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Opening

Prof. Dimitrios MAVRAKIS

Director of KEPA

Coordinator of PROMITHEASnet

Excellences, dear colleagues,

It is a great honour and pleasure for me to welcome you to the 5th International Scientific Conference on Energy and Climate Change in this historical building of our University under the sacred rock of Acropolis.

Our Conference is set under the Aegis of the Turkish Chairmanship of the Black Sea Economic Cooperation Organization and also under the aegis of the United Nations Academic Impact Initiative.

The conference is organized by the Energy Policy and Development Centre – KEPA of the National and Kapodistrian University of Athens in the content of PROMITHEASnet activities.

For those participating for the first time allow me to inform you that our network covers a spectrum of multidimensional activities carried out by our institutes that are established in the countries of European Union, Black Sea, Caspian Sea and Central Asia while we are open and welcome cooperation with institutes from Mediterranean, Africa, and Far East.

We have just finished and submitted α join competitive proposal together with twenty universities from the broad area of EU, Black Sea and Mediterranean in the content of FP7 competitive calls. We intend to continue these efforts in the content of the forthcoming HORIZON 2020 program and we invite you to join us.

This year we welcome colleagues from Taiwan, China and Africa who come for first time to Athens. We look forward enhancing our bonds of cooperation with them and their institutions.

We, in PROMITHEASnet, believe in our mission not only to broaden and deepen our scientific cooperation but also as to assist our societies to confront the key challenges that we do face as a global society.

Human population has rocketed to seven billions and new societies and markets emerge, mainly in Asia and Africa. Developing countries are striving for economic development while developed countries find difficulties to adapt their economies to new realities. An increasing number of young people remains jobless while poor and uneducated fight for their survival.

It is time to understand that we have entered an era where education and knowledge transfer and share are the substantial factors for our prosperity. Sustainable economic development and competitiveness in our economies cannot be achieved through austerity measures lowering or diminishing the living standards but by increasing the value of knowledge to products and services.

We cannot ignore the increasing societal pressures for equitable development, in our societies, nor can we ignore the environmental degradation and the Climate Change all over our planet.

We have to act now.

Sustainable economic development is closely associated with the effective confrontation of the Climate Change. Both of them have a global dimension and necessitate the development and implementation of policies and measures characterized by the density of the required new knowledge. New markets and green technologies require decision makers, market players and citizens with the appropriate knowledge.

It is thus knowledge and education that plays and will play a crucial role in the common efforts of our societies to shape our future. As scientists we cannot refrain of our responsibility to join efforts to confront the common challenges.

Our network works on this perspective for more than ten years with the encouragement of the Black Sea Economic Cooperation Organization and recently with the acknowledgement of our efforts by the UNAI.

Apart from this annual scientific conference, we publish a bilingual scientific journal, an Energy and Climate change policy review for the twelve countries of BSEC, a worldwide disseminated newsletter and we also organize a number of ad-hoc events, workshops and seminars.

We promote the establishment of an effective *"Green Alliance"* between the Academicians and the market stakeholders, in our region, with the aim to facilitate the transfer of knowledge and the dissemination of the green policies and technologies in our societies. In this content we are in the final stage to develop and assess Mitigation – Adaptation policy portfolios for twelve countries of the broader area of the Black Sea and of the Central Asia.

I can announce you that in our next 6^{th} International Conference, apart from the usual thematic areas, will focus on the aforementioned portfolios in the context of the relevant EU policies and financing instruments and we do hope that in our discussion members of the BSEC and associated bodies of BSEC will participate actively.

We receive scientists from abroad for short period scientific visits in our premises and we are open to innovative activities promoting and facilitating the economic cooperation and development in our fields of activities with the relevant market stakeholders.

For the information of our distinguished guests allow me to provide some statistical info that describes the identity of our Conference and our continuous efforts to upgrade it.

The Conference is structured among three scientific topics, corresponding to: *i) Energy and Climate Change Policy, ii) Renewable Energy Sources – Energy Efficiency, iii) Environment – Climate Change* plus a Session devoted to the presentation of *Programs and Projects* where we plan to investigate actual ways of future cooperation.

Further to that presentations of this conference, properly upgraded can be published in our scientific "Euro – Asian Journal of Sustainable energy development policy", copies of the last copies of which are available to you.

Dr. Popi Konidari, in her capacity as the Scientific Secretary of the Conference, has carried out successfully and smoothly her difficult tasks. She has received a total number of 73 abstracts that were disseminated for peer view to the international Scientific Committee of the Conference. 24 of them were rejected and 8 of them revised. A total number of 49 have been accepted for presentation and 27 of them will be discussed in the following two days.

Finally allow me to express my deep gratitude to our sponsors, the *Hellenic Public Power Corporation (ΔΕΗ), the National Bank of Greece (ETE) and the Hellenic Public Gas Corporation (ΔΕΠΑ)* that supported us in this difficult economic period, to our media sponsor "SCIENCE VIEW" and last but not least to all people of KEPA for their devotion to the successful organization of the Conference and to the people of this museum for their kind cooperation and availability to provide us any requested assistance plus a tour to the halls of this museum after the end of this opening session.

Ladies and Gentlemen dear colleagues today we are honored by the presence of their Excellences:

- The Secretary General of the Permanent Secretariat of the Black Sea Economic Cooperation, Ambassador *Victor TVIRCUN*
- The Ambassador of Moldova in Athens *Valentin CIUMAC.*
- The Head of Taipei Representative office in Greece, *Ms. Agnes Hwa-Yue CHEN*
- The Economic Counselor of Ukrainian Embassy in Athens, *Mr. Micola TARANENKO*
- The Second Secretary of Russian Embassy in Athens, *Mr. Sergey NIKITIN*
- The Economic Officer of U.S. Embassy in Athens, *Mr. Nicolas WORDY*
- The Economic Officer of U.S. Embassy in Athens, *Mr. Stephen J. O' SULLIVAN*
- The Economic Specialist of U.S. Embassy in Athens, *Mr. Konst. KONSTANTOPOULOS*

Ambassador *Victor TVIRCUN* comes from Moldova and has recently elected as Secretary General of PERMIS.

He is a distinguished diplomat, professor and researcher with more than 200 publications and 12 books. His election as Secretary General of the Permanent Secretariat of BSEC reflects the respect and the recognition of the countries of the region to his ability to carry out the difficult but still challenging task of coordinating an organization where so many different and sometime diverging policies meet, requesting converge.

He honors us with his participation and we do hope that we will continue and further increase the level of our cooperation with PERMIS that former Secretary General Ambassador *Leonidas Chrysanthopoulos* has granted to us.

In this context allow me the honor to invite Amb Victor TVIRCUN to open our 5th Annual Conference.

Amb. Victor TVIRCUN

Secretary General of PERMIS - BSEC

Mr. Chairman,

Professor Dimitrios Mavrakis,

Distinguished Participants,

Ladies and Gentlemen.

I have a great pleasure to represent the Black Sea Economic Cooperation Organization at this 5th International Scientific Conference on Energy and Climate Change, organized by *Promitheas* Network, directed by the Energy Policy and Development Centre (KEPA) and hosted by the National and Kapodistrian University of Athens. On behalf of the Permanent International Secretariat of the BSEC, I would like to convey the organizers and the distinguished participants, best of success.

Our Organization is proud that the origin of the *Promitheas* Network, which consists today of prestigious academic and research institutions from all the BSEC Member States, was a project supported by the Project Development Fund of BSEC. Later the project expanded with funds from the European Union and with generous contributions of the Hellenic Government.

We are also proud that all the previous four *Promitheas* Scientific Conferences were held under the auspices of the successive BSEC Chairmanships-in-Office, and currently the Turkish BSEC Chairmanship.

Since its commencement in 2008, this conference developed into one of the best established discussion fora in the Black Sea Region for energy and climate change issues. The fact that this year the Conference is part of the United Nations Academic Impact (UNAI) activities, after the KEPA inclusion and *Promitheas* Network to the United Nations initiative, testifies to the prestige it gained at international level, benefiting of the participation of scientists, researchers and policy makers from all over the world.

Over the years, these scientific conferences and, more generally, activities of *Promitheas* Network have made significant contributions to the knowledge transfer and development on energy and climate change issues in the BSEC Region. Scientific conferences' papers and discussions, as well as the prepared publications have been very valuable for us, providing food for thought as to where and what BSEC should focus on, so that it could bring added value and act really in support of the needs and interests of its 12 Member States in these fields. I would mention only the *Energy View of BSEC Countries* that has been a useful instrument in investment planning and in promoting regional policies of cooperation in the fields of energy and environment protection.

Energy and environment protection are major areas of action of our Organization, as both are essential elements for sustainable development of the BSEC Member States.

Earlier this year, the Council of the Ministers of Foreign Affairs adopted the *Economic Agenda Towards an Enhanced BSEC Partnership*, endorsed by the BSEC Summit Meeting held in Istanbul on 26 June. It is a major document guiding cooperation in the BSEC framework in order to meet the goals set by the Charter of the Organization and the new challenges and opportunities that the Member States face. The Economic Agenda includes the goal of Sustainable Energy and Development of the Black Sea Energy Market among the priority areas of action of the Organization.

We are beginning a new road of a BSEC regional cooperation in Green Energy. The bases were laid down during the Ministerial Meeting in Nafplion (Greece) on 12 October 2010, which decided to set up a Task Force on Green Energy Development, with the aim of identifying relevant issues within which regional cooperation can be most effective, and also exploring ways to promote green energy investments and innovative green energy projects. Earlier this year we had the first meeting of the Task Force, which decided to start working on the BSEC Green Energy Strategy Paper.

We are grateful to Professor Dimitrios Mavrakis and his team for sending us in this year a significant contribution for the elaboration of this Strategy Paper, in particular very useful considerations on how to proceed in order to bring about an agreement on the content of such a paper and to create the necessary momentum for its implementation. This contribution will be of a great help, I am sure, when the Task Force will take up this issue, at its second meeting scheduled for 12 November 2012.

Our efforts to deepen regional cooperation in the energy and climate sector are usefully complemented by activities undertaken with the contribution and the support from countries and institutions having Observer or Sectoral Dialogue Partner statuses. Among the most prominent ones are precisely those developed by the *Promitheas* Energy and Climate Change Network, which is a good example of BSEC-EU collaboration, as the EU Commission has the status of Observer to our Organization.

As the most welcome trend has prevailed in the last few years in BSEC, to strengthen the project-oriented dimension of the Organization, in 2010, two projects, one regarding climate change and another green economy, were initiated.

The first one is a joint BSEC-UNDP project on “Introducing Climate Change Strategy for the Protection of the Black Sea”, financed by Austria and by the BSEC Project Development Fund, which will commence to be implemented this year. The project’s goals are preparation of a review on the impact of climate change on the Black Sea region ecosystem; development of dialogue between policy-makers, scientists, and civil society; and promoting green entrepreneurship.

The other one is the joint BSEC-GIZ (*Gesellschaft für Internationale Zusammenarbeit* of Germany) project, aimed at developing the legal framework for a green economy in the BSEC Member States. Up to now, three workshops for national audience have been held in all three pilot countries of the project – Azerbaijan, Russia and Ukraine. The studies that are currently worked out by the national experts of these countries will assess legal conditions for a green economy and advise regarding further possible policies and incentives for greening the economy, in particular, in the field of renewable energy and energy efficiency.

One more example which I would mention is the series of Joint Workshops on energy efficiency that BSEC has been organizing in the last years of cooperation with the Japan International Cooperation Agency (JICA) and the Ministry of Energy and Natural Resources of the Republic of Turkey.

BSEC attaches great importance to regional projects that promote sustainable energy development. The Project Development Fund of BSEC is currently financing 30,000 Euros to a feasibility study for renewable energy sources and energy efficiency. Also, the BSEC Hellenic Development Fund (HDF) is currently financing six projects in Renewable Energy Sources and Energy Efficiency, with a total funding of 400,000 Euros.

We look forward to the activities of *Promitheas* Network to continue the contribution of bringing our Member States closer together, and providing valuable input to our activities within the institutional framework of BSEC aimed at enhancing the regional cooperation in the fields of energy and environmental protection. To this effect, we, in the Permanent International Secretariat of the BSEC, will do our best to bring to the attention of the governments of our Member States the aims of *Promitheas* Project and encourage them to take advantage of the knowledge transfer and training it offers.

I would like to conclude by expressing my high appreciation and thanks for the excellent organization and warm hospitality offered by our hosts and by wishing all of you fruitful exchanges in today’s and tomorrow’s meetings.

Energy and Climate Change Policy

Post-Kyoto global emissions trading: Perspectives for linking national emissions trading schemes with the EU ETS in a bottom-up approach

MMag.Dr. Barbara PFLUEGLMAYER
Research Fellow, Department of Energy Law, Energy Institute at the JKU, University Linz
(Corresponding Author)

Dipl.- Volksw. Sebastian GOERS
Researcher, Department of Energy Economics, Energy Institute at the JKU, University Linz

Tel: +43-732-2468-5669
Fax: +43-732-2468-5651
e-mail: pflueglmayer@energieinstitut-linz.at

Address
Energy Institute at the Johannes Kepler University Linz, Altenberger Str. 69, A-4040 Linz, Austria

Abstract: The analysis at hand constitutes a legal, institutional and in particular qualitatively economic assessment of a global climate change policy architecture evolving from the linkage of the European Emissions Trading Scheme (EU ETS) with emerging domestic emissions trading schemes (ETS) worldwide. Initially, the marked-based climate change regimes on global as well as on EU level are reviewed. The efficiency of the complex negotiation process at the global level is assessed by its outcome according to international law. The analysis of EU legislation sets the stage for deducing essential criteria as provisions for an effective linking with other national ETS. These critical design issues are then revealed for each linking candidate in order to evaluate the linking potentials of specific domestic ETS. Moreover, the results of this multi-dimensional approach enable statements on the economic efficiency and ecological effectiveness. In particular the inefficiencies of centralized and decentralized regimes are analyzed. Due to these findings subsequent challenges for a fair and effective allocation of allowances in a bottom-up system without a centralized institution responsible for the limitation of the total amount of certificates are dealt with. As starting point for a discussion on conceivable legal constructions thereto the latter may play a role within the negotiation process towards future climate change combat strategies and agreements.

Keywords: Post-Kyoto, Emissions trading schemes, Bottom-up linking

1. Introduction: The rise and fall of the Kyoto-Protocol

As for the time being the odds are not very promising for a follow-up treaty to the Kyoto Protocol (KP) beyond 2012. Although the United Nations Climate Change Conference in Durban in 2011 has agreed to prepare a legally binding and comprehensive agreement by 2015 which shall enter into force by 2020, there will be only self-imposed greenhouse gas (GHG) reduction targets based on the Copenhagen Accords[1] in the short term. Thus, the question arises whether and which alternatives for a global climate policy exist, allowing the continued application of such market-based mechanisms. For a start a short glance is cast at the performance of international climate policy up to now.

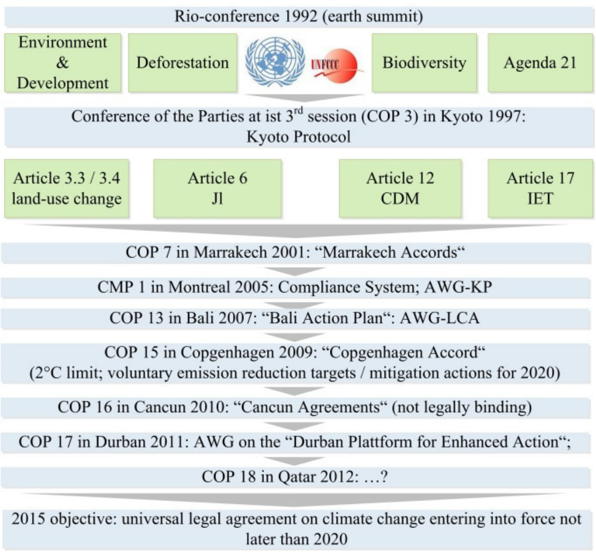
1.1 International climate policy in a nutshell

Figure 1 illustrates that climate protection on a global level comprises a quite complex system of institutionalized multilateral negotiations. Initially, they dealt with a wide range of globally important environmental and humanitarian problems at the earth summit in Rio de Janeiro. With the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) the international community of states finally agreed on particular efforts for abating climate change by reducing the global GHG-emissions. As, in fact, the UNFCCC with 195 Parties has near universal membership, it has to be considered as the starting point of a protracted process of global climate politics on the one hand and the parent treaty of the Kyoto Protocol from 1997 on the other hand.

[1] FCCC/SB/2011/INF.1/Rev.1, pp.3. Compilation of economy-wide emission reduction targets to be implemented by Parties included in Annex I to the Convention.

With the entry into force of the Kyoto-Protocol on 16 February, 2005 its GHG-reduction targets actually have become legally binding on a global level for the first time. Moreover, an important shift to the application of market-based policy instruments has taken place by the introduction of the international emissions trading (IET) and the flexible instruments Joint Implementation (JI) and Clean Development Mechanism (CDM) according to this internationally binding treaty.

Figure 1: Simplified structure of the UNFCCC-regime and its negotiation pathway(s)



Source: Own composition

Besides the above mentioned marked-based instruments the UNFCCC-regime comprises numerous additional mechanisms and programmes aiming at the achievement of the overall political target of a 2-degree limitation to global temperature rise. Hence, a constitutive connection with other important tasks of the Rio-agenda cannot be denied. Missing an appropriate consensus when the KP has been adopted, the latter only contains certain objectives for the subsequent legal implementation. Important examples in this regard are:

- Reducing Emissions from Deforestation and Forest Degradation (REDD, meanwhile enhanced to REDD+),
- Technology Mechanism (established by the Cancun agreements[2]),
- Adaption Fund Board (Article 12, paragraph 8 KP) and
- Green Climate Fund (established in Durban).

All in all, the UNFCCC regulations represent a complex and highly branched network of climate change abatement measures where each aspect of climate change encounters a separate solution and almost each of these approaches entails the establishment of a corresponding institution again. Creating the impression of an almost confusing aggregation of starting-points today, a future aspired really comprehensive follow-up treaty will, on the one hand, certainly have to tackle the challenge of structural simplification, e.g. starting with the consolidation of the "two-track" negotiation process characterized by more or less parallel proceedings of the Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) and the Ad Hoc Working Group on Long-term Cooperative Action (AWG-LCA) as stated by Marauhn and Böhringer (2011). On the other hand the question of international equity has to be answered more sufficiently.

That is affected e.g. by the phenomenon of the so called "low-hanging fruits" which means that the favoured use of flexible mechanisms like CDM restricts the availability of low-cost abatement measures of developing countries in the future. Unless the principle of "common but differentiated responsibilities and respective capabilities" as already proclaimed in the Berlin Mandate (Holtwisch 2006, p.40) is not sincerely taken into consideration in this regard as well as in the context of the global allocation of climate change mitigation burdens and development opportunities, the prospects for gaining a new global climate treaty look rather poor.

1.2 "Bottom-up" climate policies: paradigm shift or temporary solution

In a way all climate law, including the UNFCCC and the Kyoto Protocol, might be subsumed under the term "bottom-up", since there is no world government or other centralized authority that imposes obligations upon states. Accordingly, it is necessary to clarify and define the usage of this important term in the analysis at hand: the notion of "bottom-up" in the present context refers to initiatives taking place at lower scales of organization than the international level. This interpretation is in line with other contributions cited by Peel et al. (2011, pp.462) that describe this trend in climate law as "polycentric", "multilevel" or "sub-global" regulations for instance.

Thus, the legal framework imposed by the international community of states within the UNFCCC negotiation process is regarded as top-down regulation in this context anyway.

Against the backdrop of uncertainty about a follow-up treaty the prevailing dynamic in international climate policy has already changed with the Copenhagen Accord. The top-down specification of targets has then been succeeded by a "bottom-up" oriented approach whereby countries submit their own pledges concerning their envisaged national emissions reductions.

More and more countries try to reach their self-imposed GHG-targets by implementing national

[2] Paragraph 117 of Decision 1/CP.16.

emissions trading systems. From an economic point of view, the global linkage of as many domestic emission trading schemes as possible is expected to increase efficiency and reduce abatement costs in the first place. Moreover, the problem of "carbon leakage" is the further diminishing the more countries are involved in a coordinated climate regime.

After outlining qualitatively the essential requirements of such an alternative bottom-up approach, an overview and a classification of potential candidates for linking is provided. In section 4 the future prospects of the assumed paradigm shift to such a bottom-up approach will finally be critically reviewed.

2. Key design issues for linkages with the EU ETS

As far as factual emission reductions are concerned the European ETS can be considered as quite successful for the time being. However, in a critical view, it has to be admitted that a good deal of the accounted reductions are due to flexible instruments like JI and CDM and therefore they have to be regarded at least sceptically.[3]

The EU ETS contains a legal provision offering the explicit option for linking with other domestic ETS in Article 25 of the ETS Directive[4] itself. After its revision in the course of the EU climate and energy package in 2009, the additional paragraph 1a specifies that "[a]greements may be made to provide for the recognition of allowances between the Community scheme and compatible mandatory greenhouse gas emission trading systems with absolute emissions caps established in any other country or in sub-federal or regional entities" which will enter into force at the beginning of 2013.
Accordingly Schüle and Sterk (2009) highlight a key role by the EU in the process of linking provided that a potential linking candidate meets certain quality criteria. Hence, the European scheme has been looked at and particularly analyzed with regard to such characteristic elements that are critical for other domestic ETS for linking with the EU-ETS.[5]

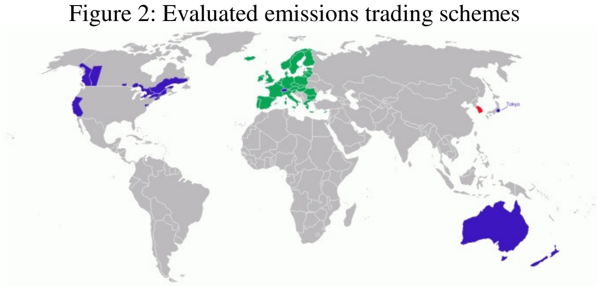
Table 1 provides an overview of the considered key design issues which are assessed regarding their characteristics for linking (with the EU ETS).

3. Potential linking candidates

3.1 Existing and planned ETS – an overview

Various ETS are already in place around the world, are being planned or enter into an important stage of design. The following existing and planned ETS in 2012 are examined with regard to the above discussed key design elements:
- ETS of Switzerland
- Japan Voluntary Emission Trading Scheme (JVETS)
- Japan – Integrated Domestic Market of Emissions Trading (IDMET)
- Tokyo ETS
- South Korea ETS
- Australia – Carbon Price Mechanism (CPM)
- New Zealand ETS
- USA – Regional Greenhouse Gas Initiative (RRGI)
- USA and Canada: Western Climate Initiative (WCI)
- USA / California: Global Warming Solutions Act of 2006 (GWSA)
- Canada / Alberta: Greenhouse Gas Reduction Program

Figure 2: Evaluated emissions trading schemes



Note: EU ETS is displayed in green color, operating ETS are displayed in blue color and planned ETS are displayed in red color.
Source: Own compilation

The authors are aware that this does not represent a complete overview. Because of the lack of publicly available information, particular ETS cannot be considered for the analysis (Hood 2010, pp. 29-30):

- Brazil
- China
- Ukraine/Russia/Kazakhstan/Belarus
- Chile
- Turkey
- Mexico

The New South Wales Greenhouse Gas Reduction Scheme (GGAS) was closed by July 2012.
As far as the United States of America is concerned, all imposed initiatives are regionally negotiated to fix a model rule and are then implemented on state level. In this regard the RGGI and the WCI are examined, with California being analyzed as an example of a WCI member state. The Chicago Climate Exchange, a voluntary but legally binding emission trading system, is also not taken into consideration as it was closed in

[3] Remember e.g. the "low-hanging fruits" mentioned in section 2 above.
[4] Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community as amended by Directive 2004/101/EC, Directive 2008/101/EC, Regulation (EC) No 219/2009 and Directive 2009/29/EC.
[5] Based on the legal rules for the up-coming trading period 2013 -2020.

2010. Federal legislative proposals on climate and energy in the US Congress, such as the Waxman-Markey Bill, the Kerry-Boxer Bill and the Kerry-Liebermann Bill were also not evaluated as their entry into force is rather improbable.

Table 1: Key design elements and implications for linking - Overview

Key design elements		Possible linking effects & obstacles	Economic efficiency	Environmental effectiveness	Consistency with EU ETS
Scheme's coverage	Gas coverage	Linking to an ETS with a broader (lower) coverage → abatement options ↑ (↓)	basically given	basically given	desirable but not essential
	Sector coverage	Double-counting is possible, competition concerns may arise	basically given	basically given	desirable but not essential
	Mandatory / voluntary	Voluntary market may induce leakage and entrance of net allowance sellers	highly at risk	highly at risk	essential
	Direct / indirect emissions	Double-counting is possible, competition concerns may arise	basically given	basically given	desirable but not essential
	Opt-in and opt-out provisions	Unrestricted provisions may distort the coverage of the system and its ecological effectiveness, provision should be defined before linking in case of costless allocation in the linking partner's ETS	basically given	basically given	desirable but not essential
Definition and recognitions of trading units		Mal-functioning legal framework may disable a fair recognition, trading and eligibility of diverse units	basically given	basically given	desirable but not essential
Cap setting	Absolute / relative caps	Total emissions of ETS with relative cap are not known in advance → Liquidity of allowance ↓	highly at risk	highly at risk	essential
	Stringency of caps	Significant wealth transfers between linking partners in case of non-comparable stringency levels	basically given *(if overall cap is stringent)*	basically given *(if overall cap is stringent)*	politically required
Allocation Methodology		Differences may occur because of subsequent allocation rules that imply distributional impacts	given	basically given *(if overall cap is stringent)*	desirable but not essential
Temporal Flexibility	Continuance	Same continuance levels are necessary regarding credibility and commitment	highly at risk	highly at risk	essential
	Banking	Market and competition distortions in case of heterogeneous banking rules	basically given	basically given	politically essential
	(unrestricted) Borrowing	Destabilisation of penalty and compliance system	highly at risk	highly at risk	essential
Monitoring, reporting and verification		In equally stringent frameworks rigorous monitoring processes and robust basis for verification and calculations by equal MRV standards	basically given	basically given *(if systems are equally stringent)*	not essential if systems are equally stringent
Compliance and penalty framework	Use of offsets	Market and competition distortions in case of heterogeneous crediting rules, eligibility criteria and quantitative limits	basically given	basically given	politically required
	Penalty system	In equally stringent frameworks, high penalties lead to incentives to reduce CO_2 emissions	basically given *(if systems are equally stringent)*	basically given *(if systems are equally stringent)*	not essential if systems are equally stringent
	Price cap	Price cap will be applied in the overall linked systems	highly at risk	highly at risk	essential

Source: Own composition, partly based on Mace et al. (2008)

Table 2: General issues of different emissions trading schemes

	Level of imple-mentation	Starting date	Time scale / continuance	Participating countries	Relative vs. absolute cap	Cap
EU ETS	Operating	1st January 2005	2005-2007 2008-2012 2013-2020	EU-27 + Iceland + Liechtenstein + Norway	absolute	2005-2007: 4.3% reduction of proposed amount of allowances 2008-2012: 6.5% reduction of 2005 emissions 2013-2020: 21% reduction of 2005 emissions
ETS Switzerland	Operating	1st January 2008	2008-2012	Switzerland	absolute	8% reduction of 1990 levels 2008: 3.3 $MtCO_2$, 2009: 3.1 $MtCO_2$, 2010: 3.4 $MtCO_2$
JVETS	Operating	1st January 2005	since 2005	Japan	absolute	2005: 1.3 $MtCO_2$, 2006: 1.1 $MtCO_2$, 2007: 1.6 $MtCO_2$, 2008: 3.4 $MtCO_2$, 2009: 0.6 $MtCO_2$
IDMET	Operating	Autumn 2008	2008-2012	Japan	absolute / relative	50% of Japanese CO_2 emissions, 70% of the Japanese industry's CO_2 emissions
Tokyo ETS	Operating	1st April 2010	since 2010	Tokyo (Japan)	absolute	2010-2014: 6% reduction for 5 year average 2015-2019: 17% reduction for 5 year average
South Korea ETS	Planned	2015	2015-2020	South Korea	absolute	30% cut from "business as usual" emissions by 2020
CPM	Operating	1st July 2012	1st July 2012-30th June 2015 from 1st July 2015 on	Australia	absolute	5% cut from 2000 emissions by 2020; from 1st July 2015 annual cap setting
New Zealand ETS	Operating	2008	2008-2009 2009-2010 2010-2012 2013-2020	New Zealand	absolute	No overall reduction target; emitting as long as allowances are available
RGGI	Operating	1st January 2009	2009-2011 2012-2014 2015-2017	9 North-Eastern + Mid-Atlantic US States	absolute	2009-2014: stabilisation at 2009 levels; 10% reduction below 2009 levels by 2018
WCI	Operating	1st January 2012	2012-2014 2015-2017 2018-2020	California + 4 Canadian Provinces	absolute	15% reduction below 2005 levels by 2020
GWSA	Operating	1st January 2012	2012-2014 2015-2017 2018-2020	California	absolute	15% reduction below 2005 levels by 2020
Alberta	Operating	2007	since 2007	Alberta	relative	Annual reduction of energy intensity by 12%

Source: Own compilation based on publicly available information retrieved from related governmental websites as of 30 June 2012.

Table 3: Coverage issues in different emissions trading schemes

	Gas coverage	Sector coverage	Mandatory vs. voluntary participation	Direct vs. indirect emissions	Opt-in and opt-out provisions
EU ETS	CO_2, N_2O from acid production, PFCs from the aluminium sector	Power stations, combustion plants, oil refineries, coke ovens, iron and steel plants and factories making cement, glass, lime, bricks, ceramics, pulp, paper and board, aviation	Mandatory	Direct	Opt-out for small emitters and hospitals from 2013 to 2020
ETS Switzerland	CO_2	Cement, pulp and paper, glass, ceramic production	Voluntary alternative to mandatory CO_2 tax	Direct	Participation of private sectors is possible
JVETS	CO_2	energy-intensive industry, power generation, transport and service	Voluntary	Direct	-
IDMET	CO_2	energy-intensive industry, power generation, transport and service	Voluntary	Direct	-
Tokyo ETS	CO_2	Commercial buildings and industrial facilities with consumption of fuels, heat and electricity $\geq$ 1,500 kBOE	Mandatory	Direct	-
South Korea ETS	CO_2	Industry (power generation, manufacturing), buildings (universities, amusement parks), waste (incineration, waste water treatment), agriculture and forestry	Mandatory	Direct	-
CPM	CO_2, CH_4, N_2O, HCFs, PHCs, SF_6	Entities with emissions $\geq$ 25 ktCO_2; stationary energy, industrial and fugitive processes, non-legacy waste, partly transport	Mandatory	Direct	Entities acquiring, generating or importing amounts of taxable fuel
New Zealand ETS	CO_2, CH_4, N_2O, HCFs, PHCs, SF_6	Certain production and deforestation activities, fuel users and suppliers	Mandatory for certain production and deforestation activities and fuel users and suppliers	Direct and indirect	-
RGGI	CO_2	Electricity sector (fossil fueled electric power plants $\geq$ 25MW)	Mandatory	Direct	Single states can opt in and out
WCI	CO_2, CH_4, N_2O, JDCs, SF_6 and NF_3	Electricity and Industry (facilities $\geq$ 25 k t CO_2e) from 2012, transport, commercial and residential fuel from 2015	Mandatory	Direct and indirect	Single states can opt in and out
GWSA	CO_2, CH_4, N_2O, JDCs, SF_6 and NF_3	Electricity and Industry (facilities $\geq$ 25 k t CO_2e) from 2012, natural gas and liquid fuels and transport fuels from 2015	Mandatory	Direct and indirect	-
Alberta	CO_2	Facilities emitting $\geq$ 100 k t CO_2 per year	Mandatory	Direct	-

Source: See Table 2.

Table 4: Issues regarding trading, allocation, temporal flexibility and compliance in different emissions trading schemes

	Allocation	Banking	Borrowing	Use of offsets	Penalty system	Price cap
EU ETS	Gratuitous (Grandfathering, benchmarking) 2005-2012: at least 90-95% 2013-2020: ~ 50%	Yes	No	JI- and CDM-Offsets	100 €/tCO_2 & delivery in next period	No
ETS Switzerland	Gratuitous, according to the firm's targets	No	No	JI- and CDM-Offsets	From 2010: 36 CHF/tCO_2	CO_2 tax: 36 €/t CO_2
JVETS	Gratuitous, amount = base year emissions, average for past 3 years – committed reduction	Yes	No	JI- and CDM-Offsets	Disclosure of performance & redemption of subsidies for CO_2 reduction	No
IDMET	Gratuitous	Yes	Yes	JI- and CDM-Offsets	-	No
Tokyo ETS	Gratuitous, amount = base year emissions x (1-compliance factor) x compliance period (5 years)	Yes	No	Domestic Offsets	Monetary fine (¥ 500,000) & requirement to reduce 1.3 times the shortage & disclosure of performance	No
South Korea ETS	Gratuitous (95%) based on historical emissions, designed capacity and best available technology (BAT)	-	-	CDM Offsets	3 times of market price, disclosure of performance	-
CPM	Full auctioning from 1st July 2015; gratuitous allocation for emissions-intensive trade-exposed sectors	Yes (from 1st July 2015)	5% of year ahead (from 1st July 2015)	JI-, CDM- and domestic ACCU-Offsets from 1st July 2015	Strict civil and criminal penalties	$A 20/t$CO_2$ above international carbon price from July 2015 – July 2018; yearly increase by 5%
New Zealand ETS	Partial gratuitous allocation	Yes	No	JI-, CDM-, Carbon Sinks-, Kyoto-Offsets	30 - 60 NZ$/t$CO_2$ & delivery in next period	25NZ$/t$CO_2$
RGGI	Auctioning of approx. 90% of allowances, allocation of rest is up to individual state law	Yes	No	JI- and CDM-Offsets	3 allowances per missed t CO_2 are automatically deducted for the next period	-
WCI	Auctioning of approx. 10% of allowances; rest is up to individual state law	Yes	No	JI- and CDM-Offsets	3 allowances per missed t CO_2 are automatically deducted for the next period	-
GWSA	At the beginning high degree of free allocation, then gradual shifts to auctioning	Yes	No	JI- and CDM-Offsets	3 allowances per missed t CO_2 are automatically deducted for the next period	-
Alberta	-	Yes	No	-	Purchase of Alberta-based offset credits, Emission Performance Credits or pay to the Climate Change and Emissions Management Fund	-

Source: See Table 2.

3.2. Identification of linking candidates

In economic terms the central principles of climate policy in the context of linking are the generation of economic efficiency by an overall cost-minimisation and by environmental effectiveness through the decrease of GHG emissions as defined by the reduction target.

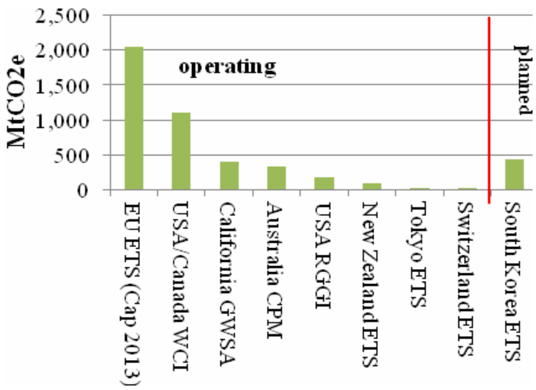
Recalling the above mentioned key design elements the following requirements are crucial in order to provide economic efficiency and ecological effectiveness of a linked ETS:

- The participation is mandatory for all relevant emitters, and all important emissions and sectors are covered by the scheme.

- The cap is designed absolutely and stringently and displays serious but realistic ecological targets.
- Allocation is achieved by auctioning whereas temporal flexibility is induced and guaranteed by the possibility of linking, but no unrestricted borrowing is allowed.
- Ecologically ambitious offsets are accepted for compliance only to a certain degree whereas price caps may endanger the ecologic and economic performance depending on the actual carbon price.
- Monitoring, reporting, verification and registry are operated via electronic systems.
- Penalty frameworks contain a monetary fine and the obligatory delivery of missing allowances.

In order to identify serious candidates for a reasonable bottom-up approach, the selected schemes have been studied with regard to the revealed key design elements where consistency with the EU ETS is essential for an economically efficient and environmentally effective linking. From this analyses as disclosed in Tables 2, 3 and 4 a basic linking scenario is derived. It is defined by the combination of the EU ETS with the following linking candidates: ETS of Switzerland, Tokyo ETS, South Korea ETS, Australia CPM, New Zealand ETS, USA – Regional Greenhouse Gas Initiative, USA and Canada – Western Climate Initiative and USA / California – Global Warming Solutions Act of 2006. Hence, in this scenario the linked system covers approx. 4,200 m tCO_2e. As the Australian scheme fixes the allowance price within the first three years of trading, a linkage in the short term is not possible. However, an efficient cap-and-trade design is focused from July 2015, turning Australia into a serious linking partner.

Figure 3: Covered CO_2e emissions of linking candidates



Source: Own compilation based on the results of Section 3.2.

4. From Global Commons to Global Governance

On the one hand, from an economic point of view linking the EU ETS and other existing or emerging domestic ETS is highly desirable, because a linkage between two or more ETS will generate a market with a larger number of participants, increasing the diversity of control costs and increasing the liquidity of the market (Flachsland 2009). This will further contribute to reducing the overall cost of compliance in the concerned systems while improving the overall economic efficiencies of the ETS. Furthermore, linking ETS also provides internationally competing companies a wider regulatory framework with a single price of carbon. Finally, an ETS linkage does not only promote technology transfer and sustainable development, but also the creation of a larger global market (Jaffe and Stavins 2008).

On the other hand, the risk that the cap setting process of the linking partners turns into a multi-stage game with strategically acting states cannot be denied. This again may increase the overall cap and reduce the total abatement and lead to lower economic efficiency and ecological effectiveness as compared to a situation without linkage.

Hence, a polycentric climate governance approach system will also require a central authority to a certain extent – in particular concerning the allocation of allowances and compliance. The crucial point is eventually, how to limit the amount of certificates in a fair and also effective way – so that the ecologically necessary climate change mitigation is promoted.

A solution may be found in the area of global governance which can be defined as governing beyond the nation state. Governance without government indicates that activities at the international level are characterized by shared goals but are not backed by a formal legal authority. The focus of global governance is thus on cooperation and harmonization in order to attain compliance (Behrens, 2009).

4.1 Notes on the institutional design of a bottom-up-approach

In principle, also in a decentralized system bilateral and/or multilateral treaties might be the main mechanism for meeting the necessary regulations, because in the context of international law this is the only way to create a binding type of cooperation. But though such agreements are based on reciprocal obligations and in some cases even safeguarded by the possibility of sanctions and measures to remedy default, an effective implementation still has to face several challenges.

Above all, a country's sovereignty is not limited by the conclusion of an international treaty in principle. A single state party might change its mind any time and decide to cancel its participation, as it never has lost its full capacity to act that way. Hence, the application as well as the withdrawal from a treaty itself, often depends above all on political and not least economic considerations. In particular, a country's reputation plays a very important role in international law and beyond doubt, has a significant impact on a country's decision to enter into a climate change treaty or a linking agreement with the EU.

Recalling the above mentioned economic preference of a common mandatory cap (Helm 2003, D'Amato and Valentini 2011), a realistic approach will have to concede that national governments might neither be willing to give up their sovereignty and subordinate to a global government, e.g. by transferring the competence of cap setting to a particular central authority. Nevertheless, the question has to be raised which opportunities can be envisaged to settle this conflict. Answering the problem of a global common, any proposals thereto will obviously relate more or less to the field of global governance.

4.2 Creation of a new institution or improvement of the UNFCCC

In principle, a new institution could be installed by the means of bi- and/or multilateral linking agreements, which is responsible for matters that need to be dealt with concerning the linkage of ETS. These include in particular the setting of reduction targets for each participating country, the managing of the auctioning of the corresponding overall allowances if required, and the monitoring of their compliance as ultimate authority. In practice, such structures do already exist within the UNFCCC, so that it seems more reasonable to look for a way to adopt and improve these frameworks with the aim of harnessing them in a bottom-up driven system. For the latter, simplification and tightening of the UNFCCC structures seem to be especially necessary. In addition, global fairness aspects have to be taken into account more seriously, with respect to the permits allocation (Cao 2010, Ekardt and von Hövel 2009, Onigkeit et.al. 2009).

Despite such future improvements of the UNFCCC, political acceptance will be hard to attain, as Canada's recently announced withdrawal from the KP shows. Hence, even a stronger compliance system might not guarantee enduring adherence.

In this context the authors propose to uncouple the crucial matter of centralized cap-setting from the political negotiation procedure – perhaps by installing an independent scientific body for that purpose. In general the widely accepted Intergovernmental Panel on Climate Change (IPCC) seems to be predestined for this task. Based on future provisions in a follow-up treaty to the KP for instance, this scientific body could be assigned to appoint a nationally and politically independent executive board responsible for a science-based and comprehensive cap-setting, comprising all states involved in a globally linked ETS.

4.3 Linking climate and trade

Traditionally, international trade and climate change communities look at each other with suspicion, judging "globalisation" as key source of climate problems on the one hand and criticising that climate policies are harming trade and economic growth on the other hand. Nevertheless, a future reconciliation of both regimes might show the greatest promise concerning climate politics. For instance, the WTO constitutes one of the most effective international organisations due to compliance rules that are thoroughly implemented. Without bringing together the objectives of fostering trade and climate change, and recognising them as two sides of the same coin, effective emissions reductions measures will be slowed down significantly.

Additionally, it should be taken into account that every – more or less globally – linked ETS will have to face carbon-leakage problems (Monjion and Quirion 2011) depending inversely on the number of schemes involved. Thus, such a system might in any case have to introduce some kind of adjustments and need to take WTO rules into consideration.

5. Conclusions and Outlook

In face of the uncertainty about a binding post-2012 climate policy agreement and thus for a consolidated top-down global emissions trading scheme, building such a system step by step by national links could be an important contribution to a sustained development of market-based climate policies.

Based on the findings of the presented evaluation of possible linking candidates, the crucial question is whether such a bottom-up system will be able to meet the climate change challenges in an adequate manner without any centralized institution adopting certain common regulations at an international level such as the allocation of certificates within a certain cap.

The finally presented ideas of creating an independent cap-setting authority on the international level as well as the – also only touched upon – issue of reconciling trade and climate interests open up a wide field for more profound investigation. In addition, they might have to face significant political obstacles. Nevertheless, a discussion on new legal structures has to be launched urgently in order to promote the future development of international climate politics.

Acknowledgments

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Strengthening Sustainable Energy Policies within the Covenant of Mayors Initiative

Vangelis MARINAKIS[1]
M.Sc. Electrical & Computer Engineer

Alexandra G. PAPADOPOULOU
Dr. Chemical Engineer

John PSARRAS
Professor

[1]Corresponding Author
Tel: +30-210-772-2083/3514
Fax: +30-210-772-3550
e-mail: vmarinakis@epu.ntua.gr

Address
National Technical University of Athens, School of Electrical & Computer Engineering,
Management & Decision Support Systems Laboratory (EPU-NTUA), 9 Iroon Polytechniou str.,
157 80, Athens, Greece

Abstract: Nowadays, the regional authorities demonstrate their willingness to implement sustainable local energy policies, especially through their participation in the Covenant of Mayors. Due to the several difficulties the regional governments are facing, it is important for them to be adequately supported at the technical level. This is particularly true for the rural communities. In this context, the necessity for customization of existing methodologies and tools for Sustainable Energy Action Plans (SEAPs) preparation to the rural communities' needs is becoming more evident. The aim of this paper is to present a coherent and transparent approach, properly adapted to the rural communities' characteristics, in order to support the regional authorities in the required procedures for the development and monitoring of a SEAP. The proposed approach consists of six basic steps, including among others identification of the community's characteristics and needs, energy registry development, energy and emissions baseline elaboration, stakeholders' engagement, scenario analysis and monitoring. The adopted approach has been incorporated into an integrated web application, thus constituting an intelligent tool for the elaboration of rural communities' SEAPs. The proposed approach is partly based on emerging insights from the project "Rural Web Energy Learning Network for Action (eReNet)", supported by the Intelligent Energy Europe programme.

1. Introduction

The new European Union 2020 sustainable development vision provides an opportunity to tackle the current financial and economic crisis through maintaining local jobs and wealth (EC, 2008). The regional authorities demonstrate their willingness to implement sound energy policies at their territories, especially through their participation in the Covenant of Mayors. It is important for them to be adequately supported, in this respect.

This is particularly true for the rural communities. Some rural communities, and in particular those which are most remote, depopulated or dependent on agriculture, already face particular challenges as regards growth, jobs and sustainability, situation that will be aggravated by the financial and economic crisis in the coming years. These challenges include lower income levels, an unfavourable demographic situation, higher unemployment rates, a slower development of the tertiary sector, weaknesses in skills and human capital, a lack of opportunities for young people and a lack of necessary skills in parts of the agricultural sector and food processing industry.

These areas do not possess adequate capacity to implement Sustainable Energy Actions Plans (SEAPs) and promote Renewable Energy Sources (RES) and Rationale Use of Energy (RUE) applications towards the development of sustainable energy communities. In particular, some typical problems in these communities' route towards energy sustainability are:

- Lack of technical capacity and resources;
- Lack of direct initiatives at local/regional authority level;
- Unawareness to the state-of-the-art, potential

benefits, best practices and successful applications;

- The experience and best practices of energy sustainable development has not yet been systematically disseminated in these communities;
- Misconceptions of related local key actors (developers, architects and facilities' managers) about new or unfamiliar technologies - Difficulties in achieving economies of scale, as in the case of the major cities or territories with urban characteristics;
- Poor understanding of the broader community that the cost of inaction is far more than the cost of action and of the development opportunities arising from sustainable energy investments for the region.

In this context, the necessity for customization of existing methodologies and tools for SEAPs' preparation are becoming more evident.

The aim of this paper is to present a coherent and transparent approach, properly adapted to the rural communities' characteristics, in order to simplify the required procedures for the development and monitoring of a SEAP. The adopted approach has been incorporated into an integrated web application, thus consisting an intelligent tool for the elaboration of rural communities' SEAPs.

Apart from the introduction, the paper is structured along four sections. The second section outlines the most known methodologies and tools for SEAPs' elaboration. The main steps of the proposed approach are presented in the third section. The fourth section is devoted to a short description of the methodology's web application. Finally, the last section is summarizing the key conclusions that have arisen in this paper.

2. Background

In the international literature, many existing studies propose methodologies and tools for the SEAPs' development and elaboration, especially within the framework of co-financed Intelligent Energy Europe (IEE) activities, as reviewed by Bertoldi et al. (2009):

- Multiplying Sustainable Energy Communities – A Blueprint for Action (MUSEC);
- "Energy Planning Guidance", Partnership Energy Planning as a tool for realising European Sustainable Energy Communities (PEPESEC);
- "Sustainable Urban Transport Plans", Moving Sustainably, etc.

In particular, there are methodologies that lay emphasis on the collection of energy data, while others provide alternative methods for stakeholders' engagement in the development of SEAPs, as shown in Figure 1. At the same time, some methodologies provide targeted guidance for different sectors of SEAPs, such as industry and transport. Moreover, relevant tools provide a series of guidelines, such as «Toolbox of Methodologies on Climate & Energy», «Covenant capaCITY Training Platform» and «CoMO's e-learning».

	Energy Data Collection	Local Stakeholders Participation	Actions Evaluation	Monitoring & Targeting	Buildings, Institutions/ Facilities	Industry	Transportation	Local Electricity Production	Awareness Raising
ENOVA	★★	★	★★	★	√	√	√	√	
BELIEF	★	★★★	★	★					
CLIMATE	★	★	★	★★★	√	√	√	√	√
ICLEI	★★	★	★	★	√	√	√	√	√
MODEL	★★★	★	★	★					
MOVING	★	★★★	★★	★★			√		
MUSEC	★★	★	★	★★★					
PEPESEC	★★	★★	★	★					
SECURE	★	★	★	★					

Figure 1. Existing Methodologies and Tools

Therefore, based on the detailed review of the abovementioned methodologies, the following points can be noted:

- Focused on urban territories, overlooking the special characteristics of rural communities;
- Emphasizing on specific SEAP sectors, such as urban transportation (rail, buses etc) and industry;
- Do not offer an integrated framework for the SEAPs' development and especially the selection of sustainable RES/RUE technologies.

In this context, there is the need for a methodology, appropriately customized to the rural communities' characteristics, addressing especially the interested stakeholders who are not "experts" in the field, saving resources and time. Indeed, the methodology should be a useful instrument towards strengthening of learning local communities and the development of SEAPs, taking into consideration the lack of technical capacity and the limited human and financial resources of the rural communities.
A detailed description of the customized methodology is presented in the following section.

3. Methodology

The general philosophy of the customized methodology is presented in Figure 2. It should be noted that the contribution of the methodology is highlighted with the "green" color in the following figure. The main steps of the methodology are based on the Covenant of Mayors guidelines and the available SEAP methodologies and tools developed in the past, taking also into consideration the specific characteristics of the rural communities (EC, 2010; Bertoldi et al., 2009). More specifically, the approach consists of 6 basic steps as described in the following paragraphs:

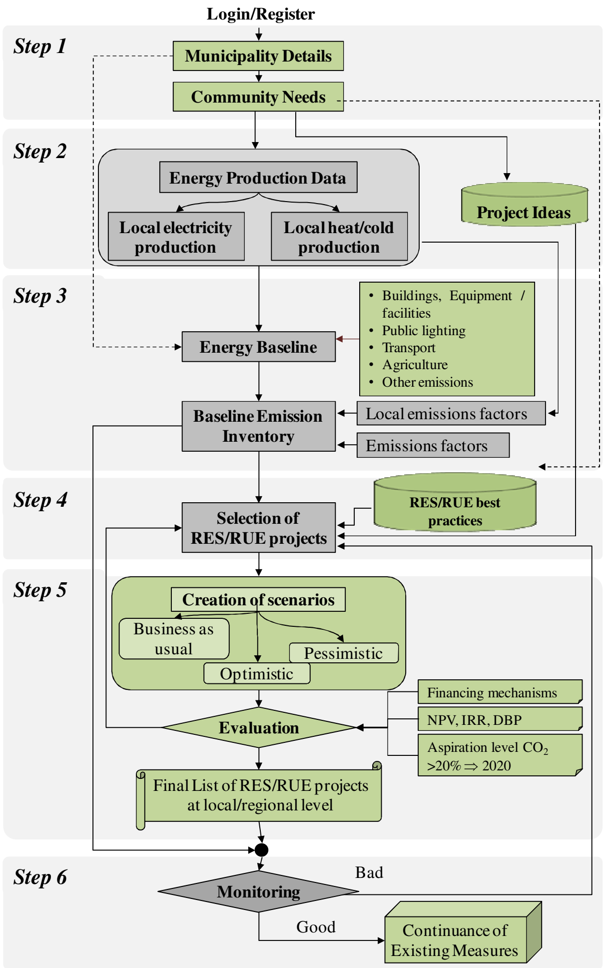

Figure 2. The General Philosophy

3.1 Rural Community's Characteristics and Needs

The 1st step includes the following:

– Municipality details: Basic facts about the community (population and housing statistics, land use statistics, waste data), providing an overview of the community characteristics. The population and housing statistics can be used in Step 3, for the energy consumption estimation under the different approaches.
– Community needs: Information about the general climatic characteristics (e.g. temperature, wind speed, solar radiation, etc), as well as indication (with "√" in the checklist) of the RES/RUE actions of interest/ priority in the region (wind, hydro, RUE actions in municipal buildings etc). These data are used in Step 4 for the prioritization of the alternative RES/RUE best practices according to the community needs.

3.2 Energy Registry

The 2nd step includes energy production data and project ideas, as follows:

– Energy production data: Development of an energy registry of the already operating thermal power stations, RES and selected RUE (co-generation, district heating etc) projects in the region, based on input by the related energy companies. Based on the collected data, the local emission factor for electricity and heat/cold is calculated.
– Project ideas: Identification of promising RES/RUE projects for the development of the apposite registry. The provided information will be used in Step 4 for the selection of RES/RUE projects by the local authorities. Project ideas may originate from the public or private sector

3.3 Developing Energy and GHG Emissions Baselines

The user can choose among eReNet customized methodology and selected existing SEAPs' methodologies and tools for the development of the Baseline Emission Inventory.

– Existing methodologies: Web development of the technical approach suggested by selected methodologies such as ENOVA and MODEL. The user should also provide the relevant data for the development of the Baseline Emission Inventory.
– Customized methodology: A common technical approach has been adopted, as well as the necessary algorithms for the calculations of the energy and GHG emissions baseline have been developed. It should be noted that specific emphasis has been given in the sectors of agriculture, forestry and fishery, taking into consideration that these sectors constitute an important part of the energy consumption and thus the Baseline Emission Inventory of the rural communities. The main aim is to facilitate the calculation of energy consumption per sector (especially for tertiary sector, residential buildings, private and commercial transport, agriculture, etc), providing alternative calculation methods to the users.
  Indeed, the approach used for the data entry regarding all buildings and facilities' energy consumptions is either based on existing aggregated data for a specific type of facilities (e.g. schools), either on the bottom up approach and/or use of appropriate estimations based on the international literature where considered necessary.

3.4 Stakeholders' Engagement in the Decision Making Process and RES/RUE Priorities' Identification

For the selection of the key stakeholders in the municipality, a list of stakeholders has been developed. In addition, a series of activities for the stakeholders' engagement has been identified, based on the relevant initiatives within the framework of IEE, namely PEPESEC, BELIEF, MODEL, SECURE, etc.
Moreover, a database with the alternative RES/RUE

best practices has been developed for rural communities, based on existing SEAP methodologies and tools, that have already been developed, also in other IEE initiatives, as well as existing SEAPs accepted within the Covenant of Mayors framework.

The user can choose among the RES/RUE best practices database and the identified RES/RUE projects' registry (Step 2). The user will have the possibility to modify the related data (installed capacity, amount of energy production or energy savings etc), thus supporting the users in the identification of major opportunities for interventions, in order to facilitate the local authorities' energy and climate strategy (quantitative objectives for establishing the medium and long term energy vision).

More than 100 alternative RES and RUE best practices have been identified from PEPESEC, MUSEC, SEC Tools, Network of small rural communities of energetic neutrality (RURENER), RES and RUE Stimulation in Mountainous - Agricultural Communities towards Sustainable Development (Mountain RES/RUE), managEnergy etc, as presented in Figure 3.

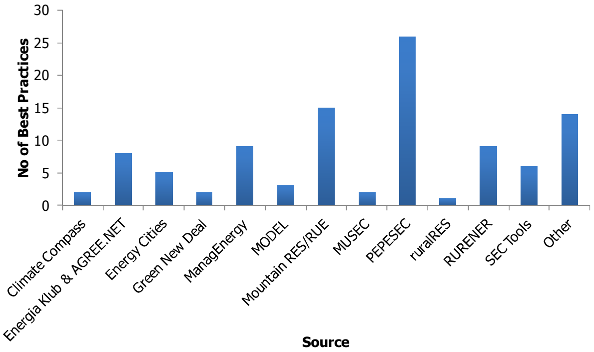

Figure 3. Sources of the RES/RUE Best Practices

Moreover, the number of RES/RUE best practices per project type is presented in Figure 4.

