes | 17,646.00 | 20,500.00 | 21,100.00 | 21,700.00 | 22,300.00 | 22,900.00 | 23,500.00 | 26,700.00 |
| 3. | Solvent and Other Product use | 210.00 | 270.00 | 280.00 | 280.00 | 290.00 | 290.00 | 300.00 | 340.00 |
| 4 | Land Use, Land Use Change and Forestry | -37,495.00 | -37,788.00 | -37,832.00 | -37,876.00 | -37,920.00 | -37,964.00 | -38,008.00 | -38,228.00 |
| 5 | Waste | 338.00 | 380.00 | 380.00 | 380.00 | 380.00 | 380.00 | 390.00 | 480.00 |
| **Total $CO_2$ emisiions without LULUCF** | | **111,011.00** | **133,450.00** | **137,060.00** | **140,810.00** | **144,520.00** | **148,070.00** | **151,690.00** | **169,420.00** |
| **Total $CO_2$ emisiions including LULUCF** | | **73,516.00** | **95,662.00** | **99,228.00** | **102,934.00** | **106,600.00** | **110,106.00** | **113,682.00** | **131,192.00** |
| **Total $CO_2$ under ETS** | | **69,898.00** | **87,710.00** | **90,050.00** | **92,600.00** | **94,700.00** | **96,780.00** | **99,310.00** | **111,060.00** |

Table 10: Evolution of the $CH_4$ emissions for "BAU" scenario, 2000 – 2020.

| No | Source of emissions | $CH_4$ emissions (GgCO2 equiv) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Historical | Estimated | | Forecasted | | | | | | | |
| | | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 12,215.07 | 12,467.70 | 12,726.00 | 13,125.00 | 13,477.80 | 13,830.60 | 14,179.20 | 14,502.60 | 14,811.30 | 15,134.70 | 16,388.40 |
| | A. Fuel combustion | 847.35 | 871.50 | 896.70 | 940.80 | 989.10 | 1,041.60 | 1,089.90 | 1,134.00 | 1,188.60 | 1,245.30 | 1,354.50 |
| | 1. Energy Industries | 20.16 | 21.00 | 23.10 | 27.30 | 29.40 | 35.70 | 39.90 | 44.10 | 48.30 | 54.60 | 63.00 |
| | 2. Manufacturing Industries and Construction | 33.81 | 35.70 | 37.80 | 42.00 | 44.10 | 48.30 | 54.60 | 58.80 | 63.00 | 69.30 | 79.80 |
| | 3. Transport | 38.43 | 39.90 | 42.00 | 44.10 | 48.30 | 52.50 | 60.90 | 65.10 | 69.30 | 75.60 | 84.00 |
| | 4. Other Sources | 754.95 | 774.90 | 793.80 | 827.40 | 867.30 | 905.10 | 934.50 | 966.00 | 1,008.00 | 1,045.80 | 1,127.70 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,596.20 | 11,829.30 | 12,184.20 | 12,488.70 | 12,789.00 | 13,089.30 | 13,368.60 | 13,622.70 | 13,889.40 | 15,033.90 |
| 2 | Industrial Processes | 27.30 | 31.50 | 35.70 | 37.80 | 42.00 | 44.10 | 44.10 | 46.20 | 48.30 | 50.40 | 63.00 |
| 3 | Agriculture | 7,837.20 | 7,994.70 | 8,145.90 | 8,309.70 | 8,511.30 | 8,681.40 | 8,857.80 | 9,053.10 | 9,250.50 | 9,424.80 | 9,912.00 |
| 4 | Land Use, Land Use Change and Forestry | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 4.20 | 4.20 | 4.20 | 4.20 | 4.20 | 8.40 |
| 5 | Waste | 8,979.60 | 9,248.40 | 9,479.40 | 9,678.90 | 9,901.50 | 10,128.30 | 10,355.10 | 10,560.90 | 10,775.10 | 11,006.10 | 12,117.00 |
| **TOTAL $CH_4$ Emissions** | | **29,059.17** | **29,742.30** | **30,387.00** | **31,151.40** | **31,932.60** | **32,684.40** | **33,436.20** | **34,162.80** | **34,885.20** | **35,616.00** | **38,480.40** |

Table 11: Evolution of the $CH_4$ emissions for “with measures” scenario, 2006 – 2020.

| No | Source of emissions | $CH_4$ emissions (GgCO2 equiv) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 12,215.07 | 12,948.60 | 13,230.00 | 13,511.40 | 13,792.80 | 14,078.40 | 14,357.70 | 15,120.00 |
| | A. Fuel combustion | 847.35 | 968.10 | 993.30 | 1,020.60 | 1,045.80 | 1,073.10 | 1,098.30 | 1,228.50 |
| | 1. Energy Industries | 20.16 | 27.30 | 29.40 | 33.60 | 35.70 | 37.80 | 39.90 | 48.30 |
| | 2. Manufacturing Industries and Construction | 33.81 | 42.00 | 44.10 | 48.30 | 50.40 | 52.50 | 54.60 | 63.00 |
| | 3. Transport | 38.43 | 44.10 | 48.30 | 50.40 | 52.50 | 56.70 | 60.90 | 69.30 |
| | 4. Other Sources | 754.95 | 854.70 | 871.50 | 888.30 | 907.20 | 926.10 | 942.90 | 1,047.90 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,980.50 | 12,236.70 | 12,490.80 | 12,747.00 | 13,005.30 | 13,259.40 | 13,891.50 |
| 2 | Industrial Processes | 27.30 | 33.60 | 35.70 | 37.80 | 39.90 | 39.90 | 42.00 | 56.70 |
| 3 | Agriculture | 7,837.20 | 8,085.00 | 8,169.00 | 8,253.00 | 8,337.00 | 8,421.00 | 8,505.00 | 9,156.00 |
| 4 | Land Use, Land Use Change and Forestry | 2.10 | 2.10 | 4.20 | 4.20 | 4.20 | 4.20 | 4.20 | 8.40 |
| 5 | Waste | 8,979.60 | 9,481.50 | 9,559.20 | 9,678.90 | 9,798.60 | 9,918.30 | 10,080.00 | 10,825.50 |
| **TOTAL $CH_4$ Emissions** | | **29,059.17** | **30,548.70** | **30,993.90** | **31,481.10** | **31,968.30** | **32,457.60** | **32,984.70** | **35,158.20** |

Table 12: Evolution of the $CH_4$ emissions for “with additional measures” scenario, 2006 – 2020.

| No | Source of emissions | $CH_4$ emissions (GgCO2 equiv) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 12,215.07 | 12,717.60 | 12,940.20 | 13,188.00 | 13,433.70 | 13,677.30 | 13,918.80 | 14,592.90 |
| | A. Fuel combustion | 847.35 | 947.10 | 959.70 | 976.50 | 991.20 | 1,003.80 | 1,014.30 | 1,123.50 |
| | 1. Energy Industries | 20.16 | 25.20 | 27.30 | 29.40 | 31.50 | 33.60 | 35.70 | 35.70 |
| | 2. Manufacturing Industries and Construction | 33.81 | 39.90 | 42.00 | 44.10 | 48.30 | 50.40 | 52.50 | 54.60 |
| | 3. Transport | 38.43 | 42.00 | 46.20 | 48.30 | 50.40 | 52.50 | 54.60 | 56.70 |
| | 4. Other Sources | 754.95 | 840.00 | 844.20 | 854.70 | 861.00 | 867.30 | 871.50 | 976.50 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,770.50 | 11,980.50 | 12,211.50 | 12,442.50 | 12,673.50 | 12,904.50 | 13,469.40 |
| 2 | Industrial Processes | 27.30 | 31.50 | 33.60 | 35.70 | 37.80 | 39.90 | 42.00 | 52.50 |
| 3 | Agriculture | 7,837.20 | 8,043.00 | 8,085.00 | 8,127.00 | 8,169.00 | 8,211.00 | 8,253.00 | 8,862.00 |
| 4 | Land Use, Land Use Change and Forestry | 2.10 | 2.10 | 4.20 | 4.20 | 4.20 | 4.20 | 4.20 | 8.40 |
| 5 | Waste | 8,979.60 | 9,219.00 | 9,399.60 | 9,559.20 | 9,655.80 | 9,733.50 | 9,912.00 | 10,405.50 |
| **TOTAL $CH_4$ Emissions** | | **29,059.17** | **30,011.10** | **30,458.40** | **30,909.90** | **31,296.30** | **31,661.70** | **32,125.80** | **33,912.90** |

Table 13: Evolution of the $N_2O$ emissions for “BAU” scenario, 2000 – 2020.