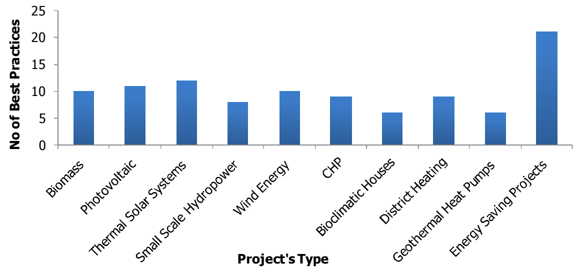

Figure 4. RES/RUE Best Practices per Project Type

3.5 Scenario Analysis

Based on the projections for a series of parameters (indicatively the community's population growth, personal income, etc), a series of scenarios ("Business As Usual – BAU", "Economic Prosperity Scenario" and "Economic Recession Scenario") have been developed (Swan and Ugursal, 2009; Simões et al., 2008; Mirasgedis et al., 2007).

More specifically, these scenarios will present the growth of the community's energy demand and CO_2 emissions by the year 2020, in order to evaluate whether the selected combination of actions is concerned enough to achieve the target of at least 20% CO_2 reduction by 2020.

The required data at national level for the development of the related algorithms are the following:

- Rate of population growth at national level by 2020
- Rate of electricity and fuels prices by 2020;
- Rate of energy consumption growth by 2020 of the tertiary, residential, industry, transport and agriculture sector;
- Rate of per capita gross domestic product by 2020;
- Annual heating and cooling degree days.

Table 1. Contribution of each Parameter to the Projected Energy Consumption

	Tertiary	Residential	Industry	Transport	Agriculture/ Forestry/Fishery
Rate of population growth at municipal level	20%	35%	-	35%	30%
Rate of per capita gross domestic product at municipal level	35%	25%	-	15%	-
Annual heating and cooling degree days at municipal level	10%	10%	-	-	-
Rate of electricity and fuel prices	10%	10%	40%	20%	20%
Rate of energy consumption growth of the relevant sector at national level	25%	20%	60%	25%	50%
Development of the road network	-	-	-	5%	-

Table 1 presents the key parameters for each sector (tertiary, residential, transport, agriculture/ forestry/ fishery and industry sector). However, each parameter has a different weight on the projected energy consumption. To this end, the level of contribution of each parameter to the projected energy consumption is based on experts' contribution.

In addition, this step includes financial feasibility assessment of potential bankable RES/RUE projects through the development of web forms for the financial data entry and of the algorithm for the calculation of a series of financial indicators, such as Net Present Value (NPV), Internal rate of Return (IRR) and Discounted Pay Back Period (DBP). These web forms will also take into consideration the possibility of developing these projects under different financing mechanisms (loans, subsidies, third party financing). This financial assessment will also allow the stakeholders to select the most promising options to include them under the local or national structural funds.

3.6 Monitoring

The final step includes the monitoring of the overall procedure. During this step, the user will provide updated data about the energy production and energy consumption per sector. In this way, the new GHG emissions will be compared with the initial GHG emissions of the Baseline Emission Inventory. In this context, the user will identify if the proposed targets are being successfully achieved, so the selected actions should continue or further measures should be taken.

4. Web Application

The customized methodology has been realized into web application, thus consisting an intelligent tool for the elaboration of rural communities' SEAPs. Basic aim is to simplify the required procedures for the development and monitoring of a SEAP and to provide the necessary support to the user, utilizing the possibilities of incorporating help features, explanatory texts and real life examples, in order to significantly reduce the required elaboration time for the development of a SEAP.

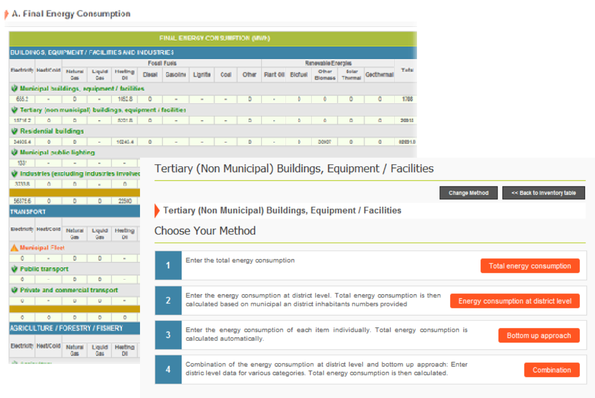

Figure 5. Web Application

In this context, a 1st version of the tool for SEAPs' elaboration is publicly accessible through the web address http://erenet-tools.epu.ntua.gr (Figure 5). The final tool available in 6 languages (EN, BG, GR, DE, PT, CR) will be accessible in February 2013.

5. Conclusions

Most of the existing methodologies and tools for SEAPs' elaboration are focused on urban territories, overlooking the special characteristics of rural communities, emphasizing also on specific SEAP sectors (e.g. urban transportation, industry). For instance, the agricultural sector (agriculture, forestry, fishery) distinguishes for its high energy consumptions in the rural communities, but it is generally treated as part of the tertiary sector and installations..

In this context, the proposed customized methodology will be a very useful instrument towards strengthening learning local communities in the development of SEAPs. In particular, the methodology will support the communities to the following:

- Development and implementation of SEAPs (e.g. measures to be implemented, indicators linked to specific technical and/or organizational measures, monitoring);
- Elaboration of baseline CO_2 emission inventory at municipal level (boundaries, sectors, emission factors, calculations);
- Identification and pre-feasibility analysis of bankable projects.

The realization into web application of the customized methodology contributes to the simplification of the required procedures for the development and monitoring of a SEAP resulting in the consequent reduction of the overall time required, and the development of bankable projects answering the local needs.

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Sustainable Development and Climate Change

Dr. Andrea MANESCHI
Professor of Economics, Vanderbilt University

Tel: +01-615-383-0298
Fax: +01-615-343-8495
e-mail: andrea.maneschi@vanderbilt.edu
Address: Vanderbilt University, Box 1819-B, Nashville, TN 37235, USA

Abstract: This paper aims to trace the connections between sustainable development (or sustainability) and climate change, where "sustainable development" is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". In a simple aggregative macroeconomic framework, climate change can be viewed as an externality that affects output negatively via the buildup of greenhouse gases in the atmosphere. If greenhouse gases are incorporated in an economy-wide production function, their effects militate against the realization of sustainable development, and lend credence to the "strong sustainability" assumption according to which neither physical capital nor human capital nor technical change can substitute for natural capital in the form of climatic conditions. Sustainable development is consistent with the ethical perspective of intergenerational equity, whereby future generations are entitled to a climate (and related standard of living) comparable to the present one.

Keywords: climate change, sustainable development, strong sustainability

1. Aggregate production functions and the environment

"Sustainable development" was defined in 1987 by the World Commission on Environment and Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This paper traces the connections between sustainable development (or sustainability) and climate change, where climate change is regarded as the most important externality or external diseconomy that affects output negatively on a global scale. The aim of the paper is the pedagogical one of illustrating in simple economic terms the nature of this externality and deriving its policy implications.

In an aggregative macroeconomic framework, environmental quality is increasingly seen as an important variable that conditions the level of overall output together with more traditional variables such as labor, capital or the level of technology. If Y is total output or real Gross Domestic Product (GDP), K is capital, L labor, T the level of technology, and Q environmental quality, total output in any year can be expressed as

$$Y = f(K, L, T, Q), \qquad (1)$$

where Y varies positively with all the variables in the production function f. Expressions of this type have often been used to portray the influence of the environment on the macroeconomic level of activity.[1]

Each of the independent variables in the production function (1) presents challenges of conceptual definition as well as statistical estimation. Of the many factors that affect the quality of the environment Q, environmental economists have increasingly focused their attention on the atmospheric concentration of greenhouse gases, G, as a variable that affects negatively not only the level of output, but the quality of life more generally via a rise in global temperature, with its adverse ecological and economic effects that include extreme and potentially catastrophic weather patterns. If G is regarded as a proxy variable for Q, eq. (1) is rewritten as

$$Y = F(K, L, T, G), \qquad (2)$$

where $\partial F/\partial K$, $\partial F/\partial L$ and $\partial F/\partial T$ are all positive and $\partial F/\partial G$ is negative. Technical progress is portrayed by an increase in T, and labor force growth and capital accumulation by increases in L and K. Hence increments of capital, labor and the level of technology have positive effects on output, while emissions of greenhouse gases affect it negatively. Writing FK for $\partial F/\partial K$, etc., and differentiating Y with respect to time t, we obtain

$$dY/dt = FK(dK/dt) + FL(dL/dt) + FT(dT/dt) + FG(dG/dt). \qquad (3)$$

[1] For example, Stern (2007, p. 140)

If I is the rate of gross investment and D the annual depreciation of the capital stock, the growth of the capital stock is given by the accounting identity

$dK/dt = I - D.$ (4)

Let A be the amount of greenhouse gases that is naturally absorbed within the year by the land biosphere and the surface water of the ocean, as well as by policies such as reforestation. By analogy with (4), the growth of the stock of greenhouse gases is given by the accounting identity

$dG/dt = E - A,$ (5)

where E is their rate of emissions. Substituting (4) and (5) into (3), we obtain

$dY/dt = FK (I - D) + FL(dL/dt) + FT(dT/dt) + FG (E - A).$ (6)

Since $FG < 0$, emissions that are not absorbed tend to reduce the level of output and thus threaten its sustainability. The first term on the right hand side of (6), FK (I - D), is the marginal product of capital multiplied by the rate of net investment. In order to maintain the level of output in the face of the environmental degradation caused by emissions, a fraction of net national investment is thus not available to augment either consumption or the capital stock.

2. The Kaya Identity

The level E of emissions can be decomposed by the so-called Kaya Identity[2] into

$E = N \times (Y/N) \times (J/Y) \times (E/J),$ (7)

where N is population, Y/N is per capita income (= GDP per capita), J/Y is the energy intensity of GDP measured in joules J of energy per unit of GDP, and E/J is the carbon intensity of energy use measured in emissions of carbon dioxide per joule of energy use. This identity shows that emissions will be greater, the greater are population, per capita income, energy intensity and carbon intensity. It may alternatively be written in terms of emissions per capita as

$E/N = (Y/N) \times (J/Y) \times (E/J).$ (7a)

In recent years a close correlation has been observed between emissions per capita and income per capita: “Across 163 countries, from 1960 to 1999, the correlation between CO_2 emissions per head and GDP per head (expressed as natural logarithms) was nearly 0.9”[3]. Another study found that in the United States, over a period of several decades, a 1% rise in GDP per head led to a nearly 1% increase in emissions per head, holding other variables constant. However, emissions per capita remained practically constant after GDP per capita reached around $15,000 (in 1987 dollars).[4] The relationship between emissions per capita and income per capita must be interpreted with great caution since it has been subject to unpredictable structural breaks due to changes in the last two variables on the right hand side of (7a). Energy intensity has declined substantially in most developed countries as economies shifted from being primarily oriented toward manufacturing to becoming relatively “weightless” and oriented toward services. Carbon intensity has also fallen globally, though to a lesser extent.

Some writers have argued in favor of an “environmental Kuznets curve” where emissions or concentrations of pollutants per capita increase with per capita income as an economy develops, reach a peak, then continue declining after per capita income reaches a threshold level. One explanation offered for this is that environmental improvements are income elastic: as economies develop and consumers get richer, they wish to spend a higher fraction of their income on cleaning and improving the environment. If this were true with regard to carbon dioxide, economic development would automatically lead to a decline in global emissions without the need for additional policies on the part of the government. While the environmental Kuznets curve has been confirmed for some local pollutants such as nitrogen oxides and sulfur dioxide, it fails with regard to greenhouse gases such as carbon dioxide (CO_2). The reduction of the emissions of CO_2 (used here as a shorthand for greenhouse gases) takes the nature of a public good, since such a reduction implemented by a particular society has almost no effect on the concentration of CO_2 around the globe. Most members of society may not even be aware that their own behavior leads to an increase in greenhouse gases. Even if they were aware of this, they would have no incentive to curb their behavior unless they were assured that other countries were taking similar steps.

A sounder rationale for the incipient negative relationship between emissions per capita and income per capita observed in the US5 is a structural shift in the pattern of production toward services and similar weightless commodities. Developing countries have a long way to go before they reach levels of income per capita comparable to that of the US, and reverse the steep increase in their emissions per capita in the past few decades. Even in wealthy countries structural changes are unpredictable, and a positive link between emissions and income per capita may reappear in the future. Some goods and services continue to have a high income elasticity of demand, as is true for example of air transport and car transport (the latter of growing importance in less developed countries). The

[2] Kaya (1990). It is also referred to as the IPAT relation or $I = P \times A \times T$, where I is the impact on the environment caused by the emissions of greenhouse gases, P is population, A is affluence or income per capita, and T is technology.

[3] Neumayer (2004), as reported in Stern (2007), p. 205

[4] Huntington (2005)

[5] Schmalensee et al. (1998)

recent lack of responsiveness of emissions to income growth in wealthy countries such as the US can also reflect the outsourcing of manufacturing activity to less developed countries, with a corresponding increase in global emissions.[6]

Other variables that govern emissions per capita in (7a) are the technology used and the sectoral structure of the economy, represented by energy intensity J/Y and carbon intensity E/J. The product of energy intensity and carbon intensity in identity (7a), (J/Y) × (E/J) = E/Y, yields emissions per unit of GDP, referred to as greenhouse-gas intensity. Since both energy intensity and carbon intensity have fallen globally over the past three or four decades, the former more than the latter, greenhouse-gas intensity has fallen even more. Energy intensity depends first on the sectoral structure of the economy in terms of agriculture, manufacturing, services and other sectors; and secondly on the efficiency with which each sector uses energy, some uses being much more energy-intensive than others. Some changes in technology are gradual in nature, others (such as the current revolution in lighting technology from incandescent bulbs to fluorescent lights to LED light bulbs) occur more quickly.

Carbon intensity, E/J, which represents the volume of greenhouse gases emitted per joule of energy generated, depends on the fuels used and the accompanying technologies. The extent to which different fuels are used, in turn, depends on their relative prices, whose trends are subject to considerable volatility. Some fuels and technologies create much larger emissions than others. Energy sources such as hydroelectric, nuclear, wind or solar produce negligible amounts of carbon dioxide. Different fossil fuels produce different emissions per unit of energy generated. Natural gas (or methane) has a much lower carbon intensity than petroleum, which in turn has a lower carbon intensity than coal. The widely different mix of technologies and fuels used across the world means that nuclear-energy oriented countries such as France show a much lower carbon intensity than the US or China.

In terms of the Kaya Identity (7), we can conclude that global emissions have risen over time because of the worldwide growth of population and per capita income, both of which expanded by around 80% over the period 1970-2005. Greenhouse gas intensity fell much more modestly by around 20% over the same period, so that "the net change in emissions between 1970 and 2005 was an increase of 75%".[7] These global statistics mask huge differences in growth rates among countries, since the growth rates of both population and per capita income in developed countries have recently been much lower than those registered in developing economies. Moreover, none of these variables change over time independently of each other in either set of countries. As is well known, affluence represented by per capita income has strongly affected population growth over the past few centuries. Other variables, such as health care and education, have also affected demographic growth via their effects on mortality and morbidity.

3. Ecological and economic impacts of greenhouse gas emissions

The Intergovernmental Panel on Climate Change (or IPCC) has published several emissions scenarios based on different assumptions about how the world's ecology and economy might evolve in the course of the 21st century.[8] These scenarios differ in terms of the rates of economic growth and population growth in the poorer and the richer parts of the world, the effects of economic growth on population growth, the introduction of new technologies versus increased reliance on fossil fuels such as coal, their policies (or lack of policies) addressed toward sustainable growth and environmental protection leading to a reduction in energy intensity. The divergence in growth rates between rich and poor countries in some scenarios, or the convergence among them, are important alternatives portrayed by these scenarios. By integrating equation (5) over time, these emissions scenarios are then converted by means of carbon-cycle models into time series of the atmospheric concentration of CO_2, starting from a level of 390 ppm (parts per million) in 2010 and reaching levels between 550 and 900 ppm in 2100. Even the lower limit of 550 ppm represents twice the atmospheric concentration of CO_2 in pre-industrial times, while the upper limit more than triples that level. The IPCC plotted similar scenarios for other greenhouse gases such as methane and aerosols, and for anticipated land-use changes, but their significance is much smaller than the anticipated buildup of CO_2.

The atmospheric concentrations of CO_2 produced by the different emissions scenarios are then fed into climate change models to calculate the projected radiative forcing. The ensuing rise in average global surface temperature by the end of the 21st century ranges between 1.8 and 3.6°C (compared to the increase of 0.7°C experienced in the 20th century). Even if emissions were to fall abruptly to zero after the year 2000, temperatures would continue to increase by 0.4°C throughout the 21st century (a phenomenon referred to as "committed warming"), because of the buildup of CO_2 in the world's atmosphere and the need for the Earth to re-establish thermal equilibrium. Projections of atmospheric carbon buildup and the associated temperature anomaly are plotted as far as

[6] On the empirical realism of the environmental Kuznets curve hypothesis, see Stern (2007), chapter 7 and Annex 7.A, on which much of the above argument is based.

[7] Dessler (2012, p. 122). The last few paragraphs are indebted to Dessler (2012, chapter 8).

[8] IPCC (2000).

the year 3000 based on varying assumptions about the growth of emissions and their possible phase out at various points in time. The atmospheric concentrations of CO_2 are expected to reach values as high as 1200 ppm leading to temperature anomalies as high as 8°C.

The temperature increases projected for the 21st century as a consequence of the build up of greenhouse gases will have marked and, in some countries, dire impacts on their economic welfare, symbolized in (2) by the negative partial derivative $\partial F/\partial G$ of the production function. Estimates of the macroeconomic costs of climate change are described in chapter 6 of Stern (2007), titled "Economic Modelling of Climate-Change Impacts", on the assumption of continued business as usual (BAU) instead of attempts at climate mitigation. One of Stern's conclusions is that "With 5-6°C warming, models that include the risk of abrupt and large-scale climate change estimate a 5-10 % loss in global GDP, with poor countries suffering costs in excess of 10%. The risks, however, cover a very broad range and involve the possibility of much higher losses" (Stern, 2007, p. 161). In addition to the purely economic effects of climate change, Stern takes into account three additional factors that multiply the possibilities of adverse effects: the direct "non-market" impacts on the environment and human health, the scientific evidence that amplifying feedback in the climate system can cause it to be more responsive to greenhouse gas emissions than was previously thought, and the disproportionate burden these may have on poor countries. "Putting these three additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in current per-capita consumption, now and forever".[9]

4. Climate change and the sustainability of output

"Sustainable development" defined by the World Commission on Environment and Development in 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" is an ethical as well as an economic goal. Its definition is sufficiently elastic as to allow much leeway in interpreting it and promoting its implementation (Solow, 1993). An alternative way of defining this goal is in terms of non-declining per capita economic welfare over time. Since 1987 several international conferences have attempted to flesh out and elucidate the concept further. The last of these, the United Nations Conference on Sustainable Development (or "Rio + 20 Summit"), was held in Rio de Janeiro, Brazil, in June 2012 to commemorate the Earth Summit celebrated in the same city twenty years earlier.

[9] Stern (2007), pp.161-2. This list omits " 'socially contingent' impacts such as social and political instability, which are very difficult to measure in monetary terms".

Sustainable development, or sustainability, can be defined in terms of the composition of a society's aggregate capital stock, and how it has changed over time in response to ecological and economic trends. The literature distinguishes between weak and strong sustainability. Weak sustainability assumes that all types of capital – natural, produced and human – are inherently substitutable, so that any depletion of natural capital (the climate, agricultural land, biomass, fisheries, national parks, the ozone layer, unpolluted air and water, fossil fuels, and so on) can be compensated for by appropriate increases in human capital (skilled labor, an educated population, scientists and engineers, managerial staff) or in produced or physical capital (factories, machines, buildings, infrastructure of various types).[10] Strong sustainability holds that no other type of capital can substitute for natural capital: "Instead, proponents of strong sustainability maintain that some forms of natural capital are essential to human welfare, particularly key ecological goods and services, unique environments and natural habitats, and even irreplaceable natural resource attributes (such as biodiversity)" (Barbier, 2011, p. 238). The preservation of irreplaceable ecosystems is especially important. However, strong sustainability does not imply that all forms of natural capital should be maintained in their pristine form, which would be an impossible stipulation. The depletion of some fossil fuels need not violate it as long as the development of other forms of natural capital such as biofuels compensates for it. However, the degradation of the climate, an essential or "critical" form of natural capital, through global warming clearly violates the strong sustainability criterion. Proponents of strong sustainability argue that natural capital is a complement and not a substitute for other forms of capital.

5. Strong sustainability and intergenerational equity

Sustainability clearly encompasses future generations as well as the current one. The buildup of greenhouse gases affects output not only in the present, but even more significantly, in the future and in fact, as noted above, for centuries if not millennia to come. It is important to adopt the ethical perspective of intergenerational equity, whereby future generations are entitled to a climate (and related standard of living) comparable to the present one. This calls for the mitigation of the emission of greenhouse gases (GHGs) and preliminary steps toward adaptation to the global warming that will occur even if the emission of GHGs were to come to an immediate end. This concern enters the very definition of sustainability

[10] Weak sustainability is related to Hartwick's rule (Hartwick, 1977), also referred to as the Hartwick-Solow rule in view of the fact that Solow (1974) was the first to postulate that the rents generated by the use of exhaustible natural resources should be reinvested in reproducible capital so as ensure a non-declining level of consumption over time.

according to the Stern Review: "A concept related to the idea of the rights of future generations is that of sustainable development: future generations should have a right to a standard of living no lower than the current one" (Stern, 2007, p. 48). This is further elaborated by Pearson:

What are the rights that future generations should enjoy? Sustainability provides an easy answer. Sustainability has a clear meaning, at least to economists, as non-declining per-capita utility or real income. If we accept the idea that there is some critical level of natural capital (some critical change in global climate) the loss of which would violate sustainability, we then have a constrained maximization problem – maximize NPV [net present value] subject to the constraint that utility does not fall. (Pearson, 2011, p. 36)

Strong sustainability calls for a reformulation of the model sketched out above based on production function (2). As shown by its differential form (3), a buildup of greenhouse gases represented by $dG/dt > 0$ would lead to a fall in output unless compensated for by capital accumulation, labor force growth, or technical progress. In particular, given that $FG < 0$, if we assume that $dL/dt = dT/dt = 0$ and that capital accumulation is such that

$$dK/dt = - (FG /FK)(dG/dt), \qquad (8)$$

then according to (3) the level of output would remain constant. The harmful effects of greenhouse gases and the resulting loss of natural capital would thereby be neutralized, satisfying the criterion of weak sustainability. However, the harmful effects on welfare would in fact go beyond the negative effects on output represented by FG (dG/dt), which suggests the superiority of the strong sustainability criterion. For this purpose, (3) should be modified to

$$dY/dt = FK(dK/dt) + FL(dL/dt) + FT(dT/dt) + FG(dG/dt), \text{ where } dG/dt \leq 0. \qquad (3a)$$

In light of (5), the constraint on dY/dt set by the weak inequality $dG/dt \leq 0$ in (3a) can alternatively be written as $A \geq E$, which stipulates that the natural and policy-induced absorption of greenhouse gases should be no smaller than the level of emissions.11

6. Conclusions

Two other principles are consistent with and complement strong sustainability, although neither has been rigorously defined. The adoption of "safe minimum standards" can guard against the uncertainty and potential harm surrounding long-term environmental outcomes. Sustainable development is also consistent with the adoption of the "precautionary principle" advanced in Article 15 of the 1992 Rio Declaration on Environment and Development: "Where there is a threat of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation". Pearson advocates it when he states: "In the case of climate change, a precautionary approach would involve committing substantial resources to mitigating greenhouse gas emissions now to reduce the possibility of potentially severe but uncertain future damages". As Stern also maintains, "the global environmental and ecological system, which provides us with life support functions such as stable and tolerable climatic conditions, cannot be substituted" (Stern, 2007, p. 48). If sustainable development is to be more than a popular slogan or a passing fad, it should be firmly anchored in the concept of "strong sustainability", which implies that neither technical change nor any other form of capital can substitute for natural capital, particularly in the form of climatic conditions.

[11] Chapter 8 of Stern (2007) is appropriately titled "The Challenge of Stabilisation" of greenhouse gases, since it highlights the difficulties facing humankind in achieving such stabilization over the next few decades.

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Designing strategies for optimal spatial distribution of wind power

Dr. Nikolaos S. THOMAIDIS
Adjunct Lecturer in Computational Methods for Finance

Tel: +30-210-35454
Fax: +30-210-35499
e-mail: nthomaid@fme.aegean.gr

Address
Management & Decision Engineering (MDE) Lab, Department of Financial & Management Engineering, University of the Aegean, 41 Kountouriotou Str, 82100 Chios, Greece.

Abstract: One of the common problems with the production of wind energy is the increased uncertainty surrounding the delivered output. Wind power producers adopt various strategies to reduce production risk, one of the most popular being the dispersion of wind farms across distant locations. The purpose of this paper is to examine the effectiveness of different methodologies for deriving optimal capacity allocation schemes. We collect a large dataset of wind-speed measurements for various locations across the Netherlands and use copula techniques to capture seasonal variations and cross-site dependencies in wind profiles. We exploit the information provided by statistical models to determine optimal resource allocation plans assuming a variety of operational and investment objectives. Experimental results designate the importance of accurately modelling site dependencies when deciding how to optimally allocate the overall wind capacity. Carefully chosen subgroups of sites can result in a more reliable energy supply as opposed to other allocation schemes that ignore spatial correlations.

Keywords: Spatial resource allocation, wind power, copulas, capacity distribution plan.

1. Introduction

Over the last twenty years, wind power has become one of the basic constituents of new-era national energy programmes for decentralised and carbon-free electricity generation. As wind has been holding bigger and bigger share in the global power supply portfolio, new challenges and risks have risen for both investors and system operators.

No doubt, the most important obstacle to the large-scale deployment of wind farms is the variability in the delivered energy output. Many studies conducted in the past have indicated that the correlation of winds measured at different time scales typically weakens with the distance between sites (Giebel, 2000; Katzenstein et al., 2010). Hence, by interconnecting several distant wind farms, one hopes to obtain a smoother aggregate generation profile. But how far from each other should wind generators be placed so that smoothing becomes effective? Giebel (2000, ch.6) shows that the minimum distance required before correlation decreases to almost 1/3 is 723 km for the European region. For the Dutch case, Gibescu et al. (2006) estimated this characteristic distance to over 600 km. As the correlation decays slowly with distance, it makes sense not to consider for wind farm development all sites for which reliable data are available, but to isolate a selected network of locations. Geographic proximity is certainly not the only selection criterion. The horizontal variability of terrains could also play an important role in terms of smoothing out the combined energy output. Certainly, the exact number and topology of the sites participating in the generation portfolio will depend on the objective that the aggregate production plan should meet. E.g. it could be designed to optimise the availability in low-wind days or to maximise the average yearly energy production.

Individual research initiatives with the aim to quantify the benefits from aggregate wind energy generation have appeared in the literature as early as in the late 70's[6]. Archer and Jabonson (2007) analyse the effects of combining nineteen sites for wind power harnessing in the midwestern US. Although their goal is not to come up with an optimal energy plan, the authors present array-averaged statistics for farm networks of different size. Their empirical results support the widely-held conviction that the performance and reliability of the aggregate array improves with the number of farms included in the generation mix. However, they also find that "smart" combinations of sites could be proven more productive than an interconnection of all available farms. Cassola et al. (2008) present a methodology for deriving wind-based

[6] See Archer and Jacobson (2007) and Katzenstein et al. (2010) for a comprehensive literature survey.

power plants with an improved aggregate output profile. They determine optimal configurations of interconnected wind farms on the basis of two criteria: variability in energy supply and the ratio of average dispersion over the total energy production. As a test-bed for their methodology, Cassola et al. (2008) choose a network of ten anemometric regions in the island of Corsica. Despite the small scale of this case-study, the authors demonstrate how their methodology could be extended to higher-dimensionality problems using a decomposition technique. Its basic idea is to group sites with similar wind profiles.

Of those works most relevant to our study is Grothe and Schnieders (2011). They integrate univariate statistical models with copula theory to describe temporal variations and nonlinear dependences in the 80-m German wind map. By collecting wind data for a system of forty dispersed sites, they determine optimal powering schemes with the emphasis to maximise the aggregate energy supply during low-wind events. Gibescu et al. (2006) and Papaefthymiou and Kurowicka (2009) are two more examples where an explicit model for the spatial correlation of geographically dispersed sites is used to study the generation profile of the aggregate wind power plan.

In this article, we examine the performance of different methodologies for deriving optimal distributions of wind power production in the Netherlands. “Optimality” is conceived in different ways depending on which operational aspect the decision-maker is focused on. Similarly to Papaefthymiou and Kurowicka (2009) and Grothe and Schnieders (2011), we combine univariate time-series models with copula techniques to capture both seasonal and regional wind variations. Based on the estimated models, we simulate future power supply scenarios and then derive optimal allocations of wind capacity. Our formulation of the energy production problem does not fix in advance the number of candidate locations but allows for sub-arrays of selected members. What is also important to this study is that the performance of model-based energy plans is compared with those derived from heuristic arguments and simple rules of thumb. The latter are in everyday use by wind industry experts and, in a sense, present a challenge to more sophisticated and computationally-intensive modelling tools.

The rest of the article is organised as follows: in Section 2 we describe the data set and in Section 3 we provide a preliminary wind resource assessment using basic statistical measures. Sections 4 & 5 present a multivariate framework for modelling wind time series and Section 6 details the methodology for detecting optimal interconnections of wind power plants. The efficiency of these resource allocations is evaluated in Section 7 using an array of performance metrics. Section 8 summarises the main findings and concludes the paper.

1. Sample data

Our sample data consist of hourly potential wind speed measurements for 54 locations spread around the Netherlands. Raw data were collected from the website of the Royal Netherlands Meteorological Institute (KNMI) for a period of ten full operating years (01/01/2001 - 31/12/2010), ignoring leap days7. From hourly data, we computed daily averages and filtered-out stations for which more than 40% of daily measurements were not available over the corresponding sample period and the maximum number of consecutive missing observations is more than 30. We also disregarded measurements for offshore sites. For the rest of the stations passing the above data quality criteria, we treated missing values as in Grothe and Schnieders (2011) and replaced them using sample observations with the same day and month index but belonging to a randomly chosen year. Daily wind speed measurements were extrapolated to 80 m above the surface, the typical tower height of modern turbines. As in Katzenstein et al. (2010) and Grothe and Schnieders (2011), we assumed a logarithmic vertical wind profile and chose the appropriate value for the roughness length at each site. Information on the local roughness of the stations-surrounding area was also provided by KNMI files.

Of all available sites, only 39 fulfilled the above requirements and are henceforth called active weather stations. More information on active stations is given in Table 1 and Figure 1. Apart from their exact location, as described by the latitude and longitude in decimal format, Table 1 also reports the height at which wind speed measurements correspond to. The time period from 01/01/2001 to 31/12/2006 was used for determining the optimal power allocation, and will be henceforth called estimation period. This amounts to 60% of the available number of observations. The rest 40%, i.e. the period from 01/01/2007 to 31/12/2010, was used for evaluation purposes and will be henceforth called evaluation period.

[7] See http://www.knmi.nl/klimatologie/onderzoeksgegevens/potentiele_wind/

Table 1: Information on active weather stations.

Station name	Station ID	Lat	Long	Anem height (m)
VALKENBURG	210	52.16	4.42	10.0
IJMUIDEN	225	52.46	4.58	18.5
TEXELHORS	229	53.00	4.72	10.0
DE KOOY	235	52.92	4.79	10.0
SCHIPHOL	240	52.30	4.77	10.0
WIJDENES	248	52.63	5.17	10.0
BERKHOUT	249	52.64	4.98	10.0
DE BILT	260	52.10	5.18	20.0
STAVOREN	267	52.90	5.38	10.0
LELYSTAD	269	52.46	5.53	10.0
LEEUWARDEN	270	53.23	5.75	10.0
MARKNESSE	273	52.70	5.89	10.0
DEELEN	275	52.06	5.89	10.0
LAUWERSOOG	277	53.41	6.20	10.0
HEINO	278	52.44	6.26	10.0
HOOGEVEEN	279	52.75	6.57	10.0
EELDE	280	53.13	6.59	10.0
HUPSEL	283	52.07	6.65	10.0
NIEUW BEERTA	286	53.20	7.15	10.0
TWENTHE	290	52.27	6.90	10.0
CADZAND	308	51.38	3.38	17.0
VLISSINGEN	310	51.44	3.60	27.0
HANSWEERT	315	51.45	4.00	16.0
SCHAAR	316	51.66	3.69	16.5
WESTDORPE	319	51.23	3.86	10.0
WILHELMINA-DORP	323	51.53	3.88	10.0
STAVENISSE	324	51.60	4.01	16.5
HOEK VAN HOLLAND	330	51.99	4.12	15.0
WOENSDRECHT	340	51.45	4.35	10.0
R'DAM-GEULHAVEN	343	51.89	4.31	10.0
ROTTERDAM	344	51.95	4.44	10.0
CABAUW	348	51.97	4.93	10.0
GILZE-RIJEN	350	51.57	4.93	10.0
HERWIJNEN	356	51.86	5.15	10.0
EINDHOVEN	370	51.45	5.41	10.0
VOLKEL	375	51.66	5.71	10.0
ELL	377	51.20	5.76	10.0
MAASTRICHT	380	50.91	5.77	10.0
ARCEN	391	51.50	6.20	10.0

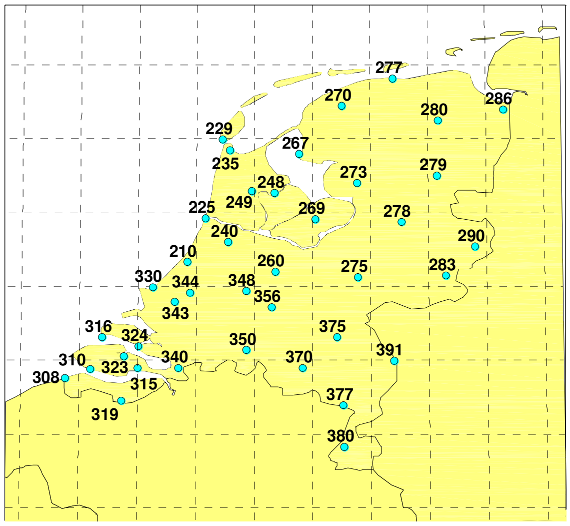

Figure 1: Location of active weather stations[8].

3. Preliminary data analysis

3.1. Site potential

Figures 2-5 visualise descriptive statistics on daily wind speeds reported by each station over the estimation sample period. To facilitate a direct comparison of figures, we report statistics for the wind velocities estimated at the hub height (80m), although a data analysis of the as-reported potential wind measurements is also available upon request.

Some interesting remarks can be easily drawn as concerns the energy potential of each site. As seen from Figure 2, the strongest average winds are recorded for stations TEXELHORS (229) and LAUWERSOOG (277), which are both on the Northwestern cost. The DE BILT (260) and ARCEN (391) sites are characterised by the lowest average wind velocity. Figure 3 shows that the speed of the winds blowing over IJMUIDEN (225) and TEXELHORS (229) tends to show high variability, as measured by the standard deviation of daily wind speeds. On the other hand, the wind capacity of sites like DE BILT (260) and ARCEN (391) is more predictable over time with a much lower average daily dispersion (1.87 and 2.22 m/s, respectively).

Figure 4 gives site-wise information on the coefficient of variation (CV) of extrapolated wind speed measurements. This is the ratio of standard deviation over the mean wind speed, showing the trade-off between risk and reward from the development of a wind farm at each site. As Figure 4 shows, in most of the stations considered in our study, the standard deviation of daily wind speeds is slightly less than half the mean value. The lowest dispersion per mean wind

[8] Maps in this paper were created using the World Borders Database available from http://thematicmapping.org/downloads/world_borders.php.

is 0.40, being recorded for station R'DAM-GEULHAVEN (343), while in the nearby ROTTERDAM (344) site the CV ratio attains the highest value among all locations considered in this study (0.49).

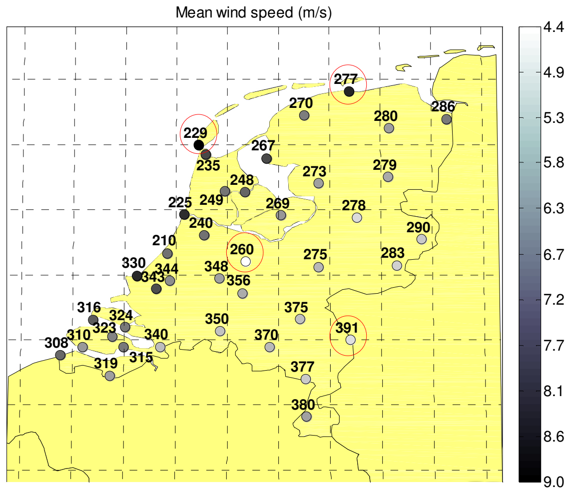

Figure 2: Average of wind speeds extrapolated at hub height.

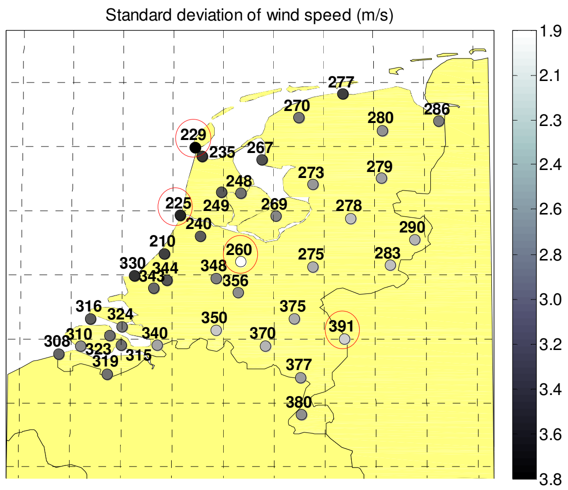

Figure 3: Standard deviation of wind speeds extrapolated at hub height.

Figure 5 sheds light on the lower tail of the empirical distribution of the $u(80)$ estimates. For each site, we report the 15th percentile of the empirical distribution, i.e. the cutoff point below which fall 15% of the sample observations. Figure 5 shows that sites 229 and 277, being the top two in terms of mean daily speed, are also characterised by high availability during calm days.

3.2. Temporal evolution of wind speeds

Figure 6 shows the evolution of $u(80)$ over the estimation period for a typical sample station (ELL-377). As observed, the path of wind speeds extrapolated to 80 m is characterised by random shocks and periodic changes in the volatility level. Figure 7 shows the sample correlation between ELL $u(t,80)$ and $u(t-k,80)$ for $t=1,\dots,2190$ and different values of $k=1,\dots,30$. The correlation decays slowly with the time difference between two observations; a sudden shock (rise or fall) is not absorbed instantly but it takes up to 10 days for the wind speed to return to its normal historical level.

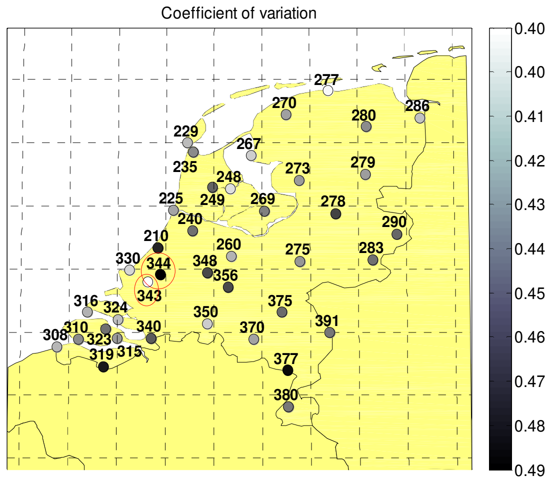

Figure 4: Coefficient of variation of wind speeds extrapolated at hub height.

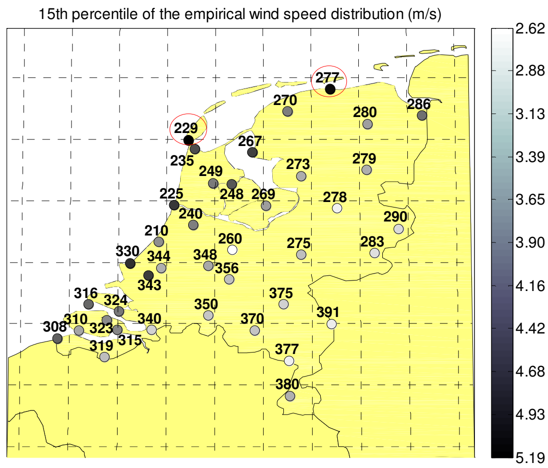

Figure 5: The 15th percentile of the empirical distribution of wind speeds extrapolated at hub height.

Significant fluctuations in 80-m wind speeds are also observed across seasons. In Figure 8, we show how ELL $u(80)$ values are distributed across calendar months. The solid line interpolates between medians and each box marks the position of the 25th and the 75th percentile of the empirical distribution of all observations with the same month index. Stronger winds are typically recorded during winter months (especially in January), while the average daily wind speed gets lower in August and September. Although suppressed for space, the analysis of 80-m wind data for other locations shows similar patterns of temporal evolution.

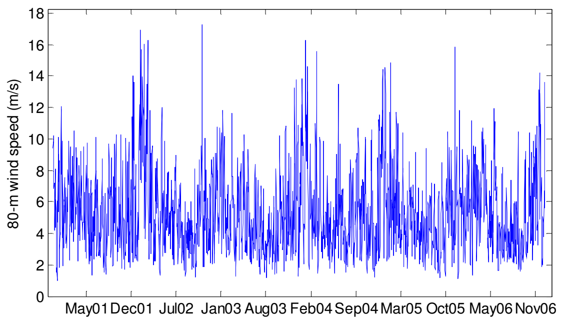

Figure 6: Daily extrapolated wind speed measurements for the ELL (377) site.

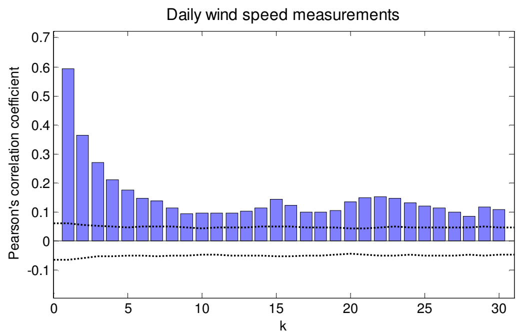

Figure 7: The autocorrelogram for daily extrapolated wind speed measurements.

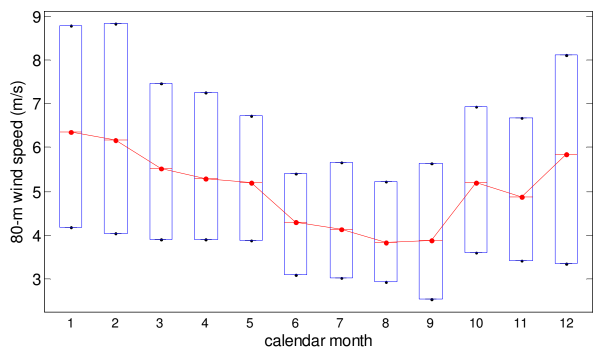

Figure 8: A box plot of extrapolated wind measurements for the ELL (377) site.

4. Univariate time series modelling

For capturing the dynamics of wind speed measurements, we employed the seasonal ARMA time-series framework proposed by Benth and Benth (2010) (see also Grothe and Schnieders, 2011, for details). First, the series of $\{u(t,80); t = 1, \dots, 2190\}$ is transformed into an approximately normally distributed data sequence $\{v_t; t = 1, \dots, 2190\}$ using the power Box-Cox transformation. Each v_t measurement is assumed to be composed of:

- a predictable mean component p_t, being determined on the basis of both historical data and calendar information
- a predictable variance component σ_t, incorporating seasonal effects.
- a surprise (noise) term ε_t, capturing unexpected changes in wind speed levels.

In mathematical terms, this decomposition is achieved assuming the following stochastic law:

$$v_t = p_t + z_t \tag{1.1}$$

where

$$z_t = \sigma_t \varepsilon_t \tag{1.2}$$

$$p_t = b_0 + b_1 v(t-1) + b_2 v(t-2) + \sum_{j=0}^{1} b_{2j+3}\cos(365^{-1}(2j+2)\pi t) + \sum_{j=0}^{1} b_{2j+4}\sin(365^{-1}(2j+2)\pi t) \tag{1.3}$$

and

$$\sigma_t^2 = a_0 + \sum_{j=1}^{3} a_j \sin\left(\frac{2j\pi t}{365}\right) \tag{1.4}$$

In general, $\{b_j; j = 0, \dots, 6\}$ are the coefficients of the mean model and $\{a_j; j = 0, \dots, 3\}$ are the coefficients of the variance equation. The terms in the summations account for seasonal effects in both moments. In our set of experiments, consistent estimates for the mean parameters were determined using ordinary least squares. Based on the derived values $\hat{b}_j$, we computed the series of model residuals $\hat{z}_t$ and thus obtained an approximation of the day t volatility by setting $\hat{\sigma}_t^2 = \hat{z}_t^2$. We then ran another regression of $\hat{\sigma}_t^2$ on to the sinusoidal functions of time, to calculate the parameters a_j of the volatility formula (1.4). The addition of an explicit model for the volatility dynamics is justified by seasonal patterns in the size of unexpected wind events. Figure 8 shows a Box plot of the absolute residuals of the ELL regression versus calendar month. The volatility of winds follows a similar v-shape as in Figure 8; unexpected changes in wind speed are greater in magnitude during winter and seem to decrease during spring and summer.

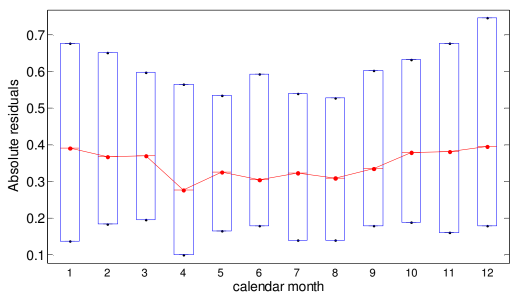

Figure 9: A box plot of absolute residual wind measurements for the ELL (377) site.

5. The cross-section of residual wind speeds

5.1. Descriptive statistics

The current practice in power allocation suggests dispersing wind farms over a large area. This way one hopes to increase the overall reliability of power generation, as wind drought events occurring in one site can be counterbalanced by distant windy locations. However, the key point to the success of this strategy is to investigate how wind correlation changes with the geographical proximity of sites.

Table 2 reports descriptive statistics and Figure 10 plots the empirical distribution of the sample (Pearson's) correlation coefficient for all pairs of sites. Instead of raw wind data, the correlation analysis is focused on what has been left unexplained by univariate statistical models, i.e. on all combinations of standardised residuals series $\{[\varepsilon]_t, t = 1, \ldots, 2190\}$ (see equation 1.2).

The average correlation between residual wind speeds is pretty high (0.82), with a standard deviation of 0.09. The maximum correlation is 0.97 and is noted for the pair of stations CABAUW (348) and HERWIJNEN (356) which are 19.6 km apart (see Figure 1). The lowest possible correlation in standardised residuals (0.53) is observed between two relatively distant weather stations, MAASTRICHT (380) in the south and LAUWERSOOG (277) in the north, whose great-circle distance is about 279.6 km. This pattern suggests that, although high, the correlation may get weaker with the distance between two sites. Figure 11 shows a scatter plot of residual correlations versus distance for all station pairs. Despite the fact that points are in generally greatly dispersed, there is a clear proportional relationship between correlation and geographical proximity. A similar pattern has also been noted by Gibescu et al. (2006) for eighteen measurement sites in the Dutch region. This observation suggests that one may be able to obtain a smoother aggregate power production by combining distant wind farms. However, to increase the efficiency of the overall installation one has to take into account not only the correlation structure but also the mean and the variability in the wind energy generation at each site.

Table 2: Statistics on the cross-site correlation between wind speed residuals.

Max	0.97
Min	0.53
Mean	0.82
Stdev	0.09

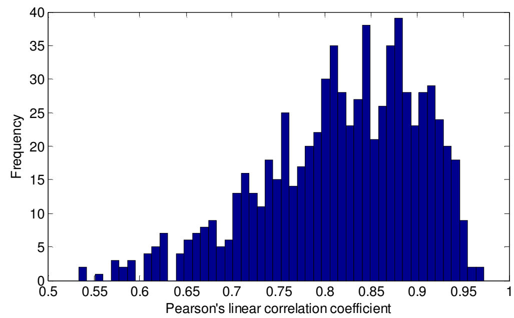

Figure 10: The empirical distribution of cross-site correlations.

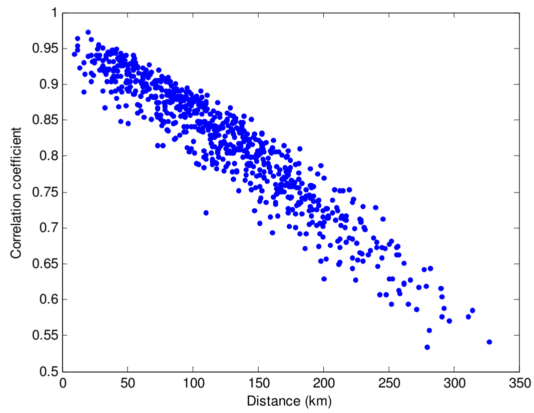

Figure 11: Correlation versus distance.

5.2. Modelling the correlation structure of wind data.

Cross-dependencies between standardised residual series were analysed using the simplest family of Gaussian copulas (see also Papaefthymiou and Kurowicka 2009 for a similar approach). To apply copula theory, we transformed the sequence of $\hat{\varepsilon}_t$'s into a set of near-uniformly distributed random variables using the Gaussian cumulative probability density function.

6. Optimal power allocation

6.1. Power output models

To find optimal plans of aggregate power generation for 2011, we simulated 1000 year-round scenarios of daily wind speed data for each of the 39 sites considered in our study. Apart from seasonal variations, the use of Gaussian copula models helped us simulate wind speed scenarios preserving cross-site dependencies. Based on 80-m wind speed simulated data, we generated 1000 annual scenarios of actual power using as a benchmark the GE 1.5MW turbine. The power curve corresponding to this turbine (also depicted in Figure 11) was constructed following Archer and Jacobson (2007) and Grothe and Schnieders (2011) using a composition of third-order polynomials. Note that the curve assumes a sudden drop in energy production at 25 m/s, which is due to a safety cut-out of the wind turbine that typically takes place at such strong wind levels.

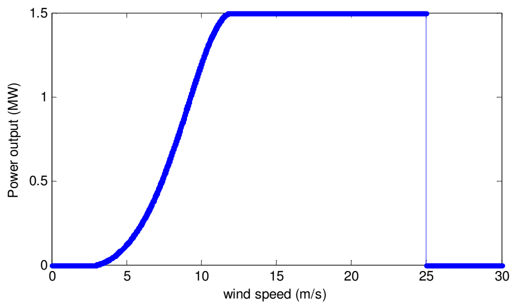

Figure 12: Power curve of our benchmark GE 1.5 MW turbine

6.2. Deriving optimal spatial distributions of wind power generation

The purpose of the optimisation exercise is to determine a vector of weights $\omega = (\omega_1, \omega_2, \ldots, \omega_N)$, where $N = 39$ is the number of available sites and ω_i denotes the proportion of the overall capacity allocated at site i ($0.02 \leq \omega_i \leq 0.98$). We also consider the possibility that a particular site is trivially assigned a zero weight, meaning that it is excluded from the generation mix. The optimal power distribution was found assuming a variety of operational and investment objectives. In this paper, we report results for two operational scenarios where the goal is to:

Obj1: maximise the 15th percentile (p_{15}) of the overall daily power generation. In other words, we seek to maximise the total amount of energy delivered during the worst 15% of our sample days.

Obj2: minimise the coefficient of variation for the aggregate daily output. In this case, our aim is to combine resources in such a way so that we experience the lowest possible average fluctuation per unit of delivered power.

Table 3, columns 1-2, present the results of the optimisation exercise for each of the objectives defined above. Numbers in the cells show the percentage of the available capacity allocated at each site. An inspection of Table 3 surprisingly reveals that optimal powering strategies involve only three coastal stations: TEXELHORS (229) and LAUWERSOOG (277) and HOEK VAN HOLLAND (330). According to the Obj1 generation mix, 41.12% of the overall capacity goes to TEXELHORS, 38.26% goes to LAUWERSOOG and the rest 20.62% remains with HOEK VAN HOLLAND. The solution corresponding to the second objective suggests a slight repowering of the previous scheme, placing more capacity at TEXELHORS and HOEK VAN HOLLAND. The elaboration on these particular three sites is justified by their relatively high and decoupled wind potential. Figures 5 and 4 show that these regions are characterised by relatively strong winds in calm days and low risk-to-reward ratios. Furthermore, the correlation between all pair measurements is moderate and ranges between 0.68 and 0.80. To examine the validity of the suggested optimal installations, we examined several alternative powering schemes:

A uniform distribution plan, spreading the total capacity equally among all available sites.

Two so-called heuristic allocation rules, whose idea is to allocate more power to locations with richer wind resources. Depending on whether Obj1 or Obj2 is employed, the rules allocate the capacity according to either the 15th percentile or the CV ratio. Both statistics are computed based on the empirical distribution of the daily estimated power output of each site.

The energy mix suggested by heuristic schemes is presented in Table 3, columns 3-4. Note that both strategies also put the highest proportion of the available capacity at TEXELHORS (229) and the second highest at LAUWERSOOG (277), being two of the most promising sites in terms of wind potential. The rest of the available capacity is distributed to other sites according to their individual scores in the ranking criterion used in each case.

7. Efficiency measurement

The alternative power allocation schemes discussed in Section 6 are compared in terms of their ability to deliver energy in a consistent and reliable manner. We introduce an array of performance metrics that capture different aspects of the risk and return profile of the aggregate production. Those are outlined below:

- Mean daily power (mean).
- Standard deviation of daily power (std).
- Coefficient of variation (CV).
- The $(100 \times a)$th percentile of the empirical daily power distribution (p_{100a}), where $a = 0.05$, 0.15 and 0.30.

To avoid biasing comparisons towards simulation-driven optimal allocations, we choose to report performance statistics directly on sample data.

Table 3: Spatial capacity distribution plans.

Station ID	Optimal allocation (Obj1) (%)	Optimal allocation (Obj2) (%)	Heuristic allocation (Obj1) (%)	Heuristic allocation (Obj2) (%)
210	0.00	0.00	2.09	2.68
225	0.00	0.00	6.69	3.40
229	**41.12**	**43.84**	11.04	3.93
235	0.00	0.00	5.31	3.16
240	0.00	0.00	2.74	2.74
248	0.00	0.00	4.75	2.94
249	0.00	0.00	2.89	2.69
260	0.00	0.00	0.00	1.60
267	0.00	0.00	6.15	3.21
269	0.00	0.00	1.55	2.42
270	0.00	0.00	2.77	2.66
273	0.00	0.00	1.08	2.37
275	0.00	0.00	0.59	2.21
277	**38.26**	**32.91**	10.16	3.66
278	0.00	0.00	0.00	1.86
279	0.00	0.00	1.01	2.30
280	0.00	0.00	1.49	2.36
283	0.00	0.00	0.00	1.97
286	0.00	0.00	3.42	2.74
290	0.00	0.00	0.00	2.03
308	0.00	0.00	4.25	2.88
310	0.00	0.00	1.30	2.42
315	0.00	0.00	2.43	2.70
316	0.00	0.00	3.89	2.99
319	0.00	0.00	0.61	2.30
323	0.00	0.00	2.22	2.58
324	0.00	0.00	3.04	2.73
330	**20.62**	**23.25**	7.21	3.56
340	0.00	0.00	0.13	2.12
343	0.00	0.00	6.48	3.23
344	0.00	0.00	1.00	2.42
348	0.00	0.00	1.24	2.31
350	0.00	0.00	0.41	2.15
356	0.00	0.00	0.54	2.24
370	0.00	0.00	0.43	2.20
375	0.00	0.00	0.15	2.07
377	0.00	0.00	0.00	1.98
380	0.00	0.00	0.95	2.31
391	0.00	0.00	0.00	1.87

Table 4 shows the performance of alternative power allocation schemes over the estimation sample period (01/01/2001 – 31/12/2006). To facilitate comparison, we express all figures as percentages of the total installed capacity. A uniform power distribution would deliver on average 29.41% of the overall power rating. This relatively good capacity factor is overshadowed by an equal magnitude standard deviation of 27.63%, hence the relatively high risk-to-reward ratio (0.94). Heuristic allocation schemes manage to deliver on average 39.76-29.41=10.35 and 31.48-29.41=2.07 additional percentage points per day, though with an increase in output uncertainty.