| No | Source of emissions | $N_2O$ emissions (GgCO2 equiv) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Historical | Estimated | | Forecasted | | | | | | | |
| | | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 399.90 | 421.60 | 434.00 | 458.80 | 471.20 | 477.40 | 483.60 | 489.80 | 496.00 | 505.30 | 523.90 |
| | A. Fuel combustion | 399.90 | 421.60 | 434.00 | 458.80 | 471.20 | 477.40 | 483.60 | 489.80 | 496.00 | 505.30 | 523.90 |
| | 1. Energy Industries | 164.30 | 173.60 | 182.90 | 186.00 | 189.10 | 192.20 | 195.30 | 195.30 | 195.30 | 198.40 | 201.50 |
| | 2. Manufacturing Industries and Construction | 49.60 | 49.60 | 49.60 | 55.80 | 58.90 | 58.90 | 62.00 | 62.00 | 65.10 | 65.10 | 68.20 |
| | 3. Transport | 31.00 | 31.00 | 34.10 | 37.20 | 40.30 | 40.30 | 40.30 | 43.40 | 46.50 | 46.50 | 49.60 |
| | 4. Other Sources | 155.00 | 167.40 | 167.40 | 179.80 | 182.90 | 186.00 | 186.00 | 189.10 | 189.10 | 195.30 | 204.60 |
| 2 | Industrial Processes | 2,507.90 | 3,165.10 | 3,348.00 | 3,689.00 | 3,937.00 | 4,185.00 | 4,371.00 | 4,588.00 | 4,774.00 | 4,929.00 | 5,332.00 |
| 3 | Agriculture | 12,353.50 | 12,803.00 | 13,361.00 | 13,733.00 | 14,074.00 | 14,291.00 | 14,632.00 | 15,004.00 | 15,314.00 | 15,624.00 | 16,988.00 |
| 5 | Waste | 719.20 | 722.30 | 728.50 | 728.50 | 731.60 | 734.70 | 740.90 | 747.10 | 756.40 | 765.70 | 812.20 |
| **TOTAL $N_2O$ Emissions** | | **15,980.50** | **17,112.00** | **17,871.50** | **18,609.30** | **19,213.80** | **19,688.10** | **20,227.50** | **20,828.90** | **21,340.40** | **21,824.00** | **23,656.10** |

Table 14: Evolution of the $N_2O$ emissions for “with measures” scenario, 2006 – 2020.

| No | Source of emissions | $N_2O$ emissions (GgCO2 equiv) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 399.90 | 434.00 | 446.40 | 452.60 | 461.90 | 471.20 | 480.50 | 511.50 |
| | A. Fuel combustion | 399.90 | 434.00 | 446.40 | 452.60 | 461.90 | 471.20 | 480.50 | 511.50 |
| | 1. Energy Industries | 164.30 | 182.90 | 186.00 | 189.10 | 195.30 | 198.40 | 201.50 | 210.80 |
| | 2. Manufacturing Industries and Construction | 49.60 | 52.70 | 52.70 | 52.70 | 55.80 | 55.80 | 58.90 | 58.90 |
| | 3. Transport | 31.00 | 34.10 | 34.10 | 37.20 | 37.20 | 40.30 | 40.30 | 43.40 |
| | 4. Other Sources | 155.00 | 164.30 | 173.60 | 173.60 | 173.60 | 176.70 | 179.80 | 198.40 |
| 2 | Industrial Processes | 2,507.90 | 3,441.00 | 3,658.00 | 3,906.00 | 4,123.00 | 4,340.00 | 4,588.00 | 4,975.50 |
| 3 | Agriculture | 12,353.50 | 13,051.00 | 13,379.60 | 13,708.20 | 14,043.00 | 14,365.40 | 14,694.00 | 15,965.00 |
| 5 | Waste | 719.20 | 728.50 | 731.60 | 734.70 | 737.80 | 740.90 | 744.00 | 787.40 |
| **TOTAL $N_2O$ Emissions** | | **15,980.50** | **17,654.50** | **18,215.60** | **18,801.50** | **19,365.70** | **19,917.50** | **20,506.50** | **22,239.40** |

Table 15: Evolution of the $N_2O$ emissions for “with additional measures” scenario, 2006 – 2020.

| No | Source of emissions | $N_2O$ emissions (GgCO2 equiv) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 |
| 1 | Energy | 399.90 | 427.80 | 437.10 | 443.30 | 449.50 | 455.70 | 461.90 | 502.20 |
| | A. Fuel combustion | 399.90 | 427.80 | 437.10 | 443.30 | 449.50 | 455.70 | 461.90 | 502.20 |
| | 1. Energy Industries | 164.30 | 179.80 | 182.90 | 186.00 | 186.00 | 189.10 | 192.20 | 204.60 |
| | 2. Manufacturing Industries and Construction | 49.60 | 52.70 | 52.70 | 52.70 | 55.80 | 55.80 | 58.90 | 58.90 |
| | 3. Transport | 31.00 | 34.10 | 34.10 | 37.20 | 37.20 | 37.20 | 37.20 | 43.40 |
| | 4. Other Sources | 155.00 | 161.20 | 167.40 | 167.40 | 170.50 | 173.60 | 173.60 | 195.30 |
| 2 | Industrial Processes | 2,507.90 | 3,348.00 | 3,534.00 | 3,720.00 | 3,906.00 | 4,092.00 | 4,278.00 | 4,929.00 |
| 3 | Agriculture | 12,353.50 | 12,958.00 | 13,237.00 | 13,516.00 | 13,795.00 | 14,074.00 | 14,353.00 | 15,252.00 |
| 5 | Waste | 719.20 | 728.50 | 731.60 | 734.70 | 737.80 | 740.90 | 744.00 | 787.40 |
| **TOTAL $N_2O$ Emissions** | | **15,980.50** | **17,462.30** | **17,939.70** | **18,414.00** | **18,888.30** | **19,362.60** | **19,836.90** | **21,470.60** |

Table 16: Evolution of HFCs, PFCs and $SF_6$ emissions, 2000 – 2020.

**[Gg $CO_2$ equivalent]**

| | **Historical** | | | | | | | **Estimated** | | **Forecasted** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2020** |
| HFCs emissions | 2.93 | 2.78 | 3.25 | 5.12 | 6.94 | 4.00 | 21.70 | 23.87 | 26.01 | 28.09 | 30.62 | 33.07 | 36.05 | 38.90 | 42.05 | 45.41 | 58.70 |
| PFCs emissions | 413.14 | 428.75 | 444.59 | 471.90 | 513.34 | 569.63 | 609.65 | 670.53 | 730.88 | 789.29 | 860.35 | 929.19 | 1012.80 | 1092.94 | 1181.38 | 1275.90 | 1649.06 |
| $SF_6$ emissions | 0.00 | 0.00 | 0.01 | 0.00 | 0.08 | 0.11 | 0.09 | 0.10 | 0.11 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | 0.19 | 0.24 |
| **HFCs, PFCs and $SF_6$ emissions - total** | **416.07** | **431.53** | **447.85** | **477.02** | **520.36** | **573.74** | **631.44** | **694.50** | **757.00** | **817.50** | **891.10** | **962.40** | **1049.00** | **1132.00** | **1223.60** | **1321.50** | **1708.00** |

**Source**: National Inventory Report – March 2008

Table 17: Evolution of the total GHG emissions for "BAU" scenario, 2000 – 2020.