Table 4: In-sample performance of power allocations (% of total installed power).

Perfor-mance metric	Optimal allocations		Heuristic allocations		Uniform allocation
	Obj1	Obj2	Obj1	Obj2	
Mean	50.57	50.76	39.76	31.48	29.41
Std	34.06	34.17	31.23	28.35	27.63
CV	0.67	0.67	0.79	0.90	0.94
p_5	3.43	3.43	2.28	1.27	1.06
p_{15}	10.75	10.74	6.71	4.09	3.40
p_{30}	23.39	23.23	15.13	10.12	8.82

The risk per unit of return experienced by heuristic powering schemes is smaller (0.79 & 0.90, respectively), meaning that, in principle, more efficient sites have been selected for wind farm development. Model-based power allocations achieve an add-on of 50.57-39.76=10.81 and 50.76-31.48=19.28 percentage units per day to the generating capacity, compared to their heuristic counterparts. This improvement in daily output comes with a disproportional increase in risk, hence the lower value for the coefficient of variation (approximately 0.67 in both cases). In terms of reliability, optimal power distributions have the highest guaranteed generating capacity in adverse weather conditions. The values of p_5 , p_{15} and p_{30} are always larger than the corresponding statistics reported for alternative allocation schemes. Note that by distributing power among sites 229, 277 and 330, one is safe that in $85\% \times 365 \cong 310$ days of a year the aggregate power plan will deliver no less than roughly 10.7% of the nameplate capacity.

Table 4 sheds light on the relative performance of alternative generation plans using estimation sample data. It would be though instructive to see how well these plans perform on a dataset beyond the one used to calibrate model parameters and run the optimisation exercise. Table 5 presents a performance assessment over the evaluation sample period (01/01/2007-31/12/2010). A straightforward comparison of the results given in Tables 4 & 5 shows that the alternative energy mixes show relatively stable performance over time. Although individual plan assessments may change between estimation and evaluation periods, the relative ranking between alternative distributions seems to be preserved. Model-based optimal distributions remain superior with respect to all performance measures.

Table 5: Out of sample performance of power allocations (% of total installed power).

Perfor-mance metric	Optimal allocations		Heuristic allocations		Uniform allocation
	Obj1	Obj2	Obj1	Obj2	
Mean	52.98	53.13	40.85	31.85	29.62
Std	33.34	33.44	30.52	27.59	26.87
CV	0.63	0.63	0.75	0.87	0.91
p_5	4.70	4.65	3.09	1.81	1.45
p_{15}	12.16	11.91	7.62	4.73	4.10
p_{30}	27.73	27.88	17.21	10.95	9.54

8. Conclusions

In this article, we examine different methodologies for deriving optimal configurations of geographically dispersed wind farms with a view on improving the profile of the aggregate energy generation. Using a multivariate copula framework, we model the dynamics of upper winds blowing over thirty-nine Dutch sites considered for wind power harnessing. Based on the parameters of copula models, we simulate year-round aggregate power generation scenarios and derive optimal capacity distribution plans. Model-driven wind farm configurations are compared with simpler allocation schemes based on site-wise historical performance analysis.

Experimental results support the superiority of model-driven approaches to energy production planning. This is mainly because copula-based allocation schemes not only take into account site-specific information but also the horizontal correlation of wind resources. This proves to be very important when it comes to designing combined energy systems with desirable aggregate properties. What is equally important is to make a cautious selection of those locations participating in the final generation mix. Our experience from the Dutch case indicates that a small – yet systematically chosen - grid of sites can more efficiently meet the generation targets compared to a full-scale wind farm deployment.

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Transformation of German- and European-Style Feed-in Tariff Schemes in East Asia in the Post-Fukushima Age: Recent Developments in Japan, South Korea, and Taiwan

Anton Ming-Zhi GAO
Assistant professor, The Institute of Law for Science and Technology (ILST)
National Tsing Hua University,
101, Sec. 2, Kuang-Fu Road, HsinChu 30013, Taiwan
Tel: +886-3-571-5131 ext. 62515
antongao@mx.nthu.edu.tw

Abstract: Since the1970s, renewable electricity has been promoted in response to energy crisis and climate challenge. A wide range of energy schemes emerged including feed-in tariffs (FITs), renewable portfolio standard (RPS), net metering, and so forth. German- or European-style FIT scheme appeared as the prevailing way to facilitate the deployment of renewable electricity (RE) technology, as witnessed by the recent booming development in Germany. A group of advanced Asian countries had pondered both RPS and FIT long before the Fukushima accident occurred. Since the early 2000s, an "adapted" version of the promotion scheme became popular as an alternative of traditional FIT or RPS. Especially after the Fukushima accident, 1) in 2011 Japan adopted a combined regime of FIT and a net-metering scheme in substitute for RPS, 2) in 2010 South Korea adopted a RPS scheme as the alternative of FIT, and 3) in 2010 Taiwan innovated a combined regime of FIT and tendering scheme. The scientific contribution of this article is to study the transformational track of the legal regimes concerning the renewable "electricity" development in Asian countries. A comparative legal approach has been conducted to compare and contrast the adapted form in Japan, South Korea and Taiwan. This study places emphasis on the creation of parameters to compare detailed sub-mechanisms under the main RE schemes. The expected outcomes would be the detection of difference in eligibility for RE payment, tariff eligible period, tariff schedule, tariff degression, hard or soft cap, funding sources, and so on.

Keywords: FIT; Post-Fukushima; advanced Asian countries

I. Introduction

From the 1970s onward, the EC (and afterward the EU) adopted a wide range of measures to promote the development of electricity derived from renewable sources. Since then, many mechanisms have been implemented, including investment subsidies, tax incentives, feed-in tariffs (FITs), and net metering. FITs emerged as the prevailing way to facilitate the deployment of renewable electricity technology, as witnessed by the pioneering developments in Germany. In Asia, this shift to clean forms of energy gained extra impetus after the Fukushima Daiichi nuclear power plant accident and countries have altered their renewable energy policies to spur the development of renewable electricity. The purpose of this article is to observe the transitional track of development of the legal regimes concerning the renewable electricity sector in three Asian countries (Japan, South Korea, and Taiwan) and then compare the adapted form of the FIT schemes in these three countries with the mainstream German model.

II. Post-Fukushima Renewable Electricity Promotion Schemes in Japan, South Korea, and Taiwan

1. Japan

(1) 2011 FIT with Mandatory Small PV Net Metering

After the Fukushima accident and closure of the nuclear power plants, Japan faced a large-scale shortage of electricity and a resulting electricity crisis. Thus, renewable energy was considered a priority for development. A more favorable scheme than the then-current mandatory net metering underwent more serious discussion.[9] The Fukushima accident played a key role in this more favorable approach gaining ground in 2011. After revision of the Act on Special Measures Concerning the Procurement of Renewable

[9] See METI, Present Status and Promotion Measures for the introduction of Renewable Energy in Japan, available at: http://www.meti.go.jp/english/policy/energy_environment/renewable/index.html (visited on 1 September 2012).:"On the basis of the study results by the "Project Team on Japan's Feed-in Tariff Scheme", which was established in November 2009, the Ministry of Trade, Economy and Industry (METI) drew up the framework (basic idea) of the Japan's feed-in tariff scheme for renewable energy. This material was studied at the fifth meeting of the above project team held on July 23, 2010 and corrected with taking into consideration the opinions of knowledgeable people."

Energy by Electric Utilities (hereafter the “2011 FIT Law”),[10] a FIT scheme was introduced in July 2012, with mandatory net metering remaining applicable to new residential PV systems <10 kWh. This scheme can be considered an expansion of the previous PV net-metering scheme, as discussed below.

A. Comparison with PV Net Metering Scheme

First, the renewable electricity types included had been expanded. Formerly, only PV was eligible, but now all types of renewables were included.[11] However, not all renewable electricity installations under each renewable energy type benefitted from this new favored scheme. For instance, hydropower could not exceed 30,000 kW, while biomass power generation systems not affecting existing businesses such as the pulp and paper industry were eligible.[12]

Second, for eligible facilities, all electricity was fed into the tariff, rather than just surplus electricity.

Third, there were mandatory grid connection[13] and contracting requirements[14] for electric utilities, an expansion of the former net-metering scheme. Only under certain circumstances could electric utilities refuse to buy, enter into a contract, or connect. The Act sets forth exceptions to the requirement that operators of electric utilities purchase the full amount of renewable electricity generated by the Specified Suppliers. Operators are excused from their obligation to enter into power purchase agreements and make related interconnections if there is “a likelihood of unjust harm to the benefits of operators of electric utilities,” “a likelihood of the occurrence of damage to securing the smooth supply of electricity,” or “a just reason as set forth in the [Implementing Regulations].”[15] Finally, an electric power company may also be exempt from the obligation to connect if:

- The specified supplier does not bear the cost necessary for the connection as stipulated in the Ordinances of the Ministry of Economy, Trade and Industry,
- Electricity supply by the electric power company may be interrupted, or
- There exists any good reason as stipulated in the Ordinances of the Ministry of Economy, Trade and Industry.[16]

Fourth, under the former scheme the rate was set by the Ministry but under the current scheme there was a professional commission in charge of setting rates.[17] The rates were also more favorable than the previous scheme. For example, >10 kW PV systems enjoy a rate of 42 JPY/kWh, compared to the previous rate of 40 JPY/kWh. Taking into account payment for all electricity (rather than surplus electricity), 20 years (rather than 10 years), and that technology costs decreased between 2011 and 2012, the new rate is substantially improved. The rates for other types of renewable electricity were also higher than under the former voluntary net metering scheme. The detailed rate schedule[18] in Table 1 will be valid until the end of March 2013. METI is responsible for readjusting the tariffs and rates for future periods.[19]

Table 1 Rate Schedule for Feed-in Tariffs in 2012

Renewable Tariffs in Japan					
18-Jun-12					
			103.374	1.299	1.315
	Years	JPY/kWh	€/kWh	CAD/kWh	USD/kWh
Wind	20				
<20 kW		57.75	0.559	0.725	0.735
>20 kW		23.10	0.223	0.290	0.294
Geothermal	15				
<15 MW		42.00	0.406	0.528	0.534
>15 MW		27.30	0.264	0.343	0.347
Hydro	20				
<200 kW		35.70	0.345	0.448	0.454
>200 kW<1 MW		30.45	0.295	0.383	0.387
>1 MW<30 MW		25.20	0.244	0.317	0.321
Photovoltaics					
<10 kW for surplus generation	10	42.00	0.406	0.528	0.534
>10 kW	20	42.00	0.406	0.528	0.534
Biogas from sewage sludge and animals	20	40.95	0.396	0.514	0.521
Biomass (solid fuel incineration)					
Sewage sludge & municipal waste	20	17.85	0.173	0.224	0.227
Forest thinnings	20	33.60	0.325	0.422	0.428
Whole timber	20	25.20	0.244	0.317	0.321
Construction waste	20	13.65	0.132	0.171	0.174
Approved 18 June 2012.					
Effective 1 July 2012.					

Source: Paul Gipe, Japan Approves Feed in Tariffs, available at: http://www.wind-works.org/FeedLaws/Japan/JapanApprovesFeed%20inTariffs%20.html. (visited on 1 September 2012).

Finally, there is a more comprehensive cost recovery scheme in the new FIT Law than for the previous PV net metering. The FIT Law deals with the cost recovery issue in Chapter III, addressing cost sharing among different electric utilities (Art. 8–18), and Chapter IV,

[10] Act on Special Measures Concerning the Procurement of Renewable Energy by Electric Utilities, available at: http://law.e-gov.go.jp/announce/H23HO108.html (visited on 1 September 2012).
[11] Art. 2 of 2011 FIT Law.
[12] METI, Feed in Tariff Scheme for Renewable Energy, October 2011, available at: http://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/summary201209.pdf (visited on 1 September 2012).
[13] Art. 5 of 2011 FIT Law.
[14] Art. 4 of 2011 FIT Law.
[15] Michael C. Graffagna and Yoshinobu Mizutani, Outline of Japan’s Feed-In Tariff Law for Renewable Electric Energy, at p. 2, available at: http://www.mofo.com/files/Uploads/Images/110913-Outline-of-Japans-Feed-In-Tariff-Law-for-Renewable-Electric-Energy.pdf (visited on 1 September 2012). See also, New Feed-in-Tariff System for Renewable Energy, October 2011, at p.4, available at: http://www.lexology.com/library/detail.aspx?g=c4ec04a4-3a79-46d6-9157-75783b894f38 (visited on 1 September 2012): “An electric power company may be exempt from the obligation to enter into a purchase agreement "if the terms may unduly prejudice the interests of the relevant electric power company or there exists any good reason as stipulated in the Ordinances of the Ministry of Economy, Trade and Industry".”

[16] New Feed-in-Tariff System for Renewable Energy, October 2011, at p.4, available at: http://www.lexology.com/library/detail.aspx?g=c4ec04a4-3a79-46d6-9157-75783b894f38 (visited on 1 September 2012).
[17] Art. 31-37 under Chapter V. Feed in tariff Setting Commission.
[18] ERIC JOHNSTON, FEED-IN TARIFF New feed-in tariff system a rush to get renewables in play, Tuesday, May 29, 2012, available at:http://www.japantimes.co.jp/text/nn20120529i1.html (visited on 1 September 2012).
[19] Japan: Feed-in tariff scheme confirmed, 25. June 2012, available at: http://www.sunwindenergy.com/news/japan2012-feed-tariff-scheme-confirmed-0. (visited on 1 September 2012).

The Authority of Cost Burden Adjustment (Procurement Price Calculation Committee),[20] to determine who should bear the surcharge. All electricity carries the surcharge by kWh, other than 1) those affected by the Great East Japan Earthquake (exempted from surcharge payment from 1 July 2012 to 31 March 2013)[21] and 2) enterprises that consume a large amount of energy (exempted from payment of 80% or more of the surcharge).[22] An equal surcharge/kWh will be assessed nationwide. The government determines the surcharge/kWh based on the results of the previous fiscal year. Because it is possible that the introduction timeframe for renewable energy may vary depending on the region, an organization to adjust the burden will be established. The surcharge collected by the electric utilities will first be collected by the cost-bearing adjustment organization (Procurement Price Calculation Committee), and then delivered to the electric utilities as grants proportional to the actual purchase costs.[23] Therefore, compared with potentially varying regional renewable surcharges, under the new scheme, the surcharge will be the same for everyone.

B. Results

PV and wind power benefit greatly under this new scheme. By 2 July 2012, the government had approved 44 solar or wind power facilities with a combined output of 41,605 kW to join the system, according to an official at the Agency for Natural Resources and Energy, part of the Industry ministry.[24] Under this scheme, the electricity price per kW would increase by 0.22 JPY, which corresponds to an increase in the electricity bill for an ordinary family of ~87 JPY/month, and an annual total cost of 2000 JPY to consumers and companies.[25]

C. Potential Challenges

Even with this new program, there are still some challenges ahead. For instance, for PV, with the introduction of the FIT, solar power is expected to expand rapidly, but other energy sources will be limited to the growth of small-scale plants because of geography, technological limitations, time required for environmental impact assessments, and weak grid connections that make it difficult to alternate between sources of renewable power.[26] In a recent interview, Tetsuro Nagata, head of the Japan Windpower Association, said wind power is concentrated in Hokkaido and the Tohoku region and that unless grid connections to deliver the power from remote areas are strengthened, it will be difficult to expand, even with the new tariff. For geothermal energy, due to strict environmental regulations and construction standards, 10 years may be required for a geothermal plant to begin operation.[27]

2. South Korea

Promotion of renewable electricity in Korea can be divided into three main phases. During Phase I an early law was enacted (the New and Renewable Energy Development and Promotion Act of 1987) promoting the overall development of renewable energy.[28] Then, in the 2000s, there was a series of legal actions giving rise to a "feed-in tariff scheme." However, this scheme faced some political challenges and was replaced by an RPS scheme in 2010.[29]

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[20] Art. 8-18 of Chapter III Cost Sharing Among Electricity Utilities; Art. 19-30 of Chapter IV Authority of Cost Burden Adjustment

[21] Price Relief for Earthquake Victims – Electricity users of offices, residences and other facilities and equipment that were severely damaged in the Great East Japan Earthquake and who meet additional requirements (if any) provided for in the applicable government ordinances will not be invoiced the surcharge during the nine month period from July 1, 2012 to March 31, 2013.
See Michael C. Graffagna and Yoshinobu Mizutani, Outline of Japan's Feed-In Tariff Law for
Renewable Electric Energy, available at: http://www.mofo.com/files/Uploads/Images/110913-Outline-of-Japans-Feed-In-Tariff-Law-for-Renewable-Electric-Energy.pdf (visited on 1 September 2012).

[22] Price Relief for Industrial Users – A reduction in the surcharge of 80% or more is to be provided to business facilities whose annual electricity usage amount exceeds an amount to be set forth in the Implementing Regulations, upon application by a business operator whose ratio of electricity usage (in kWh) to sales volume (per 1000 yen) (i) exceeds 8 times the average ratio in the manufacturing industry (if a manufacturer) or (ii) exceeds the average ratio in the non-manufacturing industry (if a non-manufacturer) by a factor to be determined in the Implementing Regulations See Michael C. Graffagna and Yoshinobu Mizutani, Outline of Japan's Feed-In Tariff Law for
Renewable Electric Energy, available at: http://www.mofo.com/files/Uploads/Images/110913-Outline-of-Japans-Feed-In-Tariff-Law-for-Renewable-Electric-Energy.pdf (visited on 1 September 2012).

[23] METI, Feed in Tariff Scheme for Renewable Energy-Launched on July 1 2012, at p. 8, available at:http://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/summary201209.pdf (visited on 1 September 2012).

[24] Feed-in tariff era gets under way, Monday, July 2, 2012 available at: http://www.japantimes.co.jp/text/nn20120702a2.html (visited on 1 September 2012).

[25] Japanese Times, Electric nuclear power phase guarantee new Japan, 2012/07/02, available at: http://zh.cn.nikkei.com/industry/ienvironment/2838-20120702.html (visited on 1 September 2012).

[26] ERIC JOHNSTON, Feed-in tariff has solar advocates sky high, Saturday, June 30, 2012, available at:http://www.japantimes.co.jp/text/nn20120630f1.html (visited on 1 September 2012).

[27] ERIC JOHNSTON, Feed-in tariff has solar advocates sky high, Saturday, June 30, 2012, available at:http://www.japantimes.co.jp/text/nn20120630f1.html (visited on 1 September 2012).

[28] IEA, ENERGY POLICIES OF IEA COUNTRIES:SOUTH KOREA 2002 48 (2002).

[29] ACT ON THE PROMOTION OF THE DEVELOPMENT, USE, AND DIFFUSION OF NEW AND RENEWABLE ENERGY, Amended by Act No. 10253, April 12, 2010.

(1) RPS and Mandatory Capacity Installation of PV (2012)

A. RPS

Due to the proliferation of PV in 2008, South Korea began to consider changing its FIT scheme to an RPS scheme. The RPS law, Act on the Promotion of the Development, Use, and Diffusion of New and Renewable Energy, Amended by Act No. 10253, 12 April 2010, was adopted in 2010 and became effective in January 2012. The official rationale for this policy remains the pursuit of energy policy goals, but it is unclear why a more effective FIT could not achieve the same goal. It is quite ironic that President Lee Myung-bak promoted such a scheme in his Green Energy Strategy of September 2008 and the Third Renewable Energy Plan of December 2008 under his ambitious plan to pursue low carbon green growth. The FIT scheme and RPA were completely abolished at the end of 2011.

Under the new RPS scheme, electricity generation companies (electricity suppliers)[30] are required to provide a certain percentage of electricity from renewable electricity sources.[31] Electricity generation companies include all those with capacities >500 MW,[32] 6 large-capacity companies (with installation capacity much larger than 500 MW),[33] and 7 smaller companies.[34] Not all renewable electricity qualifies; the Act only applies to those renewable energy sources whose technologies and costs can be verified and commercialized.[35] Under this definition, only PV, wind, hydropower, tidal, bio-gas, landfill gas (LFG), biomass, fuel cells, integrated gasification combined cycle (IGCC), waste, and refuse-derived fuel (RDF) are included.

The compulsory RPS rate is set at 2% in 2012, increasing gradually to 10% in 2022.[36] With respect to the rate, it is important to note that not all renewable energy output is counted in the same manner. It was anticipated that without an adjustment factor, the RPS scheme would only encourage low-cost renewable energy generation. Thus, to promote diverse types of renewable energy simultaneously, a "multiplier" is included that takes into account five factors (Table 2): 1) economics, 2) environment,③3) potential, 4) industrial effects, and 5) consistency with the policy direction. For example, because offshore wind is more expensive, a multiplier of >1.5 is applied. For waste, due to environmental concerns and its relatively low cost, its contribution to renewable energy goals is discounted by 50%.

KEMCO provide primary administration of this RPS.[37] The requirement can be fulfilled in three ways: 1) generation by the company, 2) buying electricity from

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[30] It is really strange that Korea considers these two companies to be of the same idea. See e.g., Min-Cheol, Kang, Renewable Portfolio Standard in the Replublic of Korea, May 03,, 2011, available at: http://www.oav.de/uploads/tx_ttnews/kr_110503_kemco_rps.pdf (visited on 1 September 2012).
Yet in Europe, electricity generation companies is different from electricity supply company. See e.g.,

[31] Article 12-5 (Establishing Responsibility for Supply of New and Renewable Energy, etc.):"
(1) Where the Minister of Knowledge Economy deems it necessary to promote use and diffusion of new and renewable energy and facilitate the new and renewable energy industry, he/she may require an entity prescribed by Presidential Decree from among those falling under any of the following subparagraphs (hereinafter referred to as "entity with responsibility to supply") to supply a certain or larger amount of power generation with new and renewable energy:
1. An operator of an electric power generation business under Article 2 of the Electric Business Act;
2. An entity deemed to have acquired a license to run an electric power generation business under Article 7 (1) of the Electricity Business Act in accordance with Articles 9 and 48 of the Integrated Energy Supply Act; and
3. Public institutions;
(2) The total quantity of power that an entity with responsibility to supply should mandatorily supply by new and renewable energy under paragraph (1) (hereinafter referred to as "mandatory supply quantity") shall be annually prescribed by Presidential Decree within 10% of the quantity of total power generation. With regard to the kinds of new and renewable energy that require balanced use and diffusion, part of the total mandatory supply quantity may be supplied using the appropriate kind of new and renewable energy as prescribed by Presidential Decree.
(3) The mandatory supply quantity of an entity with responsibility to supply shall be prescribed and publicly announced by the Minister of Knowledge Economy for each responsible entity after hearing the opinions of the responsible entities. The Minister of Knowledge Economy shall consider the total amount of power generation of responsible entities, sources of power generation, etc."

[32] REEGLE, South Korea 2012, available at: http://www.reegle.info/policy-and-regulatory-overviews/KR (visited on 1 September 2012).

[33] Korea Hydro Nuclear Power Co., Ltd. (KHNP) – 2,449 GWh; South East Power Co., Ltd (SEP) – 1,080 GWh; Korea West Power Co., Ltd. (KWP) – 976 GWh; Korea Southern Power Co., Ltd., (KOSPO) – 965 GWh; Korea Midland Power Co., Ltd (KOMIPO) – 953 GWh; Korea East West Power Co., Ltd. (KEWP) – 875 GWh.

[34] Korea District Heating Corporation (KDHC);K-Water Corporation; SK E&S (SK E&S is under M&A process. Used to be K-Power);GS EPS;GS Power; POSCO Power; MPC (Yulchon).

[35] MKE, Renewable Portfolio Standard in the Republic of Korea, available at: http://www.bcbioenergy.com/wp-content/uploads/2012/03/2-Korean-Policy-Environment-for-Renewable-Fuels-Tae-Jun-Choi.pdf (visited on 1 September 2012).

[36]

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Compulsory Ratio (%)	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	10.0

MKE, Renewable Portfolio Standard in the Republic of Korea, available at: http://www.bcbioenergy.com/wp-content/uploads/2012/03/2-Korean-Policy-Environment-for-Renewable-Fuels-Tae-Jun-Choi.pdf (visited on 1 September 2012).

[37] KEMCO, Certificate of NRE systems, available at:http://www.kemco.or.kr/new_eng/pg02/pg02040703.asp (visited on 1 September 2012).

other companies, and 3) acquiring sufficient certificates.[38]

Table 2 RPS Rate Multipliers in South Korea

Grouping	Multiplier	Eligible Resources		
		Installation type	Land Type	Capacity
Solar Energy	0.7	In case of not use 'Building and Existing Facilities'	5 lands(Rice field, Dry field, Orchard, Pasture, Forest land)	
	1.0		Other	Excess 30KW
	1.2			Under 30KW
	1.5	Building and Existing Facilities		
General Renewable	0.25	■ IGCC		
	0.5	■ Waste ■ LFG(Land fill gas)		
	1.0	■ Hydro ■ Wind(on-shore) ■ Bio-gas ■ Bio-mass ■ Tidal I(construction under having its tide embankment)		
	1.5	■ Off-shore Wind(connecting point length is under 5km)		
	2.0	■ Off-shore Wind(connecting point length is over 5km) ■ Tidal II (newly construction its tide embankment) ■ Fuel-cell		

Source: MKE, Renewable Portfolio Standard in the Republic of Korea, available at: http://www.bcbioenergy.com/wp-content/uploads/2012/03/2-Korean-Policy-Environment-for-Renewable-Fuels-Tae-Jun-Choi.pdf (visited on 1 September 2012).

B. Mandatory Capacity Installation of PV

For solar energy, the South Korean government adopted two protective measures. First, as PV is very competitive among Korean industries, there is a dedicated set of multipliers designed specifically for PV; building-integrated PV (BIPV) is relatively expensive, and larger PV systems are less expensive than smaller ones. Therefore, different multipliers apply. There is also a minimum requirement for PV electricity output and installation on an annual basis to provide further protection to PV (Table 3). However, it is unclear how this requirement should be distributed among electricity users, i.e., whether all should divide this requirement proportionately.

Table 3 Minimum Requirement for PV Electricity Output Each Year

Year	2012	2013	2014	2015	2016~
Obligation	276 GWh	591 GWh	907 GWh	1,235 GWh	1,577 GWh

Year	2012	2013	2014	2015	2016~
Capacity	220 MW	450 MW	690 MW	1040 MW	1200 MW

C. Other measures

Other measures are provided in the 2010 revision of the Law for support of renewable electricity development:

- Basic plan[39] and yearly implementation plan.[40]
- Establishment of a special task force.[41]
- Development of financial tools,[42] such as 1) all renewable energy technologies receive a 5% tax credit,[43] 2) in 2009, import duties were halved on all components/equipment used in renewable energy power plants, 3) government subsidies are available to local governments of up to 60% for installation of renewable facilities, as well as low-interest loans (5.5–7.5%) for renewable energy projects with a 5-year grace period followed by a 10-year repayment period.[44]
- Establishment of a Research Centre responsible for renewable energy R&D.[45]

3. Taiwan

(1) Post-PV Boom and Post-Fukushima: New Energy Policy of November 2011: FIT + PV Tendering

Due to the PV boom in 2010, the Taiwanese government reformed its PV promotion scheme in 2011. The original FIT for all renewable electricity was revised to a dual-track system. In general, most types of renewable electricity and small-scale PV installations are still subject to a favorable FIT scheme. However, Taiwan incorporated a tendering system into FIT on 17 March 2011.[46]

A. Eligibility

After the PV boom, Taiwan adopted a mixed scheme of fixed FIT and bidding mechanisms. Installations are classified into 4 categories: Type I) rooftop

[38] Art. 12-5:"5) Responsible entities may meet the mandatory supply quantity by purchasing supply certification of new and renewable energy under Article 12-7."

[39] Article 5 (Establishment of Basic Plan)

[40] Article 6 (Yearly Implementation Plan)

[41] Article 8 (New and Renewable Energy Policy Council):" (1) For the purpose of deliberating on important matters concerning the technological development, use, and diffusion of new and renewable energy, the New and Renewable Energy Policy Council (hereinafter referred to as "Council") shall be established within the Ministry of Knowledge Economy."

[42] Article 29 (Financial Measures, etc.):"The State shall take necessary measures, such as providing financial or tax support, where it is necessary, to an entity that is recommended pursuant to Article 12 or that must comply with duties, an entity engaged in the technological development, use, and diffusion of new and renewable energy, or an entity that has obtained certification of facilities under Article 13"

[43] REEEP, Policy DB Details: South Korea (2012), available at: http://www.reeep.org/index.php?id=9353&text=policy-db&special=viewitem&cid=151 (visited on 1 September 2012).

[44]Young Il Choung, Quick Look: Renewable Energy Development in South Korea, available at:http://www.renewableenergyworld.com/rea/news/article/2010/12/quick-look-renewable-energy-development-in-south-korea (visited on 1 September 2012).

[45] Article 31 (New and Renewable Energy Center):" (1) The Minister of Knowledge Economy may establish a new and renewable energy center (hereinafter referred to as "Center") under an energy agency prescribed by Presidential Decree, in order to professionally and efficiently promote the use and diffusion of new and renewable energy, and may have the Center perform the projects falling under each of the following subparagraphs:"

[46] R.O.C. One hundred Years (2011). First phase of the photovoltaic power generation equipment bid, Operational Guidelines of the Ministry of Economic Affairs, Ministry of Economic March 17, No. 10004601330.

installations with a capacity of 1–10 kW, when the applicant is the building owner and the roof is owned by the building owner; Type II) same as Type I, but the applicant does not own the building; Type III) ≥10-kW rooftop PV installations; and Type IV) ≥1-kW ground-mounted PV installations conforming to the land code. Generally, a minimum capacity of 1 kW is still required. In addition, there is a cap for applications (1–2000 kW)[47] for Types II, III, and IV.[48] Similar measures are included in the Bidding Guideline for PV Installations Electricity Generation Installation 2011, Ministry of Economic Affairs, Phase II, but additional restrictions on systems with an installed capacity of 1 MW are imposed on ground-mounted installations. The guideline also excludes from bidding eligibility related government bodies whose public buildings are required to use 6% green energy, as well as installations that have ever received investment subsidies or grants from the Bureau of Energy.

However, to reflect the need to promote renewable electricity, a new energy policy was announced in November 2011. Eligibility for applying for the FIT was broadened so that only larger rooftop PV installations (>30 kW, rather than the original 10 kW) would be subject to the tendering scheme.

B. Duration

Taiwan does not plan to adjust the FIT duration of 20 years for PV installations.

C. Rate Schedule

Due to the preferential rate of 2010, a PV boom occurred,[49] and the Taiwanese government was forced to take some countermeasures. Initially, the government attempted to greatly decrease the rate schedule for PV installations,[50] which faced a strong outcry[51] from the PV industry. However, as described above, a PV bidding scheme was introduced with 4 PV categories. For Type I, the full rate applied without the need to enter the bidding process.[52] The remaining three categories (Types II, III, and IV) must undergo the PV bidding process and are highly unlikely to receive the pre-defined rate schedule (so-called “cap rate”). In other words, the government will develop a fixed yearly installed capacity plan and cap (12,000 kW for rooftop and 3000 kW for ground-mounted) for installers to bid on. During the bidding process, the applied capacity for a single case cannot exceed 2000 kW, and normally the bidder offers a bid price lower than the cap rate. Only the winners with allocated capacity (those with lower prices are prioritized) are eligible to enter into a contract.[53]

Phase I of the bidding process for PV installations has been executed, and as a result, 123 rooftop installations have been awarded the bid, with an accumulated awarded capacity of 12,173.123 kW. Discount rates range from 0 to 25%, with an average discount rate of 2.62%. For ground-mounted installations, 2 have been awarded the bid, with an accumulated awarded capacity of 1379.4 kW. Discount rates range from 0 to 0.51%, with an average discount rate of 0.31%.[54]

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[47] Bidding Guideline of PV Installations Electricity Generation Plant (Photovoltaic power generation equipment bid Operating Guidelines) 2011, Ministry of Economic Affairs with reference to the Ministry of Economic Affairs, the first period of a hundred years of photovoltaic power generation equipment bid Operating Guidelines).

[48] Bidding Guideline for PV Installations Electricity Generation Plant 2011, Ministry of Economic Affairs, Vol. II, article 3: eligible entities: The applicant shall apply for the PV Electricity Generation Plant according to the article VI of the Managing Rules on the Installation of the Renewable Energy Electricity Generation Plant for approval, and the installed capacity applied by each case shall be between 1kW – 2000kW, and shall fulfill the following requirements:
Rooftop with an installed capacity between 1kW – 10kW and not owned by the building owner.
Rooftop installation with an installed capacity superior to 10kW.
Stand-alone(ground type) installation with an installed capacity superior to 1kW which fulfills the “Land Use Regulations”.

[49] Reference, Linyi Zhang: the policy turn photovoltaic wholesale purchase this heated debate（2010-12-27）Liberty Times, Source: http://www.libertytimes.com.tw/2010/new/dec/27/today-e8.htm (last visited August 3, 2011). Policy changing, violent debates on PV installation FIT tariff (2010-12-27), by Linyi Zhang, Litery Times, information source: http://www.libertytimes.com.tw/2010/new/dec/27/today-e8.htm (last visited August 3, 2011).

[50] Renewable Energy Electricity FIT Tariff and the Formula, 2011.

[51] Reference: Yang Yi, Sun the photoelectric acquisition rates fell three percent of the industry: Arrested Development (2011-03-15), the Economic Daily News, Source: http://www.ezsell.com.tw/mep082/app/eip.asp?dblabel=mep082&apid=message.asp&act=detail&dept_id=370_310&fno=11901&dsn=&sort=a&seo=%A4%D3%B6%A7%A5%FA%B9q%A6%AC%C1%CA%B6O%B2v%B6%5E%A4T%A6%A8+%B7~%AA%CC%A1G%B5o%AEi%A8%FC%AA%FD+1000415 (last visited August 3, 2011). PV FIT Tariff decreased by 30% Operators: development hindered, Economics Daily, information source: http://www.ezsell.com.tw/mep082/app/eip.asp?dblabel=mep082&apid=message.asp&act=detail&dept_id=370_310&fno=11901&dsn=&sort=a&seo=%A4%D3%B6%A7%A5%FA%B9q%A6%AC%C1%CA%B6O%B2v%B6%5E%A4T%A6%A8+%B7~%AA%CC%A1G%B5o%AEi%A8%FC%AA%FD+1000415(last visited August 3, 2011).

[52]

Renewable energy category	Category	Installed capacity	Cap rate (NT/kW)
Photovoltaics (PV)	Rooftop	1–10 kW	10.3185
		10–100 kW	9.1799
		100–500 kW	8.8241
		>500 kW	7.9701
	Ground-mounted	>1 kW	7.3297

[53] PV Electricity Generation Plant Bidding Procedure 2011 Phase I, Ministry of Economic Affairs.

[54] See: Bureau of Energy, Ministry of Economic Affairs, a photovoltaic power generation equipment bidding jobs successfully completed (2011-04-29) Source: http://www.moeaboe.gov.tw/Policy/Renewable/news/SENewsDetail.aspx?serno=01116&TYPE_KIND=News (last visited

Immediately afterwards, on 29 July 2011, the Taiwanese government proceeded with Phase II, Stage 1 of the PV Electricity Generation Plant Bidding Procedure;[55] 40 rooftop installations won the bid, with an accumulated awarded capacity of 2583.181 kW. The discount rate ranged from 1.25 to 6%, with an average discount rate of 2.95%. Only 1 ground-mounted installation was awarded the bid with a capacity of 248.64 kW and a discount rate of 0.31%. The total accumulated awarded capacity is 2831.821 kW with a remaining capacity of 2168.179 kW.[56] Therefore, only Type I can be awarded the pre-defined rate under the Decree, but the rates under the decree for the other types of PV can be only seen as a cap rate or a "reference rate for submitting a bid." The rate awarded was determined by the bidding process.

Item			Tariff of 2010 (A)	Tariff of 2011 (B)	% change (B/A - 1) × 100%
Photovoltaic (PV)	Rooftop	1–10 kW	11.1883 (equiv. to 14.6030)	10.3185	-29.34 %
		10–100 kW	12.9722	9.1799	-29.23 %
		100–500 kW		8.8241	-31.98 %
		>500 kW	11.1190	7.9701	-28.32 %
	Ground-mounted			7.3297	-34.08 %

Table 4: Comparison Table for the FIT Tariff for Renewable Energy in 2010 and 2011, Taiwan
Source: compiled from this article.

D. Development Target and Cap

According to Art. 6(2) of the Renewable Energy Act of 2009, the total installation capacity cap of renewable energy development was set at 6,500–10,000 MW, but no total installation cap was specified for PV installations.

While planning the FIT promotion scheme of 2011 at the end of 2010, Taiwan was expected to limit the development of PV electricity to within 70 MW. Such measures were intended to avoid reaching the development target too quickly; the rapid installation of too many PV systems would dramatically affect the price of electricity. At that time, various measures were being considered, such as creating a bidding system or adopting a "first applied, first reviewed" system.[57] The wording of "first applied, first verified" implied an annual hard cap for PV.

It was strongly disputed whether Art. 6 of the Renewable Energy Act could provide a legal basis for establishing an annual hard cap on development. Thus, at the beginning of 2011, the government decided to use its Feed-in Tariff Ordinance for Managing the Application Process[58] to officially establish a "PV annual installed capacity hard cap."[59] On this basis,[60] the Taiwanese government simultaneously developed a bidding system for the PV industry by publishing the Bidding Guideline for PV Installations Electricity Generation Plant 2011, phase I, Ministry of Economic Affairs, establishing an annual PV hard cap of 70 MW for 2011.[61]

September 2, 2011).
Bureau of Energy, Ministry of Economic Affairs: PV Electricity Generation Plant Bidding Procedure 2011 Phase I successfully completed.(2011-04-29), information source: http://www.moeaboe.gov.tw/Policy/Renewable/news/SENewsDetail.aspx?serno=01116&TYPE_KIND=News (last visited July 5, 2011).

55 Bidding Guideline of PV Installations Electricity Generation Plant 2011 Phase II

56 See: Bureau of Energy, Ministry of Economic Affairs, 100 years two of the first stage of photovoltaic bid bid opening, a total of 41 bid, he will have a marked capacity 2831.821 kW (2011-07-29) Source: http://www.moeaboe.gov.tw/Policy/Renewable/news/SENewsDetail.aspx?serno=01150&TYPE_KIND=News (last visited September 2, 2011).

57 Reference: auction, or a first-come, first-served basis trial Photovoltaic acquisition austerity (2010/12/13), the Commercial Times, Source: http://money.chinatimes.com/news/news-content.aspx?id=20101213000018&cid=1211 (last visit Date: August 3, 2011). price comteting or first applied first verified, purchase tightened on PV electricity, Commercial Times, information source: http://money.chinatimes.com/news/news-content.aspx?id=20101213000018&cid=1211 (last visited: 2011/8//3).

58 Renewable energy power generation equipment management approach identified approaches renewable energy equipment

59 Art. 5 of the Managing Regulation of Renewable Energy Generation Installation: according to c1 of the previous article, the central administration authorities can, based upon the annual promotion target and its status of allocation, decide to accept, suspend to accept or refuse to recognize.

60 In order to proceed the bidding procedure on PV installations electricity generation plant, the Ministry of Economic Affairs (referred to as the Ministry) created this guideline based upon the promotion target allocation defined by the Art. 5 of the Managing Regulation of Renewable Energy Generation Installation as well as the Renewable Energy Electricity FIT Tariff and the Formula 2011, R.O.C.", referred to: Bidding Guideline of PV Installations Electricity Generation Plant 2011, phase I, Ministry of Economic Affairs.

61 Refer to: PV installation capacity targeted at 2500MW for 2013, (2011/04/15),IDN.com, information source:http://www.idn.com.tw/news/news_content.php?catid=2&catsid=3&catdid=0&artid=20110416abcd00 (last visited: 2011/08/13) Reference: renewable energy solar target amount for 2030 the 2500MW (2011/04/15), the Independence Evening Post, Source: http://www.idn.com.tw/news/news_content.php?catid=2&cat

Under this mechanism, the new scheme categorized PV installations into 4 types. Type I, the first category, included all of the self-owned, small-scale rooftop PV installations (installed on the rooftop by the residence owner with a capacity of 1–10 kW), which were favored by the government. No annual hard cap was created for this category. The installers are eligible for the full subsidy based on the "renewable energy electricity FIT formula 2011"[62] and thus do not need to go through the bidding process.

For the other categories (Types II–IV), the Taiwanese government was rather discrete in its concern over a PV boom and providing an excess subsidy. The total capacity for the first bidding process, including Types II–IV, was 15,000 kW, among which the restrictions were still more favorable for small-scale non-self-owned and large-scale rooftop installations in comparison with ground-mounted installations. This policy is apparent in that the capacity cap allocated for rooftop installations was 4 times that for ground-mounted installations; the total bidding capacity for rooftop installations was 12,000 kW and 3,000 kW for ground-mounted installations.[63] Moreover, as the tariff can only be determined through the bidding procedure, the installer is not guaranteed the provisional FIT rate. As stated previously, the first stage of the bidding procedure was completed in April 2011 and the total capacity awarded was 13,552.523 kW,[64] which represented only 20% of the scheduled target for 2011 (70,000 kW); therefore, considerable growth could be expected in the future. After the second stage of the bidding procedure in 2011, in which a similar process was followed, the installed capacity had increased by 2831.821 kW and 4951.23 kW after conclusion of the first and second stages, respectively.[65]

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sid=3&catdid =0 & artid = 20110416abcd00 (Last Visit Date: 13/08/2011)

[62] 100th Year (2011) renewable energy the electricity wholesale purchase rates formula

[63] Bidding Guideline of PV Installations Electricity Generation Plant 2011 Phase I

[64] Reference: the completion of a solar bidding of the Ministry of Economic Affairs, Source : http://www.idn.com.tw/news/news_content.php?catid=2&catsid=3&catdid=0&artid=20110430abcd013 (Last visited: 2011/08/13) PV Installations Electricity Generation Plant Bidding procedure phase I completed, Ministry of Economic Affairs, information source: http://www.idn.com.tw/news/news_content.php?catid=2&catsid=3&catdid=0&artid=20110430abcd013(last visited: 2011/08/13)

[65] PV installation electricity generation plant biding, phase I stage II of 2011, 41 bids are awarded with a total bidding capacity of 2831.821kW http://www.moea.gov.tw/Mns/populace/news/News.aspx?kind=1&menu_id=40&news_id=22239
PV installation electricity generation plant biding, phase II stage II of 2011, 39 bids are awarded with a total bidding capacity of 4951.23kW: http://www.moea.gov.tw/Mns/populace/news/News.aspx?kind=1&menu_id=40&news_id=22239 (last visited August 3, 2011).
http://www.moeaboe.gov.tw/news/newsdetail.aspx?no=03&serno=01172 (last visited August 3, 2011).

III. Comparison with German-style FIT: Unique FITs in Japan, South Korea, and Taiwan

Even though these countries shared similar backgrounds before the introduction of FITs and declared their intentions in their energy policies, they did not all adopt ambitious versions of FIT schemes in promoting renewable electricity. Based on the results of this study, Asian-style FITs are quite different from the German-style FIT in many aspects.

(1) Eligibility

As the basic idea of a FIT is to provide complete support for development of renewable electricity, eligibility requirements are often easy to meet. For instance, under Germany's FIT, most types of renewable electricity are eligible for the FIT. In addition, the rate schedule is designed in a very detailed manner to reflect different sizes (and different input fuels) of renewable electricity installations.

In the FIT laws of Japan, Taiwan, and South Korea, it also appears as if most types of renewable electricity are subject to the FIT scheme. Yet, looking more closely, this may not be the case. For instance, the FITs in Japan and Taiwan have many restrictions on the renewable electricity installations that qualify for the FIT. In contrast, the FIT in South Korea is closer to that of Germany, although there are fewer types of renewable electricity on the FIT list.

(2) Duration

Germany adopted differential durations (15, 20, 30) for different types of renewable electricity installations. Japan adopted a 10-15-20 regime and South Korea a 15-20 regime, while Taiwan adopted 20 years for all types.

(3) Rate Schedule

A. Rate Schedule

A successful aspect of Germany's FIT is its multi-year rate schedule, which provides a stable investment environment for the renewable electricity industry and potential installers. Even after several years of PV boom in Germany and many European countries, the multi-year rate schedule (with tariff degression) was maintained.

The most similar rate schedule among the surveyed countries is that of South Korea, which remains effective until 2020. However, in Taiwan and Japan, an annual rate schedule is used, which provides less investment security.

B. Tariff Degression

The FIT in Germany includes a predetermined degression rate or target-responsive degression rate for new installers, including annual, semi-annual, and seasonal degression rates. This scheme supplements the multi-year schedule to provide a secure investment environment for renewable electricity. Among the surveyed countries, South Korea's FIT adopted a similar approach with detailed degression rates for different types of renewable electricity.

However, as noted above, this approach was not adopted by Taiwan and Japan. There is no pre-determined degression rate for late-comers. However, tariffs in subsequent years are likely to be degressed somewhat to respond to technology development.

(4) Cost-sharing Scheme

To support their costly FIT, Germany passes the cost on to all consumers via a system surcharge under the German Renewable Energy Act. Thus, a stable funding source for the FIT is not a concern. Among the survey countries, Japan has also adopted a comprehensive cost-sharing scheme. However, the funding schemes are relatively weak in Taiwan and South Korea.

(5) Cap

The concept of a FIT in Germany is a program without a cap. Even if Germany introduces a cap this year, this will have resulted from multiple years of PV boom. Japan has not yet adopted a cap.

In Taiwan and South Korea, there has always been a long-term cap in their Acts. Furthermore, since the PV boom, annual caps for certain types of renewable electricity have come into play.

(6) Grid Connection and Mandatory Contracting Duty

The importance of the FIT in Germany is reflected in its comprehensive regulations on mandatory grid connections, usage rules, and mandatory contracting requirements in the German Renewable Energy Act.

However, these rules are less clear in Japan, South Korea, and Taiwan, which may give too much discretion to the electricity incumbents to the detriment of other project proponents.

(7) Summary

Table 5 summarizes the above comparisons and indicates how difficult it has been for Asian countries to adopt all of the essential elements of the German-style FIT. Without a comprehensive design that includes all FIT elements, there is always a concern over sustainability.

Table 5: Comparison of FIT Elements in Germany, Japan, Taiwan, and South Korea

	Germany	Japan	Taiwan	South Korea
Eligibility	●●●	●	●	●●
Duration	●●●	●●●	●	●●●
Rate scheme	●●●	●	●	●●●
Cost sharing	●●●	●●●	●	●
Cap	●●●	●●●	●	●
Grid connection and usage	●●●	●	●	●

Source: compiled by this author.

For instance, the failure of South Korea's and Taiwan's FITs may be related to the flawed design of their cost-sharing mechanisms, which led to a change in direction from the FIT to RPS and PV tendering. Due to concerns over the bankruptcy of Tai-Power in Taiwan and the financial burden on the Korean Government, the FITs in these countries have been adjusted or changed. Although the FIT in Japan is closer to Germany's design, unclear grid connection and usage rules and unclear flexibility in eligibility guidelines may present potential barriers in the future.

IV. Conclusions

Effects of Fukushima? After the Fukushima accident, it may appear that Japan, Taiwan, and South Korea have all adopted a new renewable electricity incentive scheme. Yet, after a closer look, we find that only Japan's new FIT scheme actually responds to energy policy needs in a post-Fukushima age. The post-Fukushima measures in Taiwan and South Korea had already been drafted and proposed before Fukushima.

Due to the need to promote renewable electricity in Japan, a move from its original net metering or RPS to a system closer to the German-style FIT to encourage large-scale domestic application of PV and other renewable electricity took place. Because the new schemes in Taiwan and South Korea had little or nothing to do with the Fukushima accident, both are moving away from the FIT: South Korea has abolished the FIT entirely, while Taiwan has introduced a PV tendering scheme.

Contribution. From this comparison, we have determined that Asian countries have had difficulty adopting all of the important design elements of German- or European-style FITs; the closest approach is that of South Korea. However, even this scheme did not remain in application for very long. Via comparative evaluation, this study has brought to light that these Asian countries all have unique schemes for promoting PV that are also different from the schemes in Germany. Therefore, by comparing these three countries with a properly designed analysis structure, it is possible to find "coherent incentive patterns" that cannot be distinguished from country-by-country introductory studies.

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Feed in Tariff Reform in Photovoltaic Sector at a Post Fukushima Era: The Dilemma of Multi Goals of Developing PV

Dr. Dino R PONNAMPALAM (corresponding author)
Postdoctoral Research Associate, Institute of Law for Science and Technology (ILST)
National Tsing Hua University
Tel: +886-3571-15131 ext.62515
Email:pdr@mx.nthu.edu.tw

Dr Ming-Zhi (Anton) GAO
Assistant Professor, Department of Law, Institute of Law for Science and Technology (ILST)
National Tsing Hua University
antongao@mx.nthu.edu.tw

Dr Yi-Yuan SU
Assistant Professor, Department of Law, National Chung Hsing University

Abstract: In the face of climate change challenges, a wide range of legal regime has been adopted with a view to promote renewable electricity, green energy technology and industry. Right several years before the Fukushima accident, some European countries has experienced a prosperity of wind power and photovoltaic (PV) development as the result from the implementation of feed in tariff (FIT) incentive scheme. However, since late 2011, a wave to evaluate and revise the PV FIT scheme has been launched all around the Europe. Even after the Fukushima accident, which is usually recognized as an impetus to "whole" renewable electricity, this wave of reform seems unstoppable. The purpose of this article is to study the evolution of PV FIT scheme before and after Fukushima in main supporting FIT countries, including Germany, Italy, Spain, UK, and France, and to identify how these five countries transform their FIT regime to reconcile the multi-values and multi-policy goals, including: the needs to develop renewable electricity in carbon reduction, the creation of domestic green jobs, the side-effect of PV boom on local electricity price, the challenge of gradual phasing out nuclear after Fukushima accident, etc. Preliminarily, there are two main approaches in the FIT reform: 1) Fine-tuning the elements of FIT, such as reducing tariff schedule, re-define the eligibility technology or PV installations, etc; and 2) Integrating bidding scheme to the original fixed FIT scheme, such as France. In this regards, the potential rational for choosing reform approach will be also provided.

Keywords: FIT, PV Boom, countermeasures

1. Introduction

The frequency for abnormal climate events is increasing. According to the Intergovernmental Panel on Climate Change (IPCC) the main reason behind this is the increasing density of greenhouse gases. In order to solve this problem, all nations are dedicated to developing countermeasures against the climate crisis. In the past decade, the major countermeasure for all nations focused on the development of renewable energy, and a steady growth of this can be observed in every nation.[66,67] One major plank of this development is the use of a feed-in tariff (FIT) mechanism.

[66] IEA, Energy Statistics: Electricity generation by Fuel, available online at http://www.iea.org/stats/pdf_graphs/DEELEC.pdf (last visited August 2, 2011).

[67] What to be noticed is that, early before the coming up of the climate changing issues, the role played by the renewable energy was catching attention since the 2nd oil crisis during the 1970s. As the crisis did not last for long, thus the issue of the renewable energy did not meet a global development like that of the emission reduction issues. Regarding the documents related to the renewable energy development after the energy crisis, See e.g., Dan Tarlock et al., V. USA, in ENERGY EFFICIENCY AND RENEWABLE ENERGIES IN TOWN PLANNING LAW 52. (Stephan Mitschang ed., 2010).

1974 ~ 1985, the renewable energy development in Europe after the oil crisis, please refer to Hildingsson, R. et al., Renewable Energies: A Continuing Balancing Act?, in CLIMATE CHANGE POLICY IN THE EUROPEAN UNION: CONFRONTING THE DILEMMAS OF MITIGATION AND

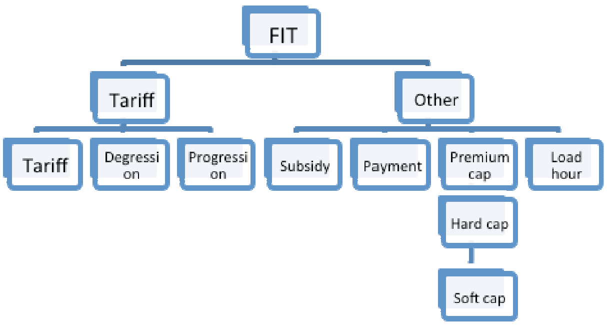
The study is expected to provide answers for the following major questions: what are the major system design issues of the FIT scheme for PV installations for a select group of countries? And following a PV boom phenomenon, what are the systematic countermeasures taken by these countries?

The research will analyze the countermeasures against the PV boom taken by the following European countries: Germany, France, Spain, Italy and the UK.

2. The the promotion mechanism of renewable energy power

A compilation of the important FIT scheme designs for PV installations is completed in this research, as shown in Figure 1:

Figure 1: FIT scheme design of PV installations discussed in this research



Source: (compiled from this research)

From Figure 1, the main mechanism in the FIT scheme is the Tariff levels. In practice, it is not only the tariff-level itself [68] that is the most important but also the regular degression and progression mechanisms. In addition, other supplementary mechanisms are needed to satisfy the function and purpose of finetuning the system. For example, the entities entitled to the subsidization can be adjusted by defining the eligibility of the entities. Another concern is that the cost of electricity might rise if the electricity market is overwhelmed by PV installations in a short time, so nations would install a cap for the installed capacity to control PV development. The components shown in Figure 1 shall be detailed: the eligibility, tariff, cap for installed capacity, and finally, loading hours.

3. Eligibility for FIT

PV installations are generally listed as eligible technology for FIT schemes in most countries, except for certain high altitude countries such as Finland. Yet, there may be additional requirements or criteria for certain PV installations to be eligible. Overall, most countries set up restriction at the early stage of launching FIT scheme, but then loosen the criteria which can lead to PV boom. After PV boom, most countries would re-introduce the limitation on the eligibility.

1. Germany

In general, the PV installations eligible under German FIT scheme involves two types: traditional feed-into-grid type and self-use type. Feed-into-grid type is eligible but under certain conditions. According to the Article 2(2)[69,70] of the Renewable Energy Act of 2000, the maximum installation capacity eligible for FIT should be less than 5 megawatt (MW). However, this changed and the cap of 5MW was then annulled in the Renewable Energy Act of 2004[71,72]. Following a PV boom, the Renewable Energy Act of 2010 gradually abolished the FIT for ground-mounted installations located on the farmland, while Article 16 of the Renewable Energy Act requires large PV installations with a capacity over 100 KW to install technical devices to reduce the electricity output.

Under the traditional sense of FIT, self-use PV is often not eligible for PV. Yet, in order to promote the development of PV and taking into account line loss and the complexity of grid development, Germany introduced such an innovative scheme. Under the Renewable Energy Act of 2008, small PV installations less than 30 kilowatt (kW), were eligible. Yet, after PV boom, there was a change, including additional limitations and incentives, in the Renewable Energy Act of 2010. On the one hand, to consider the advantage of self use type PV, the eligible entities, the eligibility for self-use FIT payment is broadened from

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ADAPTATION 104-111 (Andrew Jordan et al. eds., 2010). The first phase of the American Renewable Energy Development is related to the Public Utility Regulatory Policies Act of 1978. See e.g., FERC, Federal Energy Regulatory Commission, Public Utility Regulatory Policies Act of 1978, available online at http://www.ferc.gov/students/energyweregulate/fedacts.htm (last visited 2 August 2011).

[68] Ex.: In Taiwan, while creating this Tariff, 5 meetings have been called which revealed the discreet attitude of the government. Refered to: the Review and Approval Meeting for Renewable Energy Development Act Bureau of Energy, Ministry of Economic Affairs, source from: http://www.moeaboe.gov.tw/Policy/Renewable/meeting/SEmeetingMain.aspx?pageid=exam (the last visit date: 2011/08/27).

[69] Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act - EEG), available online at http://www.lexadin.nl/wlg/legis/nofr/eur/arch/ger/resact.pdf (last visited September 2, 2011).

[70] Act on Granting Priority to Renewable Energy Sources (Renewable Energy Sources Act - EEG), available online at http://www.lexadin.nl/wlg/legis/nofr/eur/arch/ger/resact.pdf (last visited August 2, 2011). (" Renewable Energy Law of Germany, 2000")

[71] Erneuerbare-Energien-Gesetz (EEG) am 1. August 2004, available online at http://www.bmu.de/erneuerbare/energien/doc/5982.php (last visited September 2, 2011).

[72] Erneuerbare-Energien-Gesetz (EEG) am 1. August 2004, available online at http://www.bmu.de/erneuerbare/energien/doc/5982.php (last visited July 5, 2011). (" Renewable Energy Law of Germany, 2004")

30kW to 500kW. On the other hand, to tackle the PV boom and to avoid the abuse of such scheme, certain limitations were put into place.

2. France

According to the Electricity Liberalization Act 2000 and its related administrative decrees, the size of the PV subsidized entities are limited for the installations with a capacity less than 12MW.[73,74] In an administrative decree in 2006, the French government decided to adopt a more favorable FIT measure[75,76] and the 12MW limitation remained.

Facing the PV boom, the French government decided to temporarily suspend the application of PV Installations over 3kW for 3 month in the administrative decree published the Dec. 9, 2010[77,78]. Afterwards on March 4, 2011, the government issued 3 new administrative decrees, integrating a bidding element into the current FIT scheme for PV, a combined fixed FIT, and a tendering scheme.[79,80] According to these decrees, only rooftop installations less than 100kW will qualify for the FIT and be entitled to the prefered tariff. On the other hand, the rooftop installations greater than 100kW as well as all ground-mounted installations were subject to the bidding scheme.

To sum up, it is evident that in order to deal with the PV boom issue, apart from the existing capacity cap of 12MW, the French government also set up many additional requirements for the eligibility of FIT payment from March 2011.

3. Spain

The Electricity Act of 1997 set up a threshold of 50MW installation capacity for eligible projects.[81,82] This was cancelled under a decree in 2004[83,84]. Yet, in 2007, the Spanish government again put up restrictions on the eligibility of installations less than 100MW [85,86]. After the PV boom, the Spanish government adopted stricter requirement on the eligibility of the subsidized entities for only rooftop installations less than 2MW and ground-mounted installations less than 10MW [87,88].

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[73] Art. 10(1), Loi n°2000-108 ("Electricity Liberation Act of France, 2000"); Art. 2, Décret n°2000-1196 du 6 décembre 2000 fixant par catégorie d'installations les limites de puissance des installations pouvant bénéficier de l'obligation d'achat d'électricité, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000005630236&dateTexte=20090828(last visited August 2, 2011). ("Décret n°2000-1196")

[74] Art. 10(1), Loi n°2000-108; Art. 2, Décret n°2000-1196 du 6 décembre 2000 fixant par catégorie d'installations les limites de puissance des installations pouvant bénéficier de l'obligation d'achat d'électricité, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000005630236&dateTexte=20090828 (last visited September 2, 2011). ("Décret n°2000-1196")

[75] Annexes Tarifs mentionnés à l'article 3 de l'arrêté, Arrêté du 10 juillet 2006 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative du soleil ("Arrêté du 10 juillet 2006 l'énergie radiative du soleil")

[76] Annexes Tarifs mentionnés à l'article 3 de l'arrêté, Arrêté du 10 juillet 2006 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative du soleil ("Arrêté du 10 juillet 2006 l'énergie radiative du soleil")

[77] Décret n° 2010-1510 du 9 décembre 2010 suspendant l'obligation d'achat de l'électricité produite par certaines installations utilisant l'énergie radiative du soleil ("Décret n° 2010-1510")

[78] Décret n° 2010-1510 du 9 décembre 2010 suspendant l'obligation d'achat de l'électricité produite par certaines installations utilisant l'énergie radiative du soleil ("Décret n° 2010-1510")

[79] Bidding system introduced in France; See: Fräss-Ehrfeld, supra note 10, at 370.

[80] Introduction on the bidding systme of France, please refer to : Fräss-Ehrfeld, supra note 10, at 370.

[81] Ley 54/1997, de 27 de noviembre, del Sector Eléctrico.

[82] Ley 54/1997, de 27 de noviembre, del Sector Eléctrico.

[83] Article 33, Tariffs, premiums and incentives for installations in category b, group b.1: solar power)。See Royal Decree 436/2004, Dated March 12th, Establishing The Methodology for The Updating and Systematisation of The Legal and Economic Regime for Electric Power Production in The Special Regime. (Published in the Official State Journal, B.O.E., issue no. 75, on March 27th 2004), available online at http://cms.isi.fraunhofer.de/wDefault_7/wDefault_7/download-files/documents/National-documents/Spain/rd436_2004_en.pdf?WSESSIONID=08ac68f2e91910cdb07a82cabe29235d (last visited August 2, 2011).("Real Decreto 436/2004")

[84] The Article 33 in the Royal Decree 2004 did not put a restriction of 50MW on the PV installations; on the contrary, a restriction of 50MW was imposed on the geothermal electricity in article 35. See Royal Decree 436/2004, Dated March 12th, Establishing The Methodology for The Updating and Systematisation of The Legal and Economic Regime for Electric Power Production in The Special Regime. (Published in the Official State Journal, B.O.E., issue no. 75, on March 27th 2004), available online at http://cms.isi.fraunhofer.de/wDefault_7/wDefault_7/download-files/documents/National-documents/Spain/rd436_2004_en.pdf?WSESSIONID=08ac68f2e91910cdb07a82cabe29235d (last visited August 2, 2011).("Real Decreto 436/2004")

[85] See Real Decreto 661/2007, de 25 de mayo, por el que se regula la actividad de producción de energía eléctrica en régimen especial, at 22862, available online at http://www.boe.es/boe/dias/2007/05/26/pdfs/A22846-22886.pdf (last visited September 2, 2011).("Real Decreto 661/2007")

[86] See Real Decreto 661/2007, de 25 de mayo, por el que se regula la actividad de producción de energía eléctrica en régimen especial, at 22862, available online at http://www.boe.es/boe/dias/2007/05/26/pdfs/A22846-22886.pdf (last visited August 2, 2011).("Real Decreto 661/2007")

[87] See Art. 10(1), Real Decreto 1578/2008, de 26 de septiembre, de retribución de la actividad de producción de energía eléctrica mediante tecnología solar fotovoltaica para instalaciones posteriores a la fecha límite de mantenimiento de la retribución del Real Decreto 661/2007, de 25 de mayo, para dicha tecnología,available online at http://www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=2008/15595 (last visited September 2, 2011).("Real Decreto 1578/2008")

[88] See Art. 10(1), Real Decreto 1578/2008, de 26 de

In sum, it shows that the Spanish government tried to control the PV boom by imposing a cap on the application installation capacity of individual project.

4. Italy

Italy is one of the few European countries that adopted the RPS system as a promotion mechanism in early 2000. In 2003, Italy decided to adopt the FIT scheme[89,90] to encourage the development of certain renewable energies. After a controversial negotiation, a Decree for PV installations finally passed in 2005.[91,92]

In Conto Energia I, the Italian government stipulated that the FIT scheme was only applicable to those installations with a capacity between 1kW – 1MW[93,94]. Yet, two years later in the 2007 Act, the project cap of 1MW was eliminated,[95,96] which resulted in PV boom.

In spite of this PV boom in 2010, Italy did not set up any project cap.[97,98] However in 2011, to deal with PV boom, the project cap of 1MW was reinstated.[99,100] In addition, the government installed some measures similar to those adopted by Germany, and put an extra restriction[101,102] on future ground-mounted installations.

Additional limitations were also put in place for the three types of PV installations: (1) regular PV installations;[103,104] (2) building-integrated PV

septiembre, de retribución de la actividad de producción de energía eléctrica mediante tecnología solar fotovoltaica para instalaciones posteriores a la fecha límite de mantenimiento de la retribución del Real Decreto 661/2007, de 25 de mayo, para dicha tecnología,available online at http://www.boe.es/aeboe/consultas/bases_datos/doc.php?coleccion=iberlex&id=2008/15595 (last visited August 2, 2011).("Real Decreto 1578/2008")

89 Regulation of the Mandatory Offer on Renewable Energy Obligation, 2003, Italy, referred to: Decreto Legislativo 29 dicembre 2003, n. 387. Attuazione della direttiva 2001/77/CE relativa alla promozione dell'energia elettrica prodotta da fonti energetiche rinnovabili nel mercato interno dell'elettricita., available online at http://www.ambientediritto.it/Legislazione/Energia/2003/dlgs%202003%20n.387.htm (last visited August 2, 2011).("DL 387/03")

90 Italy, 2003 Renewable Energy compulsory acquisition obligations Act, with reference to：Decreto Legislativo 29 dicembre 2003, n. 387. Attuazione della direttiva 2001/77/CE relativa alla promozione dell'energia elettrica prodotta da fonti energetiche rinnovabili nel mercato interno dell'elettricita., available online at http://www.ambientediritto.it/Legislazione/Energia/2003/dlgs%202003%20n.387.htm (last visited September 2, 2011).("DL 387/03")

91 Photovoltaics, PV Legislation, referred to: Decreto 28 luglio 2005. Criteri per l'incentivazione del la produzione di energia elettrica mediante conversione fotovoltaica della fonte solare ("DM 28/07/05"), available online at http://www.parcodelpo-vcal.it/Word/Scheda_fotovoltaico.pdf (last visited October 7, 2009); decided by the Energy Control Organization in 2005, referred to: Delibera n. 34/05. Modalità e condizioni economiche per il ritiro dell'energia elettrica di cui all'articolo 13, commi 3 e 4, del decreto legislativo 29 dicembre 2003, n. 387, e al comma 41 della legge 23 agosto 2004, n. 239, available online at http://www.autorita.energia.it/docs/05/188-05.htm (last visited August 2, 2011)..

92 Photovoltaic Act 2005, reference: Decreto 28 luglio 2005. Criteri per l'incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare ("DM 28/07/05"), available online at http://www.parcodelpo-vcal.it/Word/Scheda_fotovoltaico.pdf (last visited October 7, 2009); Energy Regulatory authorities in 2005 decided with reference to: Delibera n. 34/05. Modalità e condizioni economiche per il ritiro dell'energia elettrica di cui all'articolo 13, commi 3 e 4, del decreto legislativo 29 dicembre 2003, n. 387, e al comma 41 della legge 23 agosto 2004, n. 239, available online at http://www.autorita.energia.it/docs/05/188-05.htm (last visited September 2, 2011)..

93 Art. 4(1), DM 28/07/05.

94 Art. 4(1), DM 28/07/05.

95 See Legge 24 Dicembre 2007, n. 244. Disposizioni per la formazione del bilancio annuale e pluriennale dello Stato. Legge finanziaria 2008 (L 244/07), at 109, available online at http://www.parlamento.it/parlam/leggi/07244l.pdf (last visited August 2, 2011).("Legge 24 Dicembre 2007")

96 See Legge 24 Dicembre 2007, n. 244. Disposizioni per la formazione del bilancio annuale e pluriennale dello Stato. Legge finanziaria 2008 (L 244/07), at 109, available online at http://www.parlamento.it/parlam/leggi/07244l.pdf (last visited September 2, 2011).("Legge 24 Dicembre 2007")

97 Art. 7, par. 2, l.a., Decreto Ministeriale 6 agosto 2010. Incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare.("DM 06/08/10")

98 Art. 7, par. 2, l.a., Decreto Ministeriale 6 agosto 2010. Incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare.("DM 06/08/10")

99 Art. 10, c. 4, l. a., Decreto Legislativo 3 marzo 2011, n. 28. Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE.("DL 28/2011")

100 Art. 10, c. 4, l. a., Decreto Legislativo 3 marzo 2011, n. 28. Attuazione della direttiva 2009/28/CE sulla promozione dell'uso dell'energia da fonti rinnovabili recante modifica e successiva abrogazione delle direttive 2001/77/CE e 2003/30/CE.("DL 28/2011")

101 Art.11, c. 2, l.e., Decreto Ministeriale 5 maggio 2011. Incentivazione della produzione di energia elettrica da impianti solari fotovoltaici (" DM 05/05/11 ») ; Art. 10, c. 4., DL 28/11.

102 Art.11, c. 2, l.e., Decreto Ministeriale 5 maggio 2011. Incentivazione della produzione di energia elettrica da impianti solari fotovoltaici (" DM 05/05/11 ») ; Art. 10, c. 4., DL 28/11.

103 Including small facilities and large-scale facilities. Small facilities include: 1. Installed capacity is less than the solar facilities in the a 1000kW building on; 200kW following applies to power more than the wholesale purchase system (net-metering) solar facilities; 3. Government buildings or any area photovoltaic facilities of any size. Large facilities, or any facilities other than the aforementioned small-scale facilities. See also：Art. 3, c.1, l. u.and Art. 3, c.1, l. v, DM 05/05/11.

104 Installations of small and large scale are included. Installations of small-scale include: 1. building-integrated PV installations of which the installed capacity is inferior to 1000kW; 2. PV installations inferior to 200kW and eligible for net-metering system; 3. PV installations of any scale located in the government-owned buildings or in any area. All those not included in the small-scale installations will be

installation equipped with technological innovative elements; and (3) concentrated solar power (CSP) under the decree of May 5, 2011

To conclude, it can be found that in order to control boom the Italian authorities began to restrict FIT eligibility, including project installation caps, further restrictions on ground-mounted PV, and redefining the three types of PV installations.

5.UK

The UK adopted the RPS scheme to encourage the development of renewable electricity. From 2010, in order to advance the development, a dual track system of FIT and RPS was adopted. There are two types of PV installations: "retrofit or new build PV" and "stand alone (not attached to a building and not wired to provide electricity to an occupied building) PV."[105,106]

However in 2011, facing a PV boom, the UK government, after having reviewed the FIT scheme in advance[107,108], decided to reduce the tariff levels for PV installations greater than 50kW[109,110].

IV. Duration of FIT Payment

One important function of the FIT scheme is to provide investors with stability.

1. Germany

According to the Renewable Energy Act of 2000, the FIT duration was 20 years.[111,112] The Renewable Energy Act of 2008 provided a duration of 20 years for PV installations as well as for other renewable electricity plant, except few installations would be still bound to a duration of 15 years (ex. large-hydropower with installed capacity greater than 5MW).[113,114]

2. France

According to the Electricity Liberalization Act of 2000[115,116] and related administrative decrees,[117,118] the FIT duration was 20 years for both PV installation and hydropower. In an PV-specific administrative decree of 2006, the FIT duration remained at 20 years.[119,120] After the PV boom, the administrative decree on PV of 2010, the duration of PV installations remained at 20 years[121,122] and the decree of March 2011 did not alter the duration.[123,124]

3. Spain

Spain adopted a fixed FIT scheme to pomote the development of renewable electricity. Yet, the duration was slightly different from other duration schemes. The favorable FIT duration could be divided into two phases: the first stage offers the full favourable tariff rate for 15, 20 and 25 years for all the eligible entities; and the second phase would offer a reduced but still favourable rate.

However, such preferable scheme resulted in PV boom. In the Royal Decree of 2008, the duration was changed in accordance with their registration date and in 2010,

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defined as installations of large-scale, referred to: Art. 3, c.1, l. u.and Art. 3, c.1, l. v, DM 05/05/11.

105 See Tariff Levels Table, available online at http://www.fitariffs.co.uk/eligible/levels/ (last visited September 2, 2011).

106 See Tariff Levels Table, available online at http://www.fitariffs.co.U.K./eligible/levels/ (last visited August 2, 2011).

107 DECC, FITs Review, 02-07-2011, available online at http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx (last visited September 2, 2011).

108 DECC, FITs Review, 02-07-2011 , available online at http://www.decc.gov.U.K./en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx (last visited August 2, 2011).

109 Department of Energy and Climate Change (DECC), Feed-in Tariffs Scheme: Summary of Responses to the Fast-Track Consultation and Government Instruction, at 6, available online at http://www.decc.gov.uk/assets/decc/Consultations/fits-review/fits-fast-track-government-response---final.pdf. (last visited September 2, 2011).

110 Department of Energy and Climate Change (DECC), Feed-in Tariffs Scheme: Summary of Responses to the Fast-Track Consultation and Government Instruction, at 6, available online at http://www.decc.gov.U.K./assets/decc/Consultations/fits-review/fits-fast-track-government-response---final.pdf. (last visited August 2, 2011).

111 Art. 9, c.3, E of the Renewable Energy Law of Germany2000.

112 Germany 2000 Renewable Energy Law 9, and 3 12 E models

113 Germany 2008 Renewable Energy Law Article 21, Paragraph one

114 Art. 21, c.2, first sentence of the Renewable Energy Law of Germany2008.

115 France 2000 Liberalization law 10

116 Art. 10 of the Electricity Liberalization Law of France 2000.

117 Art. 5, Arrêté du 13 mars 2002 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative dusoleil telles que visées au 3o de l'article 2 du décret no 2000-1196 du 6 décembre 2000, available online at http://admi.net/jo/20020314/ECOI0200002A.html (last visited September 2, 2011).(" Arrêté du 13 mars 2002")

118 Art. 5, Arrêté du 13 mars 2002 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative dusoleil telles que visées au 3o de l'article 2 du décret no 2000-1196 du 6 décembre 2000, available online at http://admi.net/jo/20020314/ECOI0200002A.html. (last visited August 2, 2011).(" Arrêté du 13 mars 2002")

119 Art. 5, Arrêté du 10 juillet 2006 l'énergie radiative du soleil

120 Art. 5, Arrêté du 10 juillet 2006 l'énergie radiative du soleil

121 Art. 6, Arrêté du 31 août 2010.

122 Art. 6, Arrêté du 31 août 2010.

123 See ,Wind-Work, Electricity Feed Laws, Feed-in Laws, Feed-in Tariffs, Advanced Renewable Tariffs, and Renewable Energy Payments,22-07-2011 , available online at http://www.wind-works.org/articles/feed_laws.html (last visited August 2, 2011).

124 See Wind-Work, Electricity Feed Laws, Feed-in Laws, Feed-in Tariffs, Advanced Renewable Tariffs, and Renewable Energy Payments,22-07-2011, available online at http://www.wind-works.org/articles/feed_laws.html (last visited September 2, 2011).

the Spanish government proposed to remove the extra favorable duration of years 26 – 30. The FIT duration was shortened to 25 years[125,126] However, due to strong objections, the government changed its measures again within one month and retained 30 years.[127,128] However, due to the retroactive nature of such measures, it also drew the objection again. [129,130]

4.Italy

According to the 2005 Decree, the FIT duration for PV was 20 years.[131,132] Similarly in the 2007 Act, the rule remained unchanged.[133,134] Even after PV boom, the duration remained 20 years under the Conto Energia III.

5.U.K.

The FIT scheme adopted in 2010 set a favourable duration of 25 years for PV, and even after the boom the duration remained unchanged. [135,136]

V. Tariff Scheme of FIT

The core of FIT scheme is the tariff element of the FIT. There are two additional parts used for finetuning the FIT system: a tariff degression scheme and a tariff progression. For the contracted installations, the tariff increases allow the project concerned to adjust the tariff according to the increase of the consumer price index (CPI). The tariff degression is a mechanism which, in consideration of technological development of PV, and the cost reduction of PV, or the practical deployment of PV, would regularly reduce the tariff schedule based upon a pre-fixed or dynamically-adjusted reduction rate.

1. Germany

(1) Tariff Scheme of FIT

Due to the boom, on the July 8, 2010, the German Parliament decided to revise the rate schedule under Renewable Energy Act of 2008. The revision was issued on August 11 and with retroactive effect from July 1, 2010. The PV boom in 2010[137,138] led to further reviews of the rate schedule by the Federal House of Representatives. On Feburary 24, 2011, a revision on the Renewable Energy Act was made so that the rate schedule originally scheduled to be in force only from 2012 would come into effect one year early.[139,140] The

[125] Real Decreto 1565/2010, de 19 de noviembre, por el que se regulan y modifican determinados aspectos relativos a la actividad de producción de energía eléctrica en régimen especial. Available online at http://www.boe.es/aeboe/consultas/bases_datos/doc.php?id=BOE-A-2010-17976 (last visited July 5, 2011). ("Real Decreto 1565/2010")

[126] Real Decreto 1565/2010, de 19 de noviembre, por el que se regulan y modifican determinados aspectos relativos a la actividad de producción de energía eléctrica en régimen especial. Available online at http://www.boe.es/aeboe/consultas/bases_datos/doc.php?id=BOE-A-2010-17976 (last visited September 2, 2011). ("Real Decreto 1565/2010")

[127] Real Decreto-ley 14/2010, de 23 de diciembre, por el que se establecen medidas urgentes para la corrección del déficit tarifario del sector eléctrico., available online at http://noticias.juridicas.com/base_datos/Admin/rdl14-2010.html (last visited September 2, 2011). ("Real Decreto-ley 14/2010")

[128] Real Decreto-ley 14/2010, de 23 de diciembre, por el que se establecen medidas urgentes para la corrección del déficit tarifario del sector eléctrico., available online at http://noticias.juridicas.com/base_datos/Admin/rdl14-2010.html (last visited August 2, 2011). ("Real Decreto-ley 14/2010")

[129] See Infrastructure Investor, Spanish PV Industry up in Arms against New Retroactive Cuts, 07-01-2011, available online at http://www.infrastructureinvestor.com/Article.aspx?article=58618 (last visited August 2, 2011).

[130] See Infrastructure Investor, Spanish PV Industry up in Arms against New Retroactive Cuts, 07-01-2011, available online at http://www.infrastructureinvestor.com/Article.aspx?article=58618 (last visited September 2, 2011).

[131] See Decreto 28 luglio 2005, Criteri per l'incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare, available online at http://www.autorita.energia.it/it/docs/riferimenti/decreto_050728.htm. (last visited September 2, 2011). ("Decreto 28 luglio 2005")

[132] See Decreto 28 luglio 2005, Criteri per l'incentivazione della produzione di energia elettrica mediante conversione fotovoltaica della fonte solare, available online at http://www.autorita.energia.it/it/docs/riferimenti/decreto_050728.htm . (last visited August 2, 2011). ("Decreto 28 luglio 2005")

[133] Art. 2(145), Legge 24 Dicembre 2007.

[134] Art. 2(145), Legge 24 Dicembre 2007.

[135] See DECC, FITs Review,07-02-2011, available online at http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx (last visited September 2, 2011).

[136] See DECC, FITs Review,07-02-2011, available online at http://www.decc.gov.U.K./en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx (last visited August 2, 2011).

[137] Development of the amount of information, see: BMU, Renewables' Contribution to Energy Supply in Germany continued to Rise in 2010, 16-03-2011, available online at http://www.umweltministerium.de/english/current_press_releases/pm/47124.php. (last visited September 2, 2011).

[138] Information about the development quantity, please refer to: BMU, Renewables' Contribution to Energy Supply in Germany continued to Rise in 2010, 16-03-2011, available online at http://www.umweltministerium.de/english/current_press_releases/pm/47124.php. (last visited August 2, 2011).

[139] See Deutscher Bundestag, 17. Wahlperiode, available online at http://dip21.bundestag.de/dip21/btd/17/048/1704895.pdf. (last visited September 2, 2011). See also, German Energy Blog, Bundestag Adopts Renewable Energy Amendments, including 2011 Solar Feed-In Tariff Reduction, 25-02-2011, available online at http://www.germanenergyblog.de/?p=5464. (last visited September 2, 2011).

[140] See Deutscher Bundestag, 17. Wahlperiode, available online at http://dip21.bundestag.de/dip21/btd/17/048/1704895.pdf . (last visited August 2, 2011). See also, German Energy Blog, Bundestag Adopts Renewable Energy Amendments, including 2011 Solar Feed-In Tariff Reduction, 25-02-2011,

revision was approved by the Parliament.[141,142] In this revision, different tariff rules would apply to two different installations. First, the rate for "general type" PV will be in effect since July 1, 2011, and the tariff for "ground-mounted non-integrated installation" shall enter in force since Sept. 1, 2011. The new version of rate will be cut from 3~15%, but no more than 15%,[143] depending on the quantity of new PV equipments installed between March and May 2011 (target responsive tariff degression), compared with the rate in 2010 Act.[144]

Regarding the FIT tariff for new contracted installations installed in 2012, based upon the PV development of the year before end of September 2011, if the capacity of new contracted installations is less than 1500MW, the FIT rate will be reduced by 15% compared to 2011.

2. France

(1) Rate Schedule of FIT

According to the administrative decree of 2002[145,146], different PV rate schedules were provided in relation to their location: mainland France or French overseas territories. For PV located on mainland France, the tariff would be 0.1525€/kW; the tariff would be twice for overseas territories (0.305€/kW).

The PV FIT administrative decree of 2010 continued to make adjustments on the rate schedule for PV[147,148] forming a differential rate schedule based upon the following three factors: "building types", "generating capacity" and "integrity of the building (divided into full-integrated, simple-integrated and non-integrated).

Due to the 2010 PV boom, the government began to review whether such preferential rate would be appropriate. According to the new decree in March 2011, the tariff, which would enter into effect March 10, 2011, was expected to be reduced by 20%.[149,150] Therefore, in order to tackle the PV boom, the rate schedule was slashed from original 0.58~0.352€ under the Decree of 2010 to 0.46~0.12€ under the 2011 Decree.

3. Spain

(1) Tariff Schedule

Even though the Spanish government responded to PV boom by issuing a new royal decree in 2008, the whole country suffered from a financial problem. The government was forced to take a further measure to tackle those projects developed under Royal Decree 2007 and 2008. At the end of 2010, the Spanish government issued two administrative decrees. [151,152] For "boom" installations developed in 2007 and before Sept. 29 2008, there would be a cap on the permitted electricity generation hours. For the installations after September 29 2008, the decree intends to reduce the

available online at http://www.germanenergyblog.de/?p=5464 . (last visited August 2, 2011).

[141] See BMU, Erneuerbare-Energien-Gesetz (EEG) 2012, 04.08.2011, available online at http://www.erneuerbare-energien.de/inhalt/47585/4596/#; German Energy Blog, Bundesrat Clears Renewable Energies Package, including 2011 Solar Feed-In Tariff Reduction, 18-03-2011, available online at http://www.germanenergyblog.de/?p=5683. (last visited September 2, 2011).

[142] See BMU, Erneuerbare-Energien-Gesetz (EEG) 2012, 04.08.2011, available online at http://www.erneuerbare-energien.de/inhalt/47585/4596/#; German Energy Blog, Bundesrat Clears Renewable Energies Package, including 2011 Solar Feed-In Tariff Reduction, 18-03-2011, available online at http://www.germanenergyblog.de/?p=5683. (last visited August 2, 2011).

[143] See Federal Cabinet confirms adaptation concerning solar support and green electricity privilege, available online at http://www.umweltministerium.de/english/current_press_releases/pm/47055.php. (last visited September 2, 2011).The details of the rate of decline set, as described later.

[144] See Federal Cabinet confirms adaptation concerning solar support and green electricity privilege, available online at http://www.umweltministerium.de/english/current_press_releases/pm/47055.php. (last visited August 2, 2011). Detailed tariff degression, please refer to the following.

[145] Annexe 1 Tarifs mentionnés a l'article 5 de l'arrêté, Arrêté du 13 mars 2002.

[146] Annexe 1 Tarifs mentionnés a l'article 5 de l'arrêté, Arrêté du 13 mars 2002.

[147] Annexe 1 Tarifs d'achat, Arrêté du 31 août 2010.

[148] Annexe 1 Tarifs d'achat, Arrêté du 31 août 2010.

[149] See New feed-in tariffs in France and negotiations in Italy, available online at http://www.renewablesinternational.net/new-pv-feed-in-tariffs-in-france-and-negotiations-in-italy/150/510/30408/; Énergie solaire photovoltaïque : le nouveau dispositif, available online at http://www.developpement-durable.gouv.fr/Quels-sont-les-nouveaux-tarifs-d.html. (last visited September 2, 2011). See also Arrêté du 4 mars 2011 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative du soleil telles que visées au 3° de l'article 2 du décret n° 2000-1196 du 6 décembre 2000, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000023661449&categorieLien=id ("Arrêté du 4 mars 2011") ; Craig McGinty, Solar Feed-in Tariff to be Cut, 08-03-2011, available online at http://www.thisfrenchlife.com/thisfrenchlife/2011/03/solar-tariff-cut.html (last visited September 2, 2011).

[150] See New feed-in tariffs in France and negotiations in Italy, available online at http://www.renewablesinternational.net/new-pv-feed-in-tariffs-in-france-and-negotiations-in-italy/150/510/30408/; **Énergie solaire photovoltaïque : le nouveau dispositif,** available online at http://www.developpement-durable.gouv.fr/Quels-sont-les-nouveaux-tarifs-d.html. (last visited August 2, 2011). See also Arrêté du 4 mars 2011 fixant les conditions d'achat de l'électricité produite par les installations utilisant l'énergie radiative du soleil telles que visées au 3° de l'article 2 du décret n° 2000-1196 du 6 décembre 2000, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000023661449&categorieLien=id ("Arrêté du 4 mars 2011") ; Craig McGinty, Solar feed-in tariff to be cut, 08-03-2011, available online at http://www.thisfrenchlife.com/thisfrenchlife/2011/03/solar-tariff-cut.html (last visited August 2, 2011).

[151] Real Decreto-ley 14/2010; Real Decreto 1565/2010

[152] Real Decreto-ley 14/2010; Real Decreto 1565/2010

rate schedule (rate cut) retroactively[153,154]; however, this solution was not adopted by the Senate.[155,156] Regarding the new rooftop installations in 2011, an aggressive degression of 5% was imposed on installations less than 20kW, 25% for installations between 20kW-2MW, and 45% for ground-mounted installations less than 10MW.

4. Italy

(1) Tariff Rate Schedule

In order to promote PV development, Italy adopted a mixture of both RPS and FIT. The government adopted preliminarily the Green Power Certification System (i.e. RPS) allowing PV installers to sell PV green power certification on the electricity market. For instance, in 2006, by selling the green power certification (0.12528€) plus the electricity price (average market electricity price was 0.07467€), the operator could generate a profit of about 0.19995€/per KW[157,158].

In order to create a more stable investment environment for the development of PV, Italy began to adopt the FIT scheme in 2005. The eligible projects were those under 1MW and ineligible for the green power certification scheme. [159,160]

With a view to advancing the deployment of PV, the government issued a second phase PV FIT scheme (Conto Energia II) in February 2007.[161,162] The tariff regulated by this mechanism would be based on three types of installations and installed capacity.

As the rate schedule under the Second phase ended in end of 2010, the government began to plan a new PV FIT rate schedule for 2011-2013. In August 2010, the Ministry of Economic Development brought in the third stage PV FIT tariff (Conto Energia III 2011-2013). [163,164] In order to respond to the PV boom in 2007, the revised rate schedule became very complex: the rate schedule further differentiated the three categories:[165,166] general PV installation [167,168];

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153 See Spain to Cut Subsidies for New Solar Power Plants–Bloomberg, available online at http://www.businessweek.com/news/2010-08-01/spain-to-cut-subsidies-for-new-solar-power-plants.html?utmsource=twitterfeedutmmedium=twitterutmcampaign=greenenergy(last visited August 2, 2011).

154 See Spain to Cut Subsidies for New Solar Power Plants–Bloomberg, available online at http://www.businessweek.com/news/2010-08-01/spain-to-cut-subsidies-for-new-solar-power-plants.html?utmsource=twitterfeedutmmedium=twitterutmcampaign=greenenergy (last visited September 2, 2011).

155 Bruno Alves, Spain Cuts PV Tariffs by 45%, Limits Length Retroactively, available online at http://www.infrastructureinvestor.com/Article.aspx article=57590&hashID=B570208885B8F48F0DE30956C730273393748C98 (last visited September 2, 2011); Bruno Alves, Spanish Senate Overturns Retroactive Solar Cuts, available online at http://www.infrastructureinvestor.com/Article.aspx?article=59862&hashID=5DA9ABEED566943DB63CEABE993FD3005B6D2372 (last visited September 2, 2011).

156 Bruno Alves, Spain cuts PV tariffs by 45%, limits length retroactively, available online http://www.infrastructureinvestor.com/Article.aspx?article=57590&hashID=B570208885B8F48F0DE30956C730273393748C98 (last visited August 2, 2011). Spanish Senate overturns retroactive solar cuts http://www.infrastructureinvestor.com/Article.aspx?article=59862&hashID=5DA9ABEED566943DB63CEABE993FD3005B6D2372

157 See Doerte Fouquet , Prices for Renewable Energies in Europe: Feed in Tariffs Versus Quota Systems – A Comparison, Report 2006/2007 , at 46- 47, 2007, available online at http://www.eref-europe.org/dls/pdf/2007/eref_price_report_06_07.pdf (last visited August 2, 2011).

158 See Doerte Fouquet, Prices for Renewable Energies in Europe: Feed in Tariffs Versus Quota Systems – A Comparison, Report 2006/2007, at 46- 47, 2007, available online at http://www.eref-europe.org/dls/pdf/2007/eref_price_report_06_07.pdf (last visited September 2, 2011).

159 PV Policy Group Improving the European and National Support Systems for Photovoltaics European Best Practice Report, at 34, available online at http://www.pvpolicy.org/documents/PVPolicyEuropeanBestPracticeReport_id205.pdf, (last visited September 2, 2011).

160 PV Policy Group Improving the European and National Support Systems for Photovoltaics European Best Practice Report, at 34, available online at http://www.pvpolicy.org/documents/PVPolicyEuropeanBestPracticeReport_id205.pdf, (last visited August 2, 2011).

161 Ministero dello sviluppo economico, Decreto 19 febbraio 2007 Criteri e modalita' per incentivare la produzione di energia elettrica mediante conversione fotovoltaica della fonte solare, in attuazione dell'articolo 7 del decreto legislativo 29 dicembre 2003, n. 387., available online at http://www.enerpoint.it/PDF/DecretoFotovoltaico22-02-07.pdf (last visited September 2, 2011). ("Decreto Fotovoltaico 22/02/07")

162 Ministero dello sviluppo economico, Decreto 19 febbraio 2007 Criteri e modalita' per incentivare la produzione di energia elettrica mediante conversione fotovoltaica della fonte solare, in attuazione dell'articolo 7 del decreto legislativo 29 dicembre 2003, n. 387.,available online at http://www.enerpoint.it/PDF/DecretoFotovoltaico22-02-07.pdf (last visited August 2, 2011). ("Decreto Fotovoltaico 22/02/07")

163 Art.8 (Tariffe incentivanti), paragraph 2, DM 06/08/10.

164 Art.8 (Tariffe incentivanti), paragraph 2, DM 06/08/10.

165 Alliance for Renewable Energy, Italy 2011 Solar PV Tariffs, 19-08-2010, available online at http://www.allianceforrenewableenergy.org/2010/08/italy-2011-solar-pv-tariffs.html; Thermosolar, Conto Energia – Italian Feed-in Tariff, at 5-6, available online at http://www.thermosolar.it/db_img/uploaded/conto-energia/GSE_uk.pdf. (last visited September 2, 2011).

166 Alliance for Renewable Energy, Italy 2011 Solar PV Tariffs , 19-08-2010, available online at http://www.allianceforrenewableenergy.org/2010/08/italy-2011-solar-pv-tariffs.html; Thermosolar, Conto Energia – Italian Feed-in Tariff, at 5-6, available online at http://www.thermosolar.it/db_img/uploaded/conto-energia/GSE_U.K..pdf. (last visited August 2, 2011).

167 Art. 8(2), DM 06/08/10.

168 Art. 8(2), DM 06/08/10.

technologically-innovative BIPV [169,170;] and CSP ground-mounted PV installation. [171.172]

According to Conto Energia III, the rate schedule tariff for 2011 was expected to be applied till the end of 2013 and contained an annual tariff degression scheme.[173,174] Nevertheless, Italy kept on suffering from a PV boom phenomenon, which forced the Italian government to review and cut the tariff.[175,176] After going through a series of violent debates, the PV FIT of Conto Energia IV was finally decided on 5 May 2011.[177,178]

Under this wave of reform, the main rate schedule follows the three categories (general, innovative BIPV, and ground-type CSP) introduced in Phase III, but slight differences exist.

In sum, in order to respond to the PV boom, Italy not only reduced the rate schedule but also changed from two-year or yearly rate schedule to half-year, four-month or monthly rate schedule (which also implies a faster tariff degression scheme).

5. U.K.

(1) Rate Schedule

The U.K. adopted the FIT scheme for small size (under 5MW) PV installations. The rational behind different rate schedule is mainly related to the installation scale and the degrees of integration with the building, while the type of installation (old or new buildings) was also taken into consideration.

However, less than 1 year after the FIT scheme started, the U.K. began to evaluate the scheme.[179,180] Due to PV boom (for installations greater than 50kW), the U.K. government responded by reducing the original 2-year rate schedule. Initially, the government sought to adopt a very tough cut by reducing the tariff by 75%.[181,182] Followed by a strong outcry from the PV industry, the tariff was finally reduced by a lower 40~70%[183,184] and was effective from August 1 2010.[185,186] In comparison

[169] Art. 12(2), DM 06/08/10.
[170] Art. 12(2), DM 06/08/10.
[171] Art. 14(2), DM 06/08/10.
[172] Art. 14(2), DM 06/08/10.
[173] Sector Spotlight - Q1 2011 Renewable Energy Roundup, 12-04- 2011, available online at http://www.free-press-release.com/news-sector-spotlight-q1-2011-renewable-energy-roundup-1302598503.html (last visited August 13, 2011)
[174] Sector Spotlight - Q1 2011 Renewable Energy Roundup, 12-04- 2011, available online at http://www.free-press-release.com/news-sector-spotlight-q1-2011-renewable-energy-roundup-1302598503.html (last visited August 13, 2011)
[175] See e.g., Association of Corporate Counsel, The Renewables Decree: Introduction of aNew System of Incentives for Renewable Energy Plants, 29-03-2011, available online at http://www.lexology.com/library/detail.aspx?g=72b77ef0-8196-4f22-a128-4c468ddc76c5 (last visited August 3, 2011). See also, Reuters, Italy Plans to Set Cap on Solar Incentives-draft, 19-04- 2011, available online at http://www.reuters.com/article/2011/04/19/italy-solar-idUSLDE73I1V020110419; Renewable Energy World, Translating Italy's New Solar Policy Draft, available online at http://www.renewableenergyworld.com/rea/news/article/2011/04/translating-italys-new-solar-policy-draft; PV-Tech, Italy Set to Announce New Solar Subsidy Bill, 20-04- 2011, available online at http://www.pv-tech.org/news/italy_set_to_announce_new_solar_subsidy_bill (last visited August 3, 2011).
[176] See e.g. Association of Corporate Counsel, The renewables decree: introduction of a new system of incentives for renewable energy plants, 29-03-2011, available online at http://www.lexology.com/library/detail.aspx?g=72b77ef0-8196-4f22-a128-4c468ddc76c5 (last visited August 3, 2011). See also , REUTERS,Italy plans to set cap on solar incentives-draft, 19-04- 2011, available online at http://www.reuters.com/article/2011/04/19/italy-solar-idUSLDE73I1V020110419; RENEWABLE ENERGY WORLD.COM, Translating Italy's New Solar Policy Draft, available online at http://www.renewableenergyworld.com/rea/news/article/2011/04/translating-italys-new-solar-policy-draft; PV-Tech, Italy set to announce new solar subsidy bill,20-04- 2011, available online at http://www.pv-tech.org/news/italy_set_to_announce_new_solar_subsidy_bill (last visited August 3, 2011).
[177] DM 05/05/11. Important regulations which are complementary to this decree, please refer to: DL 28/2011.
[178] DM 05/05/11. Complement the specification of this command, see：DL 28/2011.
[179] See DECC, Fits Review, available online at http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx(last visited August 3, 2011).
[180] See DECC, FITS REVIEW, available online at http://www.decc.gov.U.K./en/content/cms/meeting_energy/renewable_ener/feedin_tariff/fits_review/fits_review.aspx(last visited August 3, 2011).
[181] See e.g., James Murray, Updated : Solar Firms File for Judicial Review against Feed-in Tariff Cuts, 19-04-2011, available online at http://www.businessgreen.com/bg/news/2044601/solar-firms-file-judicial-review-feed-tariff-cuts. (last visited August 3, 2011).
[182] See e.g., James Murray, Updated : Solar firms file for judicial review against feed-in tariff cuts, 19-04-2011, available online at http://www.businessgreen.com/bg/news/2044601/solar-firms-file-judicial-review-feed-tariff-cuts . (last visited August 3, 2011).
[183] See James Murray, Government Confirms Deep Solar Incentive Cuts,09-01-2011, available online at http://www.businessgreen.com/bg/news/2077699/government-confirms-deep-solar-incentive-cuts(last visited August 3, 2011).
[184] See James Murray, Government confirms deep solar incentive cuts,09-01-2011, available online at http://www.businessgreen.com/bg/news/2077699/government-confirms-deep-solar-incentive-cuts(last visited August 3, 2011).
[185] See James Murray, Updated : Solar firms file for judicial review against feed-in tariff cuts, 19-04-2011, available online at http://www.businessgreen.com/bg/news/2044601/solar-firms-file-judicial-review-feed-tariff-cuts . (last visited August 3, 2011).
[186] See James Murray, Updated : Solar firms File for Judicial Review against Feed-in Tariff Cuts, 19-04-2011, available

with the rate schedule of 2010 regime, the tariff of the final version not only revealed the rate schedule for the following 3 years, but revealed also in advance the tariffs till March 31 2021,[187,188] and a more comprehensive installation grade design for large-scale ground-mounted installations.

VI. Hard and Soft Cap on the installed capacity for PV installations

The cap on the installed capacity, based on its effective nature, can be divided into hard cap or soft cap. The hard cap means once the development capacity is fulfilled, the installations applied from then on won't be eligible to any preferred rate. As for soft cap, if the annual or seasonal development target is achieved, the new contracted installations within that period are still eligible to the rate, but for installations of the following season or year, there will be an aggressive rate tariff degression.

1. Germany

The Renewable Energy Act of 2000 installed a total development hard cap of 350MW for PV[189,190]. However, in order to aggressively promote the development of PV deployment, Germany decided not to mention the concept of cap. Instead, the Renewable Energy Act of 2008 mentions a development target, the purpose of such target was to serve as a reference for the tariff degression of the following year to based on the PV development of the present year, rather than a hard cap of that present year.[191,192]

In spite of no hard cap, Germany did have a soft cap, i.e. responsive tariff degression scheme (Development Target Responsive Degression Scheme) to control PV boom (Renewable Energy Act of 2008).

2. France

France had a hard cap at the very beginning, with a total development capacity of 500MW[193,194]. But in the PV Decree of 2009, the target was revised as a 'referential' target (neither hard cap nor soft cap), and the total development target set up till the end of 2012 would be 1100MW; 5400MW for 2020[195,196].

However, facing PV boom, France decided in 2011 to reset the annual development cap at 500MW for PV installation[197198] with different installation types having different annual and seasonal caps.

3. Spain

Before 2007, Spain did not bring in any PV hard cap.[199,200] In the Royal Decree of 2007, the hard cap for PVwas brought in with a total target of 371MW[201,202], while a higher target of 500MW for solar thermal energy was set up.[203,204]

Facing the issue of PV boom, the government brought in a very detailed annual cap and seasonal cap mechanism in the Royal Decree of 2008[205,206]. Taking

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online at http://www.businessgreen.com/bg/news/2044601/solar-firms-file-judicial-review-feed-tariff-cuts. (last visited August 3, 2011).

187 http://www.ofgem.gov.U.K./Sustainability/Environment/fits/Documents1/Feed-in%20Tariff%20Table%201%20August%202011.pdf http://www.decc.gov.U.K./assets/decc/Consultations/fits-review/fits-fast-track-government-response---final.pdf , at 6.

188 See FIT Payment Rate Table with Retail Price Index adjustments & Fast Track Review Amendments – Tariff rates are Effective from 1 August 2011, available online at http://www.ofgem.gov.uk/Sustainability/Environment/fits/Documents1/Feed-in%20Tariff%20Table%201%20August%202011.pdf ; Department of Energy & Climate Change, Summary of Responses to the Fast-Track Consultation and Government Response, at 6, available online at http://www.decc.gov.uk/assets/decc/Consultations/fits-review/fits-fast-track-government-response---final.pdf (last visited August 3, 2011).

189 Article 8 of the 2000 Renewable Energy Law in Germany

190 Art. 8, c.2 of Renewable Energy Law 2000, Germany

191 126 Germany 2008 Renewable Energy Law, the first paragraph of Article 20, the third to the fourth paragraph.

192 Art. 20, c.3 (1-4) of Renewable Energy Law 2008, Germany

193 See Grace, R. C. et al., Exploring Feed-in Tariffs for California, at 61, 2008, available online at http://www.energy.ca.gov/2008publications/CEC-300-2008-003/CEC-300-2008-003-D.PDF. (last visited August 3, 2011).

194 See Grace, R. C. et al., Exploring Feed-in Tariffs for California, at 61, 2008, available online at http://www.energy.ca.gov/2008publications/CEC-300-2008-003/CEC-300-2008-003-D.PDF . (last visited August 3, 2011).

195 See Art. 1(1), Arrêté du 15 décembre 2009 relatif à la programmation pluriannuelle des investissements de production d'électricité, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000021645812&dateTexte=&categorieLien=id. (last visited August 3, 2011).

196 See Art. 1(1), Arrêté du 15 décembre 2009 relatif à la programmation pluriannuelle des investissements de production d'électricité, available online at http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000021645812&dateTexte=&categorieLien=id . (last visited August 3, 2011).

197 See French PV tariff levels announced, 10 March 2011, available online at http://www.pv-magazine.com/news/details/beitrag/french-pv-tariff-levels-announced_100002421/.(last visited August 3, 2011).

198 See French PV tariff levels announced, 10 March 2011, available online at http://www.pv-magazine.com/news/details/beitrag/french-pv-tariff-levels-announced_100002421/.(last visited August 3, 2011).

199 For example：Real Decreto 1663/2000及Real Decreto 436/2004. No mention the solar photovoltaic incentives ceiling.

200 Ex. : in Real Decreto 1663/2000 and Real Decreto 436/2004, the premium cap for PV installationwas never mentioned.

201 Art. 37, Real Decreto 661/2007.

202 Art.37, Real Decreto 661/2007.

203 Art. 37, Real Decreto 661/2007.

204 Art.37, Real Decreto 661/2007.

205 Art. 5(3), REAL DECRETO 1578/2008.

206 Art. 5(3), Real Decreto 1578/2008.

2008 as an example, the annual cap was 400MW among which 267MW was allocated to rooftop, a quota much higher than the 133MW that was allocated to ground-mounted; the seasonal cap was 100MW among which 66.75MW was allocated to rooftop and 33.25 for ground-mounted installation[207,208].

4. Italy

In Conto Energia I, Italy set up a referential target for 2015 as 300MW[209,210], and brought in at the same time a total capacity cap of 100MW for PV installations.[211,212]

Then in the FIT decree of 2006, the referential development target of 2015 was 1500MW. The government also added a new annual cap, from 2006 to 2012, of 60MW for small-scale installations under 50 kW and 25MW for large-scale installations over 50 kW.[213,214]

For Conto Energia II and II, the cap was raised to finally show a referential target of 8000MW by 2020.[215,216]

A chaotic scene surrounded Conto Energia IV, but the referential target was revised from 8000MW to 23,000MW.

5. UK

The FIT scheme in UK in 2010 did not set any cap for PV installations, nor did this change in the face of a PV boom.[217,218]

VII. Loading Hour Caps(Resource Quality Cap)

In order to avoid over-subsidising PV installations located in regions with better resource quality, and to give low-resource quality areas more consideration, a scheme of different loading hour according to local resource quality was designed (of which only France and Spain adopted for the prupose of this study).

1、France

For PV installations situated on mainlad France, the annual loading hour was 1200 hours; for overseas installations the annual loading hour was 1500 hours[219,220]. The PV Decree of 2006 raised the figure to 1500 (mainland) and 1800 (overseas).[221,222]

The PV Decree of 2010 maintained loading hours cap.[223,224]. However, for PV installations of single axis sun tracking and dual axis sun tracking system the loading hour caps were respectively raised to 2200 (mainland) and 2600 (overseas) [225,226] and remained so even after the boom.[227,228]

2. Spain

The resource-quality related loading hour cap scheme did not exist in Spain before the PV boom. However, after the boom began, Spain brought in the loading hour cap scheme through the royal decree at the end of 2010.[229,230] To reduce the issues of introducing a loading cap, the duration of the subsidy was prolonged from 25 to 30 years.[231]

The loading hour cap scheme would officially apply to new installations after 2011 as well with different loading hour caps for PV installations created according to the technology type and climate zone with different sunshine hours and degrees.[232,233] For example, from 1,232 hours to 1,753 hours for fixed-type PV.

VIII. Conclusions

1. A Summary of European countries' reaction to the PV- Boom

The main reason for PV boom in most countries is the over-favorable rate schedule leading to a dash in application cases. Therefore, the most direct countermeasure is to deal with the tariff itself: prevent the occurrence of PV boom by cutting the rate schedule. However, in order to tackle PV boom in a more comprehensive manner, other supplementary measures are needed.

Among all these countermeasures dealing with PV boom, it can be found that setting up the installed

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207 EPIA, National PV Profiles- Spain 2009, at 31, available online at http://pvaustria.at/upload/1737_EPIA%20PV%20Markt%20Spanien.pdf (last visited August 3, 2011).
208 EPIA, National PV Profiles- Spain , at 31(2009), available online at http://pvaustria.at/upload/1737_EPIA%20PV%20Markt%20Spanien.pdf (last visited August 3, 2011).
209 Art. 11, DM 28/07/05.
210 Art. 11, DM 28/07/05.
211 Art. 12(1), DM 28/07/05.
212 Art. 12(1), DM 28/07/05.
213 Art. 2(2)-(3), DM 06/02/06.
214 Art. 2(2)-(3), DM 06/02/06.
215 Art. 3(1), DM 06/08/10.
216 Art. 3(1), DM 06/08/10.
217 DECC confirms solar FiT cuts, available online at http://www.greenwisebusiness.co.U.K./news/decc-confirms-solar-fit-cuts-2402.aspx. (last visited August 3, 2011).
218 DECC Confirms Solar FiT Cuts, available online at http://www.greenwisebusiness.co.uk/news/decc-confirms-solar-fit-cuts-2402.aspx. (last visited August 3, 2011).
219 Annexe 1, Arrêté du 13 mars 2002.
220 Art. 4(1), Arrêté du 13 mars 2002.
221 Art. 4(1), Arrêté du 10 juillet 2006.
222 Art. 4(1), Arrêté du 10 juillet 2006.
223 Art. 4(1) & (3), Arrêté du 31 août 2010.
224 Art. 4(1) and (3), Arrêté du 31 août 2010.
225 Art. 4(2), Arrêté du 31 août 2010.
226 Art. 4(2), Arrêté du 31 août 2010.
227 Art. 6, Arrêté du 4 mars 2011.
228 Art. 6, Arrêté du 4 mars 2011.
229 Real Decreto-ley 14/2010
230 Real Decreto-ley 14/2010
231 At 35, http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/Taxes-Incentives-Renewable-Energy-2011.pdf
232 Additional Provision 1(Disposicion Adicional Primera), Real Decreto-ley 14/2010.
233 Additional Provision 1(Disposicion Adicional Primera), Real Decreto-ley 14/2010.

capacity hard cap is really the last-ditch of them all, even though theoretically it is the simplest and most direct way to avoid a PV boom during a fixed period (one year, one season or within two or three years). However, this mechanism could adversely affect the investment security and the development of renewable energy.

In sum, a comparison of the FIT design elements of the surveyed countries before and after the PV boom is shown in Table 1.

Table 1: Comparison of feed-in Tariff scheme before and after the PV boom

	Pre-Boom	Post-Boom
Eligibility	All PV installations (ground-mounted, partly-integrated, rooftop, BIPV; large-scale, small-scale)	➢ Small-scale rooftop and BIPV are prioritized ➢ Self-use type is more encouraged. ➢ Restriction on large-scale rooftop, large and small-scale ground-mounted, farmland type, or PV at ecological concerned locations.
Duration	20 years, 25 years and 30 years	Maintain the subsidy duration Shorten the subsidy duration
Tariff		
(a) Rate scheme	➢ Favorable ➢ Multi-year rate scheme in advance: Originally designed for long-term application Differentiation on the tariffs of each installation	➢ Large cut ➢ Promptly revise the multy-year rate scheme ➢ Singularization on the ground-mounted rate; keep the tariff differentiation of rooftop and BIPV installation ➢ Bidding system pairing with a hard cap mechanism, under high governmental control
(b) Degression	Pre-scheduled tariff degression rate Year degression or two year degression	➢ Promptly increase and revise the degression rate aggressively ➢ Shorter degression period: such as half year, monthly, seasonally The set up of responsive tariff degression rate
(c) Tariff increasing rate	➢ Yes None	Maintained Annulled
Caps	➢ No	1 Introduction of the soft cap for installations, such as responsive tariff degression with seasonal cap, annual cap 2 Introduction of the hard cap, such as a total cap for a certain length, annual cap, seasonal cap 3 Other type of hard cap: FIT total budget cap
Annual loading hours	➢ None	2.Yes

(Source: compiled from this research)

Overview of the Photovoltaic Technology Status and Perspective in China

Prof. Chien Te FAN
Professor of Law in Institute of Science& Technology Law, Director of Bioethics and Law Centre, National Tsing Hua University (Taiwan);
Director of Institute of Science& Technology Law, Chief expert in Institute of Energy Policy and Law, Huazhong University of Science& Technology(P.R.China)

Mr. Dongdong SONG *
Ph.D. student in Law School, Huazhong University of Science& Technology(P.R.China)

**Contact details of corresponding author*
Tel: 86-15972155569
e-mail: zzsongdd@gmail.com

Address
1037 Luoyu Road, Law School of Huazhong Univ. of Sci.& Tech., Wuhan, P.R.China. 430074

Abstract: The paper investigates China's strategic promotion of the photovoltaic industry, along with the warm welcome it has extended to developments and competitive trends in global green energy technology. Through gaining an important position in the photovoltaic industry and production potential, the author's main concern was with the role of the government, encouraging policies, initiating national energy projects and actively promoting and improving the competitiveness of China's photovoltaic industry. The promotion of legislation and policy-orientated strategies are all a vital path to China catching up, learning and developing competitiveness in the area of science and technology related industries. Moreover, from the perspective of technological and industrial development trends, the author carried out an analysis of China's photovoltaic industry chain, pointing out that China's photovoltaic industry has the potential to take it one step further in the areas of R&D and the possibility of acquiring breakthroughs in international cooperation.