| **No** | **Source of emissions** | **Total GHG emissions (Gg $CO_2$ equivalent)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2020** |
| 1. | Energy | 105,431.97 | 116,989.30 | 125,560.00 | 134,783.80 | 139,349.00 | 144,408.00 | 148,862.80 | 154,192.40 | 159,307.30 | 165,040.00 | 185,612.30 |
| | A. Fuel combustion | 94,064.25 | 105,393.10 | 113,730.70 | 122,599.60 | 126,860.30 | 131,619.00 | 135,773.50 | 140,823.80 | 145,684.60 | 151,150.60 | 170,578.40 |
| | 1. Energy Industries | 48,972.46 | 53,894.60 | 59,306.00 | 64,913.30 | 67,018.50 | 68,727.90 | 70,535.20 | 73,339.40 | 76,243.60 | 79,353.00 | 89,864.50 |
| | 2. Manufacturing Industries and Construction | 19,386.41 | 21,885.30 | 22,587.40 | 23,997.80 | 24,503.00 | 26,007.20 | 26,616.60 | 27,220.80 | 27,828.10 | 28,434.40 | 32,048.00 |
| | 3. Transport | 12,351.43 | 14,770.90 | 15,976.10 | 16,881.30 | 17,688.60 | 18,592.80 | 19,601.20 | 20,708.50 | 21,515.80 | 22,722.10 | 25,433.60 |
| | 4. Other Sources | 13,353.95 | 14,842.30 | 15,861.20 | 16,807.20 | 17,650.20 | 18,291.10 | 19,020.50 | 19,555.10 | 20,097.10 | 20,641.10 | 23,232.30 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,596.20 | 11,829.30 | 12,184.20 | 12,488.70 | 12,789.00 | 13,089.30 | 13,368.60 | 13,622.70 | 13,889.40 | 15,033.90 |
| 2. | Industrial Processes | 20,181.20 | 22,096.60 | 23,483.70 | 25,526.80 | 27,579.00 | 28,629.10 | 29,715.10 | 30,834.20 | 31,922.30 | 32,979.40 | 36,495.00 |
| 3. | Solvent and Other Product Use | 210.00 | 250.00 | 270.00 | 280.00 | 290.00 | 290.00 | 300.00 | 300.00 | 310.00 | 310.00 | 350.00 |
| 4. | Agriculture | 20,190.70 | 20,797.70 | 21,506.90 | 22,042.70 | 22,585.30 | 22,972.40 | 23,489.80 | 24,057.10 | 24,564.50 | 25,048.80 | 26,900.00 |
| 5. | Land Use, Land Use Change and Forestry | -37,492.90 | -37,597.90 | -37,697.90 | -37,732.90 | -37,767.90 | -37,800.80 | -37,835.80 | -37,870.80 | -37,900.80 | -37,935.80 | -38,106.60 |
| 6. | Waste | 10,036.80 | 10,370.70 | 10,607.90 | 10,807.40 | 11,033.10 | 11,263.00 | 11,496.00 | 11,708.00 | 11,931.50 | 12,171.80 | 13,429.20 |
| **Total PFC emissions** | | **631.44** | **694.5** | **757** | **817.5** | **891.1** | **962.4** | **1049** | **1132** | **1223.6** | **1321.5** | **1708** |
| **TOTAL GHG Emissions without LULUCF** | | **156,682.11** | **171,198.80** | **182,185.50** | **194,258.20** | **201,727.50** | **208,524.90** | **214,912.70** | **222,223.70** | **229,259.20** | **236,871.50** | **264,494.50** |
| **TOTAL GHG Emissions including LULUCF** | | **119,189.21** | **133,600.90** | **144,487.60** | **156,525.30** | **163,959.60** | **170,724.10** | **177,076.90** | **184,352.90** | **191,358.40** | **198,935.70** | **226,387.90** |

Table 18: Evolution of the total GHG emissions for "with measures" scenario, 2006 – 2020.

| **No** | **Source of emissions** | **Total GHG emissions (Gg $CO_2$ equivalent)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **2006** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2020** |
| 1. | Energy | 105,431.97 | 130,282.60 | 134,076.40 | 137,764.00 | 141,654.70 | 145,249.60 | 148,938.20 | 166,631.50 |
| | A. Fuel combustion | 94,064.25 | 118,302.10 | 121,839.70 | 125,273.20 | 128,907.70 | 132,244.30 | 135,678.80 | 152,740.00 |
| | 1. Energy Industries | 48,972.46 | 63,010.20 | 64,515.40 | 66,122.70 | 67,631.00 | 69,136.20 | 70,741.40 | 80,259.10 |
| | 2. Manufacturing Industries and Construction | 19,386.41 | 23,594.70 | 24,396.80 | 25,101.00 | 25,906.20 | 26,608.30 | 27,313.50 | 29,921.90 |
| | 3. Transport | 12,351.43 | 16,578.20 | 17,382.40 | 18,087.60 | 18,889.70 | 19,597.00 | 20,301.20 | 23,012.70 |
| | 4. Other Sources | 13,353.95 | 15,119.00 | 15,545.10 | 15,961.90 | 16,480.80 | 16,902.80 | 17,322.70 | 19,546.30 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,980.50 | 12,236.70 | 12,490.80 | 12,747.00 | 13,005.30 | 13,259.40 | 13,891.50 |
| 2. | Industrial Processes | 20,181.20 | 25,674.60 | 26,793.70 | 27,843.80 | 28,862.90 | 29,979.90 | 31,130.00 | 34,932.20 |
| 3. | Solvent and Other Product Use | 210.00 | 270.00 | 280.00 | 280.00 | 290.00 | 290.00 | 300.00 | 340.00 |
| 4. | Agriculture | 20,190.70 | 21,136.00 | 21,548.60 | 21,961.20 | 22,380.00 | 22,786.40 | 23,199.00 | 25,121.00 |
| 5. | Land Use, Land Use Change and Forestry | -37,492.90 | -37,777.90 | -37,815.80 | -37,855.80 | -37,885.80 | -37,935.80 | -37,975.80 | -38,171.60 |
| 6. | Waste | 10,036.80 | 10,590.00 | 10,670.80 | 10,793.60 | 10,916.40 | 11,039.20 | 11,214.00 | 12,092.90 |
| **Total PFC emissions** | | **631.44** | **891.1** | **962** | **1,049** | **1,132** | **1,224** | **1,322** | **1,708** |
| **TOTAL GHG Emissions without LULUCF** | | **156,682.11** | **188,844.30** | **194,331.90** | **199,691.60** | **205,236.00** | **210,568.70** | **216,102.70** | **240,825.60** |
| **TOTAL GHG Emissions including LULUCF** | | **119,189.21** | **151,066.40** | **156,516.10** | **161,835.80** | **167,350.20** | **172,632.90** | **178,126.90** | **202,654.00** |

Table 19. Evolution of the total GHG emissions for "with additional measures" scenario, 2006 – 2020.

| **No** | **Source of emissions** | **Total GHG emissions (Gg $CO_2$ equivalent)** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **2006** | **2010** | **2011** | **2012** | **2013** | **2014** | **2015** | **2020** |
| 1. | Energy | 105,431.97 | 125,445.40 | 128,677.30 | 132,081.30 | 135,433.20 | 138,633.00 | 141,880.70 | 156,995.10 |
| | A. Fuel combustion | 94,064.25 | 113,674.90 | 116,696.80 | 119,869.80 | 122,990.70 | 125,959.50 | 128,976.20 | 143,525.70 |
| | 1. Energy Industries | 48,972.46 | 61,005.00 | 62,110.20 | 63,315.40 | 64,417.50 | 65,622.70 | 66,727.90 | 75,240.30 |
| | 2. Manufacturing Industries and Construction | 19,386.41 | 22,592.60 | 23,294.70 | 23,996.80 | 24,704.10 | 25,406.20 | 26,111.40 | 28,113.50 |
| | 3. Transport | 12,351.43 | 15,576.10 | 16,330.30 | 17,085.50 | 17,837.60 | 18,489.70 | 19,291.80 | 22,000.10 |
| | 4. Other Sources | 13,353.95 | 14,501.20 | 14,961.60 | 15,472.10 | 16,031.50 | 16,440.90 | 16,845.10 | 18,171.80 |
| | B. Fugitive Emissions from Fuels | 11,367.72 | 11,770.50 | 11,980.50 | 12,211.50 | 12,442.50 | 12,673.50 | 12,904.50 | 13,469.40 |
| 2. | Industrial Processes | 20,181.20 | 23,879.50 | 24,667.60 | 25,455.70 | 26,243.80 | 27,031.90 | 27,820.00 | 31,681.50 |
| 3. | Solvent and Other Product Use | 210.00 | 270.00 | 280.00 | 280.00 | 290.00 | 290.00 | 300.00 | 340.00 |
| 4. | Agriculture | 20,190.70 | 21,001.00 | 21,322.00 | 21,643.00 | 21,964.00 | 22,285.00 | 22,606.00 | 24,114.00 |
| 5. | Land Use, Land Use Change and Forestry | -37,492.90 | -37,785.90 | -37,827.80 | -37,871.80 | -37,915.80 | -37,959.80 | -38,003.80 | -38,219.60 |
| 6. | Waste | 10,036.80 | 10,327.50 | 10,511.20 | 10,673.90 | 10,773.60 | 10,854.40 | 11,046.00 | 11,672.90 |
| **Total PFC emissions** | | **631.44** | **891.1** | **962.4** | **1049** | **1132** | **1223.6** | **1321.5** | **1708** |
| **TOTAL GHG Emissions without LULUCF** | | **156,682.11** | **181,814.50** | **186,420.50** | **191,182.90** | **195,836.60** | **200,317.90** | **204,974.20** | **226,511.50** |
| **TOTAL GHG Emissions including LULUCF** | | **119,189.21** | **144,028.60** | **148,592.70** | **153,311.10** | **157,920.80** | **162,358.10** | **166,970.40** | **188,291.90** |

### 7.4. Projections of F-gases Emissions (HFCs, PFCs and $SF_6$)

**Table 16** presents the levels of HFCs, PFCs and $SF_6$ emissions from the chemical and manufacturing industries. The prognosis of these emissions has been established by extrapolation from the National GHG Inventory figures from 2000-2006, considering the difficulties of estimating the activity data for the areas representing the sources of emissions.