Key words: Photovoltaic industry; Industry policy; National projects

1. Introduction

Energy is a critical foundation for economic growth and social progress (Hrayshat E.S. 2007). As economy advances and human society requires more energy, the lack of fossil energy and its pollution on the environment has given rise to the ever-serious contradiction among energy providing, environment protection and economic development. Renewable energy, with the availability of its renewability and non-pollution, will grow to be an effective and practical choice to guarantee the future development of the world (Chen F., 2007). As China is the largest developing country in the world, developing renewable energy is its inevitable choice for sustainable economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development.

The main purpose of this paper is to investigate the legislature and policy development along with the industrial strategies which the China government has pursued in order to encourage development in the photovoltaic industry and also in related R&D. Finally, from manufacturing and designing an advantageous position, consider China's photovoltaic development strategy in the future. First, this paper will take the first step in investigating the photovoltaic markets global production capacity. Next, analyze the solar energy legal and policy framework in China and the positive effects of this framework on the China's photovoltaic installation and industry. Third, discuss the PV industry development status, including the PV industry chain, PV application market in China, and R&D status of PV industry. Finally, based on China's status of PV development, suggest the future strategy of PV industry in China.

2. Global photovoltaic market and production status

The amount of energy sources such as the gas, the water, the coal and the petrol are decreasing day by day since they are used in industry intensively. On the other hand, the need of electrical energy is increasing in parallel with developing technology (Demirbas S. et al, 2008). The limited fossil energy resource is a critical issue worldwide (Yu X. & Qu H., 2010).

Renewable energy can play an important role in meeting the ultimate goal of replacing large parts of fossil fuels. One of the promising applications of renewable energy technology is the installation of photovoltaic (PV) systems to generate power without emitting pollutants and requiring no fuel (Li D.H.W. et al, 2005).

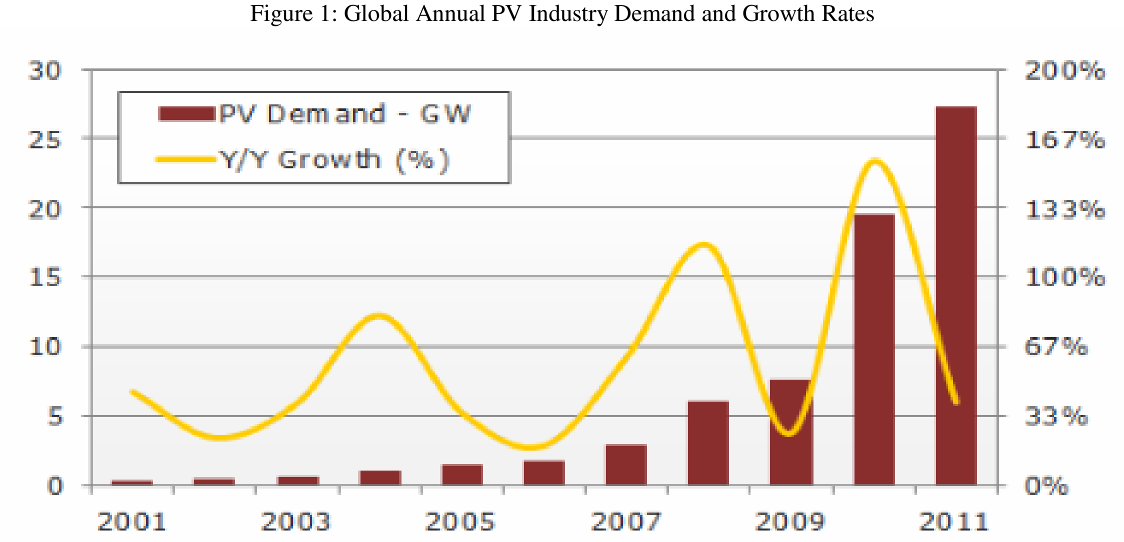
Alternative renewable energy sources such as sun energy can be substituted for exceeding human energy needs. Covering 0.16% of the land on earth with 10% efficient solar conversion systems would provide 20 TW of power, nearly twice the world's consumption rate of fossil energy (Mousazadeh H. et al, 2009). The economic barriers that typically limit the use of PV systems have been in some cases reduced by significant regulatory or governmental incentives towards wider use of PV systems (Chicco G. et al, 2009). The energy intensity of the sun to the world, the atmosphere on the kW per square meter is about 1.35. The diameter of the footprint area of the world from the solar power density is 178 × 106 MW. The entire surface of the world's solar energy falling is 1.22 × 1014 TCE (tons coal equivalent) in one year, or as imposing size is 0.814 × 1014 TOE (tons of oil equivalent). In other words, the amount of incoming solar energy in one year, fifty times the known reserves of coal, 800 times the known oil reserves.

The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an important solution in energy conservation and demand-side management during the last decades (Altas I.H. & Sharaf A.M., 2008). In terms of cell production, production volume rose by 85% in 2008 (7.9 GW) compared to the volume of 4.3 GW in 2007 (Wiese A. et al, 2009). The International Energy Agency (IEA) estimates that solar power could provide as much as 11% of global electricity production in 2050. However, this is conditional on many countries putting in place incentive schemes to support solar energy in the next 5–10 years so that investment costs come down. The share would be roughly divided equally between photovoltaic and concentrating solar power.

As a solution for the depletion of conventional fossil fuel energy sources and serious environmental problems, focus on the photovoltaic (PV) system has been increasing around the world (So J.H. et al, 2007). The photovoltaic (PV) field has given rise to a global industry capable of producing many gigawatts (GW) of additional installed capacity per year (Smestad G.P. et al, 2008).

Fig. 1 shows that PV market demand and growth rates in recent years. World solar photovoltaic (PV) market installations reached a record high of 27.4 gigawatt (GW) in 2011, representing growth of 40% over the previous year. The PV industry generated $93 billion in global revenues in 2011, while successfully rising over $8 billion in equity and debt. Overall market growth in 2011 was boosted by strong second half demand ahead of further deep cuts in solar incentives. This followed a period of over-production in the first half that triggered the sustained price decline through the PV chain that came to characterize 2011. The dominance of Chinese manufacturers in crystalline silicon wafers, cells and modules grew, the share of thin film declined, and demand in Asian markets grew rapidly.

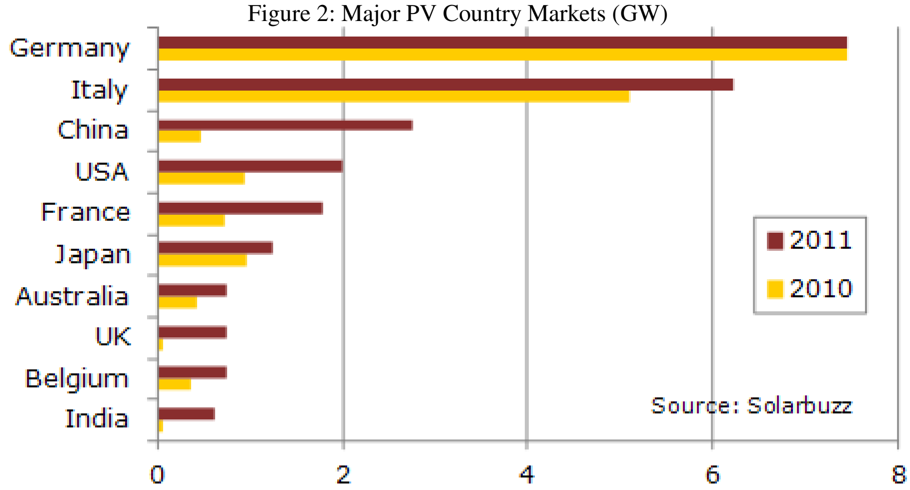
Figure 1: Global Annual PV Industry Demand and Growth Rates



It can be seen from the Fig. 2 that the top five PV markets were Germany, Italy, China, the United States, and France—74% of global demand in 2011. China soared 470% Y/Y, rising to third place from seventh in 2010.

European countries accounted for 18.7 GW, or 68% of world demand in 2011, down from 82% in 2010. Strong growth in France and Italy, combined with a year-end surge in German demand that held it flat Y/Y, meant that Germany, Italy and France collectively accounted for 82% of the European market.

Figure 2: Major PV Country Markets (GW)



The countries with most installed photovoltaic power currently are Germany, Japan, Italy and the USA, which are being the biggest photovoltaic module producing countries as well. The 90% of the whole photovoltaic modules produced in the world are produced in the USA, Japan and the European Union (EU) countries. The increase in the production rate of photovoltaic modules has been 15% annually in the last decade. Most of these photovoltaic modules were used in stand-alone applications in places where the grid-connection was non-existent (Çelik A.N., 2006).

Some key actions for the development of PV industry; provide long-term targets and supporting policies to build confidence for investments in manufacturing capacity and deployment of PV systems. There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts. Implement effective and cost-efficient PV incentive schemes that are transitional and decrease over time so as to foster innovation and technological improvement. Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term technology innovations. Increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while also supporting longer-term innovations (Dinçer F., 2011). Having environmental damage of solar energy is much less being compared today's energy generation systems. However, having high solar energy potential many leading countries in the world is not enough encouragement and attention to electrical energy generation from solar energy. The status and future of photovoltaic industry depend on national policy of countries.

3. Solar energy Legal and policy framework in China

3.1 Laws, regulations and policy

In terms of laws, regulations and administrative stipulations, Electricity Law of the PRC has been passed in 1995, Energy Conservation Law of PRC in 1997 and Air Pollution Prevention Law of PRC in 2000, which have definitely stipulated that exploitation and use of renewable energy and new energy are encouraged. The State Department has come up with a series of administrative regulations and systems, *Further Support on the Development of Renewable Energy, Contents of State Encouraged Industries, Products and Techniques, 1996–2010 New Energy and Renewable Energy Development Principles, 2000–2015 New Energy and Renewable Energy Development Principles, Comprehensive Working Programs on Energy Saving and Emission Reduction*, etc., which have made further and detailed stipulations on the following aspects, namely, renewable energy power, renewable energy key development industry, renewable energy's development goal and renewable energy's application in energy saving and emission reduction, etc (Li & Zoellick, 2012).

On 28 February 2005, PRC Law of Renewable Energy was passed in the 14th session of the 10th NPC Standing Committee, bringing the exploitation and use of renewable energy to the strategic height of "increasing energy supply, improving energy structure, guaranteeing energy safety, protecting environmental and realize the sustainable development of economy and society. This marked the trend that China is to enact relevant law so as to push the development of renewable energy. Immediately after the passage of PRC Law of Renewable Energy, NPC and concerned sectors of State Department took quick action to stipulate relevant supporting laws and regulations, including investigations on renewable energy resources, total goal, programs on exploitation and use, industrial development content, electricity price policy, cost sharing, special capital, financial support and some other policies. Currently, a total of five sets of supporting laws have been enacted, namely, *Guidance and Content for the Development of Renewable Energy Industry, Temporary Method for Managing the Special Capital of Renewable Energy Development, Temporary Management for the Price and Cost Sharing in Renewable Energy Power Generation, Administrative*

Regulations on Renewable Energy Power Generation, Mid- and Long-Term Development Programming for Renewable Energy. In Mid- and Long-Term Development Programming for Renewable Energy, passed by State Department on 7 June 2007, sets the general goal for the development of renewable energy: renewable energy accounts for up to 10% of the total energy structure in 2010 and 16% in 2020.

3.2 Economic encouragement policy

3.2.1 Financial subsidy

Financial subsidy is the most conventional economic encouragement practice. Varying in forms, the subsidy could be categorized to be investment subsidy, product subsidy and user subsidy. Investment subsidy, as its name indicates, refers to the direct subsidy to the renewable energy programs' developers and investors. Chinese government has set up a rural energy special cashing interest loan since 1987, RMB 1.2 × 108 yuan each year, with the cashing interest rate at 50%. This amount is mainly used for wind power generation, solar energy heater techniques, the technical research and development, reconstruction, promotion and application of large- and middle-sized marsh gas pools (Li & Shi, 2006); product subsidy are rarely seen in China. some local government has provided some subsidies for the development and exploitation of renewable energy, for instance, local government of Tibet, Qinghai, Inner Mongolia provide a subsidy of RMB 100–300 yuan/set to the peasants and cowpunchers in remote areas who purchase solar photovoltaic power generation system and small wind power generation system (Li & Shi, 2006).

3.2.2 Favorable taxation policy

Favorable taxation policy is a most universal encouragement policy in the world currently, but it is narrowly applied in China's renewable energy development. Only some areas could find its presentation, mainly including: the importation of some renewable energy power generation equipment and their parts that China is unable to produce (including key parts of photovoltaic cell and large wind energy power generation equipment) now shall be exempted form taxation; or in some cases, the tax is reduced. The income tax of renewable energy production enterprises have been exempted by some local government, for instance, Xinjiang, Inner Mongolia, etc. These enterprises enjoy the same favorable conditions as the high and new technology industrial enterprises. Like the projects within Great Western Development, the renewable energy power generation projects constructed in western area could enjoy the tax exemption policy.

3.2.3 Favorable price policy

Favorable price policy is mainly intended for network power produced with renewable energy, represented by guaranteeing the network access and favorable electricity price. In 1994, the previous State Power Department issued a document, which says the network electricity price should be fixed in conformance to the principle of paying back the loan and interest and making reasonable profit; the part above the networks shall adopt average electricity price, and the price difference shall be shared equally by the entire grid (Zhang et al, 2009). In 1999, the previous State Planning Committee and Science and Technology Department issued "Notice on Further Supporting Renewable Energy", confirming the abovementioned policy. On 28 March 2005, *Temporary Method for Managing Grid Electricity Price* was issued by State Commission of Development and Reform, stipulating that new energy and renewable energy enterprises such as photovoltaic solar energy did not participate in the competition for the time being; Grid enterprises should enjoy the priority in purchasing power at government-set price or bidding price. At proper time, government should stipulate the proportion that new energy and renewable energy take in the power provided by power supplying enterprises, and establish special competitive new energy and renewable energy markets.

In accordance with the requirement to implement the PRC Law of Renewable Energy, State Commission of Development and Reform is now on its way to stipulate some policies on renewable energy power generation, which are expected to be issued soon.

3.3 Industrialized support policy

In recent years, Chinese government has implemented State Technical Problem Tackling Plan, high technology research plan, industrialized development special item and key equipment special item, etc. Through these doing, the government is to support the use of solar energy, photovoltaic power generation. Besides, the government has accelerated the localization and state manufacturing process of renewable energy equipment, constructing the largest water heater industry around the world; in terms of photovoltaic power generation products, some enormous enterprises have come into existence, such as Wuxi Shangde, Tianweiyingli, Xinjiang New Energy, etc. Besides, a series of parts manufacturing enterprises have shown up too, such as Chongqing Gear, Huiteng Vane, Yongji Machinery, etc. These enterprises have laid a solid foundation for the long-term development of China's renewable energy equipment manufacturing industry (Cheng et al, 2010). It's expected that China is to grow up to be a giant country of PV machinery manufacture around the world in the coming 3–5 years.

4. Status of PV industry development in China

4.1 Development status of PV industry chain in China

Driven by a series of policies to promote the development of renewable energy in Europe, the solar energy PV industry develops dramatically in recent five years. All modules, from the high purity silicon of source products to terminal products modules, are in short supply in the whole industry. It attracts the local government and companies to focus on solar PV projects. They introduce automatic production equipments from aboard, including ingot furnace, multi-ware saw, PECVD, screen printing equipment and automatic detection equipment and conducts photoelectric competition which still exists at present. In 2005, Wuxi Suntech successfully listed on the New York stock exchange and became the most valuable company in the global solar PV industry. With the birth of Wuxi Suntech's wealth myth, it emerged rapidly a wave of capital investment boom in domestic PV industry and fostered "snowball effect". The large business opportunities brought by the development of Chinese renewable energy captured the world's attention.

Until 2007, there have been more than 600 PV enterprises and research unit in China. Among them, there are approximately 70 PV cell factories, nearly 300 PV module factory, more than 50 companies for PV application products, 50 more factories for supporting materials and almost 50 companies for producing PV equipments. About 50 colleges and research units participate in R&D of PV technology production. More than 10 thousand people were employed in this industry. The development speed of Chinese PV industry was obviously higher than the average speed of the world PV industry.

Next, it will introduce the current situation of Chinese PV industry from different perspectives, like each link of solar PV industry, PV industry equipment manufacturing, and raw materials of PV industry.

4.1.1 The status of polycrystalline silicon, crystal pulling ingot and section industry

Polycrystalline silicon production:

In 2001, total annual output of polycrystalline silicon was 80 ton, only produced by Emei Semiconductor Factory and Luoyang Monocrystalline Silicon Factory. The amount was only 0.6% of the world polycrystalline silicon production. In 2003, there was only one silicon industry, Emei Semiconductor Factory with annual amount of 60 to 70 tons. In 2005, Luoyang Monocrystalline Silicon Factory established poly silicon production line with annual production capacity of 300 tons. In 2006, total output of poly silicon reached 290 tons including 185 tons of Luoyang Silicon and 105 tons of Emei semiconductor production.

In 2007, 1260 tons of poly silicon production line started in Leshan Shin silicon industry with the annual production of 155 tons. The silicon production line in Luoyang Silicon Factory increased from 300 tons to 1000 tons with the annual production of 520 tons. In 2007, Xuzhou Zhongneng established the production line of 1500 tons and produced 150 tons poly silicon. Wuxi Zhongcai established 500 tons production line and produced 55 tons and Emei Semiconductor Factory produced 155 tons poly silicon. So China totally produced 1130 tons in 2007.

Driven by the demand of PV market at home and aboard, Chinese poly silicon industry has developed rapidly since 2005. After Luoyang Silicon, Sichuan Shin Silicon Industry, Xuzhou Zhongneng were built and expanded, many large and medium enterprises with actual strength found the development opportunities of poly silicon industry and established poly silicon production lines, which formed a boom to develop poly silicon industry in China. In 2011, the production of polycrystalline reached 82768 tons, and the sales amount reached 23 billion RMB. Until the end of 2011, the production ability of Chinese polycrystalline had reached 1480 thousand tons.

The market demand stimulates the development of a new method of purifying silicon. A lot of experts and scholars cooperate with companies to explore the new method and technology of purifying silicon. Chinese Ministry of Science and Technology and NDRC give support to certain projects by encouraging technology innovation and requiring them to have their own independent intellectual property rights.

Chinese construction of poly silicon lagged behind in technology. The industry foundation is weak. For most new industry, the key point is to achieve cyclic utilization technology of tail gas. The fact that Sichuan Silicon industry captured the cyclic utilization technology of tail gas makes us believe that Chinese poly silicon industry will develop healthily and rapidly.

Silicon Ingot/Wafer Manufacturing:

Solar-grade silicon ingot/wafer manufacturing is the second link of PV industrial chain. In the recent years, driven by PV market, solar-grade silicon ingot/wafer manufacturing keeps pace with the times and develops healthily and rapidly. So far Chinese silicon ingot/wafer manufacturers have exceeded 70 ones. The annual output of Solar-grade monocrystalline silicon in 2005, 2006, and 2007 is separately 2216, 4550 and 8070 tons. The annual output of polycrystalline silicon is separately 300, 1120 and 3740 tons. The total productions are 2516, 5670 and 11810 tons.

According to the latest statistics, by the end of 2007, national monocrystalline silicon furnaces have been about 2400 with total capacity of about 14400 tons/year. Polycrystalline silicon furnaces have been 230 with total capacity of 7000 tons/year. The total capacities of monocrystalline and polycrystalline silicon are 21400 tons/year. That is to say, that the production capacity of production is far higher than production output. One of the reasons is that many types of equipment have not played their full role in such rapid increasing speed and rapid development period. The other reason is that equipments cannot work with full production for the lack of raw materials.

Recently the industry chain links cannot work smoothly in the situation of silicon material shortage.

The development of Chinese crystal silicon ingot/silicon wafer industry has the following characters:

1. It develops rapidly and increased by 116% from 2004 to 2007.
2. It depends on raw materials of polycrystalline silicon, which mainly rely on imports, but the polycrystalline silicon materials of international market are in heavy shortage. So productions in some companies cannot work well due to the lack of material supply and high prices of materials.
3. The technology is mature. The products quality of silicon ingot and wafer is as same as that in the world's level.
4. Monocrystalline silicon continues to dominate the silicon industry. Domestic technology of drawing monocrystalline silicon is relatively mature. Monocrystalline silicon furnaces have already been achieved domestically and the prices are low. Polycrystalline silicon casting furnaces rely on imports and the prices are expensive. Because the capital investment of monocrystalline silicon is low and construction period is short, many companies are willing to choose to produce monocrystalline silicon. But the growth rate of polycrystalline silicon began to surpass that of monocrystalline silicon since 2007 (Polycrystalline silicon increased by 234%, while monocrystalline silicon increased by 77%). Saiwei LDK in Jiangxi province is now becoming the world's biggest polycrystalline silicon ingot/silicon wafer production base. Along with the domestication of polycrystalline casting furnaces, the proportion of polycrystalline silicon ingot will continue to rise and become closer to the international mainstream.

4.1.2 Status of batteries and modules manufacturing industry

Driven by the European PV market, Chinese solar battery industry still keeps a rapid growth speed in 2006 and 2007. Despite of raw materials restriction, it still attracts new companies to join the PV industry tea. According to the statistics, 50 enterprises have been engaging in the solar cell production at the end of 2007. By calculating the number of equipments in operation, reproduction capacity of solar cell has reached 2900 MWp. Chinese solar cell production outputs are separately 438 MWp and 1088 MWp in 2006 and 2007. The growth rates are relatively 201 % and 148.1%. Production in Suntech continued to lead the way and row in the national first place. The battery productions were separately 157.5 MWp and 327 MWp in 2006 and 2007, which covered 35.9% and 30.1% of the national production in 2006 and 2007.

Solar batteries cannot be used until encapsulated with modules to ensure their service life. So modules encapsulation is an important link in PV industry chain. Because the modules encapsulation technology and equipments are relatively simple with low costs and it starts rapidly with small risk, it is closest to the market and suitable for investments of small enterprises. Large enterprises with solar battery production lines are equipped with the modules encapsulation production lines. According to incomplete statistics, there are more than 200 companies with modules encapsulation production lines. They can encapsulate a total of more than 3800 MWp. Production capacity of the top 30 companies covers about 87% of total production capacity.

A production output of PV modules in 2011 is 35GW. Modules encapsulation is a relatively labor-intensive link in the industry chain. Chinese labor cost is low and its ability to encapsulate modules is stronger than the ability to produce batteries. So some of foreign battery need to be encapsulated in China, which leads that PV modules outputs are higher than the battery production. For example, German Q-cells Company produced solar battery of 389.2 MWp and was the world's biggest solar cell manufacturer, but they only produce the battery and sell them out to other modules manufacturers. This is called division of labor, which is obvious in PV industry chain. Chinese modules encapsulation is more competitive than that of developed countries.

4.1.3 Status of hull cell industry

Since China introduced unijunction amorphous silicon cell in 1980s, Chinese hull cell industry has been developing steadily. In this century the industry continues to develop rapidly boosted by the whole PV market. The lack of polycrystalline silicon materials promotes the development of hull cell industry in recent years. Before 2004, it mainly produced unijunction amorphous silicon cell in Chinese hull cell industry. Since Tianjin Jinneng began to introduce double junction amorphous silicon cell in 2004, it has been developed rapidly. There are three reasons why amorphous silicon cell developed rapidly after 2004. Firstly, it is driven by the world PV market. Secondly, the technology of hull cell industry is becoming mature. At last, the shortage of solar-grade polycrystalline silicon materials restricts the development of world PV market on one hand, but on the other it accelerates the development of hull cell industry.

At present, there are a large number of enterprises preparing to introduce a-Si/μc-Si production line with higher technology. For example, Suntech Power in Shanghai and ENN in Hebei introduced double junction amorphous silicon cell with the capacity of 50 MWp. Golden Sun in Fujian cooperated with Nankai University and established technology research and development center. When the forming production lines come into force, our hull cell industry will reach a new technical level.

At present, a lot of emphasis is given on the amorphous silicon cell because of its low cost, good appearance and weak light performance. But this kind of silicon cell is now facing some challenges, such as low efficiency and attenuation, short service life and low market awareness. In addition, hull cell industry is still in the continuous improvement process. Its technology updates rapidly. Equipments are unstable and highly invested at the initial period. So the investment risk of hull cell is higher than that of crystal silicon cell.

4.1.4 Application of PV and the status of system integration industry

BOS of PV system consist of all other components except PV array, such as controller, inverse variable device, maximum power point tracker, engineering data acquisition, display and remote monitoring, supervision, distribution system, cable rack and so on. Among them, controller is the core part. It plays an important role in improving efficiency of system, its reliability and service life. It is also crucial reduce production costs. Localization of controller process keeps pace with times. Most of independent PV system and 100-150kWp grade grid-connected system controller are basically made by domestic factories. Some large grid-connected PV power generation systems adopt imported equipments.

PV power generation system adopts exclusive measuring instruments, such as light intensity meter, solar cell phalanx tester, battery SOC tester, PV power station computer monitoring system, PV power generation system with data acquisition units. They are essential equipments for installation and operation of PV system. Their localization meets the primary needs of our PV system and market.

Representative manufacturers of exclusive controller for PV power generation system include Hefei Sunlight, Beijing Rijia, Beijing Institute of automation, Beijing Constant Electric, Beijing Corona, Zhicheng Champions and so on. Production output of Hefei Sunlight Power Supply Co., Ltd has reached 50 MWp annually and its single machine capacity is 1000 KWp (Wu H., 2009). Grid-connected inverters invented by other institutions are put into use with good properties and effects at the actual engineering.

4.2 Status of Chinese PV application market

Chinese PV market keeps pace with the times as a whole and develops steadily but slowly. China firstly applied Solar cell to DFH-2 in 1971 and to production on earth in 1973. It was only used in small power supply system, such as the beacon light, railway signal system, mountain weather station instruments, electrical fence, black light lamp, DC fluorescent lamp and etc because of its high price and slow development speed. During “The Sixth Five-year Plan” (1981-1985) and “The Seventh Five-Year Plan”, China began to give support to PV application demonstration projects and made it develop in industry and agriculture application. They are widely used in microwave relay station, communication, sluice, oil and gas pipelines cathodic protection, rural telephone carrier, village power supply system and etc (Jia X. & Cao J., 2010).

In 2002, State Development Planning Commission (SDPC) started the “no electric provinces and town energizing plan”. It solved no electric problems in more than 700 villages and towns. The whole capacity was 15.3 MWp. Since 2002, the state has launched some programs, like “Brightness Program”, “Silk Road” cooperated by China and Dutch. These programs made the PV power generation system play a full role in solving people’s electric problems. In 2002 to 2003, the program of “Sending Electric to Township” improved the development of PV market and its installation capacity reached 5 MWp in 2004 and 2005, which was respectively 0.5% and 0.3% of the installation amount in the world market.

The Renewable Energy Act implemented in 2006 stimulated the development of PV market. But PV power generation market still developed slowly because Feed-in Tariff Law in Renewable Energy Act was not put into force. In 2007, total installed capacity of PV systems was about 20MWp, only 1.84% of the time when the solar cell production output goes to 1088 MWp. It means that 98% of solar cell outputs need to be exported. At the end of 2007, the cumulative installed capacity of PV systems reached 100 MWp (approximately equivalent to less than 1% of the world’s cumulative installed capacity). From 2002 to 2003, annual installed capacity and cumulative installed volume greatly increased as China started the project of sending electricity to villages. Renewable Energy Act enacted in 2007 have a positive impact on the PV market. Installed capacity increased and local governments funded construction projects. But the start of China’s overall PV market is not obvious because there is still no specific provisions for the “Feed-in Tariff Law” in Renewable Energy Act. As a whole, the Chinese PV market growth remains slow (Li J. et al, 2007).

Approximately 53.8% of Chinese PV systems are applied for communication industry and solar PV products. 46.2% are applied for rural electrification and grid-connected PV power generation and other government support programs. The Grid-connected power generation only covers 5% and the rest parts are all independent PV systems. In 2007, a total of 20MWp PV systems are installed and the cumulative installed capacity reaches 100 MW. Stand-alone PV systems application is 18MWp, accounting for 90% of the new market share. The rest 10% is accounted by grid-connected PV systems with the application of 2MWp. Europeans countries introduced corresponding executable grid tariff, so Grid-connected systems cover 99%. Globally, accumulate installed capacity of world's PV systems is 12GWp, while grid-connected systems capacity is 10GWp, equal to 83% of the total market share.

Low proportion of Grid-connected power generation demonstrates that China's PV application is still in the primary stage. We should reconsider the strategic significance and the importance of Grid-connected PV power generation and implement "Feed-in Tariff Law", the core provision in "Renewable Energy Act".

In recent two years, enterprises played an active role in improving the application of PV power generation. Though "Tariff Act" is not implemented, some large-scale grid-connected PV programs were established by self-financing, such as Solarfun Power Holdings contracted to build 1MWp roof power station on Chongming Island in Shanghai. Wuxi Suntech built 1.2MWp airport and office power station. Shenzhen Xintiandi established 1.2 MWp grid-connected PV building power plants and so on (Zhao Yuwen, 2008). These grid-connected PV power generation station will play a positive demonstration in PV application and lead it to the grid-connected direction.

4.3. R&D status of PV industry in China

4.3.1 Technical research and development policy

As a newly risen industry, PV industry abounds in technical bottlenecks. Chinese government has long been attaching importance to the technical research and development on renewable energy. Since the sixth Five Year Plan, Chinese government has implemented State Technical Problem Tackling Plan (since 1982), 863 Plan (since 1986), 973 Plan (since 1997), arranging capital to support the research on the development and techniques of renewable energy, such as solar energy, biomass energy, geothermal energy and ocean energy, etc (Zhang et al, 2009). The research and development of renewable energy are included in many projects, namely, all the Five Year Plans, the Bright Project by the previous State Planning Commission, the Dual Pluses Project by previous State Commission of Economy and Trade. In Mid- and Long-Term Development programming for Renewable Energy which was passed on 7 June 2007, the goal was set that central finance will set up special fund for developing renewable energy in support of the technical research and industrial construction of renewable energy.

4.3.2 Government model projects

The development of China's renewable energy, especially the large projects, is closely related to the promotion of government model projects. The Table 1 is the list of principal government model projects since the 1990s.

Table 1: Principal Government model projects since the 1990s

Time	Project	Initiating institution	Brief introduction
1996	Bright Project	State Commission of Development and Reform	Provide renewable power to 2 × 107 Chinese citizens
2000	Tenth Five Year Plan	State Commission of Development and Reform	Up to 2005, the installed capacity for wind power generation reached 1500 kW
2000	Renewable Energy Industrial Development Plan	State Commission of Economy and Trade	Up to 2015, the installed capacity for wind power generation reaches 7000 MW
2002	Acceleration Plan for Bright Project	State Commission of Development and Reform	Provide a capital of RMB 1.8 × 109 yuan for solar energy and wind energy projects
2002	Electricity Delivered to Village Project	State Commission of Development and Reform	Solve the domestic power problem for 4.0 × 105 citizens
2003	Six Smalls Project	State Commission of Development and Reform	Water conservation and irrigation, human and animal drinking, rural road, rural water and electricity, pasture barrier and some other projects
2006	Scaled Development Project on Renewable Energy	Chinese Government, World Bank, World Environment Fund	Study and formulate the policy for the development of renewable energy; support the technical advances in renewable energy; construct an industrial system for renewable energy; to realize the scaled development of renewable energy

5. Future strategy of PV industry in China

With regard to the abovementioned China's PV industry development policy, standing on the point of long and effective system in renewable energy development, we have carried out systematic and insightful thought upon the policy optimization and innovation. It is hereby advised that importance should be attached to the following aspects in China's PV industry development policy.

5.1 Improving the effectiveness of policy completeness and policy grouping

Government support is the key and initial power for the development of renewable energy. China's renewable energy is usually promoted and pushed in some remote and poverty-stricken areas, where social efficiency is remarkable while economic efficiency rather low. Thus renewable energy needs more encouragement and support from the nation and all levels of government. PRC Law of Renewable Energy, issued on 28 February 2005, fixed the legal position of renewable energy and defined the development direction of renewable energy. Its effective implementation depended much upon some supporting administrative laws, regulations, technical regulations and relevant programs and plans issued by State Department and some concerned sectors. The already issued supporting regulations include five sets of supporting laws, namely, Instructions on Renewable Energy Industry Development, Management Regulations on Renewable Energy Power Generation, Temporary Management for the Price and Cost Sharing in Renewable Energy Power Generation, Administrative Regulations on Renewable Energy Power Generation and Mid- and Long-Term Development Programming for Renewable Energy. State Commission of Development and Reform is now on its way to stipulate some policies on renewable energy power generation, which is expected to be issued soon. To ensure the successful implementation of these laws and regulations, we should construct an effective system, with PRC Law of Renewable Energy as its dragon head and closely surrounded by supporting laws and regulations.

Since 1979, Chinese government has issued quite some laws, regulations and policies in terms of renewable energy; however, China's renewable energy is charged by more than one sector. This results in the lack of consistence between policies, hindering the development of renewable energy industry. The state should set up a special governing sector for renewable energy, responsible for the unified formulation, programming and management of policies, for coordinating various policies. In this way, we could better exert the role of combined policies, and formulate a long-lasting and effective mechanism to support the sustainable development of renewable energy.

5.2 Enhance the policy innovation in policy regions

Development of renewable energy must be based upon the regional situation; and the issues should be studied in accordance with the local conditions. The formulation of regional energy development policy should consult the state mid- and long-term programming on renewable energy; besides, in the programming, we should strengthen our investigation on the regional energy distribution so as to form a reasonable regional layout for industrial development; in addition, we should play an active role in encouraging regional-industry-related policies to make innovations, and ultimately reaching a benign circle of "regional policy extension"—"regional policy innovation"—"regional policy further extension". In this way, the blood making mechanism could be formulated by and large, constituting the sustainable guided transition for energy use.

5.3 Construct the regional echoing mechanism for clean development mechanism

In order to tackle the problem of world-wide warming up, Clean Development Mechanism (CDM) was put forward in Tokyo Protocol, allowing developed countries to provide additional capital and techniques to reduce the greenhouse gas emission in developing countries. Besides, the reduced emission should be regarded as emission reducing obligations for developed countries; while on the other side, the additional capital and techniques acquired by developing countries are helpful to their own sustainable development. Tokyo Protocol has now entered the phase of implementation; Chinese government adopts an active attitude toward the development of CDM. Up to 26 March 2007, China has developed 279 CDM projects in all; when all the projects are working, their emission reduction accounts for 50% of the total CDM emission reduction in the world. Currently, China has just made its first step in CDM emission reduction market, leaving us an enormous potential.

Most of China's CDM projects lie in renewable energy field, including wind energy power generation, photovoltaic cell, solar energy water heater, biomass power generation, rural marsh gas and garbage burying gas, etc. As is estimated, the carbon emission potential in this field would reach 6.28 × 107 t in 2010 and 1.98 × 108 t in 2020. With substantial investment and high cost, China's renewable energy is quite appropriate to serve as CDM project. Consequently, Chinese government should actively echo with CDM, take advantage of CDM, construct the regional echoing mechanism for CDM, striving for more capital and techniques for renewable energy development.

5.4 Enlarge investment on research and development

As renewable energy development in developed countries shows, renewable energy, as a newly risen industry, though has a rather promising future, is in great need of government fund support in the beginning. Currently, China's investment in technical research and development of renewable energy is inadequate, leading some advanced techniques and equipment to severe dependence on importation. This has plunged the industrial development into a fairly passive situation.

It's been advised that the state arrange a certain part of special capital for renewable energy so as to strengthen the technical research and development of renewable energy, to enhance our own innovative capability; in accordance with the maturity of renewable energy techniques, the government should provide sustainable fund subsidy to technical research and development projects stage by stage, so as to reduce investment risk of individual enterprises, to enhance their activity in participating the technical research and development; at the meantime, state-made photovoltaic cell manufactures should be subsidized. Through this doing, we are aimed at accelerating the localization and state-made process of renewable energy equipment manufacture and at promoting the sustainable and healthy development of China's renewable energy industry.

5.5 Develop process management, ensure the effective function of policy

Some policies related to China's renewable energy tend to get unsmooth in their transmission to lower level of units, leading to the trouble that the function of policies are sometimes undermined. As for this phenomenon, renewable energy development offices should be set up by the state at various levels of government, which would be in charge of policy implementation and industrial dynamic management; at the meantime, monitoring teams should be set up under these sectors specially to monitor policy conveying and implementation. Besides, these teams should report and feedback their information to their supervisors from lower levels of units. Upper levels and lower levels complementing each other thus form a complete and powerful policy system. In addition, in the formulation and management of industrial development policies, renewable energy development offices should keep consistence in policy implementation as well as considering the risk and predicament that the changing environment brings to policy implementation. In this way, the offices are able to actively push the organic regulation, control and the reasonable optimization of industrial policies.

5.6 Construct a market investment and financing system

Establishing the relevant investment and financing mechanism is a key condition for PV energy technical industrialization. Currently, the main body of China's renewable energy is over single; the investment and financing channels are not expedited; and domestic enterprises have not invested enough in this field. In order to formulate a long-term and effective development mechanism for renewable energy, we should made enormous efforts on exploring PV energy's capital market, including enlarging the government support, strengthening the back support and bring into full play the Build–Operate–Transfer energy fund, stocks and public fund, and some other market financing methods. In this way, we could build up a market investment and financing system. In this system, the state offer guidance with limited amount of capital while bank loan and self-raised capital shall play a more important role in enterprises.

6. Conclusions

Renewable energy such as solar energy is the inevitable choice for sustainable economic growth, for the harmonious coexistence of human and environment as well as for the sustainable development. In order to promote and ensure the rapid, effective and sustainable development of PV industry, Chinese government has formulated a series of policies on renewable energy development, including laws, regulations, economic encouragement, technical research and development, industrialized support and government renewable energy model projects, etc. These policies play a significant pushing and guiding role in the development and use of solar energy; With the continuous change in environment, however, China's renewable energy development policy begins to show certain disadvantages, which could be best represented by the following: (1) polices lack coordination and consistence; the coordinative function has not been brought to play; (2) the encouragement policy is inadequate and the system is not complete; government subsidies do not cover enough areas; the subsidies are small and not smooth in their transmission to lower levels; (3) lack of regional policies innovation; comparative advantages and industrialized competitive advantages have yet to be formulated in regional renewable energy; (4) investment and financing system is not healthy and complete; main body of the investment is more than single, domestic enterprises have not yet to invest enough; as the real investment man body of industrialized development, enterprises have not been blended into the development chains in a real sense; (5) currently, China's investment in technical research and development of PV industry is inadequate, leading some advanced techniques and equipment to severe dependence on importation. This has plunged the industrial development into a fairly passive situation.

With regard to the abovementioned problems in China's PV industry development policy, standing on the point of long and effective system in renewable energy development, we have carried out systematic and insightful thought upon the policy optimization and innovation. It is hereby advised that importance should be attached to the following aspects in China's renewable energy development policy:

(1) Improving the effectiveness of policy completeness and policy grouping.

(2) Enhance the policy innovation in policy regions, form “Extensive Promotion–Regional Innovation–Extensive Promotion” benign cycle.

(3) Construct the regional echoing mechanism for clean development mechanism (CDM).

(4) Enlarge investment on research and development, realize the localization and domestic manufacturing of renewable energy equipment.

(5) Develop process management, ensure the effective role of policy.

(6) Construct a market investment and financing system with introduction by the state, loan from bank and preparation by enterprise itself.

Mention should be made that socialized use and industrialized development of PV industry is a long-lasting and complicated process, which requires not only policy support from the state but also breakthroughs and development in techniques and markets; relentless support in terms of policy should be offered; continuous breakthroughs should be made in terms of techniques and unceasing cultivation and perfection be carried out in terms of market; only in this way could energy make enormous contributions to the further development of human race.

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Review of the Recent Developments of Energy Legal Framework in Taiwan- with the Focus on New Energy Policies & Legislations

Dr. Yueh-Hsun TSAI [1]

Associate Professor of Law, Graduate School of Sci. & Tech., National Yulin University of Sci. & Tech.(YUNYECH), Taiwan, R.O.C.

Han-Bei TAN

Research Assistant, School of Sci. & Tech., National Yulin University of Sci. & Tech.(YUNYECH), Taiwan, R.O.C.

Ding-Jang CHEN

Founding partner, CC&W attorneys-at-law, Taiwan, R.O.C

[1] Contact details of corresponding author
Tel: +886-5-534-2601 Ext.3613
Fax: +886-5-531-2179
e-mail: dennis@yuntech.edu.tw

Address

123 University Road, Section 3, Douliou, Yunlin, Taiwan 64002, R.O.C.

Abstract: In the risk of peak oil and climate change crisis, governments around the world are engaged in energy efficiency improvement, reduction of dependence on fossil energies, energy supply securing, and environmental protection. Especially, in the wake of Post-Kyoto Protocol era, the responsibility of carbon emission reduction has already formed a global consensus. Therefore, to establish a long term, stable, and predictable legal framework for the development and management of conventional and new energy has become important goal in terms of new energy legislation and policy formation. In recent years, Taiwan starts to embrace various energy policies and legislations and the government has designed numerous administrative regulations for conventional energies as well as to promoting renewable energies. In the aspect of the renewable energy, "Cleaner Energy Supply" and "Rationalized Energy Demand" are stated as the main sustainable policy principles and the latest legislation, "Regulation for Renewable Energy Development", was promulgated by the president on July 8, 2009. Although the overall deployment of renewable energy is still in initial stage in compared to some leading countries or regions, the current development in Taiwan still shows the government's intention to achieve the sustainable development as well as to create more possibilities for the green economy in Taiwan. This article focuses on reviewing the background, progress and questions aroused in forming of the energy legal framework in Taiwan in the recent years, and aims to provide an initial review and analysis of current Taiwan new energy legal frame work and its deficiencies.

Keywords: Renewable Energy, New Energy Policies and legislation, Energy-legal Framework.

1. Introduction

In the risk of peak oil and climate change crisis, governments around the world are engaged in energy efficiency improvement, reduction of dependence on fossil energies, energy supply securing, and environmental protection. Especially, in the wake of Post-Kyoto Protocol era, the responsibility of carbon emission reduction has already formed a global consensus.

Taiwan is the island and lacks of domestic energies and fossil fuels with long-tern and high imported energy dependence over 99%. The concerns of energy deficiency and climate crisis has been one of the main issues for the government and attempted to mediate it through lots of efforts.

2. Energy Legal Framework in Taiwan

The energy legal framework related policy in Taiwan could be dated back to 1968, the pass of

"Energy Policy and Implementation in Taiwan Area" in the administration. Until 1990, the policy had been issued and amended for three times to modify some focuses according to the situation around the aboard and the domestic. On the other hand, the authority for energy in the government also formed an initial organization in 1970, Energy Policy Examined Group, Ministry of Economic Affairs, and was replaced by Energy Commission, Ministry of Economic Affairs in 1979. The relative history of energy policy and authority could be depicted as the following diagram.

2.1 New Energy Policy

In 1996, Taiwan amended "Energy Policy and Implementation in Taiwan Area" and set "Reinforce Energy Research and Development (R&D) - Encourage R&D and Promote Incentives on Renewable Energies and New Energy Technologies" as one of the policy guidelines to achieve the master goal -"Free, Orderly, Efficient, and Clean energy Demand and Supply System". In addition, Taiwan hold "National Energy Conference" separately in 1998, 2005, and 2009 in order to response the Kyoto Protocol, the supplementary provision of United Nations Framework Convention on Climate Change of 1997 (UNFCCC), and the relative issues about energy. The National Energy Conferences concluded certain consensus and objectives, like "increase the share of new energies, including solar, wind, biomass, geothermal, ocean, and water, etc., up to 3% in Taiwan's total energy supply by 2020", "reach the target of renewable energy account for 10% in total energies in 2010", and combined with the "Action Program of Energy Saving and Carbon Reduction" , submitted by the "Framework of Taiwan's Sustainable Energy Policy of 2008", as "Action Program of Sustainable Energy Policy" through six aspects of energy, industry, transportation, environment, life, and law into practice.

In 2008, the Executive Yuan (the cabinet of Taiwan) approved "Framework of Taiwan's Sustainable Energy Policy" and introduced the policy guidelines of "Improving energy efficiency, Developing clean energy, and Securing stable energy supply" to achieve the policy target, "Win-Win-Win Solution for Energy, Environment and Economy".

Following the policy announced, several specific goals were also been made for establishing the a energy consumption and supply system of "Two High and Two Low- High efficiency, High value-added, Low emission, and Low dependency": (a) To decrease the energy intensity over 20% and over 50% in 2025 compared with it in 2005; (b) To reduce nationwide CO2 emission for returning it in the standard of 2008 among 2016-2020 and in the standard of 2000 in 2025.

Table 5:

Year	Policy and Authority Established	Important Meaning and Influence
1968	"Energy Policy and Implementation in Taiwan Area" was passed in the administration.	Put the emphasis on developing industry, stable the energy supply with cheaper price and encourage the exploitation and consumption.
1968	Energy Planning-Development Group, International Economic Cooperation Development Commission of Executive Yuan was founded.	The first energy authority in Taiwan to manage the relative affairs and business.
1970	Energy Policy Examined Group, Ministry of Economic Affairs was founded.	Replace Energy Planning-Development Group founded in 1968.
1973	"Energy Policy and Implementation in Taiwan Area" was issued and implemented.	The goal was to stable the supply, secure the imported, and diversify the type and source of the energy.
1979	Energy Commission, Ministry of Economic Affairs was established.	Replace Energy Policy Examined Group founded in 1970.
1979	"Energy Policy and Implementation in Taiwan Area" was amended.	Set the goal for production-domestic energy, energy saving, the import of LNG preparation, and coal consumption promoted to replace petroleum.
1984	"Energy Policy and Implementation in Taiwan Area" was amended.	Concern the electricity load, energy industry management, energy efficiency of building and facility, and environmental impacts decreasing.
1990	"Energy Policy and Implementation in Taiwan Area" was amended.	Focus on LNG power generation, CHP, nuclear waste disposal, and energy saving and educational propaganda.

Further, the share of low carbon energy in electricity generation systems should be from 40% currently to 55% in 2025; (c) To build a security system of energy supply to meet the goal of annual economic growth rate up to 6% in 2008-2012 and US$30,000 per capita income by 2015.

Based on the national policy of "Populace Economy" replied the economic structure in the post-financial-crisis period, “2010 National Establishment Plan of Republic of China (Taiwan)” was promulgated and emphasized “Green Energy” on several aspects, like industries, transportation, technologies, buildings, education, tax system, the public, and laws, etc.. Moreover, “2012 National Establishment Plan of Republic of China (Taiwan)” directed carbon emission reduction, climate change crisis policy promotion, low-carbon city and transportation boost, recycle society establishment, cleaner production and green industry development, and green tax legislation as the key points into practice.

Besides of the evolution on energy policies in Taiwan, the authority for energy also has altered the name and status gradually. In 2004, “Bureau of Energy, Ministry of Economic Affairs (MOEABOE)” was founded by legislation. Then, it would be replaced by “Ministry of Economic and Energy, the Executive Yuan” in 2012 and expected to process more executed power on relative affairs than before

2.2 New Energy Legislation

Currently, Taiwan embraces and execute several laws and regulations with its own features, including of Mining Act, The Electricity Act, Atomic Energy Law, Nuclear-related laws and regulations, Energy Management Act, Petroleum Administration Act, Regulation for Renewable Energy Development, and Natural Gas Business Act. For complying with the targets depicted in the energy policies mentioned above, there are two bills, Regulation for Energy Taxation and Greenhouse Gas Emission Reduction Act, still under legislation for years with much debate and impacts on Taiwan.

It is worth to be mentioned that Energy Management Act, Regulation for Renewable Energy Development and the two bills are called “Four Key Energies Laws” since the government take them as the significant legislations to broaden energy sources and save energy consumption in Taiwan. Energy Management Act focuses on managing the demand-supply chain of energy, energy efficiency, and energy development nationalwide; Regulation for Renewable Energy Development contains the incentive programs for producing renewable energies and operating relative facilities in order to promote the exploitation and development of the renewable.

The two bills, Regulation for Energy Taxation and Greenhouse Gas Emission Reduction Act, specify separately on ruling energy consumption and green gas emission. The former aims to adjust the energy share structure and rationalize the energy price by levying the energy tax. Meanwhile, the cancellation on the subsidy for fossil fuel is considered in the congress. The later, Greenhouse Gas Emission Reduction Act, concentrates on the term and relative measurements of the greenhouse gas emission for Taiwan to achieve the national carbon responsibility of Kyoto Protocol. It will be authorized by Environmental Protection Administration, the Executive Yuan and make the effort on setting the carbon emission standard for every sectors, providing the trading platform for the industry and the business, establishing the supervising and examining scheme, and promoting activities on saving energy and energy efficiency for administrations, schools, and organizations, etc..

The legal status and relative information of “Four Key Energies Laws” could be summed up through the form below.

2.3 Promoting programs on New Energy in Taiwan

In order to achieve the target of saving energy and broaden energy sources, Taiwan’s government has made much effort on policies and legislations issued as well as engaged in administrative actions through various subsidies from tax exemption, grant, incentive price, and loan guarantee, etc.. And it could be categorized as a energy demand-and-supply chain to survey individual parts.

Firstly, the feedstock for the energy could gain the subsidy on production. In 2005, Council of Agriculture (COA) issued “Plan for Production and Distribution of Energy Crops System Establishment” for promoting fallow lands to plant the energy crops with the subsidy of NT$60,000 per hectare. Initially, the plan selected Yunlin, Chiayi, Tainan, Kaohsiung, and Pingtung in Taiwan as the demonstrative regions and were planted soybean, rape, and sunflower. The crop was prepared to produce the transportation fuel, like diesel and ethanol.

At the manufacture sector of the demand-and-supply chain, the production of electricity generated from solar, wind, and thermal or the transportation fuel, like biodiesel and ethanol, came from waste edible oil and soybean.

Taiwanese government provides promoting incentives to encourage the production of new and renewable energies, including of the exploitation on fuel cell, ethanol blended used in the vehicle, Photovoltaic (PV) facilities in public buildings invested and set by local governments, renewable thermal, renewable electricity, power-generated equipment on the renewables, installation of offshore wind farm, etc..

Table 6:

Year	Law & Regulation	Legislated Objective	Legal Status
1980	Energy Management Act	In order to enhance the management on energy, promote energy usage with rational and efficient.	Energy Development Guidelines is under assessment by the aspect of energy, environment, and economy.
2009	Regulation for Renewable Energy Development	For promoting the use of renewable energy, increase energy diversity, improve environmental quality, drive relative industries, and encourage sustainable development nationalwide.	The incentive and purchasing price and limitation on the renewable energy and its facility are under amendment.
Bill	Regulation for Energy Taxation	Aims to focus on energy usage, environmental protection, and economic development.	Five bills version are discussed in the congress.
Bill	Greenhouse Gas Emission Reduction Act	To conciliate the climate change worldwide, lower the greenhouse gas emission, assuming the responsibility on protecting earth, and ensure national sustainable development.	Debates on supervising and examing, registration, trading, foundation of climate change mediation, and educational promoting activities are under legislation.

For example, "Millions of Solar Rooftop" has implemented from 2011 authorized by MOEABOE and aims to promote the installation of PV on the rooftop of public buildings, schools, or communities through local government. This target of "Millions of Solar Rooftop" sets 420MW in 2015, while 1020MW in 2020 (about 0.34 million rooftops installed) and 3100MW in 2030. Moreover, "Thousands of Wind Turbines" has also been issued and executed from 2011, and aims to build the first national offshore wind farm in 2015 and develop the wind turbines of 600MW (about 120 wind turbines installed) in the shallow sea before 2020.

In addition, Taiwan's government also offers the grant for consumer on buying energy saving products. For instance, in order to boost the energy efficiency of the domestic energy appliance and prevent foreign products with low energy efficiency to import in the country, Taiwan's government regulates the energy efficiency standard through Energy Management Act and found the "Certificate Scheme of Energy Saving Label". Applying for the certificate of Energy Saving Label voluntarily, the manufacturer could attach the label on the products to represent the energy consumption and energy efficiency. Once the consumer decides to purchase the product with Energy Saving Label, the government would offer the grant of NT$2,000. Currently, the kinds of electricity appliances, including of air-conditioner, refrigerator, washing machine, television, computer, and CD player, etc..

Further, some programs are emphasis on education, propaganda, and demonstration. "Program of Green Public Fleet" is a program ruled the public fleet belonged to Legislative Yuan, Judicial Yuan, Examination Yuan, Control Yuan, Executive Yuan and its subsidiary agencies, and Taipei City Government had to apply E3 (3% ethanol blended into 97% gasoline) with the subsidy for purchasing, cost differences, maintenances, and the marketing on ethanol promotion. In addition, the general public could also purchase E3 from selected gas stations which the oil price may cheaper than regular unleaded gasoline up to NT$1 per liter on account of the subsidy provided by MOEABOE. Besides, "Low-Carbon Island in Ponghu" is also planned from eight promoting aspects: renewable energies, saving energy, green transportation, low-carbon building, environment greening, sources recycled, low-carbon life, and low-carbon education.

It is estimated the electricity-generated from renewable energies could occupy 100% share of total electricity consumption and the CO2 emission of one person would be lower from 5.4 tons to 2.1 tons in one year. Also, the targets of low-carbon life and saving-energy technologies will lead the international concern and tendency, further to boost the ecological tourism and drive the industrial development. The following diagram is the subsidy and incentives executed for the demand-and-supply chain of new energies in Taiwan.

3. Development of New Energy in Taiwan

The step and achievement to promote the development of the new energy in Taiwan might be slower and less then other countries worldwide, there still has some focuses should be concerned and surveyed. Except the two bills, Regulation for Energy Taxation and Greenhouse Gas Emission Reduction Act, are introduced for realizing those aforementioned national energy policies, the latest and most noted legislation, Regulation for Renewable Energy Development, was passed on June 12, 2009 and promulgated by the president on July 8, 2009, after seven years long legislative process in the Legislative Yuan.

Regulation for Renewable Energy Development grants MOEABOE to authorize promoting the usage of renewable energies in Taiwan. It aims to increase energy diversification, reduce greenhouse gases, improve relative industries, and boost national sustainable development. The regulation contains only 23 articles but covers several aspects of renewable energies, including of operation, facilities, incentives and subsidies, developments, feed-in tariff (FiT), obligations, mediation, and penalties.

The categories of renewable energies identified in this bill are solar, ocean, wind, biofuels, geothermal, non-pump and storage hydropower, hydrogen, waste, fuel cell, and other renewable electricity.

Table 7:

Types	Subsidy & Promotion
Feedstock of Energy	* “Plan for Production and Distribution of Energy Crops System Establishment”: promote fallow lands to plant the energy crops with the subsidy of NT$ 60,000 per hectare.
Energy Production	* “Millions of Solar Rooftop” : the highest purchasing fee of electricity-generated capacity for power station is NT$9.4645 in 2012. * “Thousands of Wind Turbines”: provide the maximum grant for 50% of the project. * ”Subsidy for the fuel cell”: grant the maximum for 50% of the project cost.
Energy Facilities	*“Subsidy Program for the Application on Green Country”: designate the cities as the demonstrative regions to sell B1 in the local petroleum station which subsidy for costs.
Energy Facilities	* “Subsidy for Installation of Solar Water Heater”: subsidy the installation of small-scale and large-scale solar water heater with NT$ 0.4 million behind or exceed. * “Tariff Tax Exempted on Power-Generated Facility Imported of Renewable Energy: exempt the tariff tax for the power-generated facilities imported on PV, wind, offshore wind, water, geothermal, ocean, biomass, waste, fuel cell, and others.
Users or Consumers	*“Certificate Scheme of Energy Saving Label”: grant the consumer NT$ 2,000 when purchasing the appliance with Energy Saving Label. *“Subsidy Program for Energy Crop on Green Bus”: the BOE will subsidize the cost when the public buses use the convention diesel with 1-5% domestic biodiesel blended. *“Promoting Program for Ethanol in Taipei and Kaohsiung Metropolis”: the petroleum refiner offer and sell E3 in Taipei City and Kaohsiung City could apply the subsidy for cost differences, repairing, promotion, and marketing. *“Program of Green Public Fleet” ruled the public fleet to apply E3 with the subsidy for purchasing, cost differences, maintenances, and the marketing on ethanol promotion.
Demonstration	*“Low-Carbon Island in Ponghu”. * “Subsidy for the promoting demonstration on energy efficiency”: grant the maximum of NT$ 5 million and not exceeds one third of the expense. While maximum of the project related to LED on the streetlight is NT$ 2.5 million and not exceeds half of the expense.
Education	* “Subsidy for the civic group to hold the meeting and activity related to energy”: offers the maximum grant for 50% of the project.

The feature of “Regulation for Renewable Energy Development” is to offer the incentive for generation capacity of renewable energies by 650-1,000 MW within 20 years. Further, it is expected to achieve the goal of over 845 MW in 2025 and occupy the share over 15% in the total energy generation capacity in Taiwan.

In addition, Energy Development Guidelines, granted by article 1 (2) of Energy Management Act, with the legislated goal of ensuring the stable and security of national energy supply, considering the environmental impacts and caring the economy development (3E: Energy, Environment, Economy) is under policy assessment. According to “Policy Assessment of Energy Development Guidelines ” prepared by MOEABOE in 2010, it would be legislated following the “Principle of Prevention ”. It means the new or enlarged facilities of energy consumers in large-scale investments have to be proceeded the prior management and assessed the energy usage. It tends to conduct the energy usage of balance and steady of energy demand-and supply nationalwide in the future. Since the influence or impact of the regulation are still hard to be concluded, there has seldom statistic and result to review. However, The regulations and the bills not only represents the positive determination of the government on developing the renewable energy, but display the opportunity of energy-usage alternation in Taiwan.

4. Conclusion

Through tracking and observing the international trend, energy policies currently address some issues related to develop the technology with environmental friendly for increasing energy supplies, encouraging cleaner and more efficient energy usage, reducing air pollution and carbon dioxide emission to alleviate the global warming and climate change. Taiwan, an island with high dependency on imported energies and its environmental limitation, has more inevitable and urgency factors to develop new and renewable energy through diversity and stable demand-and-supply chain.

Taiwan's first energy policy and legislation could be traced back from "Energy Policy and Implementation in Taiwan Area" in 1968 and "Mining Act" in 1930. Initially, Taiwan's government put much emphasis on stabling the energy supply and exploiting energy sources. Then, the objectives of saving energy and the development and protection on conventional energies had become important. Following the international tendency, Kyoto Protocol signed, and short of fossil energies and the crisis of climate change, Taiwanese are aware of the damage of high dependency on imported energies and the energy crisis with the feature of inevitable and essential. Policy making has altered and concerned the renewable energy to diversify the energy sources for national security. Currently, the focuses of the energy policy and legislation are not only on the development of new energies and saving energy, but considering the 3E target of energy, environment, and economy for forming a country of sustainable development.

Since the policy of Energy Policy and Implementation in Taiwan Area promulgated in 1996, Taiwan has made efforts on new and renewable energies. Besides the policy made, legislations and administrative actions are also taking energy alternation on new, clean energies and relative schemes as the reformed key points. "Four Key Energies Laws" are regarded as the significant legislation to regulate Taiwan's energy demand-and-supply chain with 3E characters. However, energy-related policies and legislations in Taiwan are often suspended in the congress with debates and discussion for a long time since the consideration on profit and industrial growth. Further, the national development and society welfare are also influenced with impacts. In addition, based on the reviews of the formation of Taiwan's recent energy policy, it could be observed there is lacking of comprehensive and solid legal scheme, heavily relying on administrative pilot programs, short of interagency cooperation, which indicate the limitation of current policy formation. Therefore, for aiming to achieve the sustainable environment, composing a well legal framework for policy making, laws and regulation legislating, and administrative actions executing is an essential target to concern currently in Taiwan.

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Taiwan's Complementary Measures for Existing Power Plants After the Greenhouse Gases Being Categorized as Air Pollutants

Jui-Chu LIN [1]*,

Wei-Nien SU [2]

[1] Department of Humanities and Social Sciences

[2] Graduate Institutes of Applied Science and Technology

National Taiwan University of Science and Technology, No. 43, Keelung Road, Sec. 4, Taipei, 106, Taiwan, R.O.C.

Abstract: On May 9 2012, Taiwan's Environmental Protection Administration referred to a US court case and regulated six greenhouse gases including carbon dioxide as pollutants under Taiwan's Air Pollution Control Act. According to this executive order, enterprises have the obligation to report their emissions of the six new pollutants; the EPA in Taiwan also ordered local governments not to impose extra environmental tax on the emission of the six pollutants. The research has examined the U.S. Supreme Court case Massachusetts v. Environmental Protection Agency to see if Taiwan's judicial organs can learn from the case and play an active role in tackling climate change through legislation. It has also focused on the issue of greenhouse gas tax to explore the roles local governments can play in mitigating climate change. For example, though greenhouse gases have been regulated as pollutants, Kaohsiung City Government and Yunlin County Government still wished to levy "carbon tax" on polluters of air pollutants in their jurisdictions. Even though the EPA in Taiwan tried to prevent them from doing so, Kaohsiung City Government introduced a new tax instead, called "The Kaohsiung City Enterprise Climate Change Adaption Fee", under the local legislation. The issue of local governments in Taiwan wishes to levies carbon tax still remains debatable as whether the central or local governments has the authorization to levies carbon tax. Without doubt, the topic has turned into an issue of cross-border multilateral environmental governance, which is a worthy topic to explore.

Keywords: low carbon, Massachusetts v. Environmental Protection Agency, Clean Air Act

1. Introduction

On President Ma Ying-Jeou 2012 inaugural speech, the president has announced that one of the pillars to increase Taiwan's global competitiveness is to develop an environment characterized by low carbon emission and high reliance on green energy. The imbalance of supply and global change has prompted Taiwan to confront to energy and climate challenges. Taiwan understands the importance to seize this opportunity to develop clean energy technologies and green industries as green revolution is sweeping the world. Yuan, et al (2011) identified that the six key concepts of "low carbon" including low- carbon development, low-carbon economy, low- carbon society, low-carbon city, low-carbon community and low-carbon life. Low-carbon development can be divided into three phases with low-carbon economy at the primary stage, low-carbon society in the developmental stage and low-carbon world at the maturity stage. The participation of the city plays an important role among these stages. According to UN-HABITAT's 2011 report, in 2010 approximately 50.6% of the world's population lives in urban areas. UN-HABITAT estimates that by 2030, 60% of the world's population will accommodate in cities. By 2050, 70% of the world's population will be crammed in urban areas. For example, Tokyo is by far the largest city in the world with 1/4 of Japan's population and Cairo accounts for the half of Egypt's GDP. Cities are the major contributors to greenhouse gas emissions and energy consumption .As a matter of fact, high population density in urban areas has also caused serious pollution (UN-HABITAT, 2011).

Because the city government decides the policies regarding infrastructure facilities, traffic and energy investment, its residents and economic activities would directly or indirectly determine the method of energy consumption and greenhouse gas emissions (UN-HABITAT, 2011). This phenomenon has accelerated cities worldwide to develop climate mobile projects as a response to climate change. Despite the fact that The Kyoto Protocol did not clearly outline the role of cities and local governments in combating climate change. However, carbon reduction has evolved to include issues such as: what entities and people should be regulated, who are eligible for environmental subsidies and what is the ideal structure of the governing system. In other words, it has turned into an issue of cross-border multilateral environmental governance, which is a worthy topic for research.

2. Massachusetts v. Environmental Protection Agency （Supreme Court of the United States, 2007）

In June 2002, a coalition of 12 states' attorney generals led by Tom Reilly, the attorney general of Massachusetts sued Environmental Protection Agency (hereinafter referred to as EPA) asserting that the EPA has an obligation to regulate greenhouse gases. In 2003, attorney generals representing Massachusetts, Connecticut and Maine filed a lawsuit asserting the EPA has an obligation to regulate greenhouse gases. The litigation between the states and EPA had lasted for many years and was finally settled on April 2, 2007. In a 5-4 decision, the Supreme Court stated that the EPA has a mandatory duty to regulate the emissions of greenhouse gases under the Clean Air Act (CAA). However, not much happened for the balance of the Bush administration. Nevertheless, shortly after President Obama took office, EPA has upheld four actions including (1) the Endangerment Finding (74 Fed. Reg. 66,496) ;(2) the Tailpipe rule (75 Fed. Reg. 25,324); (3) the Triggering Rule (75 Fed. Reg. 17,004) and (4) the Tailoring Rule (75 Fed. Reg. 31,514). According to the Endangerment Finding, USEPA points out that thousands of scientific findings have proven that the emission of greenhouse gases caused by anthropogenic behavior has poses a significant threat to human's health and welfare of the current and future generations. Impacts will only worsen if we do not take immediate actions to address climate change. Additionally, the Endangerment Finding indicates that greenhouse gases emissions from mobile sources in the United States accounts for a significant portion of national total emissions. The finding requires the EPA to establish greenhouse gas emissions standards for light-duty vehicles (the Tailpipe Rule) as EPA aligns with the Department of Transportation. The regulation of greenhouse gases for mobile vehicles under the Clean Air Act, however, triggered further greenhouse gas permits for stationary sources such as power plants, petroleum refinery and factories (the Triggering Rule). Thus, EPA agreed to finalize permitting rules of greenhouse gas emissions for stationary sources (the Tailoring rule). The four rulings that EPA upheld have received massive attention. Significantly, more than thirty five states have directly filed lawsuits as some states advocate or oppose to at least one of the four actions. All of these lawsuits have been consolidated into three cases and were debated in February 2012 at DC Circuit Court. D.C. The court dismissed appeals form industry groups and some states to EPA's tailoring rules and found the petitioners lacked standing to challenge the regulation. Circuit Court upholds EPA's greenhouse regulations, rejecting all challenges brought by states and industry groups.

Since 1999, environmental groups have constantly petitioned the EPA, claiming that EPA had the authority under the Clean Air Act to regulate the emissions of greenhouse gases. Massachusetts and other eleven states take the same stance. In 2003, the petition was denied by the EPA. According to the General Counsel Memorandum, EPA asserted that it was not given authorization under the Clean Air Act (CAA) to regulate carbon dioxide or other greenhouse gases. Consequently, EPA does not have the power to take further actions. EPA further stated that even if the federal agency had the authority under the Clean Air Act to promulgate regulations for greenhouse gases emission, EPA would decline to do so as a matter of policy.

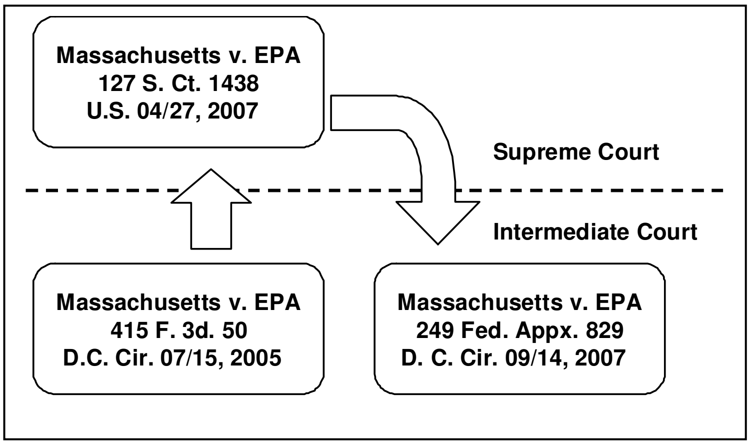
A number of environmental groups and several states decided to intervene in these appeals . Only one of the three justices admits that the Clean Air Act has clearly authorizes EPA the right to regulate greenhouse gases emission. Whereas two judges claimed that scientific research addressing the emission of greenhouse gases contributes to climate change still remain many uncertainties. Thus, the united Court of Appeals disagreed by a 2-1 vote and the court ascertained the defendant innocent.

For a prolonged battle, the US Supreme Court reversed the case in a 5-4 decision and ruled in favor of Massachusetts, finding that the EPA possess the right to regulate carbon dioxide and other greenhouse gases. The decision was agreed and led by Justice Stevens as the trial ended with four statements: (1) Massachusetts has the right to litigate ; (2) The Supreme Court is authorized to judge; whereas those who oppose believe that the case is a political issue which should not be heard; (3) If EPA affirms that the emission of greenhouse gases endangers public health and welfare, EPA has a mandatory duty to regulate greenhouse gases under the CAA202(a)(1) ; (4)The emission of greenhouse gases has proven scientifically and evidentially to be harmful to public's health and welfare.

The decision of Massachusetts v.EPA has served as an important basis for the future climate litigation. Taking the case of D.C. Circuit Court 2012, June 26, Coalition for Responsible Regulation v. EPA, 684 F.3d 102 as an example, the appellant called in question that the EPA prescribed emission standards for new motor vehicles discretionarily. However, the U.S. Court of Appeals has ruled in favor of the Supreme Court's decision. The Supreme Court believes that the EPA's emission standards for motor vehicles standards are based on scientific evidence.

For the past few years, there has been an increased involvement of lawsuits related to climate change or environmental issues. One of the many reasons leading to this phenomenon is due to the slow progress in congress on crafting climate-change legislation. This prompted the states and other environmental groups search for new ways to tackle climate change issues.

Figure 1. The Procedures of Massachusetts v. Environmental Protection Agency case



Scheme redrawn by the author

Under such circumstances, US Judiciary has absolutely become the backstage driving force molding policies of climate change in the future.

Several American scholars have offered similar views stating that one of the primary reasons that US states take part in greenhouse gases emission related lawsuits is political. Besides political factors, states or local governments also filed lawsuits with the aim to protect their own interests in environmental protection (Cecot, 2012). In other words, if a state sues the federal government it is very likely because the federal government passes a law that preempts the state and local law. Supposing someday the federal government intends to start out a new national cap-and-trade system, yet the local governments already might have established its own cap-and –trade system, local governments may probably file lawsuits against the federal government. Despite of that, the federal and local governments have been collaborating effectively on land-use planning and zoning with the aim to minimize the impact that climate change has brought (Canale, 2012).

On the other hand, the limitation of greenhouse gas emissions has restrained the public from maximizing the utilization of their own property in some way. As the number of environmental lawsuits increases gradually, a majority of claims is referred to the Takings Clause in the Fifth Amendment to the Constitution (Klass, 2011). Parties claimed that the restrictions of environmental regulations have deprived their property symbolically. However, from late twentieth century's onwards, US Court is less likely to uphold such viewpoints. In comparison, the US Court believes that environmental protection comes in the first place rather than private benefits.

3. The status of Taiwanese local governments levying "carbon tax" on polluters of air pollutants.

In the past, countries usually addressed the issue of climate change and tried to cut greenhouse gas emissions by following this model: first, central governments introduce policies and orders to meet assigned goals, and then local governments, companies and organizations cooperate. In the hope of creating a low-carbon society, issues related to low-carbon have continuously received massive attention. Correspondingly, the conflict among local governments and central government about levying carbon tax has also increased.

The Ministry of Finance refused local government levying carbon tax on companies

Hualien County Carbon Tax Self-Government Act

On 2008, based on the "polluter pays principle", the Hualien County Council passed the Hualien County Carbon Tax Self-Government Act in order to control environmental pollution caused by factories. Hualien County Council passed the three reading procedure and the proposal was then forwarded to Ministry of the Interior, Legislative Yuan and Ministry of Finance for recordation on the same year. (Hsieh, 2008) With the intervention of Legislative Yuan and the Ministry of Economic Affairs, the Ministry of Finance rejected the carbon tax proposal filed by Hualien County. It was stated the carbon tax should be regarded as a national tax, as it involves issues that should be negotiated among other counties.

Yunlin County Carbon Reduction Special Common Levy Self-Government Act

"Yunlin County Carbon Reduction Special Common Levy Self-Government Act" proposed by Yunlin County Council passed the three reading procedure on 20 February 2009. The Yunlin County Government declared that the carbon tax is one of the taxes under the Governing the Allocation of Government Revenues and Expenditures Act. Moreover, it is generally accepted that energy conservation and carbon reduction are the two main measures to construct a sustainable future. Yunlin County Government proclaimed that the central government should respect the autonomous rights of local government. The carbon tax was expected to be levied on industries that use coal, petroleum coke and fuel oil, targeting to parties that emit large amounts of greenhouse gases, in particular Formosa Petrochemicals and Naphtha Cracking Plant (Duan et al, 2009)

Nevertheless, the Ministry of Finance emphasized that the carbon tax is a national tax which the local government is not authorized to implement. This means that the carbon fee issue is a national issue, and should comply with the Constitution, not self-government laws

(B) Yunlin County Government launched Carbon Fee, but was not ratified by the Environmental Protection Administration

Yunlin County Government introduced the "Yunlin County Carbon Fee Self-Government Act" (hereinafter referred to as the YCCFSG Act) according to the special common levies described in the Local Government Act. The bill passed the third reading on March 25, 2011, and was sent by a letter to the Ministry of Finance and the EPA for ratification on May 4. According to the preamble of YCCFSG Act, "the amount of the Carbon Fee is charged based on the 'polluter pays principle and assessed on the basis of the tonnes of carbon dioxide emitted. The revenue from the fee will be used for maintaining and improving the local environment. In addition, charging the fee will help reduce carbon dioxide emissions. The bill was formulated by Yunlin County Government, which means that the bill was tailor-made for the County and complies with self-government principle of the local government body to manage finance authorized by the Local Government Act. It realizes both goals of green tax reform and the self-government of local finance. Details and comparison of proposed carbon fee and aforementioned carbon tax by these local governments are given in Table 1.

However, on August 31, 2011, the Environmental Protection Administration (hereinafter referred to as the EPA) under the Executive Yuan, an agency of the central government, sent an official letter no. 1000075360 to Yunlin County Government stating the reasons why it refused to ratify YCCFSG Act: (1) Greenhouse gases (hereinafter referred to as GHGs) such as carbon dioxide are mobile and can move across district and regional borders. Their accumulation has caused greenhouse effect, global warming and climate change for the entire planet, and they are emitted from man-made sources of around the globe, so it is a global not a local or regional environmental issue. (2) The Ministry of Finance has refused to ratify previous carbon tax bills introduced by other local governments, such as "Hualien County Carbon Tax Self-Government Act" and "Yunlin County Carbon Reduction Special Common Levy Self-Government Act". Also, the Judicial Yuan Interpretation No. 426 also states that special common levies such as environmental protection fees should be authorized by law in a specific and unequivocal manner. (3) The carbon fee should only be charged after conducting a comprehensive national evaluation, in comparison with other countries; and its design must ensure national fairness and environmental justice, realize goals of environmental protection, national economic development and increases the international competitiveness simultaneously. In other words, the carbon fee issue is a national issue, and should comply with the Constitution, not self-government laws. (4) The issue of reducing GHGs and air pollution control does not belong to matters regulated by self-government ordinances or regulation, and the local governments are not authorized by law to levy carbon tax.

Yet, Yunlin County Government believed that EPA's official letter no. 1000075360 contradicts the Constitution, especially Article 110, Paragraph 1, Subparagraph 6 of: "the county government shall be competent to legislate and execute the following matters mentioned in the left…county finance and revenues" and Article 121n: "The County shall practice county self-government." It is also contrary to Article 19, Paragraph 9, Item 2, "The self-government matters of counties/cities are as follows …Environment protection in the county/city." and Article 25 of the Local Government Act: "Special municipalities, counties/cities, and townships/cities may... formulate self-government ordinances and regulations." In other words, the EPA's response is contrary to the principle of separation of powers between the central and local government. So on December 22, 2011, authorized by the law that a local self-government body may exercise their self-governing financial and legislative powers, Yunlin County Government filed for Judicial Yuan interpretation based on Article 30, Paragraph 5 of the Local Government Act. The case is currently being reviewed by Chief Justice. (Yunlin County Government, 2011)

Table 1. The comparison of three counties that intended to levy carbon tax/carbon fee
Note: the exchange rate from Euro to New Taiwan Dollar of 1:37.5 was used in calculation.

County	Legislation title	Levied tax	Who pays for the carbon tax	Ratal	Estimated Income (million Euro €)	Proposed on
Hualien	Hualien County Carbon Tax Self-Government Act	Carbon Tax	Aimed at plants that use coal, petroleum coke and fuel oil	Targeted to industries that emit more than 10,000 tonnes of carbon dioxide per year. The carbon tax rate is €1.52 per tonne of carbon dioxide emissions.	4.8	2008
Yunlin	Yunlin County Carbon Reduction Levy Self-Government Act	Carbon Tax	Formosa Petrochemical s and Naphtha Cracking Plant.	Targeted to industries that emit carbon dioxide between 100,000~200,000 tonnes per month. The carbon tax rate is €2.63 per tonne of carbon dioxide emissions. Industries that emit more than 200,000 tonnes of carbon dioxide, the carbon tax rate is €5.27.	240	2009
Yunlin	Yunlin County Carbon Fee Self-Government Act	Carbon Fee	High polluting Industries that use coal, petroleum coke and fuel oil	Industries that emit more than 10,000 tonnes of carbon dioxide per year as the tax threshold. 1. Industries that emit less than 200 million tonnes of carbon dioxide, the carbon tax rate is €1.33 per tonne of carbon dioxide emissions. 2. Industries that emit carbon dioxide between 200 and 400 million tonnes , the carbon tax rate is €1.60 per tonne of carbon dioxide emissions 3. Industries that emit carbon dioxide between 400 and 600 million tonnes, the carbon tax rate is €5.90 per tonne of carbon dioxide emissions 4. Industries that emit between 600 and 800 million tonnes, the carbon tax rate is €9.60 per tonne of carbon dioxide emissions 5. Industries that emit between 800 and 1000 million tonnes, the carbon tax rate is €13.86 per tonne of carbon dioxide emissions 6. Industries that emit more than 1000 million tonne, the carbon tax rate is €18.67 per tonne of carbon dioxide emissions	82.7	2011

(C) The Kaohsiung City Enterprise Climate Change Adaptation Fee Act

Though there are controversies over what standards and legal grounds should the "carbon fee" be based on, Kaohsiung City Government still plans to draft "the Kaohsiung City Enterprise Climate Change Adaptation Fee" in the near future. The bill has already passed the first reading on May 7, 2012 in the meeting of legal affairs committee of the Kaohsiung City Council, and it is about to enter the second reading. The Environmental Protection Bureau of Kaohsiung City Government (hereinafter referred to as KEPB) pointed out that excessive carbon dioxide emission has led to drastic global climate changes, though it is not just produced by local or regional sources and its impact affects more than just a certain region. Enterprises should take the responsibility of mitigating climate change together with Kaohsiung City Government. To prevent further damage to the natural environment and authorized by Article 21 of the Basic Environment Act: "Government entities at all levels shall actively adopt measures to control carbon dioxide emissions and establish related plans to mitigate the greenhouse effect." and Article 18, Paragraph 9, Subparagraph 2 of the Local Government Act, "Matters related to health and environment protection [includes] Environment protection.", Kaohsiung City Government sees the issue of GHGs reduction as an obvious self-government environmental matter within the jurisdiction of a local government .In the meeting of launching the "Kaohsiung City Enterprise Climate Change Adaptation Fee", KEPB summarized opinions and comments from different related government agencies, and Mu-sheen Lee, the Director of KEPB, called for the collective efforts of the Central Government and local governments in cutting carbon emissions. The fee will be charged on all the enterprises which emit large volume of carbon dioxide, and the revenue from collecting the fee is expected to reach €24 million, as summarized in Table 2.

However, the EPA of the Executive Yuan is clearly not in favor of this bill, noting that GHGs emissions do not belong to matters regulated by self-government ordinances and regulations and that local government can levy tax on. Its response to the bill in a press release is posted on its official website (the EPA's Explanation and Response to the Sixth Public Hearing of "Kaohsiung City Enterprise Climate Change Adaptation Fee (Draft)") and the summary is as follows: "Greenhouse gases such as carbon dioxide are mobile and create greenhouse effect across district and national borders. They generate a global impact, leading to global warming and climate change, eventually endangering the existence of human beings. Greenhouse gases emitted from human sources do not cause direct threats to the human health, property or nature in the vicinity of the emission source. Therefore, the control of global greenhouse gas emitters is not a local but a cross-border pollution issue instead. It affects domestic industries, households, enterprises and government agencies which are responsible for maintaining our national competitiveness, such as transportation and agriculture. Since the tax should be levied according to proportional tax principle and take the national interest into consideration, the bills for such tax should be formulated d by the Central Government. On May 9, 2012, according to Air Pollution Control Act (hereinafter referred to as the APC Act), the EPA officially declared carbon dioxide, methane, nitrous oxide, hydro fluorocarbons (HFCs), sulfur hexafluoride (SF6) and carbon tetra fluoride as air pollutants (EPA declaration no.1010038277). As mentioned earlier, GHGs emission becomes regulated by the APC Act. The regulations and implementation details about how the fee will be calculated and charged should be formulated by the central government agency, with authorization from the APC Act. In other words, local governments are not authorized to levy carbon fee based on self-government ordinances or regulations, or it will be contradictory with the APC Act." By classifying six GHGs including carbon dioxide as air pollutants, the EPA regards the matter under the jurisdiction of the Central Government and local governments are not authorized by self-government ordinances or regulations. Also, in response to questions asked after the presentation in the Legislative Yuan, the incumbent minister of the EPA also admitted that "carbon tax" is scheduled for launch in the coming three to five years. If the tax is levied by a single local government, it will not comply with the goal of justice and fairness. (Wei, 2012).

Even though the Act has not passed third reading, the local governments and related agencies still believe that they have the right to regulate the greenhouse gas emissions and it is a local self-government matter. On the other hand, the Central Government does not believe that now is the right time to conduct green tax reform, so the central and local governments are not in consistent in view on when and how to tackle the issue. As mentioned earlier in the outline and previous parts of the research, the conflicting stances between central and local governments on carbon reduction result from different views on the legitimate legal basis for the carbon tax.

Table 2. The background information of the Kaohsiung City Enterprise Climate Change Adaption Fee

County	Legislation title	Levied tax	Who pays for the carbon tax	Ratal	Estimated Income (million Euro €)	Proposed on
Kao-hsiung	The Kaohsiung City Enterprise Climate Change Adaption Fee	Carbon Fee	Plants or Industries located in Kaohsiung	Industries that emit less than 10,000 tonnes of carbon dioxide, the carbon tax rate is €0.40 per tonne of carbon dioxide.	24	Has not passed the three reading procedure

Note: the exchange rate from Euro to New Taiwan Dollar of 1:37.5 was used in calculation.

This divergence not only shows the lack of legal analysis on all aspects of this issue, but also that the Central Government may have ignored the problems of uneven distribution of tax revenue and the fiscal shortages of local governments, which cannot be improved immediately.

Conclusion

On May 9 2012, Taiwan's Environmental Protection Administration has classified the six greenhouse gases including carbon dioxide as air pollutants and regulated by the Air Pollution Control Act. According to the executive order, enterprises are obliged to report their emission of the six air pollutants. Chinese National Federation of Industries and the Ministry of Economic Affairs are convinced that levying the tax will hamper Taiwan's competitiveness, so they are all against the bill. This research work suggests that, after announcing this regulation, the EPA should refer to similar laws and regulations of the United States and devise comprehensive measures, such as the standards for CO2 emission and levying the fee.

Furthermore, what role local governments should play in tackling climate change? Though the EPA has stated that, since greenhouse gases are regulated under the Air Pollution Control Act, local governments are forbidden to levy tax on the same matter. Kaohsiung City Government and Yunlin County Government have expressed their wish to levy "carbon tax" on emitters of air pollution within their jurisdiction. Consequently, Kaohsiung City Government plans to levy the Kaohsiung City Enterprise Climate Change Adaptation Fee according to Local Government Act instead. Whether the bill is constitutional has become a problem once again. Kaohsiung City Government pointed out that the city emits high volume of greenhouse gases, which have become the major cause for environmental degradation, so it drafted "The Kaohsiung City Enterprise Climate Change Adaption Fee" and the bill has passed first reading in the Kaohsiung City Council. It is estimated that 108 enterprises will be immediately affected by the imposition of the fee, while it will generate annual revenue worth 900 million NT Dollars for Kaohsiung City Government. Yunlin County Government has found that Formosa Plastics Corp's (FPC) sixth naphtha cracker complex emits huge amount of carbon dioxide. Not only did the local company request the company to reduce carbon emission by subsidizing local farmers in planting trees, it also introduced Yunlin County Carbon Fee Act, estimated to generate € 920 million worth of annual revenue approximately. The local governments believe that charging the carbon fee complies with the principle of "polluter pays", as they emphasize that the EPA has confused carbon fee and carbon tax. The local governments suggest the EPA reconsider and ratify the bill.

Because both Kaohsiung City Government and Yunlin County Government have drafted bills to charge fees on greenhouse gas emissions, there are several concerns arisen. Does charging the fee by local governments imply that the local government bodies will be able to use the specific revenue on specific purposes, or will the collected fee become a part of the "general budget"? Will climate change and low-carbon city become new excuses for local governments to levy new carbon taxes? Meanwhile, the EPA invited government agencies to discuss the issue and decided that giving the emission permit and charging fee is within jurisdiction of the Central Government, not local governments, so the latter may not charge the fee. According to the Judicial Yuan Interpretation No. 550 explained that: "While local self-governing bodies are protected by the constitutional system, and the availability of funds required for their administration is a matter within the scope of their self-governing financial power subject to the principle of legal reservation, the Constitution does not forbid the central government from requiring under law that local governments, which have the duty to act in concert in matters relating to the national health insurance program, share the subsidy for the premium insofar as such requirement is necessary for the overall administration of the country and to the extent that the core realm of their self-governing power is not encroached upon. The Constitution is silent in respect of the sharing of financial responsibility for matters undertaken by the central and local governments." There are already research exploring the possibilities of integrating Local Emissions Trading Scheme (LETS) and the readily established system of a state. The local emission trade scheme can be designed with a focus on the local transportation and the carbon reduction by planning the use of land. However, new policies and legislations are required to successfully integrate local and central government institutions.

In conclusion, the research found that many lawsuits related to climate changes have appeared in recent years. The judicial agencies have become another catalyst for launching climate change policies other than the Congress and USEPA. The legislation related to climate change proceeds relatively slow in Taiwan and should be accelerated. The researcher suggests the related agencies and bodies refer to the United States' experience and think about how our judicial agencies can play a more active role in responding to the issue of climate change.

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On the Optimization of Policy and Legal Environment Promoting the Development and Utilization of Biomass Energy: China's Present Situation and Path Choice

Ms. WU CHUNYAN
Director of Teaching and Researching Office of Science and Technology Law,
Lecturer of Law in Law School, Huazhong University of Science and Technology
Tel: +86-13100715097
Fax: +86-27-87547046
e-mail: yanhust@163.com

Address
Law School, Huazhong University of Science and Technology, 430074
Wuhan ,China

Abstract: The biomass energy has attracted much attention due to its features of strong renewability and less pollution. The strategic position of biomass energy is gradually promoted. The Outline of the 12th Five-Year Plan for National Economic and Social Development issued by China in 2011 emphasizes "promoting diversified and clean growth of energy" on the aspect of "promoting the reform on the way we produce and utilize energy", and further stresses the need of actively developing solar energy, biomass energy, geothermal energy and other new energy. This Paper will explore the main factors in China nowadays affecting the development and utilization of biomass energy, analyze the status of developing biomass energy in China and the major problem in existence as well as the path choice in promoting the growth and full utilization of biomass energy and the incentive measure available, and make an attempt to give recommendations on perfecting biomass energy in consideration of energy pressure and food safety.

Keywords: biomass energy   policy demand   path choice

1 The Present Situation and Influencing Factors of the Development and Utilization of Biomass Energy in China

1.1 Present Situation of the Development and Utilization of Biomass Energy in China

The biomass energy, characterized with cleanness, renewability and compatibility in use pattern, is of great significance in solving global environmental and energy issues. The major raw materials available for biomass energy in China are comprised of energy crops, straws, stalks, forestry and wood processing residua, industrial organic waste, urban organic household garbage, etc.

For the recent years, the biomass energy has been developing with diversification gradually in China , which has been manifested in that: ①the biomass power generation technologies are becoming mature generally. Industrialization of biomass direct-fired power generation and gasified power generation has been realized preliminarily. ②with the constant perfection of biogas technology, the biogas is more widely used in rural area. ③the technology of making liquid fuel with biomass has made a breakthrough. The fuel ethanol technology using cassava and other non-food crops as raw material has been initially applied and a demonstration plant producing 200,000-ton fuel ethanol annually has been established; biodiesel technology has accessed to a demonstration stage of industrialization.

Even though greater progress has been made in developing and utilizing biomass energy in some regions, entire industrialization of biomass energy production has not been realized substantially, China's superiority in biomass energy such as wider varieties, broader distribution and greater potential has not brought into full play and utilization potential of biomass resource has not been sufficiently excavated.(see Chart 1).However, there is a long distance between the 2010's total utilization of various biomass energies in China and 2010's potential of biomass energy in total according to the estimate of China Energy Medium and Long-Term Development Strategy Research Mission. (see chart 2). It is thus clear that China's biomass energy industry has a large space for improving.

Table 1: Actual Utilization of Biomass Energy in China (data source:Eleventh Five-Year Plan of Renewable Energy Development .)

	Item	Year 2000	Year 2005	Year 2010
1	Biomass power generated (10,000 kW)	170	200	550
2	Biogas (100 million m3)	35	80	140
	Including number of rural household using biogas (10,000)	850	1800	4000
3	Fuel ethanol (10,000-ton)		102	180
4	Biodiesel (10,000-ton)		5	50
5	Total utilization (10,000-ton standard coal per annual)	12000	16600	28600

Table 2: Estimate of China's Potential in Biomass Energy (data source:China Energy Medium and Long-Term Development Strategy Research Mission,2011.)

(Unit: 10,000-ton standard coal)

	Item	Year 2010	Year 2020	Year 2030	Year 2050
1	Existing potential of biomass resource available	29000	29000	29000	29000
2	New potential of biomass resource available	7000	23000	39000	61000
	A wide variety of organic wastes newly increased	6000	17000	22000	2700
	Yield increase of existing low-yield woodland	500	3000	7000	13700
	Yield of marginal land newly developed	500	3000	10000	20000
3	Total potential of biomass energy	36000	52000	68000	89000

1.2 The Influencing Factors of the Development and Utilization of China's Biomass Energy

The efficient development and utilization of biomass energy are influenced by a large number of factors such as quantity and price of raw material supplied, technology R&D level and extent, product's market price and market demand and policies.

1.2.1 The Influence of Biomass Energy's Inherent Feature on the Development and Utilization of Biomass Energy

Although China's biomass resources have a wide range of sources, their energy density is very low while their regionality and seasonality are very strong. In some Chinese regions mechanization of agricultural production has not realized yet, this has led to certain difficulty in collection, transportation and storage of biomass energy, thus causing short supply or cost up of raw material of biomass energy, e.g. farmers usually burn the straws at the field which could not be easily gathered. With no scientific and reasonable storage and transport system, it is very hard to guarantee sustainable supply and reasonable price of raw material. The prevailing scale of China's utilizing biomass energy is relatively small and is also limited by sustainable supply and price of raw material.

Secondly, it is hard to pre-process such biomass resource as straws or stalks due to their fibber structure, in addition, gasification or liquefaction of biomass resource is a complicated process. This has influenced the development and utilization of biomass energy to a certain extent. Taking gasification of straws for concentrated supply of gas as an example, straws to be used as raw materials for a gasification station must go through multiple processes of cutting, compacting and so on, furthermore, sugar content and fuel value of straws are very low, so straw gasification stations in some regions are unwilling to use straw as raw material of production(Jiao Zhe, 2012).

1.2.2 Shortage of Independent Innovation

The efficient utilization of raw material and product of biomass energy is dependent upon developmental level of gasification and liquefaction technologies of biomass energy. The early R&D in the field of biomass energy in China is concentrating upon the utilization technologies of biogas, so further breakthrough is still needed in biodiesel, direct firing of biomass and gasification technologies. With no proprietary intellectual property, we need to import foreign equipment and patent technologies; therefore, price of biomass energy product is sure to be multiplied and competitive power of biomass energy product in comparison with traditional energy product will be further weakened. With regard to the status of technology development in the field of biomass in China (see Chart 3), a large number of technologies are still on R&D stage. This has also required us to encourage businesses and scientific research institutions to improve their independent innovation capability, obtain more proprietary intellectual properties and minimize our dependence upon foreign technologies.

Table 3: Technology Development in the Field of Biomass (data source:Guidance Category for the Development of Renewable Energy Industry issued by China National Commission of Development and Reform.)

Item	Description and Technical Indexes	Developmental Status
Biomass direct-fired boiler	Used for supporting biomass direct-firing power-generating system, their technical characteristic and specification shall be applicable for biomass direct-fired boiler.	Technical Improvement
Biomass gas engine	Used for supporting biomass gasification power generation, their technical characteristic and specifications shall be applicable for biomass gasification power generation system.	R&D
Biomass gasification oil tar catalytic cracker	Used for cracking the oil tar produced in the process of biomass gasification to disposable gas available.	R&D
Complete equipment for producing biomass liquid fuel	Used for producing a wide variety of biomass liquid fuel.	R&D and project demonstration
Growing of energy plant	Used for providing non-food biomass raw material for production of various bio-fuels, including sugar sorghum, cassava, Jatropha Curcas, sugarcane, etc.	Project demonstration, application and dissemination
Breeding of energy plant	Used for breeding and fostering energy crops of high and stable yields suitable for being planted in desolated sands, deserts or saline-alkali soils and harmless to ecological environment.	R&D and project demonstration
High-efficient, wide temperature range biogas strain breeding	Used for improving the yield of biogas project and at the cryogenic temperature of biogas digester.	R&D

1.2.3 Unperfected Motivation System

The industrialized growth of biomass energy needs sustainable financial support and market drive. Since China's biomass energy industry is still on the initial stage of development, a wider range of guiding and motivating policies are required to attract more capital investment. The recent years have witnessed China's increasing financial support and tax preference to biomass energy gradually and policies of financial subsidies and tax incentive supporting the development of biomass liquid gas have been formulated, e.g. in 2006 the Opinions on Implementation of Financial and Tax Support Policies for Developing Bio-energy and Biochemical Industries enacted by five Chinese governmental authorities led by the Ministry of Finance has proposed to implementing a number of supporting policies such as elastic loss subsidy, raw material base subsidy, demonstration subsidy and tax preference. However, generally speaking, (1) financial and tax incentive in the field of biomass energy remain insufficient. On the preliminary stage, the growth of biomass energy industry is highly dependent upon governmental investment and policy support. The present policy supply in the field of biomass energy is still unable to meet the policy need of developing this industry.(2)The incentive on the social capital investment is insufficient. Although China has introduced several policies encouraging the growth of biomass energy, it is hard to attract social capital since biomass energy product is short of superiority in the rate of return.

1.2.4 The market guarantee mechanism is still unperfected

The development of biomass energy is still on the stage of "determine the sales volume according to output,planned supply"(Li zhijun,2008),which has a long distance from marketing operation.(Wang Yapeng, et.al, 2010). Moreover,due to absence of standard, product inspection and certification and quality system in connection with biomass energy technology and product, their marketization progress has been affected inordinately.

2 The Policy and Legal Environment Promoting the Development and Utilization of Biomass Energy in China

China has been attaching importance to developing and utilizing biomass energy all the time, introduced a series of policies and legislations, established a strategic objective for developing biomass energy and preliminarily developed investment incentive, pricing and compensation mechanisms. Generally speaking, the legal regime and policy system required for developing biomass energy industry has been initially established and perfected; however, their operability is still to be further enhanced.

2.1 Normative Documentations of Laws and Regulations: centering around Renewable Energy Law of the People's Republic of China and Law of the People's Republic of China on Conserving Energy

Renewable Energy Law is regulating the development and utilization of renewable energy from such aspect as "resource investigation and development plan", "industrial guidance and technical support", "dissemination and application", "price administration and expense compensation" or "economic incentive and supervision". As for biomass energy, China is encouraging cleanly high-efficiently developing and utilizing biomass fuel as well as developing energy crops. Encouraging and supporting application and dissemination of biomass resource (e.g.biogas) transformation technology based on local circumstance, which are guaranteed by such system of fully procuring electric power generated using renewable energy and Renewable Energy Development Fund. Law of the People's Republic of China on Conserving Energy has also clearly stated that "the State shall encourage and support developing and utilizing new energy and renewable energy". In addition, National Energy Administration, the Ministry of Finance and other authorities collectively or individually issued their ministerial regulations such as Interim Procedures for Managing Additional Subsidy Fund for Electrovalence of Power Generated with Renewable Energy, Interim Procedures for Managing Special Fund for Developing Renewable Energy, Interim Procedures for Managing Technologies of Green Energy Source Pilot Counties Construction, Interim Procedures for Managing Subsidy Fund for Green Energy Source Pilot Counties Construction and Administrative Measures on Major Demonstration Projects of National Energy Technologies, which have provided a legal system guarantee for developing biomass energy industry.

2.2 Industrial Planning and Finance and Tax Support Policies

2.2.1 Industrial Planning

China has not formulated a special biomass energy industry developmental plan so far and some guiding policies on developing biomass energy industry are specified in Eleventh Five-Year Plan for Renewable Energy(2008), National Twelfth Five-Year (2011-2015) Plan for Energy Science and Technology (December 2011),National Twelfth Five-Year Plan for Developing Strategic Emerging Industries(July 2012), Energy-Conservation and New Energy Automobile Industry Development Plan (2012—2020)(June 2012),etc. For instance,with regard to the biomass energy industry,China's National Twelfth Five-Year Plan for Developing Strategic Emerging Industries has clearly stated to "plan the growth of biomass energy as a while, develop biomass direct-fired power generation orderly, advance biomass gasification and power generation, biomass-formed fuel, biogas and other distributed biomass energy application actively; enhance developing new generation of bio-fuel technology, carry forward the industrialization of producing ethanol with cellulose and biodiesel with microalgae; perform detailed survey and evaluation on biomass resource in focus area, encourage utilizing marginal land and offshore for planting energy crops and energy plant". On the planning of biomass energy,China's Energy-Conservation and New Energy Automobile Industry Development Plan has clearly stated to "develop Alternative Fuel Vehicle based on actual circumstance; launch the R&D and application of automotive alternative fuel manufacturing technologies, encourage developing AFV in the regions with rich natural gas (including LNG) and bio-fuel; explore other technical application path for AFV and promote diversification of energy used for vehicles".

2.2.2 Investment, Finance and Tax Policies

The national financial input is always a main channel in the field of biomass energy. However, with the gradual advance of biomass energy technology toward industrialization, we should encourage multichannel capital input, expand capital source in the field of biomass energy infrastructure construction, energy technology R&D and production of energy product, and provide financial guarantee for scaled growth of biomass energy. In June 2012, China National Energy Administration has enacted Opinions on Encouraging and Guiding Nongovernmental Capital to Further Expand the Investment in Energy Field, which has widened the investment range of nongovernmental capital and created an impartial and normative market environment by perfecting resources allocation mechanism, improving administration service efficiency, increasing financing support, perfecting price support policies, optimizing business financing environment to protect the interest of nongovernmental investors and ensure the increase and sustainable input of nongovernmental capital. his policy orientation is undoubtedly to have a positive effect upon multichannel capital input to the field of biomass energy.

With regard to financial and tax support policies, China has established her own principle of "insisting on not contending land with food crops, promoting win-win situation of energy and food, persisting in integration of industrial growth and financial support, encouraging businesses to improve efficiency, developing bio-energy and biochemical industries actively and reliably, and piloting the industry to grow healthily and orderly, thus supporting this industry through elastic loss subsidy and tax incentive.

Table 4: The polices related to biomass energy in China (data source:The polices related to biomass energy enacted by China National Energy Administration and other authorities since the amendment of Renewable Energy Law of the People's Republic of China in December 2009

Policies and Legislations	The Authorities and Time of Issuance
Twelfth Five-Year Plan for Developing Renewable Energy	National Energy Administration (8-6-2012)
Opinions on Encouraging and Guiding Nongovernmental Capital to Further Expand the Investment in Energy Field	National Energy Administration (6-18-2012)
Shrub Energy Forest Fostering and Utilizing Guide and Chinese Soapberry Fruit Sustainable Fostering Guide	State Forestry Administration （5-14-2012)
Administrative Measures on Major Demonstration Project of National Energy Science and Technology	National Energy Administration (4-19-2012)
Notification on Further Strengthening the Work Energy Technology and Equipment Quality Management	National Energy Administration (4-14-2012)
Interim Procedures for Managing Additional Subsidy Fund for Electrovalence of Power Generated with Renewable Energy	The Ministry of Finance, National Commission of Development and Reform, and National Energy Administration (3-14-2012)
National Twelfth Five-Year (2011-2015) Plan for Energy Science and Technology	National Energy Administration (12-5-2011)
Interim Procedure on Collecting, Using and Managing Renewable Energy Development Fund	The Ministry of Finance, National Commission of Development and Reform, and National Energy Administration (11-29-2011)
Interim Procedures for Managing Technologies of Green Energy Source Pilot Counties Construction	The Ministry of Finance, National Energy Administration and the Ministry of Agriculture (11-21-2011)
Check and Acceptance Measure on Forest Bio-Energy Material Base	State Forestry Administration (5-4-2011)
Interim Procedures for Managing Subsidy Fund for Green Energy Source Pilot Counties Construction	The Ministry of Finance, National Energy Administration and the Ministry of Agriculture (4-6-2011)
Renewable Energy Law of the People's Republic of China (Amendment)	Standing Committee of the National People's Congress (12-26-2009)

3 The Path to Optimizing the Policy and Legal Environment Promoting China's Biomass Energy Development and Utilization

3.1. Establish the Developmental Mode of Driving by Technological Innovation

Although from the perspective of resources, technology and industry, China's biomass energy has great potential of growth on a large scale, to maintain sustainability and minimize negative effect upon energy-intensive sectors and GDP, we still need to upgrade the independent innovation capability of biomass energy businesses from technological innovation, with key technology as a core through university-industry collaboration, reduce production cost of biomass energy product through technological innovation and product innovation, and provide the biomass energy industry with explicit profit model and independent sustainable profitability driven by innovative technology. Therefore, the strategic position of the developing pattern driven by technological innovation shall be established gradually from industrial growth planning till specific implementation and from legal norm to policy-making.

3.2. Take the Policy Demand of Biomass Energy Industrial Chain into Full Account

The biomass energy cannot be industrialized really without sufficient supply of raw materials, support of well-established technology, product standard, quality supervision and unimpeded distribution channel.

3.2.1 The challenge in scale and price of raw material supply is answerable based on food security impact evaluation

Such factors as insufficiency of quantity, high cost of storage and transport, and low availability are all handicaps of biomass energy industrialization. For this connection, when arranging biomass energy project, we should fully consider sustainable supply of raw material in the region where the project is located and possibility or feasibility of establishing a supply, storage and transport and service system covering both urban and rural areas, and improve utilization efficiency of biomass resources based on local circumstances. Secondly, we should reasonably develop such marginal land as saline-alkali land based on China's land characteristic, reasonably breed and plant energy crops, increase non-food biomass resource supply, and encourage improving their availability through technological innovation with regard to existed biomass resources. Meanwhile attention should be focused on developing other raw material source.

3.2.2 Give full play to incentive of intellectual property system and maintain technical supply of biomass energy industrialization

On one hand, we should upgrade the maturity and innovation of biomass energy technology and reduce the risk of industrialization by formulating technical standards and technical specifications; on the other hand, we can promote the biomass energy technology to get the protection through intellectual property law and enhance the international competitiveness.

3.2.3 Expedite standardization of biomass energy and promote market access of biomass energy

The biomass energy cannot be industrialized without a perfect standard system. Now main converted forms of biomass energy shall include solid biomass fuel, fuel ethanol, biodiesel, biogas and power generated with biomass, etc. With regard to the standardization of biomass energy, China has issued National Standard on Denatured Fuel Ethanol (GB 18350-2001), National Standard on Ethanol Gasoline for Motor Vehicle (GB 18351-2001), Mandatory National Standard on New Ethanol Gasoline for Motor Vehicle (GB8351-2004) and Standard on Biodiesel for Blending of Diesel Fuel (GB/T20828-2007). Due to abundance of raw material sources for biomass energy and diversification of converted forms, developing biomass energy standards for various raw material sources is also a boosting agent of marketization of biomass energy product.

3.2.4 Establish and perfect biomass energy product procuring, allocating and distributing system

Although all works ranging from production to distribution of biomass energy products are done with the convoy of governmental policies, their price and supply remain unable to be independent of market connection. On initial stage of industrial growth, we should make reasonable policies governing biomass energy consumption and support industrial growth through "such system of fully procuring electric power generated using renewable energy" for example. However, when industrialization is stabilized gradually, we should change closed operation under the auspices of policies, foster a market environment for sustainable industrial growth and change the production and distribution of biomass energy product from supply orientation as priority to market demand.

3.3. Build and Perfect Multichannel Input Mechanism and Multilevel Financial and Tax Support Mechanism

Being conditioned by many factors,such as production cost,technological sophistication,pricing mechanism and so on, the development and utilization of biomass energy in China need the preference and support of policy.

3.3.1 Enhance the guidance of capital investment

To tackle the problem of capital bottleneck,the state should build a multichannel input mechanism by investment policy,which can guide the special fund for industrial growth,governmental financial input, social capital and business capital into biomass energy industry. And the state should incorporate the support of biomass energy growth into governmental financial budget definitely and further increase financial support such as governmental procurement, special fund and venture capital guiding fund to biomass energy.

3.3.2 Favorable taxation policy

The favorable taxation policy carried weight in the industrialization of biomass energy. In terms of tax incentive, the state can make supportive favorable policies covering various sections of biomass energy industrial chain in combination with practical situation of biomass energy industry and by comprehensively utilizing various tax incentives in VAT, income tax and customs duties, to meet the need of developing biomass energy industry.

3.3.3 Enlarge financial support

In terms of financial support, the state can guide financial institutions to establish a financing control system suitable for the characteristic of biomass energy industry and exert multilevel capital market's financing function.Meanwhile,the importance should be attached to the bond market,VC investment and equity investment fund.

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Renewable Energy Sources – Energy Efficiency

Electrification of North Aegean's islands using Floating Wind Turbines

Prof. Nikitas NIKITAKOS
Professor of Dept. of Shipping Trade and Transport (Corresponding Author)

Ms. Afrokomi-Afroula STEFANAKOU
Msc in Shipping, Transport and International Trade

Tel. + 30-22710-35201
Fax. + 30-22710-35299
e-mail: nnik@aegean.gr

Address
University of Aegean, Department of Shipping Trade and Transport
Korai 2a Chios, Greece

Abstract: he environmental problems that developed around the production of energy from fossil fuels have forced the whole planet to take thoroughly in consideration the renewable energy sources. The wind energy this time ranks in the first row of exploitation due to economic attractiveness and technological maturity. However, the lack of space, the environmental problems stem from their operation and the alteration of the landscape will be a significant barrier. So, the floating wind turbines can be an important solution. Floating structures have already been successfully used by the marine and offshore oil industries combining a wide range of benefits such as flexibility in choosing site, access to deeper water, cheaper installation systems, etc. This specific research examines the possibility of installation of wind turbines in the North Aegean. So, taking into account all the parameters like wind potential of the areas, waves, seabed, navigation, existing electricity networks, existence of natura areas etc., we came into the conclusion that it would be possible to install floating structures in the northwest part of Ag. Eustratios, in the northern part of Limnos, and in the southwest part of Chios. Furthermore, in this paper, the design of floating wind turbine and the connection of wind turbines with the mainland grid are described. Finally, inside the feasibility analysis we concluded that such an investment would be considered quite successful for all three locations with the dominant area being Limnos. Also, the results from feasibility analysis depict details for further research and discussion for future designs.

Keywords: Floating wind turbines, New offshore solutions, Project in the north Aegean.

1. Introduction

Rapid developments in the environmental field in both Europe and the world have now necessitated the use of Renewable Energy to save energy and seek a better standard of living.
There are many types of renewable energy that can be used in order to replace the use of coal and oil. Wind power, along with the solar power, is perhaps the most widely exploited source of energy right now as it is the most technologically mature, economically competitive and environmentally friendly energy option. Furthermore, let us not forget that we live in a country that is endowed by nature with strong winds, has the experience of the viability of wind energy and presents a political and investment will to shift to the production of energy from the wind. However, the lack of space, particularly in Europe, may be a significant barrier to its penetration and establishment. Furthermore, the environmental impacts arising from the operation of wind turbines and the resulted alteration of the landscape cause the opposition of public opinion, which reacts to their installation.
So, floating wind turbines can be an important solution. Floating wind farms are the future and may allow exploitation of the vast wind resources that exist in open sea, as the available wind energy at sea is much greater than on the land and the wind speed increases by 20%.[Sklavounos et all., 2007].
Floating wind farms come to offer an important solution as they combine many advantages such as flexibility in choosing site, access to deeper water, reduction of distortion of the landscape since they are not so much detected by shore compared to offshore wind turbines, cheaper installation systems than those of fixed wind turbines that are used in smaller depths, presence of smaller turbulence - hence longer life of the project, lower rate of breakdown compared to onshore [Nnadili,2009], of course, zero emissions of pollutants and waste.

Also are a very good and feasible solution for development in water deeper more than 60 meters to 100 meters -as they are more efficient at these depths according to National Renewable Energy Laboratory as they can anchor anywhere so that they can exploit the most powerful winds in the open sea, don't alter the landscape in terms of aesthetics and, of course, can be transferred very easy to another possible location after meeting the needs of a region.[Gulf Of Maine, Department of Energy, 2011] Finally they are characterized by the great ease of their installation, as they are pro-assembled in specific places near to the port and then they are towed to their final location as a complete unit. [Knudsen et all., 2011]

In summary, we find that the installation of floating wind farms in recommended regions of Greece is a more economical and efficient option compared to the traditional choice of fixed wind turbines with a comparatively lower cost and, of course, a huge environmental benefit.