## 8. Aggregated projections of GHG emissions

**Tables 17, 18** and **19** present both the total GHG emissions and GHG removals forecast.

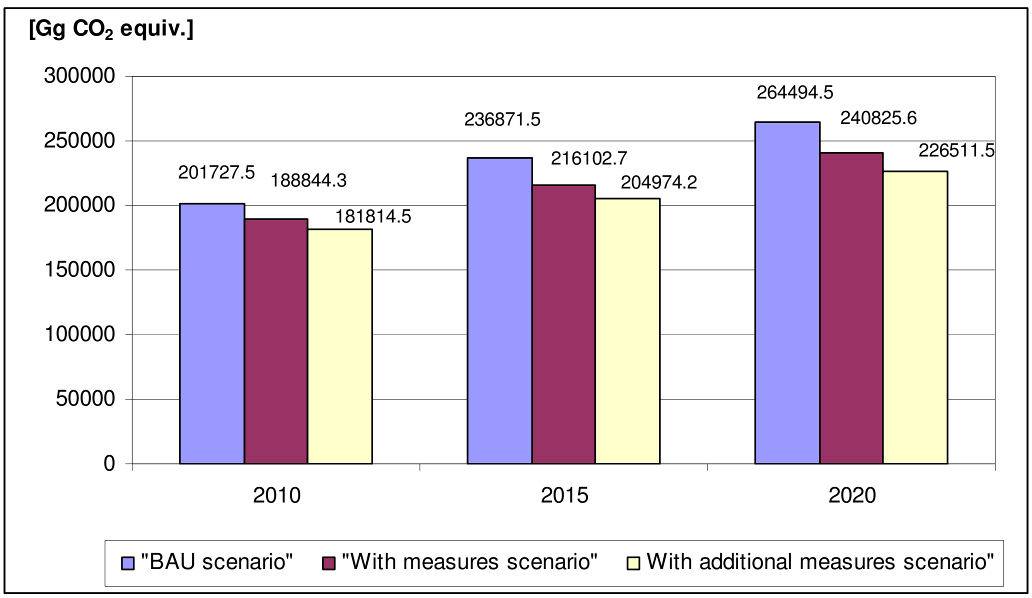
## 9. Conclusions

Both the National Greenhouse Gases Inventory and the GHG projections shows that the main source of GHG emissions (direct and indirect) is the fuel combustion. Therefore, the most important measure for the GHG mitigation is the efficient use of primary energy resources, promotion of renewable energy resources and safe nuclear technologies.

In 2006 the GHG emissions levels were 44% lower compared with the base year. In this respect the GHG emissions levels in the period 2008-2012 are expected to be lower than the Kyoto Protocol target.

The total EU-27 GHG emissions accounted 5142 Mt $CO_2$ equivalent in 2006. The GHG emissions of Romania represented 3% of the EU-27 GHG emissions in year 2006.

Figure 1: GHG emissions forecast

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# Estimation of mean maximum summer and mean minimum winter temperatures over Greece in 2070-2100 using statistical downscaling methods

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**Abstract**
*The present paper focuses on the estimation of mean maximum summer and minimum winter temperatures over Greece in 2070-2100, by applying statistical downscaling methods. Statistical downscaling is based on the view that the regional climate is conditioned by the large scale climatic state and local geographical conditions. From this perspective, regional climate information is derived by determining a statistical model which relates large scale climate variables (predictors) to local variables (predictands). As predictors, we assume the large-scale (1000-500) hPa thickness field from the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP/NCAR) reanalysis. These data cover the extended European area 0°–32.5° E and 30°–55° N with a spatial resolution 2.5°×2.5°, for the period 1958 to 2000. On the other hand, mean maximum summer and mean minimum winter temperatures for 20 meteorological stations over Greece are assumed as predictands. Models were developed individually for each station and season. On a first step, the statistical model is calibrated for the period 1958-1978+1994-2000 and then it is validated for the intermediate years 1979-1993. Afterwards, the same statistical downscaling model is applied in order to generate a present day scenario using the data from the atmospheric General Circulation Model HadAM3P (Hadley Center), for the period 1960-1990 which is the control run period of the GCM. In conclusion, two large scale outputs of IPCC-SRES are fed into these statistical models, in order to estimate the above temperatures in 2070-2100. In the first experiment with the scenario A2 there is a significant increase for the mean maximum summer temperatures (mean minimum winter temperatures) from 1.8°C to 4.9°C (0.8°C-1.7°C). In the second experiment with the more optimistic scenario B2 there is also a significant increase for the mean maximum summer temperatures (mean minimum winter temperatures) from 1.2°C to 3.2°C (0.6°C-1.2°C).*
**Keywords:** downscaling methods, future scenarios

## 1. Introduction

Atmospheric General Circulation Models (AGCMs) are powerful tools used to simulate the dynamics of the atmospheric circulation. One main application of these models is the simulation of the present or future (climate change) statistics of the atmospheric circulation. In this mode of operation the statistics of the simulate climate are compared with those of another simulated climate. GCMs are capable of simulating the global climate, for instance, the intertropical convergence zones, the tropical rainfall areas, etc (Von Storch and Zwiers, 1999). However, the global climate is to great extent the response to the differential solar forcing, the earth rotation and the large-scale structure of the earth's surface (topography). On the other hand, the regional climates are the response of the global climate to regional details. Therefore, it's obvious that GCMs reliably simulate the global climate even though none of the regional climates is simulated skillfully (Zorita and Von Storch, 1999). Their deficiency in simulating adequately the regional climate is due to the fact, that the spatial resolution (280km×280km) provides an inefficient description of the structure of the earth's surface whilst regional climate models may be as fine as tens of kilometers. However, many impact applications require the equivalent of point climate observations and are highly sensitive to fine-scale climate variations that are parameterized in coarse-scale models. This is especially true for regions of complex topography, as Greece.

Statistical downscaling (Sd) is based on the view that the regional climate is conditioned by the large scale climatic state and local geographical conditions. From this perspective, regional climate information is derived by determining a statistical model which relates large scale climate variables (predictors) to local variables (predictands) (Kyselý, 2002; von Storch et al., 1993; Gyalistras et al., 1994). The idea of the Sd consists in using the observed relationships between the large-scale circulation and the local climates to set up statistical models that could translate anomalies of the large-scale flow into anomalies of some local climate variable (Von Storch, 1995).

Predictors relevant to the local predictand should be sufficiently reproduced by the host climate model at the spatial scales used to condition the downscaled responses. Therefore, predictors have to be chosen on the balance of their relevance to the target predictands and their accurate representation by climate models (Wilby and Wigley, 2000). An important assumption that underlies the statistical approach to climate impact assessment is that the relationship between the predictors and the predictands remains valid for periods outside the fitting period (Leung et al, 2003). If the time series used to tune the statistical model are long enough, it is reasonable to assume that they contain many different situations, including those that will be stronger or more probable in an altered climate. If these situations are important for the local climate, the Sd model should be able to identify them in the historical observations and estimate sufficiently the probable impact on the local climate (Zorita and Von Storch, 1999).

The domain of interest and the datasets used in this study are outlined in section 2. In section 3 the canonical correlation analysis (CCA) for downscaling is introduced. Section 4 provides the results of the Sd model (a) in the validation period from 1979 to 1993, (b) in the control period from 1960-1990 and (c) in the future period from 2070 to 2100. Finally, in section 5 the findings of this work are summarized and suggestions for future work are discussed.

## 2. Data description

In our study, we assume as predictors (independent variables) the large-scale 1000hPa-500hPa thickness field from the National Center for Environmental Prediction /National Center for Atmospheric Research (NCEP/NCAR) reanalysis archives (Kalnay et al., 1996) to develop the downscaling models. These data cover the extended European area $0^o$-$32.5^o$ E and $30^o$- $55^o$ N with a spatial resolution $2.5^o$×$2.5^o$, for the period 1958 to 2000. In contrast, we assume as predictands (dependent variables) the mean maximum summer and the mean minimum winter temperatures for 20 meteorological stations evenly distributed over Greece provided from the National Meteorological Service (Fig.1.)

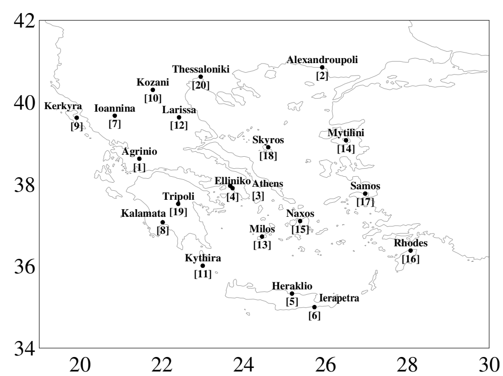

Fig.1. The distribution of the 20 Greek Stations.

Moreover, modeled data derived from the Atmospheric General Circulation Model HadAM3P (Hadley Center) which is similar to HadAM3H, except for some changes in physical parameterizations (Jones et al., 2001), in order to generate a present day scenario for the period from 1960 to 1990. This period will be the control run of the GCM.