Greece, as follows from results of measurements on the wind potential, has some of the best locations worldwide for the exploitation of wind energy.
Especially in the Aegean, a common feature of most islands is the high wind potential, which is one of the richest in all Europe and may be compared only with the wind potential of the coast of England. Thus, the Aegean is presented as a particularly attractive sea because the wind is strong and the waves aren't so high, so that the floats which will be used can be lighter and therefore cheaper.
The choice of location and installation of a floating unit is a matter which must be seriously examined, as some standards have to be met. So, the requirements which must be met are the following:

- high wind potential, perhaps one of the most important requirements
- low intensity of water
- existence of sandy sea bed
- lack of navigation and in general maritime trade routes
- project acceptance by local committee
- ease of access
- existence of networks supplying electricity
- non-existence of protected natural areas and
- reduction of visual impact

2. Presentation of three recommended areas

Taking into account the constraints mentioned, the most suitable areas were sought which could meet the above factors for the implementation and installation of a floating wind turbine in three recommended regions of Greece.
The first recommended and suitable site for installing a floating unit is an area close to Ag. Eustratios island, with latitude 39^0 32' 59.11'' N, longitude 24^0 56' 38 .72'' E, depth of 60 meters and at a distance of 3.2 kilometres from the coast.

Figure 1: Case Study N_O 1 (The yellow, chosen site)

The chosen location is characterized by average air temperature 17.2C^0, average wind speed 6.3 m / sec and average atmospheric pressure 102.1 kPa [NASA Surface Meteorology and Solar Energy, 2011, a].As can be seen from the data collected by the program «NASA Surface Meteorology and Solar Energy», the average speed of the wind potential in the area is 6.3 m / sec, which is considered to be a pretty good wind speed for the placement of a wind turbine.
Regarding the annual average wave height, it is around 0.7metres [Hellenic Centre for Marine Research, 2007, a] which is quite good because the wave is not considered high, so that the floats which will be used can be lighter and therefore cheaper.
As second case studies, was selected a site in north part of Limnos, opposite to Cape Plaka, in which the first offshore wind park is going to be installed. The area is located in the northern part of Limnos with latitude 40^0 05' 00, 28'' N, longitude 25^O 25' 13, 97'' E, depth of 60 meters and at a distance of 6.0 km from the coast.

Figure 2: Case Study N_O 2

The chosen location is characterized by average air temperature 16.9 C^0, average wind speed 6.6 m/sec and average atmospheric pressure 102.1 kPa. [NASA Surface Meteorology and Solar Energy, 2011, b]. Considering the above features of the site, we find that this area is characterized by a very high average wind potential which reaches 6.6 m / sec, while, as far as the average significant wave height is concerned, it reaches around 0.5 metres. [Hellenic Centre for Marine Research, 2007, b]
Finally, the last case studies was selected a site in southwest part of Chios with latitude 38^0 12'46.83'' N, longitude 25^0 51'13.16'' E, a depth of 88 meters and a distance of 3.37km from the coast.

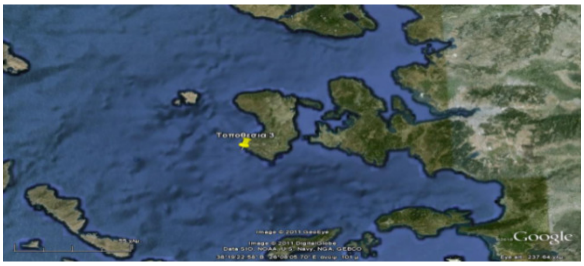


Figure 3: Case Study N_O 3

The chosen site is characterized by average air temperature 17.6 C^0, average wind speed 6.1 m/sec and average atmospheric pressure 102.1 kPa. [NASA Surface Meteorology and Solar Energy, 2011, c].
The data indicate that Chios too has a pretty good average wind potential of around 6.1 m / sec., comparatively a little lower than the previous sites but still a good average of wind speed, while the average significant wave height reaches to 0.8 meters. [Hellenic Centre for Marine Research, 2007, c].

3. Design Requirements

3.1. Wind Turbine

Table VIII: Data from the V82 Power Curve

Wind Speed (m/sec)	Power (Kw)
0	0,0
1	0,0
2	0,0
3	22,0
4	66,0
5	147,0
6	273,0
7	417,0
8	575,0
9	714,0
10	816,0
11	866,0
12	890,0
13	898,0
14	900,0
15	900,0
16	900,0
17	900,0
18	900,0
19	900,0
20	900,0
21	-
22	-
23	-
24	-
25	-

Choosing the right wind turbine is a difficult task as it must meet all the required features and conditions we seek and be able to exploit as much as possible the wind potential of an area so that we can have the desired output power.

In this particular case was chosen as the most appropriate wind turbine according to the RETScreen program a model of a Vestas, V82, with power of 900 Kw, pillar height of 59 meters, number of turbines 1, a rotor diameter per turbine of 82 meters and scanning area of 5,281.02m2 per turbine.

The table above figures the data resulting from its power curve

3.2 Floating wind turbine platform

The development of these floating structures, to meet some standards, passed over time through the following stages: 1. Study of researches regarding the optimal design of floating wind turbines and state of the art. [Bulder, et all., 20003], [Sclavounos,2006]
2. appropriate design so as to meet the conditions and standards, 3. optimization of the design characteristics to achieve maximum efficiency and cost reduction and 4. Studies and research on desired stability and load analysis.

Naturally, the objective is to minimize movements and loading from waves, improving the operating conditions of each wind turbine and increasing the resistance to extreme weather conditions.

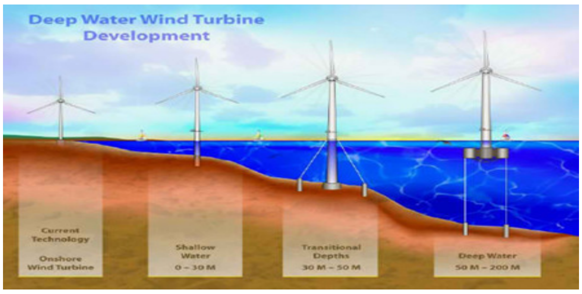


Figure 4: Design Evolution

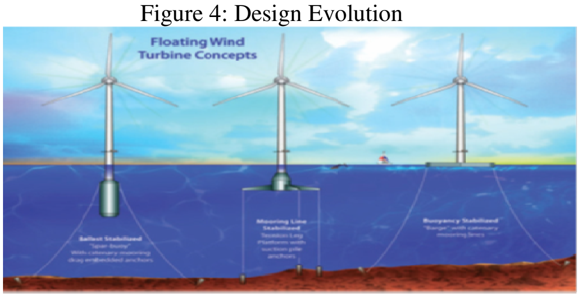


Figure 5: Typical Floating Platform

Taking into account the above requirements, the platform chosen to host the wind turbine is a semi-submerged construction used in the manufacture of Idriada as well. It consists of four peripheral cylindrical and one central shaft connected by a metal mesh-grid of such geometry as to minimize the impact of waves. This floating structure has an automatic control via GPRS for monitoring and remote control so that the presence of someone isn't needed for its functioning.

Figure 6: Peripheral Buoys on the Central Axis

This floating structure is ideal for placement in selected areas of study, with the exception that for the placement of V82 the floating platform will be twice dimensions from Idriada so that it can meet the growing needs in terms of weight in comparison with the wind turbine hosted in Idriada, which presents different characteristics such as smaller size and weight.
So it is appropriate to design a more robust construction to successfully address the problems of coupling the floating part with the wind turbine.
Finally, the platform is constructed / designed in such a way that the entire system can operate even in adverse weather conditions.

4. Connecting a Wind Turbine with the Network

If the wind farm is located by the coast, as in this project, the wind turbine can be connected to the mainland grid by means of high voltage transmission lines (in our case we have power transfer in medium voltage,) of three-phase alternating current through a submarine . Contrary to this, it would be better for us to use the HVDC when the wind farm is located at greater distances (over 50 Khm). [Hau, 2006] The transmission of alternating current over long distances presents many problems. The wires act as a large capacitor, which means that in terms of electricity they present capacitive characteristics. Above a certain distance, the reactive power is so huge that active power can no longer be transferred.
These adverse effects significantly affect the financial investment in the transmission of a three-phase alternating current over long distances.
In the present study, to reduce the power output losses of a wind turbine, we place at its base a transformer that will elevate the voltage of the wind turbine from 400 V up to 6.000 V. The voltage is reduced by a small amount proportional to the distance, its final amount being transformed through a second transformer placed near the pillars of the Public Power Corporation into low voltage, in order to be able to connect to the network.
In this way, losses due to the transfer of power are successfully reduced to 5%.

Regarding to wiring, the cables which are used in such marine constructions consist of 3-core cables with integrated fiber optics. So the cost of today's plastic sheathed cables is approximately 20%-40% higher compared to those of land.
In this specific research, the wiring used for the coupling of the wind turbine to the transformer is NYY-0 0,6/1 KV with a cross section of 1 X 630 RM, suitable for installations in water; the underwater wiring used to connect the two transformers is of NYFGY 3.6/6.0 KV type with a cross section of 3 X 50 SM.

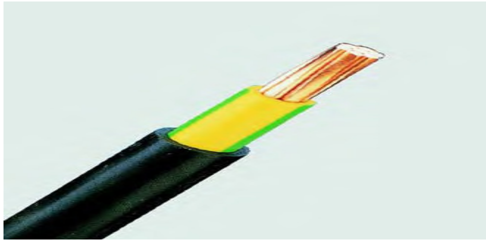


Figure 7: NYY-0 0,6/1 KV with a cross section of 1 X 630 RM

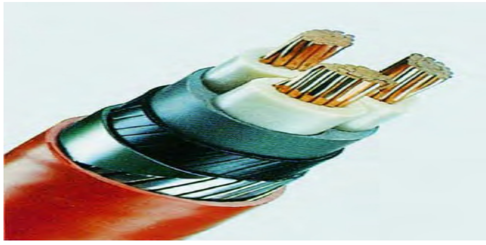


Figure 8: NYFGY 3.6/6.0 KV with a cross section of 3 X 50 SM.

5. Cost analysis of floating wind turbines

The cost analysis of a floating wind turbine depends on CAPEX (Capital Expenditure), OPEX (Operational Expenditure) and cost of energy. Both CAPEX and OPEX are real costs and represent the expenditure on goods and services, whereas the cost of energy is defined as the total revenue required per MWh to provide a given rate of return for an investor.

Moving on to cost analysis and taking into account all the parameters which play important role in the CAPEX, we can see that CAPEX is divided into five elements which are: project, turbine, foundations, electrical and installation.

More specifically Project covers tasks like as environmental and engineering researches and wildlife surveys. For projects being built in 2011, this specific cost is the 4% of total CAPEX, whereas by 2022, this cost will be less than 2%.

Turbine: including the manufacture and assembly of the turbine components. This element is regarded as the greatest part of investment, reaching 40% of total CAPEX expecting to increase to 44% by 2022. And in this study, the turbine cost is one of the largest expenses of the total investment.

Foundation: including the manufacture of the foundations of the turbine apart from the transportation and installation costs. This element is now 19% of total CAPEX, and is expected to increase to 22% by 2022.

Electrical: which covers offshore substations, array cables and export cables which links the wind farm with the onshore electrical system. This element makes up the 14% of total CAPEX, expecting only a slightly increase by 2022.

Installation: which includes the transportation of components to a construction point, onshore preparation and installation. The installation element is 23% of total CAPEX, with an expected reduction to less than 18% by 2022.

On the other hand, OPEX has to do with the operation and maintenance of the wind turbine, including condition monitoring, health and safety inspections, preventative and reactive maintenance etc. Regarding maintenance costs what is shown is that the breakdown rate is significantly less than the breakdown rate of onshore parks because manufacturers fix the constructions which are intended for sea with a stronger element of resistance. And finally the cost of energy is defined as the total revenue required per MWh of energy, so that the farm owner secures a 10% return on CAPEX and OPEX. So, in contrast with the onshore wind farms the greater part of the cost is not only the cost of wind turbine, but characterized by multiple costs.

Table IX: Breakdown of CAPEX 2011

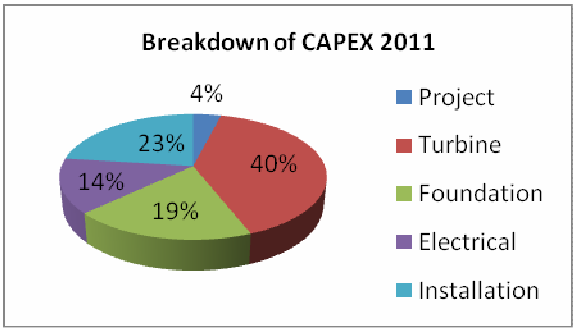
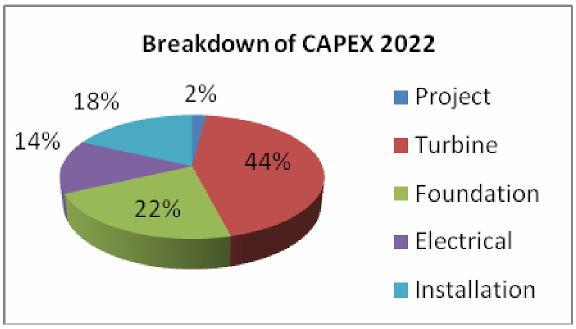


Table X: Breakdown of CAPEX 2022



Finally we can say that both CAPEX and OPEX are influenced by a range of factors like water depth, wind and wave conditions, distance from port facilities and point of grid connection, but also the technology used on the wind farm such as the wind turbine power rating, rotor diameter etc.[Renewable UK, 2011]

It has been shown that water depth plays an important role to the economy of the wind park and, accordingly we are able to conclude whether the wind park is more profitable than traditional wind farms.

Generally, it has been shown by The National Renewable Energy Laboratory that floating wind turbines are more efficient for water depths from 60m-100m.

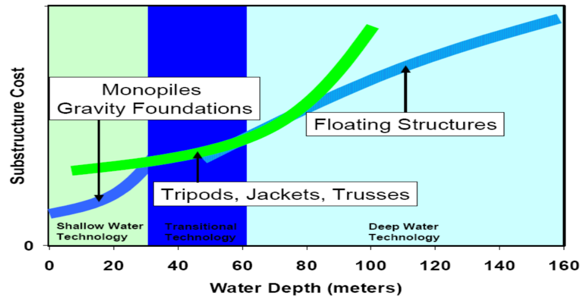


Figure 9: Cost of offshore wind turbines compared to water depths

6. Feasibility Analysis

In such investments "profit" generally means non-payment of funds for purchase of electricity from the Public Power Corporation. The amount of gross "income" of such investments is calculated by multiplying the energy production of the system (Kwh) and the selling price of Kwh by the Public Power Corporation.

This fact is a committal to the investor because, while in other cases he could develop his own economy policy depending on his business needs, the investment in power systems forces him to follow the economy policy of the Public Power Corporation.

In this specific unit, all financial data will be taken into the account and estimated based on Net Present Value and Profitability Index, so that it can be decided whether the investment is considered profitable and when it will break even according to the lifetime of project, which ranges at twenty five (25) years.

6.1 Case Study N_0 1 Project at Chios

Regarding the case study N_0 1 with the installation of a floating wind turbine in Chios, thinking and considering the average annual wind speed of 6.1 m / sec, we can easily calculate on the basis of the function curve of the wind turbine that 285 Kw are produced.

Knowing the power generated by this wind turbine on the basis of the average annual wind speed, we can easily calculate the annual energy output (by subtracting the percentage of losses), which is 2373.3MWh. The life of the project is up to 25years. The selling price of electricity produced by offshore wind farms is around 104.84 €/MWh.[234] The scheme of the investment financing chosen is as follows:

Table XI: Scheme of the Investment Financing Project N_O1

State Subsidy	40%
Equity	30%
Bank Loans	30%

Table XII : Data Project N_O 1

Features of recommended Area	
Latitude	38^0 12'46.83'' B
Longitude	25^0 51'13.16''E
Depth	88 m.
Distance from cost	3.37 Khm
Equipment	
Cost of Cable Low Voltage for connecting with transformer	13.608
Cost of Underwater Cabling Medium Voltage	97.595,02
Cabling Cost Land Medium Voltage	11.980
Cabling Installation Cost Land	2.500
Marine Cabling Installation Cost	335.000
Cost of two Transformers	52.000
Construction of Platform	1.600.000
Cost of Wind Turbine	1.260.000
Cost of anchoring and towing	120.000
Total	***3.492.683,02***
Annual Costs	
Maintenance	20.000
Economic Parameters	
Sale Price of Energy	104.84 €/MWh
Life Project	25 years
Percentage of Capital	30%
Percentage of Subsidy	40%
Borrowing Rate	30%
Borrowing Interest Rate	5%
Inflation	2,1%

The annual income of this investment, by removing the annual maintenance costs and the percentage of losses, amounts to 228,816.77 €. Lending rate stands at 5% and inflation stands at 2.1%.

Total net annual cash flows of the project for 25 years are around 4,030,704.63 €. So, the NPV of the investment, subtracting from the amount of 4,030,704.63 the initial investment cost (not including the subsidy), we conclude that the NPV amounts to 1,935,094.81 €. Specifically:

Table XIII : Parameters Installation of Wind Turbine in Chios

	Unit	Price
Total Initial Cost	€	*3.492.683,02*
Percentage of State Subsidy		40%
Payback Period	yr	10^0 -11^0 year
Net Present Value	€	1.935.094,81
Profitability Index		1.92

6.2 Case Study N_0 2 Project at Ag. Eustratios

Following the same tactic with the previous case study and taking into account the average annual wind potential of the area, which is 6.3 m / sec, we calculate from the operating curve of the wind turbine that 328 Kw are produced.

So, knowing now the power produced on the basis of the average annual wind speed, we estimate that the annual energy output (and subtracting the percentage of losses) is 2731.41 MWh. The life of the project is up to 25 years. The selling price of electricity produced by offshore wind farms is 104.84 euro/MWh. The scheme of the investment financing chosen in this case as well is as follows:

Table XIV: Scheme of the Investment Financing Project N_O 2

State Subsidy	40%
Equity	30%
Bank Loans	30%

The annual revenue generated by the investment after subtracting the annual maintenance cost is up to 266,361.02 €. Lending rate stands at 5% and inflation stands at 2.1%. Total net annual cash flows of the project for 25 years are 4,692,062.5 €. So, the NPV of the investment, subtracting from the amount of 4,692,062.5 € the initial investment cost (not including the subsidy), we conclude that the NPV is up to 2,624,668.9 €. Specifically:

[234] Law 3468/2006. Values of Law reviewed annually by decision of the competent Minister after consultation with Regulatory Authority for Energy based on weighted average of increases in tariffs of Power Public Corporation, and after the full liberalization of electricity market adjustment will take place 80% Consumer Price Index. In 2009 the guaranteed selling price of electricity from wind farms at sea was 104,84 €/MWh.

Table XV : Data Project N_O 2

Features of recommended Area	
Latitude	39^0 32' 59.11'' B
Longitude	24^0 56' 38.72'' E
Depth	60 m.
Distance from cost	3.2 Khm
Equipment	
Cost of Cable Low Voltage for connecting with transformer	13.608
Cost of Underwater Cabling Medium Voltage	92.672
Cabling Cost Land Medium Voltage	14.376
Cabling Installation Cost Land	3.000
Marine Cabling Installation Cost	290.000
Cost of two Transformers	52.000
Construction of Platform	1.600.000
Cost of Wind Turbine	1.260.000
Cost of anchoring and towing	*120.000*
Total	***3.445.656,0***
Annual Costs	
Maintenance	20.000
Economic Parameters	
Sale Price of Energy	104,84 €/MWh
Life Project	25 years
Percentage of Capital	30%
Percentage of Subsidy	40%
Borrowing Rate	30%
Borrowing Interest Rate	5%
Inflation	2,1%

Table XVI : Parameters Installation of Wind Turbine in Ag. Eustratios

	Unit	Price
Total Initial Cost	€	*3.445.656,0*
Percentage of State Subsidy		40%
Payback Period	yr	8^o -9^o year
Net Present Value	€	2.624.668,9
Profitability Index		2.3

As we can see, the application and implementation of a floating wind turbine in the chosen location by Ag. Eustratios is more efficient than the implementation in Chios since it has less total cost and the NPV is much higher.

6.3 Case Study N_0 3 Project at Limnos

Examining the case of implementation and application of a floating wind turbine in Limnos, we take here again into account the average annual wind speed, which is 6.6 m / sec, and we calculate based on the operating curve of the wind turbine a power output amounting to 363 KW.

Knowing now the output, we calculate the annual energy output (subtracting the percentage of losses), which is 3022.87 MWh. The life of the project is up to 25 years. The selling price of electricity produced by offshore wind farms is 104.84 euro/MWh.

The scheme of the investment financing chosen is analysed as follows:

Table XVII : Scheme of the Investment Financing Project N_O 3

State Subsidy	40%
Equity	30%
Bank Loans	30%

The annual revenue generated by the investment after subtracting the annual maintenance cost is up to 296,917.69 €. Lending rate stands at 5% and inflation stands at 2.1%.

Table XVIII : Data Project N_O 3

Features of recommended Area	
Latitude	40^0 05' 00, 28'' B
Longitude	25^o 25'13.97''E
Depth	60 m.
Distance from cost	6.0 Khm
Equipment	
Cost of Cable Low Voltage for connecting with transformer	13.608
Cost of Underwater Cabling Medium Voltage	173.760
Cabling Cost Land Medium Voltage	3.594
Cabling Installation Cost Land	750
Marine Cabling Installation Cost	395.000
Cost of two Transformers	52.000
Construction of Platform	1.600.000
Cost of Wind Turbine	1.260.000
Cost of anchoring and towing	*120.000*
Total	***3.618.712,0***
Annual Costs	
Maintenance	*20.000*
Economic Parameters	
Sale Price of Energy	104,84 €/MWh
Life Project	25 years
Percentage of Capital	30%
Percentage of Subsidy	40%
Borrowing Rate	30%
Borrowing Interest Rate	5%
Inflation	2,1%

Total net annual cash flows of the project for 25 years are 5,230,331.33 €.

So, the NPV of the investment, subtracting from the amount of 5,230,331.33 € the initial investment cost (not including the subsidy), we conclude that the NPV is up to 3,059,104.13 €. Specifically:

Table XIX : Parameters Installation of Wind Turbine in Limnos

	Unit	Price
Total Initial Cost	€	*3.618.712,0*
Percentage of State Subsidy		40%
Payback Period	yr	8^o -9^o year
Net Present Value	€	3.059.104,13
Profitability Index		2.4

As an assessment of all three investments we note that installing a floating wind turbine in the region of Limnos is economically more efficient since it presents an NPV higher than the other two cases, with second best in terms of cost effectiveness the area of Ag. Eustratios and last the area of Chios. The result is rather expected since the average annual wind speed potential of Limnos is comparatively higher, resulting in more amount of energy produced, which leads to higher profits.

7. Conclusions

The environmental problems that develop around the production of energy from fossil fuels force now the whole world to take seriously into account the renewable energy sources. Wind power is the flagship of green development and classifies it in the forefront of exploitation, while the lack of space, particularly in Europe, may be a significant barrier to its penetration and establishment.

So, floating wind turbines can be a significant solution combining a wide range of advantages as the following:

- More available wind power, as the wind speed is increased by 20% compared to that of the shore.
- Less wind turbulence, due to lower difference of temperatures, resulting in an increased efficiency of wind turbine
- Access to deeper water
- Flexibility in choosing site
- Flexibility regarding anchoring, as they can anchor anywhere so that they can exploit the most powerful winds in the open sea
- Reduction of distortion of the landscape since they are not so much detected by shore compared to offshore wind turbines
- When the needs of a region are fulfilled, they can easily be transported and relocated.
- Cheaper installation systems than those of fixed wind turbines that are used in smaller depths
- Operation and support of multi-megawatt wind turbines
- Finally, they have a longer life and, of course, zero emissions of pollutants and waste.

So, we can easily understand from both the research made and from feasibility analysis, that the installation of floating wind turbine in recommended regions of Greece (for. example Ag. Eustratios, Limnos and Chios) is a pretty good and profitable investment, with good payback period which can offer us a significant revenue.

As it has already been mentioned, Greece is a country with high wind potential, where, in many locations, the measurements have shown that the wind potential can be more than 6.5 m/sec, these areas pinpointed for the installation of wind farms. But, although the existence of high wind potential and the dominance of wind energy compared to other renewable sources (83% of total installed capacity in Renewable Energy Sources) is observed:

- Low utilization of wind power
- Low ecological awareness of population and little acceptance of wind farms from residents
- Serious delays between licensing and implementation due to time consuming bureaucratic procedures.

So, it would be useful to apply:

- Greater utilization of wind potential and especially in places like South Peloponnesus, East central Greece, Crete and Aegean islands, where very high wind potential is present
- Increase of ecological awareness of the population
- Shorter time of licensing and implementation of wind farms
- Existence of more incentives regarding to Renewable Energy Sources
- Existence of studies regarding the implementation floating wind turbines in specific places in Greece.

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Comparison between measurements and numerical assessment of global solar irradiation in Romania

Dr. Dragos ISVORANU[1]
Senior Lecturer

Dr. Viorel BADESCU
Professor
[1] Tel: +40-21-325-0704
Fax: +40-311-023-649
e-mail: ddisvoranu@gmail.com

Address
Faculty of Aerospace Engineering, University Politehnica of Bucharest,
1 Gheorghe Polizu Street, 011061, Bucharest, Romania

Abstract: The paper presents a comparative analysis between the surface global irradiation measured for Romania and the predicted irradiation obtained by numerical simulation. The measured data came from the Romanian National meteorological Administration. The simulation data can be obtained either directly from global forecasting models like GFS, ECMWF, GME, UKMO or ECMWF or from the local weather forecasting models like HRM, Hirlam, Lokal Model, WRF-NMM, WRF-ARW, Unified Model or MM5, whose initial conditions are provided by the global forecasting models (Lara-Fanego et al., 2011). Based on a preliminary analysis that took into account several criteria among which, performance, cost, popularity and meteorological and satellite data accessibility we concluded that a combination GFS-WRF(NMM) or GFS-WRF(ARW) is most suitable for short term global solar irradiation forecasting in order to assess the performance of the photovoltaic power stations (Badescu and Dumitrescu, 2012, Martin et al., 2011).

1. Introduction

Solar energy has a specific common characteristic: a high variability in space and time. It is highly dependent on the cloud structure, day/night cycles, the humidity and the aerosol load of the atmosphere. Due to intermittent weather patterns, solar energy power production plants cannot guarantee the amount of energy which is requested by the electrical grid operators in order to respond at any time to the end users demands. Therefore, secondary energy sources have to be considered locally or on a regional scale. Additionally, weather has a major impact on the electricity transmission and distribution grids, from the risk of outages and transmission capacity on one side and to the end users highly variable and weather dependant demands on the other side.

Electricity production is presently mostly based on centralized large production sites which feed the power into the high voltage grid from where it is transported to the end users. An increased production of solar energy will lead to a higher number of dispersed production sites with a highly variable weather dependant energy production which is fed into the medium and lower voltage grids. In such systems, production forecasts for the next minutes up to several days ahead are of high importance as they enable the utilities and the grid operators to adapt a "load schedule" in order to: (i) optimize the energy transport through the partly limited line capacities in the low voltage grid, avoid outages and congestion; (ii) allocate the needed balance energy from other sources if no solar energy is available; (iii) sell the electricity on the spot market for the best possible price and avoid penalties for wrongly predicted load schedules; (iv) plan maintenance activities at the production sites; (v) take the necessary measures to protect the production sites from extreme events;

All these items will contribute to an optimized production and distribution of solar energy and make them more competitive against classical production sources. In that sense, accurate forecasts of solar energy production as well as an optimized implementation of these forecasts for load schedules are of utmost importance. The objective of the present paper is the assessment of the quality and performance of global solar irradiance forecasting. The paper presents a comparative analysis between the surface global irradiance measured for Romania and the predicted irradiance obtained by numerical simulation. The measured data comes from the Romanian National Meteorological Administration.

2. Forecasting of solar radiation

The basic idea of numerical weather prediction is to sample the state of the atmosphere at a given time and use the equations of fluid dynamics and thermodynamics to estimate the state of the fluid at some time in the future. Models are initialized using this observed data. The irregularly spaced observations are processed by data assimilation and objective analysis methods, which perform quality control and obtain values at locations usable by the model's mathematical algorithms (usually an evenly spaced grid). The data are then used in the model as the starting point for a forecast. Commonly, the set of equations used to predict the known as the physics and dynamics of the atmosphere are called primitive equations. These equations are initialized from the analysis data and rates of change are determined. The rates of change predict the state of the atmosphere a short time into the future. The equations are then applied to this new atmospheric state to find new rates of change, and these new rates of change predict the atmosphere at a yet further time into the future. This time stepping procedure is continually repeated until the solution reaches the desired forecast time. The length of the time step is related to the distance between the points on the computational grid. Time steps for global climate models may be on the order of tens of minutes, while time steps for regional models may be a few seconds to a few minutes.
There are ten categories of forecasting ranges in the definitions of World Meteorological Organization.

Our primarily research interest lies within the first four: nowcasting, that is a description of current weather parameters and 0 -2 hours description of forecasted weather parameters; very short-range weather prediction (up to 12 hours prediction); Short-range weather forecasting (beyond 12 hours and up to 72 hours description of weather parameters); Medium-range weather forecasting (beyond 72 hours and up to 240 hours description of weather parameters).

Depending on the forecast time horizon, different methods have to be considered. In the first range, a numerical weather model cannot easily be applied: the forecast has to be based on processing of real-time measurements using the latest radar, satellite and observational data. Effective nowcasting demands a high density of weather information, particularly at the surface. Nowcasting systems use the combination of radar extrapolation techniques with satellite and Numerical Weather Prediction (NWP) model products to produce an extended short-period forecast. In the U.S., operational high-resolution data assimilation and forecasts are now available from the Rapid Update Cycle (RUC) system (Mass, 2011), which includes hourly data assimilation and frequent one-day forecasts on a 13-km grid (Benjamin et al 2004). During 2011 RUC will be replaced by the more advanced Rapid Refresh (RR) System over an expanded 13-km domain using the WRF model, with a High Resolution Rapid Refresh (HRRR) domain that will downscale RR to 3-km over the U.S. Mesoscale EnKF systems are being tested at a number of U.S. universities (Torn 2008, Zhang et al., 2009, Ancell et al. 2011) and have shown great promise compared to current operational data assimilation/nowcasting systems, such as RUC, that use three-dimensional variational data assimilation (3DVAR). The coordination of power generation by weather-dependent renewables (e.g., wind and solar) and reserve power sources (e.g., gas turbines or hydro) can be closely controlled in real-time based on weather observations and short-term forecasts.

In the very short range forecasting domain, numerical weather models are coupled with post-processing modules in combination with real-time measurements data assimilation. In the short and medium range forecasting time domains only the numerical weather model in combination with post-processing modules and satellite information is applied.

Solar yield forecast is still on an early state and very few works have dealt with the forecasting of the solar resources and its application for management of solar-based electricity power plants and grid integration strategies. Different approaches to forecast irradiance can be taken depending on the target forecasting time. For very short time forecasts (up to 3 h, nowcasting), approaches based on extrapolating the solar radiation field from cloud motion have been proposed (Heinemann et al., 2006). In addition, statistical techniques have been proposed for forecasting solar irradiance with up to 24 h (Mellit and Pavan, 2010). However, Numerical Weather Prediction (NWP) models are the basis of solar yield forecasts (IEA, 2007) with up 48 h time horizon, the time range useful for grid integration and decision making in the energy market. NWP models use atmospheric reanalysis initial and boundary conditions for the model run, which then realistically downscale (using physical equations) to a better physical resolution. The NWP model that downscales reanalysis data is termed a mesoscale model. Because the mesoscale models run over a smaller area than global scale models, the physics can include additional details. Therefore, provided enough computing power, these models can be used to forecast solar irradiance over a wide area with high temporal and spatial resolution.

Earliest evaluation studies on the MM5 (Grell et al., 1998) mesoscale model reliability for estimating global horizontal irradiance (GHI) were carried out by Zamora et al. (2003, 2005) in some locations in USA. Heinemann et al. (2006) evaluated the MM5 model GHI forecasts in Germany for lead time up to 48 h. Lorenz et al. (2009a) evaluated several NWP-based hourly GHI forecasts in Europe. Lorenz et al. (2009b) evaluated GHI forecasts, based on the European Centre for Medium-Range Weather Forecast (ECMWF) NWP model, for power prediction of PV systems in Germany. They reported relative root mean square errors (RMSE) values of about 35% for single stations for a 24 h horizon forecasts. Remund et al. (2008) evaluated different NWP-based GHI forecasts in the USA, reporting relative RMSE values ranging from 20% to 40% for a 24 h forecast horizon. Similar results were reported by Perez et al. (2009), evaluating NWP-based irradiance forecasts in several places in the USA. The Weather Research and Forecasting (WRF) model has a wide range of physical parameterizations, which allow setting the model to better describe the physical processes based on model domain, resolution, location and application (Ruiz-Arias et al. 2008).

3. WRF presentation

The weather forecast model is strongly dependent on the characteristic space scale. The meteorology scale encompasses domains ranging from the synoptic, planetary scale, regional or mesoscale domains covering from 5km to a few hundred kilometers and below 1 km, the meteorology microscale. The most popular synoptic models are GFS, ECMWF, GME, UKMO while HRM, Hirlam, Lokal Model, WRF-NMM, WRF-ARW, Unified Model, MM5 are mesoscale models (Santos-Muñoz, et al., 2009). Usually, the global models provide the initial and boundary conditions needed to start the regional models but they can also be used directly in the local analysis. The selection of the local forecasting model has been performed based on a preliminary analysis that took into account the following criteria:

a) performance,

b) cost,

c) popularity,

d) meteorological and satellite data accessibility.

The outcome of this preliminary analysis showed that HRM, Hirlam, Lokal Model are the most utilized models in Europe, while WRF and MM5 are their counterparts in USA and Canada. Similar homologues exist in Japan and Australia. The most part of the Hirlam model structure is assimilated by ECMWF. Even if the most part of the numerical mesoscale codes can be freely downloaded from internet, it is a matter of data accessibility that impedes the use of most European software as these require ECMWF formatted input data which are not free.

A common characteristic of the European numerical codes is the semi-Lagrangian, semi-implicit formulation contrary to the North-American codes devoted to Eulerian formulation. Each formulation has its pros and cons. However, we have to remember the major disappointment of the London Meteorological Office forecast based on a Lagrange formulation that failed to predict the volcanic cloud propagation resulted from Eyjafjallajökul eruption in April 2010. All weather forecast codes can run both deterministic and probabilistic (stochastic ensembles) simulations. Having this in mind, we find useful a comparison between MM5, WRF and Hirlam models.

The WRF model comprises two dynamical nuclei, ARW and NMM, the first stemming from the National Center for Atmospheric Research (NCAR) Advanced Research WRF (ARW) and the other one from the National Center for Environmental Predictions (NCEP). The NMM acronym comes from "non-hydrostatic mesoscale model" while ARW from "advanced research weather forecast system". The WRF model is a multi-grid, multi-level, non-hydrostatic Eulerian model with a wide range of microphysics options, LES (Large Eddy Simulation) turbulence model. It is capable of resolving spatial scales ranging from tens of meters to hundreds of kilometres and to support one and bidirectional coupling with various physics modules as well as nested and moving grids. The major difference between the basic nuclei resides in the type of spatial grid used in discretisation: ARW uses Arakawa-C while NMM Arakawa-E type of grid (Skamarock, et al., 2008). Historically, it is the most recent model, provided with a great flexibility and versatility through its modularity. We can add up various, different modules tailored for specific applications. From numerical point of view, it shows a less significant numerical dissipation due to high-order numerical algorithms that do not require significant filtering and spatial smoothing. For the same reason, it is found that small scale phenomena can influence higher spatial scale solutions for a given grid. Due to the full parallelization of the code, the computational expense can be drastically reduced by increasing the number of processors. Starting with WRF 3.3.1, the planetary boundary layer modelling is superior to the one found in MM5 model that was too dissipative (Bowman, 2009).

The Hirlam model is semi-Lagrangian, semi-implicit, multi-level endowed with the classical TKE-l (turbulence energy and length scale) turbulence model. Based on our analysis it lacks the non-hydrostatic option. The discretisation grid is Arakawa-C type.

The MM5 model is the precursor of the WRF model, being less elaborated and easier to implement and use.

The popularity of the WRF model has significantly increased even in Europe in the last years. Recently, studies from Spanish meteorological agency have shown that WRF model can be fully integrated as a member of the ensemble forecasting systems (Santos-Muñoz, et al., 2009). One month simulations of the various physics options of WRF-NMM model using global data from GFS and ECMWF models have shown a relative superiority compared to the results obtained from the Unified Model from UK Meteorological Office and GME from Deutsche Wetterdienst (Santos-Muñoz, et al., 2009).

Taking all these facts into account we have chosen to use WRF model for the investigation of solar radiation forecast. A major advantage is the free access both to the source code and to most of the meteorological data files.

4. Radiation model

The radiation schemes provide atmospheric heating due to radiative flux divergence and surface downward longwave and shortwave radiation for the ground heat budget. Longwave radiation includes infrared or thermal radiation absorbed and emitted by gases and surfaces. Upward longwave radiative flux from the ground is determined by the surface emissivity that in turn depends upon land-use type, as well as the ground (skin) temperature. Shortwave radiation includes visible and surrounding wavelengths that make up the solar spectrum. Hence, the only source is the Sun, but processes include absorption, reflection, and scattering in the atmosphere and at surfaces. For shortwave radiation, the upward flux is the reflection due to surface albedo. Within the atmosphere, radiation responds to model-predicted cloud and water vapor distributions, as well as specified carbon dioxide, ozone, and (optionally) small concentrations of other gases. All the radiation schemes in WRF currently are column (one-dimensional) schemes, so each column is treated independently, and the fluxes correspond to those in infinite horizontally uniform planes, which is a good approximation if the vertical thickness of the model layers is much less than the horizontal grid length. The short wave radiation microphysics has several options: Eta Geophysical Fluid Dynamics Laboratory (GFDL) version of the Lacis and Hansen (1974) parameterization; MM5 (Dudhia) based on Dudhia (1989) model; Goddard Shortwave based on Chou and Suarez (1994); CAM Shortwave which is spectral-band scheme used in the NCAR Community Atmosphere Model (CAM 3.0).

We have chosen to work with the simplest model MM5 (Dudhia) that has a simple downward integration of solar flux, accounting for clear-air scattering, water vapor absorption (Lacis and Hansen, 1974), and cloud albedo and absorption. It uses look-up tables for clouds from Stephens (1978). In WRF V3, the scheme has an option to account for terrain slope and shadowing effects on the surface solar flux.

The downward component of shortwave flux is evaluated taking into account: 1) the effects of solar zenith angle, which influences the downward component and the path length; 2) clouds, which have an albedo and absorption; 3) and clear air, where there is scattering and water-vapour absorption. Thus, the downward shortwave flux

$$S_d(z) = \mu S_0 - \int_z^{top} \left(dS_{cs} + dS_{ca} + dS_a + dS_s \right) \qquad (1)$$

where μ is the cosine of the zenith angle, S_0 is the solar constant, z is the current level and top the last level of the model. Subscripts "cs" and "ca" refer to cloud absorption and cloud scattering while "a" and "s" to absorption transmisivity and scattering transmisivity. Cloud fraction in a grid box is either 0 or 1 because of the assumed stratiform nature of the clouds. The cloud back-scattering (or albedo) and absorption are bilinearly interpolated from tabulated functions of μ and $\ln(w/\mu)$ (where w is the vertically integrated cloud water path) derived from Stephens (1978) theoretical results. The total effect of a cloud or multiple layers of cloud above a height z is found from the above function as a percentage of the downward solar flux absorbed or reflected. Then at a height $z - \Delta z$, a new total percentage is calculated from the table allowing the effect of the layer Δz to be estimated. However, this percentage is only applied to $\mu S_0 - \Delta S$ (clear air); that is, the clear-air effect above z is removed. Clear-air water vapor absorption is calculated as a function of water vapor path allowing for solar zenith angle. The absorption function is from Lacis and Hansen (1974). The method is a similar integration-difference scheme to that described above for cloud. Clear-air scattering is taken to be uniform and proportional to the atmosphere's mass path length, again allowing for the zenith angle, with a constant giving 20 percent scattering in one atmosphere (Grell et al., 1998).

5. Results and discussions

The radiometric measurement datasets were obtained at the ANM Timisoara station (see Table 1) supplied with Kipp & Zonen CM6B radiometers.

Table 1. Characteristics of ANM Timisoara station.

Station name	Station code	Geographical code	Lat. (deg N)	Long. (deg E)	Alt. (m asl)
Timisoara	15247	546115	45.77	21.26	86

The radiation measurement methodology follows standard procedures prepared at the National Meteorological Administration. Measurements are performed as follows. Solar irradiance (units: W/m^2) is measured at 1-minute intervals. The series of irradiance values are averaged over 10 minutes, 60 minutes and 1440 minutes, respectively. Irradiation values (units: J) for 10 minutes, one hour and 24 hours are obtained by multiplying the appropriate average irradiance values by the appropriate time duration.

The WRF model was operated with the WRF single-moment microphysics scheme following Hong et al. (2004), the YSU planetary boundary layer scheme (Hong et al., 2006), the Kain–Fritsch cumulus scheme (Kain and Fritsch, 1993), MM5 similarity based on Monin-Obukhov with Carslon-Boland viscous sub-layer for surface layer (Paulson, 1970, Dyer and Hicks, 1970 and Webb, 1970), the unified Noah land-surface model, the RRTM scheme for long-wave radiation (Mlawer et al., 1997) and the scheme of Dudhia for shortwave radiation (Dudhia, 1989). The synoptic meteorological data started on 06/13/2010-00:00:00 and expanded up to 06/20/2010-12:00:00 covering 180 hours of forecast of the 0 cycle. The simulation domain is centered on the geographical coordinates of the city of Timisoara and expands 1700 km in E-W direction and 850 km in N-S direction. The grid spacing is 18.5 km. For this preliminary research we chose not to use nested grids. The comparison with measured data is illustrated in Fig. 2. Due to partial lack of measured data there are only 110 recordings that have been taken into account when constructing the statistics represented in Figs. 3-4. The influence of cloudiness on the global solar irradiance statistics are presented in Table 2.

Fig.1 Romania terrain map. Location of city of Timisoara.

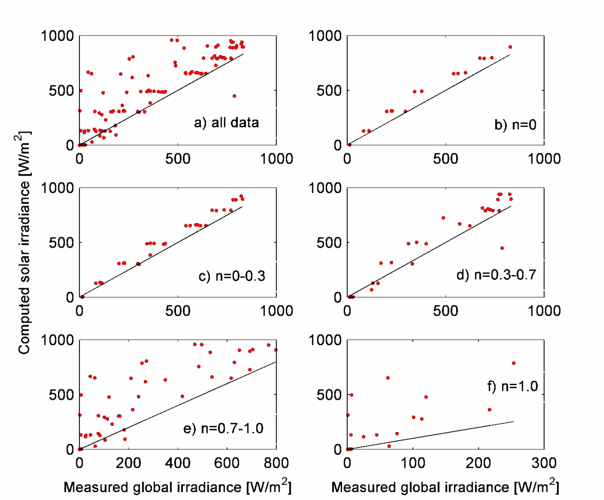

Fig. 2. Comparison between computed and experimental measurements of global solar irradiance. (red dots: simulation, black line: measurements; n: point-cloudiness ranging between 0 and 1).

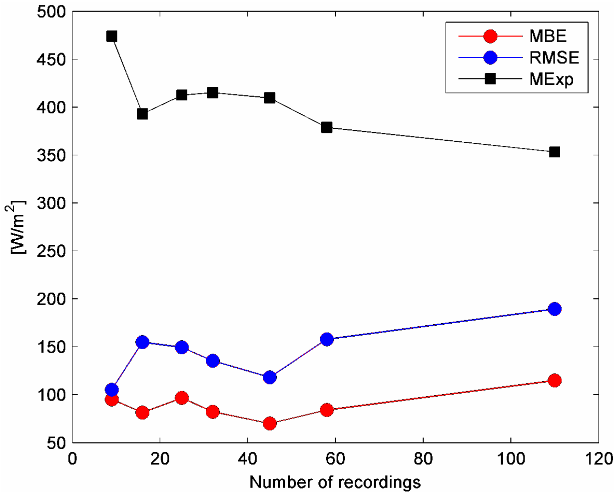

Fig. 3. Mean bias error (MBE), root mean square error (RMSE) and averaged measured data (MExp) depen- dences on the number of recordings.

Tabel 2. Relative error measures vs. classes of point-cloudiness n.

	n=0	n=0-0.3	n=0.3-0.7	n=0.7-0.1	n=1.0	all data
rMBE (%)	18.23	14.22	11.68	75.69	281.91	32.50
rRMSE (%)	21.62	17.64	26.55	105	412.84	53.63

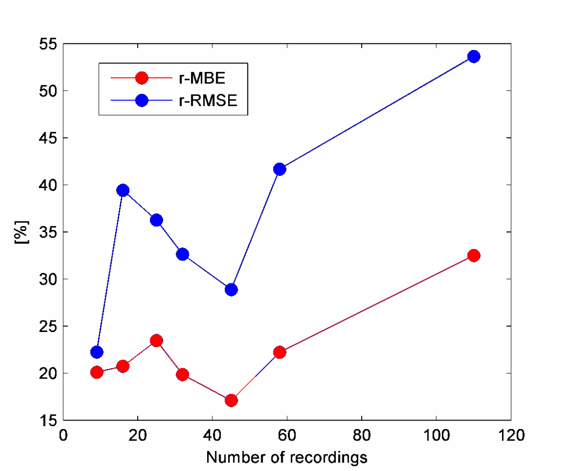

Fig. 4. Relative error measures dependences on the number of recordings.

6. Conclusions

Our preliminary analysis shows that the computed global solar irradiance fits quite well within the experimental data for situations ranging from clear sky ($n = 0$) to moderate point-cloudiness index ($n \in [0,0.7]$) (see Fig. 2). The statistics presented in Figs. 3-4 show five to ten percent larger values for the mean bias error (MBE) compared with the results of Lara-Fanego, 2011. This is most probably due to different microphysics options and to the coarser grid used. The chosen WRF microphysics model and its interactions cannot predict reasonably situations characterized by strong cloud covering. Further tests have to be performed in order to fully evaluate the possibility of solar radiation forecast.

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Comparative study of steam co-gasification of hard coal and biomass (Spartina pectinata and Miscanthus X Giganteus) focused on hydrogen-rich gas production

Dr. Adam SMOLINSKI
Associate Professor at Central Mining Institute (Corresponding Author)

MSc. Eng. Natalia HOWANIEC
Assistant at the Central Mining Institute

Tel: +48-32-259-2252
Fax: +48-32-259-2267
e-mail: smolin@gig.katowice.pl

Central Mining Institute, Department of Energy Saving and Air Protection
Plac Gwarków 1, 40-166 Katowice, Poland

Abstract: Co-gasification of coal and biomass offers the benefits of reliable supplies of abundant solid fuel – coal and credits resulting from utilization of a renewable, zero-emission energy resource – biomass. The results of experimental comparative study on steam co-gasification of hard coal and energy crops: *Spartina pectinata* and *Miscanthus X Giganteus* in a fixed bed reactor under atmospheric pressure and at the temperatures of 700, 800 and 900^{o}C are presented in the paper. The reactivities of coal and biomass blend chars in the process of steam co-gasification were determined. A synergy effect observed in the co-gasification tests process amounting in an increase in the hydrogen yield, when compared to the tests of coal and biomass gasification separately, was observed at all tested temperatures. Moreover, an increase in the total gas yield was observed in co-gasification of blends with 20 and 40% w/w. biomass content, in comparison with the tests of coal and biomass gasification at all tested temperatures.

Keywords: coal, biomass, gasification

1. Introduction

The world energy production is based mainly on fossil fuels (crude oil, natural gas, coal) which results in an environmental pollution and climate changes. Biomass, as a green and a local energy source, could contribute to diminishing of such dependence and consequences, since the CO_2 balance for biomass systems is about zero. (Beenackers and Maniatis 1998; Asadullah et al. 2002; Chen et al. 2004; Demirbas 2002). Increasing oil prices as well as stronger environmental regulations regarding greenhouse emissions make the greatest economic powers search a new, price competitive and environment friendly energy carrier, such as hydrogen. One of the promising ways of hydrogen production is coal and biomass gasification and co-gasification, combined with CO_2 capture.

The paper presents the results of experimental study on the steam gasification and co-gasification of Polish hard coal and energy crops (*Spartina pectinata* and *Miscanthus X Giganteus*) focused on hydrogen-rich gas production. The main reactions of the process of steam gasification/co-gasification of coal and biomass are as follows:

Steam reforming of coal:

$$C+H_2O_{(g)}=CO_{(g)}+H_{2(g)} \quad (1)$$

Steam reforming of Spartina pectinata:

$$2.381CH_{1.47}O_{0.58} + H_2O_{(g)} \rightarrow 2.381CO_{(g)} + 2.75H_{2(g)} \quad (2)$$

Steam reforming of Miscanthus X Giganteus:

$$1.786CH_{1.47}O_{0.44}+ H_2O_{(g)} \rightarrow 1.786CO_{(g)} + 2.313H_{2(g)} \quad (3)$$

Water gas shift reaction (WGS):

$$CO_{(g)}+H_2O(g)=CO_{2(g)}+H_{2(g)} \quad (4)$$

Boudouard reaction:

$$2CO_{(g)}=CO_{2(g)}+C \quad (5)$$

Methanation reaction:

$$C+2H_{2(g)}=CH_{4(g)} \quad (6)$$

Steam reforming of methane:

$$CH_{4(g)}+H_2O_{(g)}=CO_{(g)}+3H_{2(g)} \quad (7)$$

Dry reforming of methane:

$$CH_{4(g)}+CO_{2(g)}=2CO_{(g)}+2H_{2(g)} \quad (8)$$

2. Experimental procedure

The experiments of steam gasification and co-gasification were conducted in a laboratory scale installation with a fixed bed reactor, under atmospheric pressure at the temperatures of 700, 800 and 900^oC. The installation is presented in Fig.1. It consists of nitrogen (carrier gas) (1) and steam inlets (valves, flow regulators) (2), fixed bed reactor with resistance furnace (3), gas cleaning system (water trap, dehumidifier and solid particles filter (4)), flowmeter (5) and gas chromatograph (6) (Smoliński 2011).

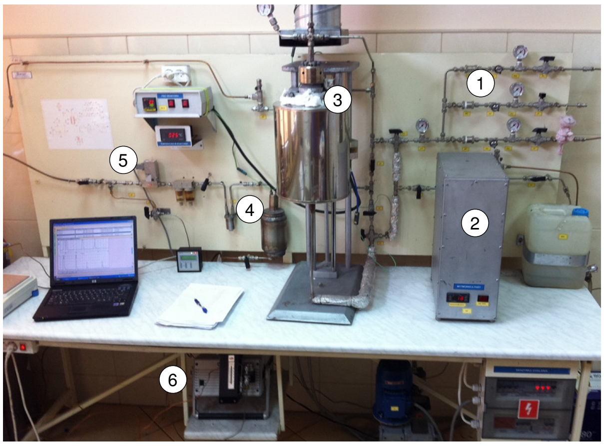

Fig.1 Laboratory scale fixed bed gasification reactor system

Two series of experiments were performed. The first one was focused on hydrogen-rich gas production through coal and biomass steam gasification at 700, 800 and 900^oC. In the second series coal and biomass samples were co-gasified under similar operating parameters as applied in the gasification tests.

The studied samples were prepared in accordance with the PN-G-04506:1996 standard. In the first series 10g of coal or energy crops was placed at the bottom of the reactor on quartz wool, used for better temperature distribution and for protection against entrainment of fuel grains by the inert gas and gasification agents passing through the reactor.

In the second series 10g of coal/biomass blends of biomass ratio of 20, 40, 60 and 80%w/w., respectively were used. In both series the samples were heated in the inert gas atmosphere to the temperature of 700, 800 and 900^oC, respectively. The heating rate was constant and equal $1.33^oC \cdot s^{-1}$. After the temperature was stabilized the steam was injected upward to the gasifier with a flow rate of $5.33 \cdot 10^{-2}$ cm^3s^{-1}. The amount of cooled and dried gas was measured on-line with a flow meter. Gas composition was analyzed via a two-channel gas chromatograph Agilent 3000A with two TCD detectors. The column PLOT U (8 x $0.32 \cdot 10^{-3}$m), with helium as a carrier gas, was used for separation of CO_2 and C_2-C_5, whereas a backflush injector module with a pre-column PLOT U (3 x $0.32 \cdot 10^{-3}$m) and an analytical column MS5A PLOT (10 x $0.32 \cdot 10^{-3}$m), with argon as a carrier gas, was used for separation of H_2, N_2, CO and CH_4.

Based on the experimental results the reactivities of fuel chars were determined:

$$R_X = dm/(m_0 \cdot dt_X) \text{ , } s^{-1} \tag{9}$$

were R_X denotes reactivity for X% of fuel conversion, m_0 denotes an initial carbon content in a sample, m denotes a time dependent carbon content in a product gas and t_X denotes time required to achieve carbon conversion of X% (Smoliński 2008). The reactivity characterizes coal/biomass and their chars in terms of the effectiveness of thermochemical processing. It determines an ability of coal/biomass and coal/biomass processing products to undergo thermochemical transformations in combustion and gasification processes and depends on many factors, like chemical composition of coal and chars: content of volatiles, ash and carbon, as well as the terms under which the physical and chemical changes during pyrolysis take place. The reactivity for 50% of carbon conversion and maximum reactivity were determined according to the procedure described elsewhere (Smoliński 2008, 2011).

3. Studied materials

Gasification tests were performed on a hard coal sample from Piast coal mine (HC) and samples of two energy crops: *Spartina pectinata* (SP) and *Miscanthus X Giganteus* (MXG) provided by the Department of Agriculture, Faculty of Agricultural Sciences in Zamość (University of Life Sciences in Lublin, Poland) and the experimental crops in Föhren, Germany, respectively. The results of ultimate and proximate analyses of tested coal and biomass samples as well as their heats of combustion and calorific values are presented in Table 1. The samples were analyzed in the accredited Laboratory of Solid Fuels Quality Assessment of the Central Mining Institute in accordance with the relevant standards in force: PN-G-04511:1980 (total moisture), PN-G-04560:1998 and PN-ISO 1171:2002 (ash), PN-G-04516:1998 and PN ISO-562:2000 (volatiles), PN-G-04513:1981 (heat of combustion, calorific value), PN-G-04584:2001 and PN-ISO 334:1997 (total sulfur), PN-G-04571:1998 (carbon, hydrogen and nitrogen content), PN-G-04516:1998 (fixed carbon calculated as 100 – total moisture – ash – volatiles).