In conclusion, two large-scale outputs of IPCC-SRES (Special Report on Emissions Scenarios) are fed into the Sd models, in order to estimate the mean maximum summer and mean minimum winter temperatures in the future period from 2070 to 2100. The A2 emission scenario assumes an increase of the present greenhouse-gas level to 715 ppm whilst under the more optimistic B2 emission scenario, the increase of the present greenhouse-gas level will be restricted at 562 ppm.

We need to address at this point, that for the winter, the study period is from 1959 to 2000, the control period is from 1961 to 1990 and the future period is from 2071 to 2100. For instance, the mean minimum winter temperature for 1961 is computed by using the December of 1960.

### 3. The Statistical downscaling method

Let the predictor's set (thickness field) be represented by the $(p \times 1)$ random vector $\mathbf{X}^{(1)}$. The predictand's set (mean maximum summer or mean minimum winter temperatures) is represented by the $(q \times 1)$ random vector $\mathbf{X}^{(2)}$. Suppose that $E\mathbf{X}^{(1)} = \boldsymbol{\mu}^{(1)}, E\mathbf{X}^{(2)} = \boldsymbol{\mu}^{(2)}$ and $\mathrm{cov}(\mathbf{X}^{(1)}) = \boldsymbol{\Sigma}_{11}, \mathrm{cov}(\mathbf{X}^{(2)}) = \boldsymbol{\Sigma}_{22}, \mathrm{cov}(\mathbf{X}^{(1)}, \mathbf{X}^{(2)}) = \boldsymbol{\Sigma}_{12}$.
The covariance matrices have full rank. The corresponding standardized vectors $\mathbf{Z}^{(1)}$, $\mathbf{Z}^{(2)}$ are given from the following equation:

$$\mathbf{Z}^{(i)} = \mathbf{V}_i^{(-1/2)} \left( \mathbf{X}^{(i)} - \boldsymbol{\mu}^{(i)} \right),\ i = 1,2 \qquad (1)$$

where $\mathbf{V}_i = \mathrm{diag}\left( \sigma_{11}^{(i)}, \sigma_{22}^{(i)}, ..., \sigma_{ss}^{(i)} \right)$, *s=p* if *i=1* and *s=q* if *i=2*.
Firstly, Principal Component Analysis (PCA) is used to explain the variance-covariance structure of the *i-th* set of variables through a few linear combinations of these variables. PCA (Pearson, 1902; Hotelling, 1933) looks for a few linear combinations which can be used to summarize the data, losing in the process as little information as possible. The new linear combinations of the standardized variables $Y_s^{(i)}$, $s = p$ when $i = 1$ and $s = q$ when $i = 2$, are uncorrelated and ordered such that:

$$\mathrm{var}(Y_1^{(i)}) \geq \mathrm{var}(Y_2^{(i)}) \geq ... \geq \mathrm{var}(Y_s^{(i)}) \qquad (2)$$

The principal components (pcs) have variances equal to the eigenvalues of the covariance matrix. The proportion of total population variance, due to the $k\text{-}th$ component in the predictor set is $\left( \lambda_k^{(1)} / p \right)$ and due to the $1\text{-}th$ component in the predictand set is $\left( \lambda_1^{(2)} / q \right)$.
Secondly, the $m$ statistically significant pcs from the domain of the predictors and the $r(r \leq m)$ statistically significant pcs from the domain of the predictands were related to each other by means of Canonical Correlation Analysis (CCA; Hotelling, 1935; 1936; Gyalistras et al., 1994). Based on the eigenvectors of the covariance matrix of the pcs $(\boldsymbol{\rho}_{12}\boldsymbol{\rho}_{21})$, CCA identifies $\min(m,r) = r$ linear combinations $(U_r)$ of the predictor pcs which optimally correlate with respective linear combinations $(V_r)$ of the predictand pcs. The pair $(U_1, V_1)$ of these linear combinations having the largest correlation is the 1st canonical pair and then we determine the 2nd and so on, canonical pairs having the largest correlation among all pairs, uncorrelated with the initially selected pair.
Let **U** and **V** be the $(r \times 1)$ vectors with components the canonical variables $U_j$ and $V_j$, $j = 1,2,...,r$. We define the matrices **A** and **B** whose rows are the canonical weights (i.e. the *m* eigenvectors of $\boldsymbol{\rho}_{12}\boldsymbol{\rho}_{21}$ for **A** and the *r* eigenvectors of $\boldsymbol{\rho}_{21}\boldsymbol{\rho}_{12}$ for the matrix **B**) given by equations (3) and (4), respectively.

$$\mathbf{A} = \begin{pmatrix} \mathbf{a}_1 & \mathbf{a}_2 & ... & \mathbf{a}_m \end{pmatrix}' \qquad (3)$$

$$\mathbf{B} = \begin{pmatrix} \mathbf{b}_1 & \mathbf{b}_2 & ... & \mathbf{b}_r \end{pmatrix}' \qquad (4)$$

$\mathbf{L}_i$ is the diagonal matrix with *j-th* diagonal element $\lambda_j^{(i)}$, *j=1,2,…,m* when *i=1* and *j=1,2,…,r* when *i=2*.
Finally, $\mathbf{Y}^{(i)}$ contains the *m* and *r* statistically significant principal components for *i=1* and *i=2*, respectively. The canonical variables $U_j,\ V_j,\ j = 1,2,...,r$ are given in vector form by the equations (5) and (6) respectively.

$$\mathbf{U} = \mathbf{A}\left( \mathbf{L}_1^{1/2} \right)^{-1} \mathbf{Y}^{(1)} \qquad (5)$$

$$\mathbf{V} = \mathbf{B}\left( \mathbf{L}_2^{1/2} \right)^{-1} \mathbf{Y}^{(2)} \qquad (6)$$

Since the canonical variables are standardized, the canonical weights are expressed in the units of the variable they represent and they indicate the "typical" strength of the mode of covariation described by the weights (Von Storch and Zwiers, 1999). The canonical correlation coefficient $r_{c_j},\ j = 1,2,...,r$ measures the strength of the overall relationships between the canonical variables. In effect, it represents the bivariate correlation between the two canonical variables. The squared canonical correlations are equal to $\lambda_j$, *j=1,2,…,r* the eigenvalues of the covariance matrix $\boldsymbol{\rho}_{12}\boldsymbol{\rho}_{21}$ and they interpret the proportion of the variance in

one of the *j-th* pair of canonical variates (variables) predictable from the other member of the pair (Stewart and Love, 1968).
Furthermore, the canonical variates $U_j$, $V_j$, *j=1,2,…,r* are optimally correlated. This means that once the value of $U_j$ at a particular time is known, an estimation of $V_j$ is possible using the regression model (Glahn, 1968, Von Storch et al., 1993):

$$V_j = \alpha U_j + \beta + \varepsilon_j,\ j = 1,2,...,r \qquad (7)$$

where the error terms $\varepsilon_j$ are assumed to have the following properties:

$$E\left(\varepsilon_j\right) = 0,\ \ \mathrm{var}\left(\varepsilon_j\right) = \sigma^2, \mathrm{cov}\left(\varepsilon_i, \varepsilon_j\right) = 0\ \forall\ i \neq j \qquad (8)$$

The least square estimators of the regression parameters $\alpha, \beta$ are $\hat{\alpha} = r_{c_j}$, *j=1,2,…,r* and $\hat{\beta} = 0$. The estimated values of $V_j$ are given by the following equation:

$$\hat{V}_j = r_{c_j} U_j,\ j = 1,2,...,r \qquad (9)$$

To sum up, the dependent variables (predictands) are estimated by the next equation:

$$\hat{\mathbf{Z}}^{(2)} = \hat{\boldsymbol{\rho}}_{22}\mathbf{Q}\mathbf{L}_2^{-1/2}\mathbf{B}\hat{\mathbf{V}} \qquad (10)$$

where $\hat{\boldsymbol{\rho}}_{22}$ is the covariance matrix of the standardized variables $Z_j^{(2)},\ j = 1,2,...,q$, **Q** an $(r \times q)$ matrix whose columns are the eigenvectors of the matrix $\hat{\boldsymbol{\rho}}_{22}$, and **B**, $\mathbf{L}_2$, $\hat{\mathbf{V}}$ are interpreted by the equations (4), (6), (9) respectively.

## 4. Results of the statistical downscaling models

In our study the predictors are the large scale 1000hPa-500hPa thickness field from NCEP/NCAR (p=154 grid points) and the predictands are the mean maximum (minimum) summer (winter) temperatures over Greece (q=20) for the period from 1958 to 2000 (n=43). Especially, for the winter the starting point is 1959 (n=42). Moreover, the standard definition of seasons was used: winter (December, January, February) and summer (June, July, August). The choice of the predictors is due to the fact that these variables are optimally correlated with the temperature than other climatic parameters (Maheras et al., 2006).
Apart from this, Sd models were developed individually for each station and season. The accuracy of downscaled values has been quantified in terms of a number of performance criteria, such as differences of the mean, variance ratios and correlation coefficients. Comparisons were made between downscaled and observed values for each season and each station.

### *a. Validation of the model*

It is important for any statistical procedure to first be trained (calibrated) and subsequently tested (validated) using different datasets. The calibration period was 1958(59)-1978 and 1994-2000 (regarded as one period, dry period), while the intermediate period 1979-1993 (wet period) was defined for validation and testing.
Standardization is widely used prior to Sd to reduce systematic biases in the mean and variance of GCM predictors relative to observations (or re-analysis data). The procedure typically involves subtraction of the mean and division by the standard deviation of the predictor for a predefined baseline period (the calibration period).
Fig.2 provides the correlation coefficients between the observed and the estimated maximum (minimum) summer (winter) from the wet period 1979-1993. On a seasonal basis the correlation between the observed and estimated temperatures remains high in summer compared to the winter. In summer, the correlation ranges between 0.7 and 0.9 with the maximum values found in Kozani, Kythira, Larissa and Samos. The lowest value (0.6) located in Heraklio.
On the contrary, in winter the maximum value for the correlation coefficient was 0.72 in Naxos and the lowest (0.22) in Kalamata. The correlation decreases in area characterized by mountain ranges and tall vegetation types, such as Thrace and the southern Peloponnese (Kostopoulou et al., 2007). In conclusion, the correlation coefficients except for Kalamata (only in winter) were found to be statistically significant at a 0.05 level.

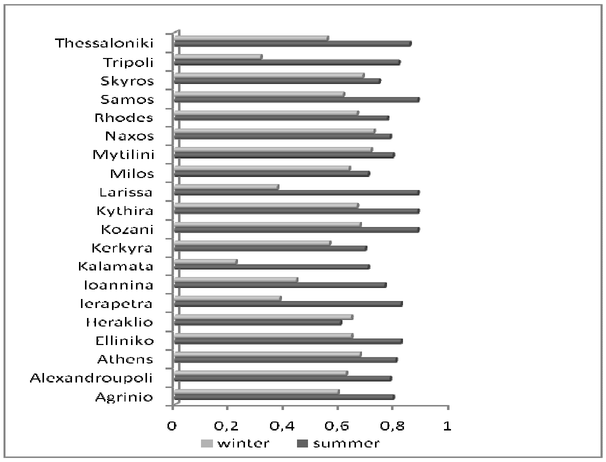


Figure 2: Correlation coefficients between the observed and the estimated temperatures in 1979-1993 for summer and winter.

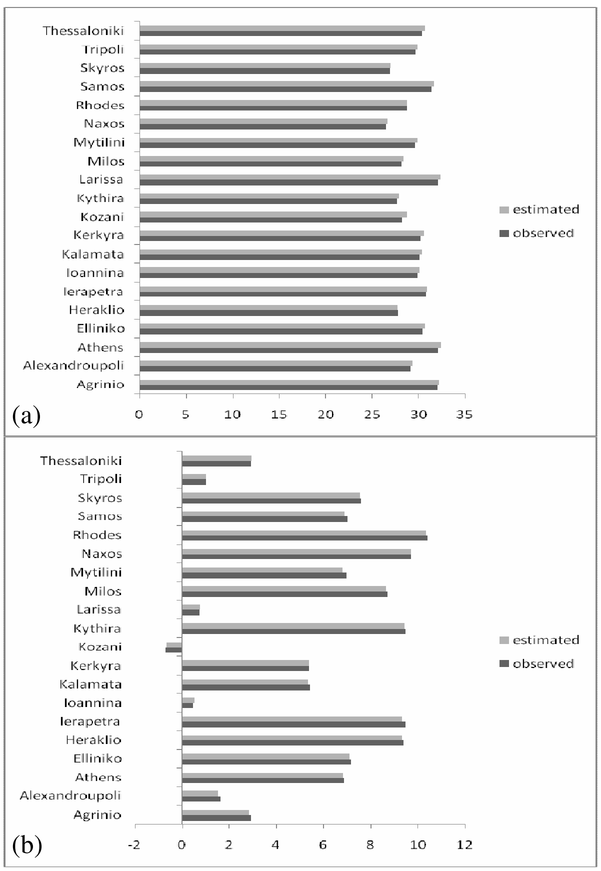


Figure 3: Mean values between the observed and the estimated temperatures in 1979-1993 for (a) summer and (b) winter.

With respect to summer (Fig.3.(a)) the mean differences were not found to be statistically significant at the 5% level. The maximum value (0.5℃) for the mean differences between the observed and the estimated temperatures for 1979-1993 was found in Kozani, whilst the minimum value (-0.06℃) was located in Heraklio. In Rhodes there was no change. Besides, in winter (Fig.3.(b)) the maximum statistical no significant value (-0.15℃) was found in Mytilini, while the minimum value (0.01℃) was located in Kerkyra, Larissa and Tripoli. Taking the above consequences into consideration, we should mention that both the winter and the summer temperatures are very well reproduced.

Another way of rating the ability of the Sd procedure in generating temperatures data is to examine the variability between the observed and the estimated maximum (minimum) summer (winter) temperatures. From this perspective, the variances of the observed and the estimated temperatures are tested at a 0.05 level.

It was found that the variability of the downscaled values is underestimated, nevertheless the variance ratios are not statistically significant at a 0.05 level (Fig.4.(a)). Moreover, in winter, the variances of the estimated temperatures are underestimated. Especially for the stations of western Greece and southern Peloponnese the variance ratios at about half of all stations were found to be statistically significant at the 5% level (Fig.4.(b)).

On the whole, regarding variances (standard deviations) maximum summer temperatures revealed better reproductions. This means, that the standard deviations for temperatures were satisfactorily simulated in summer, contrary to the winter reproductions, which revealed poor results.

*b. The control – run period 1960-1990*

The period 1960(61)-1990 for summer (winter) is widely used as a baseline, since it is of sufficient duration to establish a reliable climatology, yet not too long, nor too contemporary to include a strong global change signal. Most impact assessments, however, seek to determine the effect of climate change with respect to the present and therefore recent baseline periods such as 1960 to 1990 are usually favoured. Also, the observational climate data coverage and availability are generally better for this period compared to earlier ones (IPCC, 2001).

The use of GCM – simulated climate change scenario for the evaluation of climate impact requires a detailed validation of the GCM performance under current climate conditions. If the model is able to reproduce the present day climate reasonably well, then simulations of future climate change can be used with some confidence (Schubert, 1998). The data used for the control run are derived from the atmospheric General Circulation Model HadAM3P (Hadley Center). The calibration period was 1958(59)-2000, while the period 1960(61)-1990 was defined for validation and testing. The map shown in (Fig.5.) provides the mean differences between the observed and the simulated temperatures for the period 1960-1990.

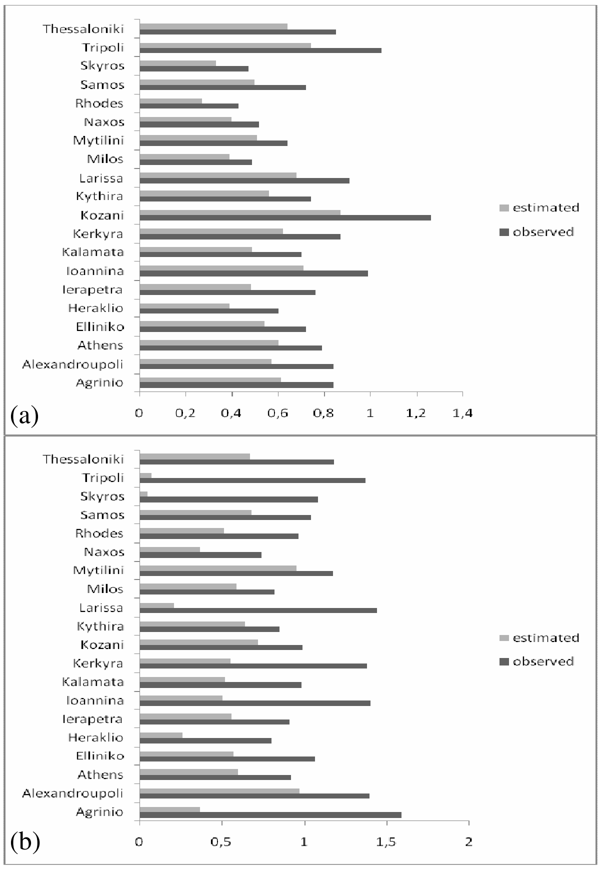


Fig.4. Standard deviations between the observed and the estimated temperatures in 1979-1993 for (a) summer and (b) winter at 20 stations.

In summer, the simulated mean maximum temperatures differ significantly from the observations at 16 stations (except for Agrinio, Ierapetra, Ioannina and Kerkyra) at a 5% level. The maximum value (1.2℃) was found in Athens, whilst the minimum value (0.2℃) was located in Agrinio. In contrast, it seems that the winter mean differences are reproduced better than the mean maximum summer temperatures for the period 1961-1990 (Fig.6). The maximum value (0.4℃) was found in Kozani, while the minimum value (-0.01℃) was located in Kalamata.

Although, the mean differences in summer at most of the stations are found to be statistically significant at a 5% level, the winter mean differences are not found to be statistically significant at all of the stations. The range of winter mean differences is smaller than the summer range. Figures 7(a) and 7(b) compare the variances of the simulated and the observed mean maximum summer and mean minimum winter temperatures, respectively.

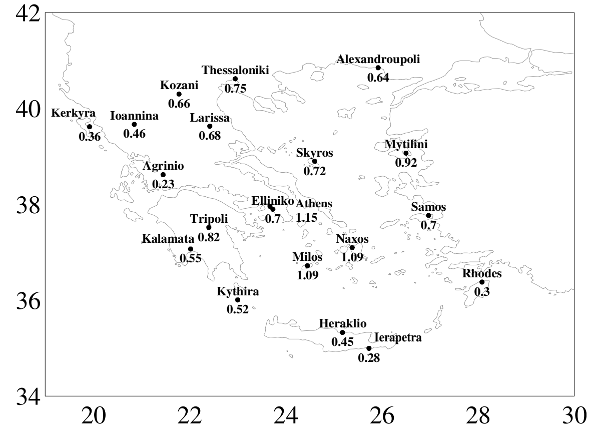


Fig.5. Mean differences between the observed and the simulated temperatures in 1960-1990 for summer.

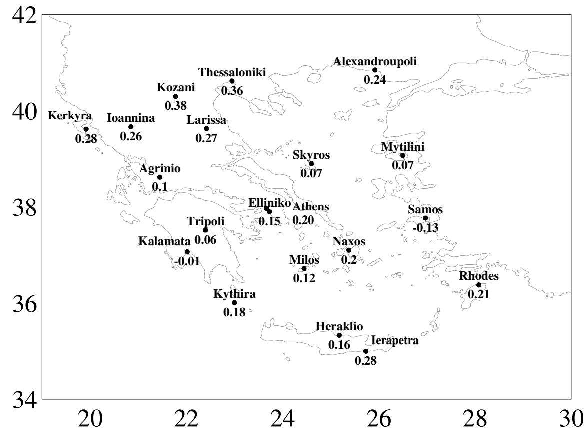


Fig.6. Mean differences between the observed and the simulated temperatures in 1961-1990 for winter.

In summer, the variances are underestimated, except for Mytilini. The variance ratios are found to be statistically no significant. On the contrary, figure 6(b) reveals the poor reproduction of winter variances. At all the stations the simulated variances were found to be underestimated. The variance ratios are statistically significant at a 5% level for the 20 stations.

Consequently, it should be noticed that the simulation of summer standard deviations provided better results. All above for the control run considered, it can be concluded that regarding mean differences, the statistical downscaling models reproduce better the winter time series while regarding the standard deviations mean summer maximum temperatures revealed better reproductions.

*c. The future period 2070-2100*

Success of the statistical downscaling method under present climate conditions does not imply that the model is valid under future climate conditions. This is because the transfer functions may become invalid or the weights attached to different predictors may change. To overcome this situation, the CCA approach assumes that the relationship between predictor and predictand will remain stable in the future climate, an assumption based on physical interpretability of the relationship found and in the ability of the statistical model to reconstruct local climate anomalies from the large scale observation in an independent historical period (Von Storch and Zwiers, 1999).

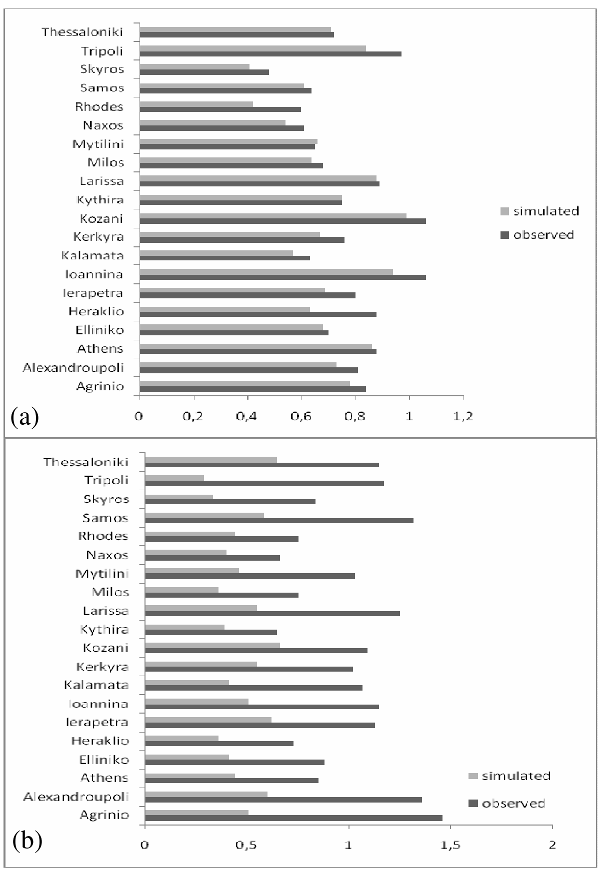


Fig.7. Standard deviations between the observed and the simulated temperatures (a) in 1960-1990 for summer and (b) in 1961-1990 for winter.

The new predictors used in this paper are derived from the IPCC (Intergovernmental Panel on Climate Change)-SRES (Special Report on Emission Scenarios) (Cubasch et al., 2001). Four different narrative storylines were developed to describe consistently the relationships between emission driving forces and their evolution. Only two of them (A2 & B2) are discussed in this study.

The A2 storyline and scenario family describe a very heterogeneous world. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and economical growth and technical changes are more fragmented (IPCC, 2001). In contrast, B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social and environmental sustaininability. It is a world with continuously increasing global population, at a rate lower than A2 and intermediate levels of economic development.

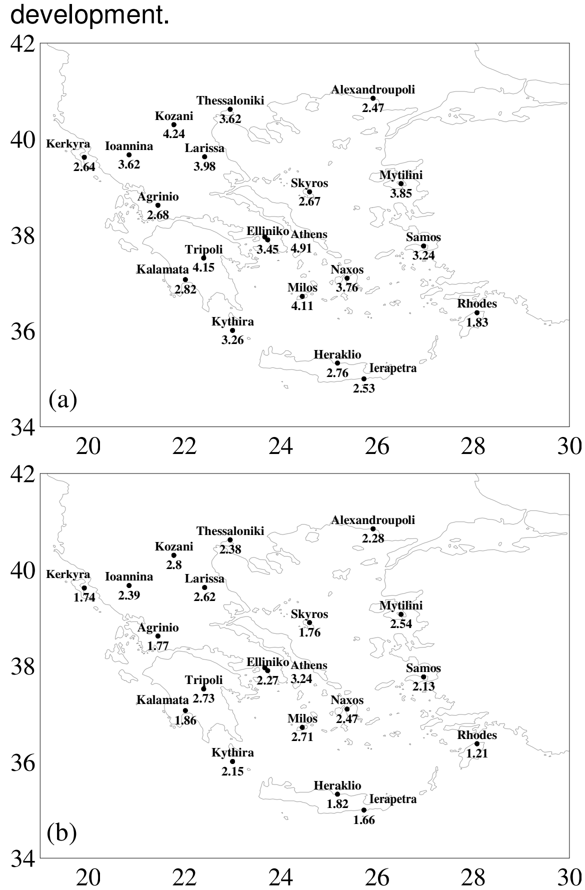


Fig.8. Mean differences of the estimated mean maximum summer temperatures in 2070-2100 compared to GCM-simulated temperatures under present day climate conditions (a) using the SRES-A2 scenario and (b) using the SRES-B2 scenario.

While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional level (IPCC, 2001).
The A2 emission scenario assumes an increase of the present greenhouse-gas level to 715 ppm, whilst, under the more optimistic B2 emission scenario, the increase of the present greenhouse-gas level will be restricted at 562 ppm (today: 370 ppm). The calibration period was 1958(59)-2000, while the period 2070(71)-2100 was defined for validation and testing.
The estimated mean maximum summer and mean minimum winter temperatures are compared with the respective simulated temperatures derived from the GCM present scenario for the control run period. The average temperature response from the HadAM3P using the SRES - A2 forcing for the 30-year average 2070-2100 relative to 1960-1990 is 3.3℃ with a range of 1.8℃ to 4.9℃ (Fig.8.(a)). The maximum value (4.9℃) was found in Athens, whilst the minimum value (1.8℃) located in Rhodes. Stations such as Kozani, Milos and Tripoli exhibit mean differences over 4℃.
On the contrary, only Rhodes provides estimation under 2℃. According to the SRES – B2 scenario, the average temperature response is 2.2℃ with a range of 1.2℃ to 3.2℃, since this scenario is more optimistic (Fig.8.(b)). Moreover, the maximum value (3.2℃) was found in Athens, while the minimum value (1.2℃) was also located in Rhodes. The order of the stations using either the two scenarios A2 and B2 didn't change except for Alexandroupoli.
Furthermore, it should be noticed that Alexandroupoli provides proximate estimations under the two scenarios, i.e. 2.3℃, using SRES-A2 and 2.5℃, using the SRES-B2 scenario.
On the other hand, the winter average temperature response from the HadAM3P using the SRES-A2 forcing for the 30-year average 2071-2100 relative to 1961-1990 is 1.2℃ with a range of 0.8℃ to 1.7℃ (Fig.9.(a)). The maximum value (1.7℃) was found in Alexandroupoli, whilst the minimum value (0.8℃) located in Tripoli. In addition to this, Ierapetra exhibits an estimation of 1.7℃. Skyros and Tripoli are the only stations provided estimations under 1℃. Using the SRES-B2 scenario the average temperature response is 0.9℃ with a range of 0.6℃ to 1.2℃ (Fig.9.(b)). Alexandroupoli exhibits the maximum mean difference (1.2℃), whilst the minimum value (0.6℃) was found in Tripoli. It is crucial at this point to mention that all the stations (except for Agrinio, Alexandroupoli, Ierapetra and Larissa) turn up estimations less than 1℃. This is in a great discrepancy with the results of the A2 emission scenario.

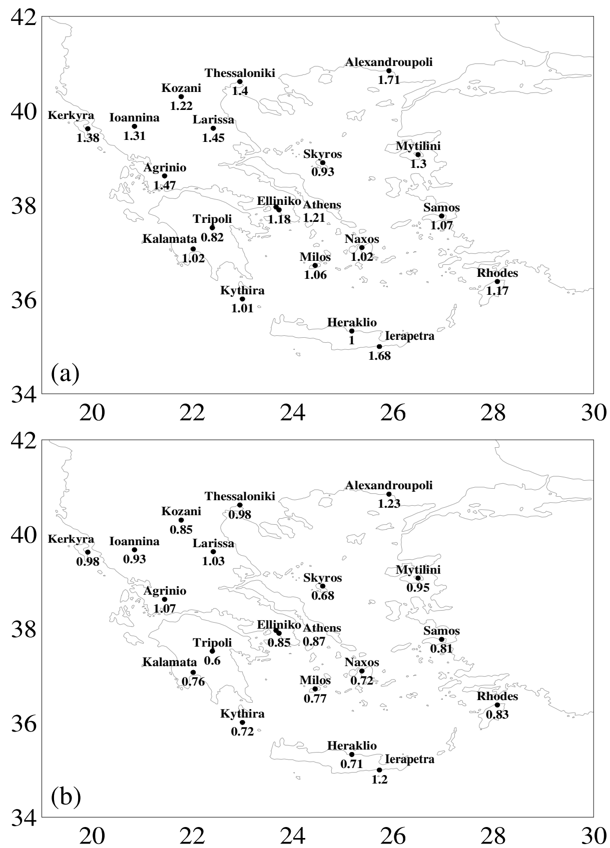


Fig.9. Mean differences of the estimated mean minimum winter temperatures in 2071-2100 compared to GCM-simulated temperatures under present day climate conditions (a) using the SRES-A2 scenario and (b) using the SRES-B2 scenario.

Regarding the standard deviations, the variability of the estimated mean summer maximum temperatures for the period 2070-2100 using the SRES–A2 scenario is overestimated at all the stations (except for Agrinio, Ioannina and Kalamata). The variance ratios for Milos, Naxos and Skyros are statistically significant at a 5% level. As far as the SRES-B2 scenario used, the variability of the estimated summer temperatures is underestimated. At the most of the stations, the variance ratios are found to be statistically significant (Fig.10.(a)).
On the contrary, it was found that the variances between the estimated mean minimum winter temperatures (SRES-A2) and the simulated GCM temperatures under present day climate conditions are of the same order of magnitude. According to the SRES-B2, the winter variances were found to be overestimated, but all of them

are statistically no significant (Fig.10.(b)). It is clear that the Sd models reproduce the winter variances better than the summer variances.

## 5. Summary and Conclusions

This study focuses on the performance of a statistical downscaling method based on CCA in an attempt to estimate the mean maximum (minimum) summer (winter) temperature for the future. The main conclusions drawn for our analysis are summarized as follows. Generally, for the training period 1979-1993, CCA performed sufficiently well and was able to adequately reproduce both the mean and standard deviation of the local variables. The correlation coefficients of the observed temperatures versus the estimated were found to be greater than 0.7 for the summer, while the winter revealed lower correlations. Both for the two seasons, the mean differences between the observed and the estimated values were satisfactorily generated. The analysis revealed the weak divergence of the reproduced standard deviations for the winter, however the summer standard deviations were sufficiently reproduced.

Moreover, for the control period 1960(61)-1990 the summer mean differences were found to be statistically significant, while the simulation of the winter temperatures were found better. Regarding the standard deviations, summer variances were better reproduced compared to the winter variances. It should be noticed, that both the summer and winter variances were found to be underestimated. According to these concludes about the training and the control period, it’s obvious that the method depends on the season and region studied.

Furthermore, before yielding the summaries for the future, it should not be forgotten that the downscaling method assumes that the established statistical relationships also remain valid under future climate conditions. For the future period 2070(71)-2100 the mean differences of the summer were found to be much higher than winter. The average temperature response for summer using SRES-A2 (B2) was 3.3℃ (2.2℃), whilst the respective winter values were 1.2℃ (0.9℃). Regarding the standard deviations, the Sd method showed that the winter variances were reproduced much better (using both scenarios A2 & B2) than in summer. The summer variance was found to be underestimated at the most of the stations, using both the A2 and B2 scenarios. Besides, winter variances under SRES-A2 were found to be underestimated at 14/20 stations. For Skyros and Tripoli was not found any change. Using the SRES-B2 the variability of the winter temperatures was overestimated.

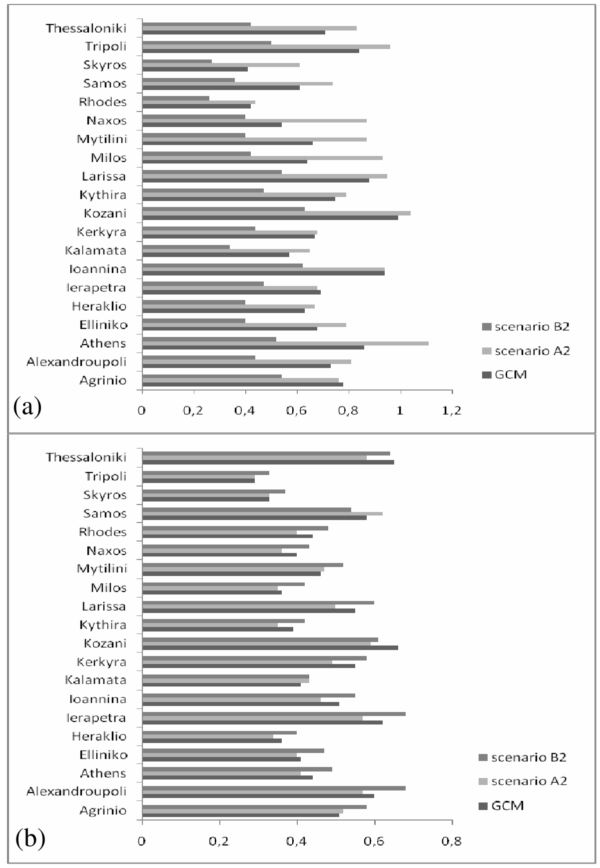


Fig.10. Standard deviations of the estimated mean temperatures in 2070(71)-2100 compared to GCM-simulated temperatures under present day climate conditions using the SRES - A2, B2 scenarios (a) for summer and (b) for winter.

The variance ratios were not found to be statistically significant, which comes in discrepancy with the summer results. On the whole, the winter results were found better than in summer. It is crucial to mention that the results presented in this paper concerning the future changes of Greek summer and winter temperatures strongly depend on the ability of the GCM to simulate large-scale changes of the atmospheric flow, and this ability is much more difficult to estimate.

For future work, our aim is to optimize the reproductions of the variability in the time series, since the downscaling methods revealed weak divergence of the reproduced standard deviations. The estimation of the local variables by the elimination of trends overall data (predictors and predictands) will also constitute the plan of an oncoming study.

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