Table 1 Basic physical and chemical parameters (in analytical state) of energy crops: Miscanthus X Giganteus (MXG), Spartina pectinata (SP) and hard coal (HC)

Parametr (analytical state)	**Sample**		
	MXG	**SP**	**HC**
Total moisture W, %w/w.	6.78	8.69	6.02
Ash A, %w/w.	1.6	4.31	5.69
Volatiles V, %w/w.	76.00	69.89	31.12
Heat of combustion Q_s, $J \cdot g^{-1}$	16546	16920	28805
Calorific value Q_i, $J \cdot g^{-1}$	14942	15481	27616
Total sulfur S_t, %w/w.	0.05	0.12	0.50
Carbon C_t, %w/w.	53.71	45.77	70.64
Hydrogen H_t, %w/w	6.59	5.62	4.08
Nitrogen N, %w/w	0.00	0.00	0.98
Oxygen O^a, %w/w	31.27	35.58	13.07
Fixed carbon, %w/w	15.62	17.11	57.17
SiO_2 (in ash), %w/w	69.01	64.82	46.55
Al_2O_3 (in ash), %w/w	0.38	0.33	25.65
Fe_2O_3 (in ash), %w/w	0.19	0.32	8.63
CaO (in ash), %w/w	15.27	9.99	7.34
MgO (in ash), %w/w	1.79	1.50	3.82
Na_2O (in ash), %w/w	0.73	1.53	2.60
K_2O (in ash), %w/w	2.98	11.48	1.92
SO_3 (in ash), %w/w	4.95	4.95	1.78
TiO_2 (in ash), %w/w	0.05	0.05	1.08
P_2O_5 (in ash), %w/w	3.99	4.45	0.36
ZnO (in ash), %w/w	0.00	0.00	0.00

4. Results and discussion

4.1 Reactivity

In the tests of reactivity of coal, biomass and coal-biomass blends in the process of gasification and co-gasification, the lowest values of the reactivity at 50% of carbon conversion, R_{50}, were obtained for coal chars: $1.98 \cdot 10^{-4}$, $2.31 \cdot 10^{-4}$ and $2.56 \cdot 10^{-4}$ s^{-1} at 700, 800 and 900^0C, respectively.

At 700^0C, the maximum values of R_{50} were reported for coal/biomass blends containing 40%w/w. of MXG biomass ($4.09 \cdot 10^{-4}$ s^{-1}) and 60%w/w. of SP biomass ($4.10 \cdot 10^{-4}$ s^{-1}).

At 800^0C, the highest values of R_{50} were observed for coal/biomass blends containing 40%w/w. of SP biomass ($4.8 \cdot 10^{-4}$ s^{-1}) and 80%w/w. MXG biomass ($4.41 \cdot 10^{-4}$ s^{-1}).

The highest values of R_{50} in the experiments performed at 900^0C were reported for coal/biomass blends with 40%w/w. content of MXG biomass ($4.84 \cdot 10^{-4}$ s^{-1}) and 60%w/w. of SP biomass ($4.91 \cdot 10^{-4}$ s^{-1}).

The maximum values of reactivity, R_{50}, observed for particular coal/biomass blends increased with the temperature from 700^0C to 900^0C. The similar trend of reactivity increase with temperature was also observed in terms of values for blends of particular biomass content, except for blends with 80%w/w. content of MXG biomass at 900^0C and blends with 20 and 40%w/w. content of SP biomass at 900^0C.

The values of reactivity R_{50} reported for coal/biomass blends in the process of steam co-gasification were higher than the values observed in biomass gasification, irrespective of the process temperature. This proves the positive impact of combined gasification of various fuels on the reactivity of a blend. Similar observations were also reported by (Collot et al. 1999; Howaniec et al. 2011; Lapuerta et al. 2008; Sjőstrom et al. 1999; Zhang et al. 2007) and (Hayashi et al. 1993, 1994; Liao et al. 1998a,b,c; Moliner et al. 1998; Suelves et al. 200, 2002).

Fuel blends of the highest values of reactivity R_{50} were characterized by low carbon content in a fuel (45.77%wag.). Fuel reactivity in the process of gasification is also claimed to be related to the alkali metals content in a fuel ash, in particularly potassium, calcium and sodium (Sjőstrom et al. 1999; Weiland et al. 2012; Zhu et al. 2008). This is also confirmed by the results presented in the paper: the SP biomass was characterized by high potassium and calcium content: 0.43%w/w. CaO and 0.49%w/w. K_2O. The results of the study of fuel reactivity R_{50} are given in Table 2.

The time needed to reach 50% of carbon conversion, $t_{50,}$ at 700^0C was shortest for SP biomass char and coal/biomass blends with 80%w/w. of SP biomass (960 s). The values of t_{50} reported for blends of coal and MXG biomass varied between 1152 and 1344 s.

The values of t_{50} for SP blends at 800^0C and 900^0C were similar (768÷1152 s). The longest time needed to reach 50% of carbon conversion, t_{50}, at each temperature were observed for coal chars: 1536 s at 700^0C and 900^0C and 1728 s at 800^0C (see Table 2).

Coal chars were also characterized by the lowest values of R_{max} (see Table 2): $3.73 \cdot 10^{-4}$, $4.68 \cdot 10^{-4}$ and $4.45 \cdot 10^{-4}$ s^{-1} at 700, 800 and 900^0C, respectively.

The highest values of R_{max} at 700^0C were observed for: coal/biomass blend with 80%w/w. of MXG biomass: $6.07 \cdot 10^{-4}$ s^{-1} and 80%w/w. SP biomass and SP biomass chars: $6.47 \cdot 10^{-4}$ and $6.94 \cdot 10^{-4}$ s^{-1}, respectively.

At 800^0C the highest values of R_{max} were reported for coal/biomass blends with 60%w/w. SP biomass content ($7.67 \cdot 10^{-4}$ s^{-1}) and 80%w/w. content of MXG biomass ($7.44 \cdot 10^{-4}$ s^{-1}).

The highest values of R_{max} at 900^0C were observed for coal/biomass blends with 80%w/w. of MXG and SP biomass: $7.26 \cdot 10^{-4}$ and $7.89 \cdot 10^{-4}$ s^{-1}, respectively.

Table 2 The results of the study of coal, biomass and coal/biomass blends reactivity in the process of steam gasification and co-gasification

Temp., ^0C	Parameter	HC and MXG blends, %w/w.		
		0	20	40
700	reactivity R_{50}, 10^{-4} s^{-1}	1.98	3.37	4.09
	reactivity R_{max}, 10^{-4} s^{-1}	3.73	4.96	4.96
	time, t_{50}, s	1536	1344	1152
	time, t_{max}, s	576	576	384
800	reactivity R_{50}, 10^{-4} s^{-1}	2.31	4.04	4.11
	reactivity R_{max}, 10^{-4} s^{-1}	4.68	5.09	5.83
	time, t_{50}, s	1728	1152	960
	time, t_{max}, s	384	384	384
900	reactivity R_{50}, 10^{-4} s^{-1}	2.56	4.78	4.84
	reactivity R_{max}, 10^{-4} s^{-1}	4.45	5.56	6.16
	time, t_{50}, s	1536	960	960
	time, t_{max}, s	384	384	384
Temp., ^0C	**Parameter**	**HC and MXG blends, %w/w.**		
		60	**80**	**100**
700	reactivity R_{50}, 10^{-4} s^{-1}	3.02	2.67	2.91
	reactivity R_{max}, 10^{-4} s^{-1}	5.31	6.07	4.45
	time, t_{50}, s	1344	1152	1344
	time, t_{max}, s	384	192	768
800	reactivity R_{50}, 10^{-4} s^{-1}	4.29	4.41	3.32
	reactivity R_{max}, 10^{-4} s^{-1}	4.94	7.44	5.9
	time, t_{50}, s	1152	768	1344
	time, t_{max}, s	384	192	192
900	reactivity R_{50}, 10^{-4} s^{-1}	4.37	4.24	3.93
	reactivity R_{max}, 10^{-4} s^{-1}	5.83	5.43	7.26
	time, t_{50}, s	960	960	960
	time, t_{max}, s	192	384	384
Temp., ^0C	**Parameter**	**HC and SP blends, %w/w.**		
		0	**20**	**40**
700	reactivity R_{50}, 10^{-4} s^{-1}	1,98	3,23	3,3
	reactivity R_{max}, 10^{-4} s^{-1}	3,73	4,69	5,46
	time, t_{50}, s	1536	1344	1152
	time, t_{max}, s	576	384	384
800	reactivity R_{50}, 10^{-4} s^{-1}	2,31	4,16	4,8
	reactivity R_{max}, 10^{-4} s^{-1}	4,68	5,05	6,16
	time, t_{50}, s	1728	1152	960
	time, t_{max}, s	384	384	384
900	reactivity R_{50}, 10^{-4} s^{-1}	2,56	4,02	4,7
	reactivity R_{max}, 10^{-4} s^{-1}	4,45	5,24	6,22
	time, t_{50}, s	1536	1152	960
	time, t_{max}, s	384	384	384
Temp., ^0C	**Parameter**	**HC and SP blends, %w/w.**		
		60	**80**	**100**
700	reactivity R_{50}, 10^{-4} s^{-1}	4,1	3,65	3,61
	reactivity R_{max}, 10^{-4} s^{-1}	6,21	6,47	6,94
	time, t_{50}, s	1152	960	960
	time, t_{max}, s	384	384	384
800	reactivity R_{50}, 10^{-4} s^{-1}	4,63	4,18	4,65
	reactivity R_{max}, 10^{-4} s^{-1}	7,67	7,29	6,73
	time, t_{50}, s	960	960	960
	time, t_{max}, s	384	384	192
900	reactivity R_{50}, 10^{-4} s^{-1}	4,91	4,74	4,72
	reactivity R_{max}, 10^{-4} s^{-1}	6,67	6,65	7,89
	time, t_{50}, s	960	960	768
	time, t_{max}, s	384	384	384

4.2. Gasification and co-gasification process efficiency

The results of the steam gasification and co-gasification experiments are given in Table 3. The total gas volume in the process of MXG biomass gasification was from $5706 \cdot 10^{-6}$ Nm^3 at 700^{o}C to $7196 \cdot 10^{-6}$ Nm^3 at 900^{o}C and in the process of steam gasification of SP biomass: from $6508 \cdot 10^{-6}$ Nm^3 at 700^{0}C to $7994 \cdot 10^{-6}$ Nm^3 at 900^{0}C. Carbon conversion in the process of MXG biomass gasification at 700^{0}C varied from 83% to 89%, and in the process of SP biomass gasification from 82 to 87% at 700 and 900^{o}C, respectively. The total gas volume in the process of steam gasification of coal was higher than in biomass gasification: $19678 \cdot 10^{-6}$, $21374 \cdot 10^{-6}$ and $24877 \cdot 10^{-6}$ Nm^3 at 700, 800 and 900^{0}C, respectively with the respective values of carbon conversion of 73, 81 and 88%.

The total gas volume in the process of coal and biomass co-gasification increased with the content of coal in a fuel blend. The highest total gas volumes in the co-gasification process were reported for coal/biomass blends with 20%w/w. of biomass. It amounted to: $16914 \cdot 10^{-6}$ Nm^3 for blends of coal and MXG and $17257 \cdot 10^{-6}$ Nm^3 for blends of coal and SP biomass at 700^{0}C. At 800^{0}C the respective values of the total gas volume in the process of co-gasification of fuel blends with 20%w/w content of MXG and SP were $18515 \cdot 10^{-6}$ Nm^3 and $19428 \cdot 10^{-6}$ Nm^3. At 900^{0}C the total gas volumes in co-gasification of 20%w/w biomass content fuel blends were $21372 \cdot 10^{-6}$ Nm^3 and $22114 \cdot 10^{-6}$ Nm^3 for blends containing MXG and SP biomass, respectively.

Table 3 Results of steam gasification of coal and biomass and coal/biomass blends co-gasification

Temp., °C	Parameter	HC and MXG blends, %w/w		
		0	20	40
700	H_2 volume, 10^{-6} Nm^3	11841	10339	9050
	CO volume, 10^{-6} Nm^3	3077	2414	1808
	CO_2 volume, 10^{-6} Nm^3	4542	4007	3701
	CH_4 volume, 10^{-6} Nm^3	218	154	125
	total gas, 10^{-6} Nm^3	19678	16914	14684
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.87	8.73	8.51
	gas efficiency, η, %	63	59	55
	carbon conversion, %	73	72	74
800	volume of H_2, 10^{-6} Nm^3	12713	11282	10017
	volume of CO, 10^{-6} Nm^3	4383	3484	2325
	volume of CO_2, 10^{-6} Nm^3	4205	3726	3754
	volume of CH_4, 10^{-6} Nm^3	73	23	18
	total gas volume, 10^{-6} Nm^3	21374	18515	16114
	calorific value Q_g, $MJ{\cdot}m^{-3}$	9.13	9.00	8.57
	gas efficiency, η, %	71	66	61
	carbon conversion, %	81	79	81
900	volume of H_2, 10^{-6} Nm^3	15454	13426	11799
	volume of CO, 10^{-6} Nm^3	5388	3900	3116
	volume of CO_2, 10^{-6} Nm^3	3992	3965	3483
	volume of CH_4, 10^{-6} Nm^3	43	81	115
	total gas volume, 10^{-6} Nm^3	24877	21372	18513
	calorific value Q_g, $MJ{\cdot}m^{-3}$	9.50	9.22	9.23
	gas efficiency, η, %	86	79	76
	carbon conversion, %	88	87	89

Temp., °C	Parameter	HC and MXG blends, %w/w.		
		60	80	100
700	volume of H_2, 10^{-6} Nm^3	7084	5065	3324
	volume of CO, 10^{-6} Nm^3	1442	886	498
	volume of CO_2, 10^{-6} Nm^3	2950	2472	1854
	volume of CH_4, 10^{-6} Nm^3	64	90	30
	total gas volume, 10^{-6} Nm^3	11540	8513	5706
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.40	8.11	7.58
	gas efficiency, η, %	48	40	29
	carbon conversion, %	74	77	82
800	volume of H_2, 10^{-6} Nm^3	7800	5912	4096
	volume of CO, 10^{-6} Nm^3	1850	1105	536
	volume of CO_2, 10^{-6} Nm^3	2860	2434	1856
	volume of CH_4, 10^{-6} Nm^3	2	32	22
	total gas volume, 10^{-6} Nm^3	12512	9483	6510
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.60	8.32	7.95
	gas efficiency, η, %	54	45	35
	carbon conversion, %	78	80	83
900	volume of H_2, 10^{-6} Nm^3	9063	6879	4670
	volume of CO, 10^{-6} Nm^3	2298	1518	670
	volume of CO_2, 10^{-6} Nm^3	2965	2303	1840
	volume of CH_4, 10^{-6} Nm^3	72	41	16
	total gas volume, 10^{-6} Nm^3	14398	10741	7196
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.99	8.83	8.26
	gas efficiency, η, %	65	54	40
	carbon conversion, %	89	86	87

Temp., °C	Parameter	HC and SP blends, %w/w.		
		0	20	40
700	volume of H_2, 10^{-6} Nm^3	11841	10624	9702
	volume of CO, 10^{-6} Nm^3	3077	2102	1459
	volume of CO_2, 10^{-6} Nm^3	4542	4328	3886
	volume of CH_4, 10^{-6} Nm^3	218	203	210
	total gas volume, 10^{-6} Nm^3	19678	17257	15257
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.87	8.61	8.56
	gas efficiency, η, %	63	59	57
	carbon conversion, %	73	72	72
800	volume of H_2, 10^{-6} Nm^3	12713	12077	10785
	volume of CO, 10^{-6} Nm^3	4383	3322	2256
	volume of CO_2, 10^{-6} Nm^3	4205	4029	3873
	volume of CH_4, 10^{-6} Nm^3	73	0	0
	total gas volume, 10^{-6} Nm^3	21374	19428	16914
	calorific value Q_g, $MJ{\cdot}m^{-3}$	9.13	8.87	8.57
	gas efficiency, η, %	71	68	64
	carbon conversion, %	81	80	80
900	volume of H_2, 10^{-6} Nm^3	15454	14002	12710

	volume of CO, 10^{-6} Nm^3	5388	3985	3165
	volume of CO_2, 10^{-6} Nm^3	3992	4127	3668
	volume of CH_4, 10^{-6} Nm^3	43	0	0
	total gas volume, 10^{-6} Nm^3	24877	22114	19543
	calorific value Q_g, $MJ{\cdot}m^{-3}$	9.50	9.11	9.06
	gas efficiency, η, %	86	80	78
	carbon conversion, %	88	88	89

Temp., ^0C	**Parameter**	**HC and SP blends, %w/w**		
		60	**80**	**100**
700	volume of H_2, 10^{-6} Nm^3	7260	5637	3858
	volume of CO, 10^{-6} Nm^3	1357	892	536
	volume of CO_2, 10^{-6} Nm^3	3194	2580	2062
	volume of CH_4, 10^{-6} Nm^3	136	89	52
	total gas volume, 10^{-6} Nm^3	11947	9198	6508
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.40	8.18	7.72
	gas efficiency, η, %	49	42	32
	carbon conversion, %	76	76	83
800	volume of H_2, 10^{-6} Nm^3	8075	6347	4630
	volume of CO, 10^{-6} Nm^3	2167	1178	644
	volume of CO_2, 10^{-6} Nm^3	2956	2873	2150
	volume of CH_4, 10^{-6} Nm^3	0	0	0
	total gas volume, 10^{-6} Nm^3	13198	10398	7424
	calorific value Q_g, $MJ{\cdot}m^{-3}$	8.68	8.02	7.83
	gas efficiency, η, %	56	47	38
	carbon conversion, %	83	86	87
900	volume of H_2, 10^{-6} Nm^3	9570	7446	5164
	volume of CO, 10^{-6} Nm^3	2614	1375	784
	volume of CO_2, 10^{-6} Nm^3	2843	2663	2020
	volume of CH_4, 10^{-6} Nm^3	0	0	26
	total gas volume, 10^{-6} Nm^3	15027	11484	7994
	calorific value Q_g, $MJ{\cdot}m^{-3}$	9.07	8.51	8.33
	gas efficiency, η, %	67	55	43
	carbon conversion, %	88	86	89

An increase in the total gas volume and hydrogen volume in the co-gasification process was observed when compared to the values reported for gasification of coal and biomass separately.

The highest hydrogen content was observed in the process of steam co-gasification of coal/biomass blends with 40%w/w. biomass content, irrespective of the process temperature and kind of biomass.

The concentration of carbon monoxide decreased with the increase in biomass content in a fuel blend, except for the coal/biomass blend with 60%w/w. biomass content blends, when an increase or no changes in the carbon monoxide concentration was observed when compared to the values reported for the process of co-gasification of fuel blends with 40%w/w. biomass content.

An increase in biomass content in a fuel blend resulted also in an increase in carbon dioxide concentration in co-gasification product gas, except for co-gasification of coal/biomass blends with 60%w/w. SP biomass content at 800^0C, when the carbon dioxide concentration was comparable with the value observed in co-gasification of coal/biomass blend with 40%w/w. SP biomass content.

The schematics of the main product gas components concentrations and flow rates in the co-gasification experiments at 700, 800 and 900^0C are given in Fig.2. An increase in hydrogen concentrations with an increase in biomass content in a fuel blend of coal and biomass was also reported by Mc Lendon et al. (2004), Velez et al. (2009), Fermoso et al. (2009) and Li et al. (2010). A decrease in carbon monoxide content in co-gasification product gas with an increase in biomass content in a fuel blend was observed by Velez et al. (2008), Li et al. (2010) and Mc Lendon et al. (2004).

a) b)

Fig.2 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and MXG fuel blends at 700^0C

4. Conclusions

In the study synergy effects in steam co-gasification of coal and biomass blends were reported under the operating parameters applied in terms of an increase in reactivities and total gas and hydrogen volumes in comparison with the values observed in the gasification process of coal and biomass separately.

Co-gasification process can be therefore considered as an alternative to gasification of coal and biomass separately, securing stable fuel supplies and offering higher economic competitiveness resulting from Langer scale of a system and reduction of CO_2 emission, since biomass as considered to be a zero emission fuel n the CO2 balance o fan installation. Another advantage is the possibility of utilization of catalytic activity of biomass ash components, increasing the gasification process efficiency, as an alternative to expensive catalysts.

The highest hydrogen concentrations in product gas were reported in the process of steam co-gasification of coal/biomass fuel blends with 40%w/w. of SP biomass content at 700, 800 and 900^{0}C (synergy effect).

a) b)

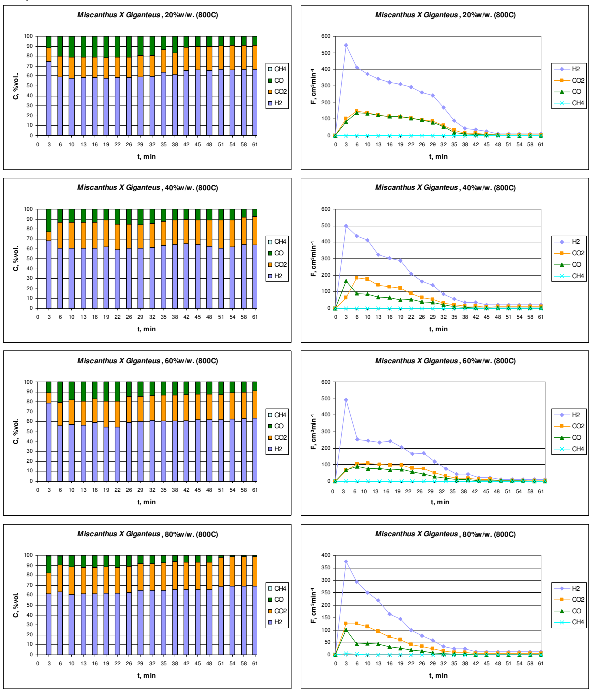

Fig.3 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and MXG fuel blends at 800^{0}C

a) b)

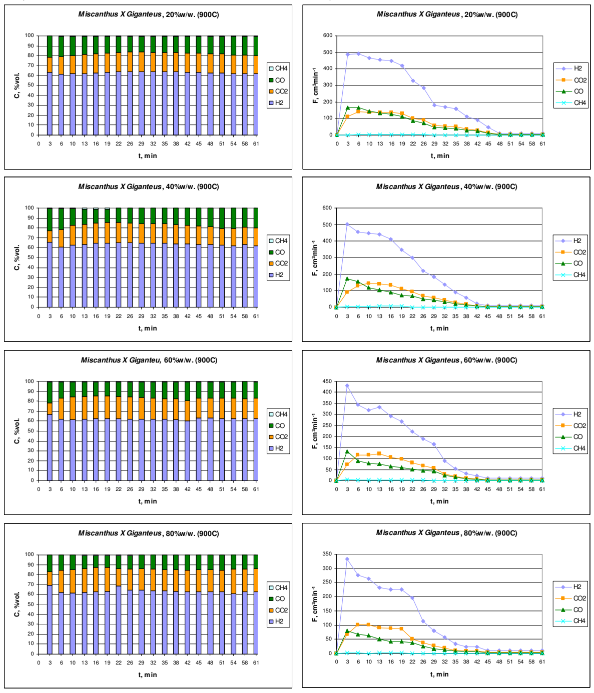

Fig.4 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and MXG fuel blends at 900^{0}C

a) b)

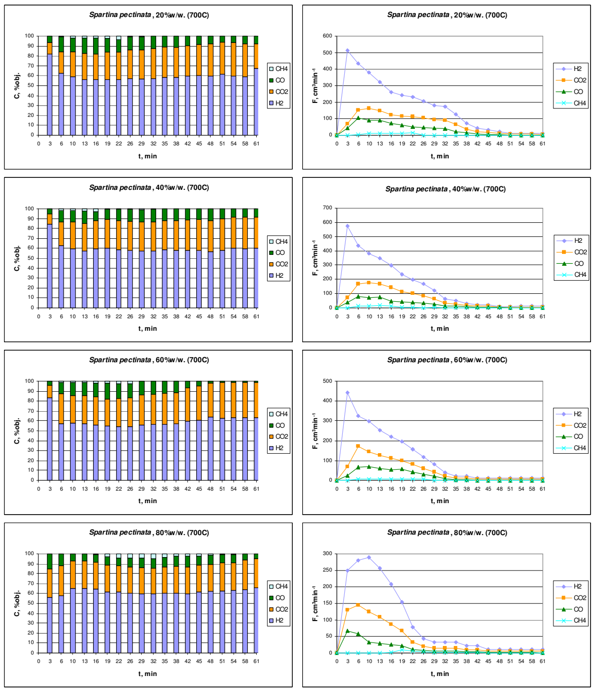

Fig.5 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and SP fuel blends at 700^{0}C

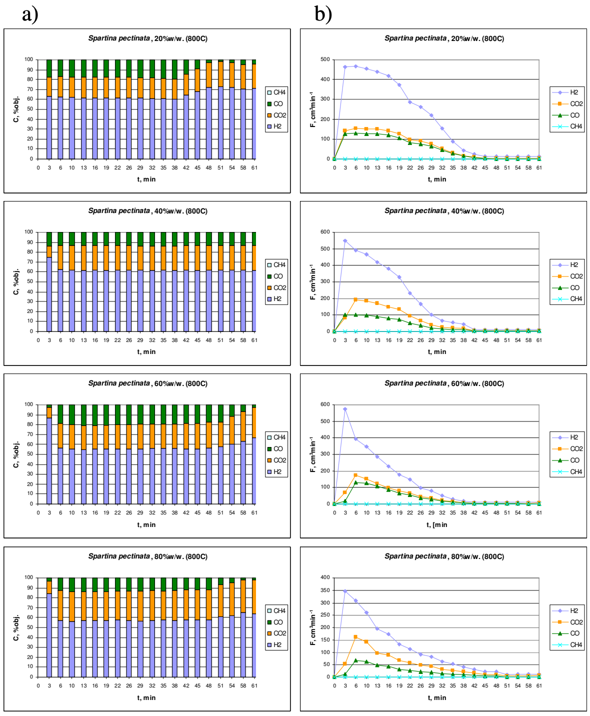

Fig.6 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and SP fuel blends at 800^0C

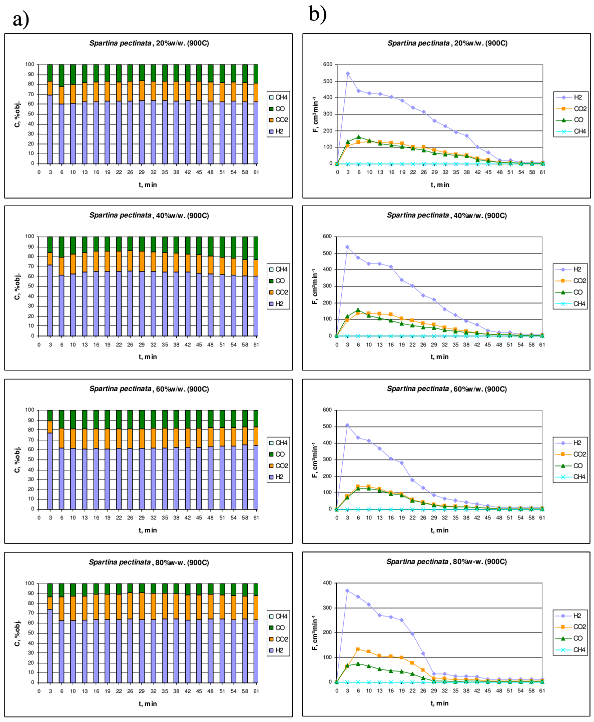

Fig.7 Schematic of main gas components: a) concentrations and b) flow rates in the process of steam co-gasification of HC and SP fuel blends at 900^0C

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Diesel Sustainability Improvement Perspectives by Incorporation Waste Cooking Oil in Existing Refinery of Thessaloniki

Dr. Stella BEZERGIANNI*[1],
Mr. Athanasios DIMITRIADIS*,
Dr. Loukia P. CHRYSIKOU*
*Center of Research and Technology Hellas CERTH

[1] Contact details of corresponding author
Chemical Process Engineering Research Institute - CPERI,
Centre for Research & Technology Hellas – CERTH,
6th km Harilaou-Thermi Rd, Thermi-Thessaloniki57001, Greece.
Tel: +30-2310-498-315
Fax: +30-2310-498-380
e-mail: sbezerg@cperi.certh.gr

Abstract: Catalytic hydroprocessing is a widespread refinery process that is used for petroleum fractions upgrading. This technology has been also explored for the conversion of lipids from vegetable oils and waste cooking oils, as the resulting paraffinic biofuels have superior quality as compared to conventional biofuels. Co-hydroprocessing of petroleum fractions with lipid feedstocks is under investigation, as it enables the incorporation of biomass in an existing refinery without large infrastructure investments. In the Centre for Research & Technology Hellas in Greece, co-hydroprocessing of heavy gas-oil (HAGO) – waste cooking oil (WCO) mixtures was studied for hybrid diesel production. The results reveal that the presence of WCO does not degrade the main fuel properties of the produced hybrid diesel (cetane index, heating value and fuel quality) as compared to conventional diesel. The main target of this project (Sustain Diesel) is to incorporate this feedstock in existing refinery of Hellenic Petroleum in Thessaloniki/Greece. Furthermore, in an attempt to investigate the sustainability improvement of the new proposed production process, the greenhouse gas emissions (GHG) are evaluated based on the existing diesel production in the local refinery.

Keywords: co-processing, biodiesel, sustainability

1. Introduction

The advanced and developing economies are strongly dependent of fossil fuels for transportation. It is expected that 90% of the increase of CO_2 emissions between 1990 and 2010 will be attributable to transport (BIOFRAC, 2006). For this reason the European Union and other developing countries have established specific action plans for the promotion of biofuels markets, such as the 2003 EU directive (2003/30/EU) which suggested that all Member States should blend biofuels in conventional fuels at a 2% ratio in 2005, which will gradually rise up to 5.75% in 2010. In 2007 the EC put forth the ambitious “20/20” energy-climate package for reducing the Green House Gas (GHG) emissions by 20%, which included a 10% share of biofuels in the transportation sector by 2020 (COM, 2007).

By far the most common biofuel within the EU is FAME (Fatty Acid Methyl Esters) biodiesel produced via the transesterification of vegetable oils. FAME has several advantages over fossil-based diesel fuel. Firstly, the cetane number of biodiesel is generally higher than that of the conventional diesel (Balat, 2005a), which up to a certain extent may improve its auto-ignition ability. Also, FAME viscosity is normally twice as high as that of conventional diesel fuel (Balat, 2005b), which is important for the engine lubricity. Moreover, FAME is biodegradable as well as free from sulfur and aromatics (Shay, 1993; Demirbas, 2009). Regarding emissions, commercial FAME biodiesel significantly reduces PM exhaust emissions, which are particularly high in large cities, but slightly increases NOx emissions (Demirbas, 2009; Knothe et al. 2006).

However, the use of FAME in vehicles and its production process face several limitations. The main disadvantage of the 1st generation biofuels such as FAME is their affiliation with the “food-versus-fuel” debate, as the food prices were raised due to the increase of energy crops cultivation over food crops; biofuel production was accountable for 3-30% of the increase in food prices in 2008. Even though FAME biodiesel has shown a potential of reducing the net carbon dioxide emissions, its high production cost, as compared to petroleum-based diesel, restrains its large-scale commercialization. Studies show that most of FAME production cost (70-95%) arises from the cost of raw material; that is, the cultivation cost of energy crops. Moreover, as FAME has lower energy content over conventional diesel, its use causes power decrease and increased fuel consumption (Demirbas, 2009). Another significant problem of FAME is that its usage in diesel engines brings up cold start problems (Demirbas, 2007) due to its long chains that increase cloud point, pour point, cold-flow plugging point (CFPP), etc.

Second generation biofuel technologies have been developed to overcome the limitations of first generation biofuels production. The goal of second generation biofuel processes is to extend biofuel production capacity by incorporating residual biomass, while increasing sustainability. This residual biomass consists of the non-food parts of food crops (such as stems, leaves and husks) as well as other non-food crops (such as switch grass, jatropha, miscanthus and cereals that bear little grain). Furthermore, the residual biomass potential is further augmented by industrial and municipal organic waste such as skins and pulp from fruit pressing, waste cooking oil, animal fats etc.

An alternative conversion route of triglyceride-containing feedstocks is catalytic hydrotreatement (HDT). Catalytic hydro-treatment is used in the petroleum refinery industry to remove undesirable atoms (S, N, and metals) from petroleum fractions, leading to upgraded products (gasoline, diesel etc) or intermediate streams (light-cycle oil, gas-oil etc). Catalytic hydrotreatment has been applied to vegetable oils and waste cooking oils (Bezergianni et al. 2010, 2012, Šimácek et al. 2011, 2010). The product is paraffinic and does not contain any oxygen, thus it is a stable and fully compatible fuel with fossil fuels. Furthermore, it exhibits superior characteristics including high cetane number, increased oxidation stability, high heating value and low sulfur content.

In this paper co-hydrotreatement of refinery streams with residual triglycerides feedstocks is studied as an alternative technology for the production of hybrid fuels. The integration of bio-based feedstocks in an existing refinery is extremely important as the utilization of existing infrastructure can expedite the large-scale integration of bio-based feedstocks in the fuels market. More specifically co-hydrotreating of heavy atmospheric gas-oil (HAGO) – waste cooking oil (WCO) is studied, aiming to examine the feasibility of integrating WCO into the HAGO hydrotreatment process of an existing refinery.

Besides the technical feasibility of the WCO integration in an existing refinery, the sustainability of the new proposed process is also assessed via Life Cycle Analysis (LCA). LCA provides quantification of greenhouse gas (GHG) emissions, rendering it a valuable tool for future decisions making regarding the production of the new biofuels. LCA has been effectively used for evaluating the sustainability of conventional diesel, since the petroleum refining industry is considered a prominent GHG emissions contributor. Based on literature data, about 0.003 to 6 Mt CO_2 are emitted from a European refinery annually (ECOFYS, 2009). In Thailand 0.447 kg CO2 eq-/kg diesel are generated from a refinery (Kochaphum et al. 2012), while higher values have also been reported (3.738 kg CO2-eq/kg diesel, Sunde et al. 2011). Generally, the production of diesel has variant GHG emissions depending on the refinery configuration and energy integration.

As market diesel consists of both diesel but also biodiesel, primarily FAME, it is important to also assess the GHG emissions of FAME production. On average FAME production contributes to 18.5 kg CO2 eq-/kg FAME, however this value can fluctuate based on the feedstock (i.e. energy crops) used (Fontaras et al. 2012). FAME from residual feedstocks such as WCO are associated with lower GHG emissions compared to FAME produced from energy crops and vary from 0.3 kg CO2 eq-/kg FAME (Peiró et al. 2010) to 2.323 kg CO2 eq-/kg FAME (des Pontes Souza et al. 2012), based on the boundaries and inputs of the LCA. The difference between the GHG emissions of FAME produced from energy crops versus residual biomass is attributed to the increased GHG emissions during the cultivation step, which is not included in the case of residual feedstocks, such as WCO.

This study is performed by CPERI/CERTH in collaboration of Hellenic Petroleum via the SustainDiesel project, which is supported by EU and National Funds.

2. Materials and methods

For all the experiments, a small-scale hydroprocessing pilot plant (VB01) was employed for this research. VB01 consists of a liquid feed system, a gas (hydrogen) feed system, a fixed bed reactor system and finally a separation product system, as schematically depicted in Figure 1.

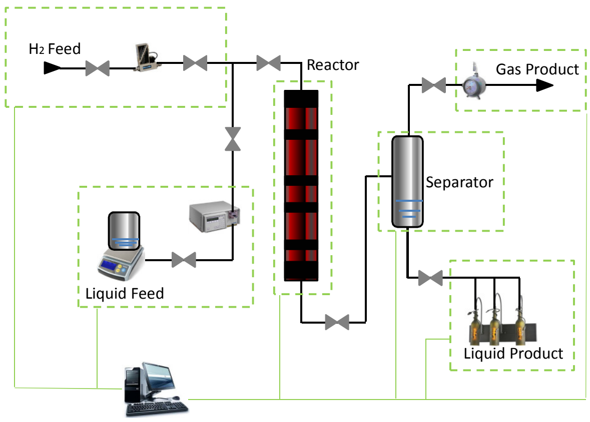

Figure 1. Schematic diagram of the CPERI/CERTH small pilot-scale hydroprocessing plant

This pilot plant resembles commercial hydrotreaters, as it can operate all nominal hydrotreating conditions (pressure, temperature etc) and is fully automated. User-friendly software allows the easy handling and control of the unit.
Product characterization was performed by collecting and analyzing total liquid product samples in terms of simulated distillation (Agilent 6890N), density (DMA4500), sulfur (ASTM D5453-93), nitrogen ASTM D 4629), bromine index (ASTM 2719), as well as carbon and hydrogen content (ASTM D 5291). The gas product is chromatographically analyzed offline. HAGO was provided by the local refinery of Hellenic Petroleum, while WCO was collected by local restaurants. The basic properties of HAGO and WCO are given in Table 1.

Properties	Density	S	N	H	C	O	Pour P.	H_2O
Units	kg/l	wppm	wppm	wt%	wt%	wt%	°C	wt%
Feedstock								
100% WCO	0.894	20.3	16.2	11.05	77	11.94	-	0.0603
100% HAGO	0.846	12450	473.5	12.64	86.99	0	>20	0.0190
HAGO/WCO (90/10)	0.884	11260	438.2	13.05	85.68	0.10	-	-
HAGO/WCO (70/30)	0.893	8340	407.1	13.57	82.78	2.77	-	-
Products								
HDT HAGO 100%	0.862	283	78.6	13.95	84.57	1.44	19	0.0005
HAGO/WCO (90/10)	0.854	215.5	54.6	14.09	83.39	0	19	0.0089
HAGO/WCO (70/30)	0.838	143	34.9	14.24	85.60	0.13	16	0.0062

Table 1. Biodiesel properties from hydroprocessing of 90/10 HAGO/WCO feedstock (Pressure=812psig, Temperature=350°C, LHSV=1hr^{-1}, H_2/Oil=500 nl/l)

For the assessment of the lifecycle GHG emissions of the suggested technology, the GEMIS software (Edition 4.7) was used (available from Öko-Institut, Darmstadt, Germany). GEMIS is a modular and valuable tool, evaluating environmental impacts of energy, material and transport systems to all processes involved in an energy system. The chain and the boundaries of the diesel production are presented in Figure 2. The production chain of market diesel fuel includes not only all the associated steps of the fossil diesel production (crude oil extraction, transportation and refining) but also the stages of FAME production (cultivation of energy crops, collection/transportation of vegetable oils, conversion to FAME, transportation to refinery.), as market diesel consists of 93% fossil diesel and 7% FAME biodiesel.

The sub-processes associated with the refinery process are extremely complicated, consuming energy and causing environmental burdens. Data for performing LCA on conventional diesel production were provided from the refinery of Hellenic Petroleum in Thessaloniki. The environmental impacts of the examined LCA are presented via the Global Warming Potential (GWP) that is measured in CO_2 equivalent. The related emissions including CO_2, CH_4 and N_2O are converted to CO_2-eq in order to compare their impact to GWP. The functional unit of 1 kg diesel was selected for the calculation of the results.

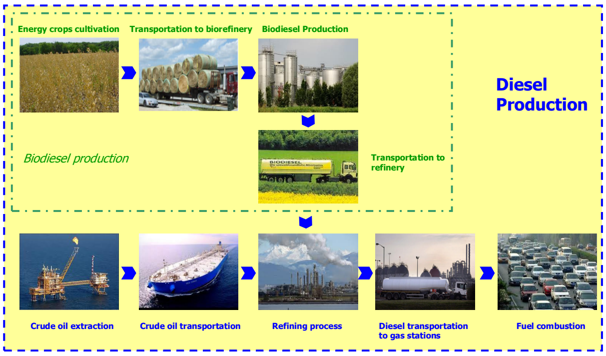

Figure 2. Flow chart of the conventional diesel production chain

3. Results-Discussion

As it has already been mentioned, the main target of the SustainDiesel project is to improve diesel sustainability by incorporating WCO as an alternative feedstock in an existing refinery of Hellenic Petroleum in Thessaloniki, Greece. The first and perhaps the most critical step defining the hydrotreating effectiveness (product yields and quality) and operability (expected run-length) is the selection of a suitable hydroprocessing catalyst (Furimsky, 2008). The most common catalysts for hydroprocessing of petroleum fractions such as HAGO, are CoMo- and NiMo-based. During the project, the process of selecting a suitable hydroprocessing catalyst for the conversion of HAGO / WCO mixtures was carried out, as there were no studies available regarding co-hydrotreatment. Two commercial catalysts have been evaluated at various temperatures regarding their effectiveness on heteroatom removal (sulfur, nitrogen and oxygen), diesel yields, saturation of double bonds and catalyst decay. Each catalyst type showed specific advantages for certain reactions over the other. For example the NiMo-catalyst had a better performance for saturation reactions, while both catalysts offer good diesel yields. The CoMo-based catalyst exhibited better performance for pure HAGO hydrotreatment, while the NiMo-based catalyst was better for processing WCO containing feedstocks. Therefore, the NiMo-based catalyst was selected as the most suitable one for co-hydrotreating of HAGO-WCO mixtures.
The next step of the SustainDiesel project was to evaluate the optimum operating parameters for NiMo catalyst. Three key operating parameters defining hydrotreating effectiveness were studied, included hydrotreating temperatures, liquid hourly space velocity (LHSV) and hydrogen-to-oil ratio (H_2/Oil). In order to identify the optimal operating parameters, several product characteristics were considered, including product yields, conversion, heteroatom removal (sulphur, nitrogen and oxygen), saturation of

double bonds and catalyst life expectancy. The experiments showed that not only does the addition of WCO in the feed limit the diesel yield but also it improves its quality. In fact the presence of WCO in the feed favors heteroatom removal reactions. The hybrid diesel products from co-hydrotreating of HAGO/WCO mixtures have lower density (desirable) and heteroatom (sulfur & nitrogen) content, as compared to conventional HAGO hydrotreatment products, as shown in Table 1. This is schematically depicted in Figures 3 and 4 where the desulfurization and denitrogenation effectiveness is compared for three different HAGO/WCO ratios (100/0, 90/10, 70/30) versus three reaction temperatures (330, 350 and 370 ºC).

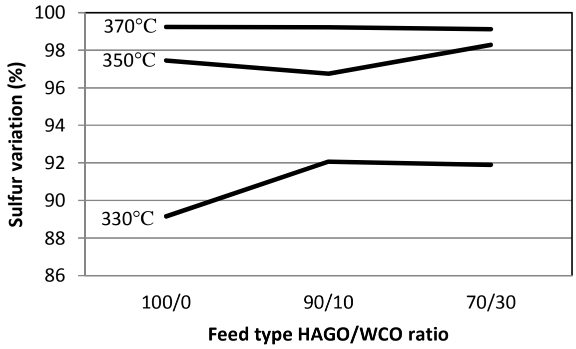

Figure 3. Sulfur variation for three different HAGO/WCO mixtures (100/0, 90/10 and 70/30) and three different operating temperatures (330°C, 350°C and 370°C)

Specifically, desulfurization of pure HAGO ranges from 89% to 99% for the three temperatures studied, for HAGO/WCO mixtures it is expected even higher, even for the lower temperatures that challenge desulfurization (Figure 3). Temperatures also affects in a similar way denitrogenation as shown in Figure 4. In both cases the reaction temperatures favors heteroatom removal. However the presence of WCO in the feedstock mitigates the catalyst inefficiency in lower reaction temperatures, which can be attributed to the negligible sulfur and nitrogen content of WCO as compared to HAGO.

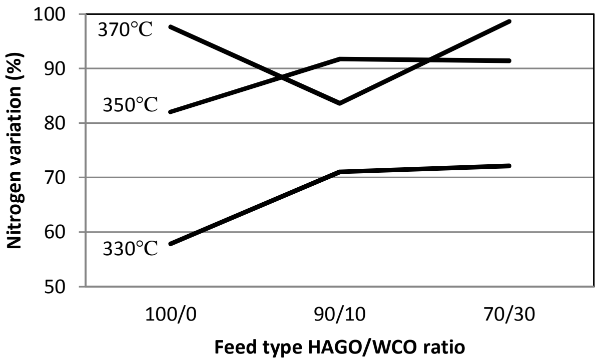

Figure 4. Nitrogen variation for three different HAGO/WCO mixtures (100/0, 90/10 and 70/30) and three different operating temperatures (330°C, 350°C and 370°C)

The distillation profiles of the hydrotreated feedstocks are presented in Table 2. The hydrotreated products show a stepwise distillation profile, less than 50% of the liquid products were distilled at temperature above 360°C. Results have shown that WCO has positive effect in the final products because it is increasing the percent of diesel range products. More specifically, according to Table 2, for pure HAGO feed only 46 wt% of the final products is in diesel range (180-360°C) while for 90/10 HAGO/WCO feed the percent increase to 49wt% and 59wt% for 70/30 HAGO/WCO feed.

Table 2. Distillation curve for pure HAGO and HAGO/WCO mixture

Distillation rate	Unit	Product HDT HAGO (100%)	Product HDT HAGO/WCO (90/10)	Product HDT HAGO/WCO (70/30)
0%	°C	155.8	152.2	148.4
10%	°C	273.2	273.8	274.4
30%	°C	332	320.2	307.8
50%	°C	363.6	358.8	338.8
70%	°C	388	386	375.4
90%	°C	416.2	416	411.6
100%	°C	458.6	462.6	474
Distillation				
Diesel potential yields (180-360°C)	wt %	46	49	59

In order to perform LCA on the proposed technology, it was imperative to combine the GHG emissions from market diesel and from WCO integration. It should be denoted that in the LCA studies of FAME from WCO, the impacts associated with the collection and delivery of the oils are negligible (Peiró et al. 2010; des Pontes Souza et al. 2012).

In the examined refinery in Thessaloniki 2,057 Mt CO_2 eq- are emitted annually, that equal to 0.556 kg CO_2 eq-/kg diesel, based on energy consumption data provided by the refinery. These values are in accordance with values previously reported for other refineries (ECOFYS 2009, Kochaphum et al. 2012). It should be noted that the factors contributing most to GHG emissions are the extraction and transportation of crude oil to the refinery (71.26% of total GHG emissions) and the combustion of carbon-containing fuels in the refinery (19.12% of total GHG emissions). The LCA was extended to the proposed technology incorporation of WCO (in about 30% ratio) in the existing diesel production. Based on related literature (Peiró et al. 2010; des Pontes Souza et al. 2012) the collection of WCO had the negligible GHG emissions. Based on the LCA analysis it is estimated that the GHG emissions will be reduced by about 21.4%, since the emissions attributed to the extraction and transportation of crude oil are employed by 70% in the proposed technology, compared to the conventional diesel production.

4. Conclusions

The main target of the SustainDiesel is to evaluated the technical feasibility and environmental potential by incorporating WCO in existing refinery Hellenic Petroleum of Thessaloniki in Greece. WCO is considered an alternative feedstock blend for catalytic hydrotreating HAGO. The technology of co-hydrotreating HAGO-WCO blends was developed by identifying optimal catalysts and operating parameters (temperature, pressure, LHSV and H_2/Oil ratio). The results have shown that the addition of WCO (10% & 30%) in HAGO not only does not affect negative the quality of the final product but also improves its properties without lowering its yield. Furthermore the environmental benefits of co-processing residual biomass (WCO) with fossil feedstocks (HAGO) was evaluated in terms of the corresponding GHG emissions via LCA. The LCA results showed that the incorporation of WCO in the existing diesel production process is exhibiting promising potential, reducing the corresponding GHG emissions by about 21.4%.

5. Acknowledgement

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Characteristics of energy consumption levels for areas in and around Athens

B. E. PSILOGLOU[1]*,
C. GIANNAKOPOULOS[1] and
A. DAGOUMAS[2]

*Corresponding Author
Tel: +30 210 8109133
Fax: +30 210 8103236
E-mail: bill@meteo.noa.gr

1Institute of Environmental Research & Sustainable Development,
National Observatory of Athens, GR 15236, P. Penteli, Athens, Greece
2Hellenic Electricity Market Operator S.A., Piraeus, Greece

Abstact: In this study, we seek to determine the factors that govern the trends in electricity consumption for various regions in and around Athens. We present the time series of diurnal, daily, monthly and yearly variations of electricity consumption for each of the selected sites. More specifically, we have gathered electricity consumption data for several locations around Athens and compare the behavior of yearly, monthly, daily and hourly electricity consumption in relation to inner Athens. In this way, we identify whether locations around Athens that Athenians use as weekend or short break destinations, present increases in their levels of consumption during weekend/ short holidays. These increases coincide with the periods that inner Athens consumption levels present substantial decreases. We have used eight locations around Athens and determine which of these locations take the weekend/short break increased load demand. The metropolitan area of Athens is a high electricity consuming area. In order to direct proper policies concerning electricity saving, a number of issues have to be taken into account such as: the combined characteristics, the seasonal variations, the detailed electricity profile during hours/weekdays/weekends and the electric infrastructure of all those locations around Athens.

Keywords: Electricity consumption, seasonal variation index, Athens

1. Introduction

Many economic activities are exposed to weather fluctuations. One of the most sensitive is the electricity market, because power demand is linked to several weather variables, mainly air temperature. Consumption of electricity is particularly sensitive to weather, since large amounts of electricity cannot be stored. This fact implies that produced electricity must be instantly consumed, so that a good model to predict future consumption is needed.

Recent studies have investigated the influence of ambient air temperature, sometimes represented by heating and cooling degree days, on electrical energy consumption (Henley and Peirson 1997; Valor et al. 2001; Sailor 2001; Pardo et al. 2002; Giannakopoulos and Psiloglou 2006; Psiloglou et al. 2009; Psiloglou et al. 2012). Other primitive independent variables, such as relative humidity, clearness index and wind speed (Sailor and Muñoz 1997, Bard and Nasr 2001), and derived variables including latent enthalpy-days, cooling radiation-days and clothing insulation units '*clo*' (Lam 1998, Yan 1998) have been used by other researchers for the development of statistical models for energy consumption.

In many cases, modelling of electric energy consumption is multivariate, consisting in a mix between climate and other important economic factors. The main constituents of these economic factors are energy prices, income and energy demand index (Zarniko 1997, Lam 1998, Nasr et al. 2000). Co-integration techniques for establishing long- and short-term energy demand relationships with climate factors have also been performed (Bard and Nasr, 2001).

This paper aims to provide a comparative analysis of electricity consumption levels between the Attica main basin and eight locations around Athens, by presenting the time series of diurnal, daily, monthly and yearly variations for each of the selected sites. We try to identify whether locations around Athens that

Athenians use as "weekend" or "short break" or even 'summer holiday' destinations, present any increases in their levels of consumption during weekend holidays. These increases coincide with the periods that inner Athens consumption levels present substantial decreases.

2. Data Description

Hourly electricity consumption data were made available by the *Hellinic Electricity Market Operator S.A.* for eight selected locations around Athens. These data refer to total *hourly* residential and commercial electricity consumption, in kWh, spanning the period from 2005 through 2011.

The selected locations, which appear in the map of Figure 1, can principally be divided into two sectors: (i) those located to the South and the West of the Greater Athens area (Megara, Korinthos, Xylokastro

Figure 4. The selected eight locations around Athens, Greece, that Athenians usually use as weekend or short break destinations.

and Salamina island) and (ii) those located to the North and the East of the Greater Athens area (Nea Makri, Ag. Stefanos, Kalamos, Chalkida).

These locations were selected primarily because they are located close to Athens and they serve as weekend/short break destinations for the citizens of the city (Korinthos, Xylokastro, Kalamos, Chalkida). Some of them have even turned into permanent residence locations for Athens citizens (Megara, Nea Makri, Ag. Stefanos, Salamina).

Additionally, hourly electricity consumption data were made available by the *Public Power Corporation of Greece* for the Greater Athens area, covering also the residential and commercial sector, in kWh, spanning the period from 1997 through 2001.

3. Electricity consumption variability

In this section we seek to determine the time periodicity in the energy load data. More specifically, we investigate whether electricity consumption has a

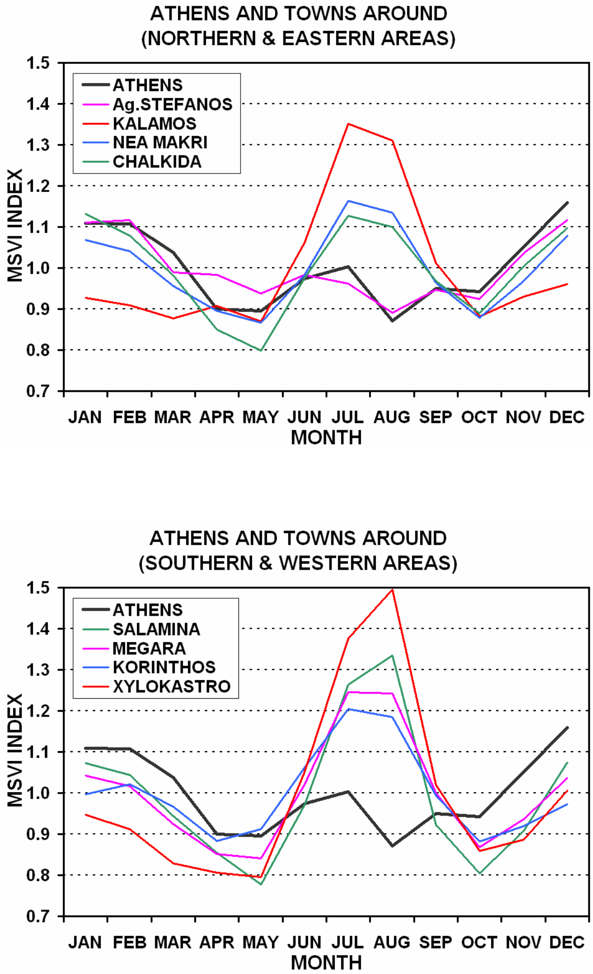


Figure 5. Mean monthly seasonal variation index (MSVI) of electricity consumption, for eight locations around Athens, Greece, for the period 2005-2011. The MSVI index for Athens is also included for comparison.

monthly, diurnal or hourly cycle. Such a cycle can be appropriately studied using seasonal variation indexes.

Monthly seasonal variation index (MSVI)

The monthly seasonal variation index (MSVI) can be defined as (Valor et al. 2001; Giannakopoulos and Psiloglou 2006; Psiloglou et al. 2009):

$$\mathrm{MSVI}_{ij} = \mathrm{ME}_{ij} / \mathrm{ME}_{j} \tag{1}$$

where:

MSVI_{ij} the index value for month i in year j,

ME_{ij} the monthly electricity consumption for month i in year j, and

ME_{j} the monthly average consumption for year j (mean of the 12 values of E_{ij} for year j).

The value of MSVI yields the relative behaviour throughout the months of the year.

Figure 2 depicts the monthly seasonal profile of MSVI for energy load from 2005 through 2011, for the eight selected locations around Athens, Greece. For the greater Athens area, the behavior of MSVI is also included for comparison (Giannakopoulos and Psiloglou 2006).

The seasonal pattern of electricity consumption is closely linked with the typical seasonal trend of air temperature, where maximum energy load values correlate with the extreme values of air temperature (maximum or minimum).

The behaviour of MSVI shows an increased consumption of electricity in January, which gradually decreases until May, which follows the decrease in demand for heating. As we move into summer, there is, as expected, an increasing tendency, mainly due to extensive air-conditioning use and increase in the number of people residing at the locations near the sea where many country houses of Athens citizens exist. The link between hot weather and increased electricity demand is also evident in other cities worldwide, where the use of air-conditioners has increased (Lam 1998).

The tendency continues throughout the summer until September, with the exception of August only for Athens and Ag. Stefanos, when a significant fall in demand is evident, due to the fact that the major part of the population of the greater Athens area is on summer vacation during this month.

Ag. Stefanos, having similar MSVI characteristics with Athens, turns to be more a location of permanent residence rather than a location for weekend/holiday destination.

Electricity demand also slightly falls in the autumn (October), which is representative of a transient season from summer to winter and gradually increases again in the coming months to reach a maximum in December. The load values in December are even higher than those in January and February (which are colder months than December) due to the increased energy needs during the Christmas festive period.

Daily seasonal variation index (DSVI)

To explore the daily fluctuation of energy load, the daily variation index (DSVI) is defined as (Valor et al. 2001; Giannakopoulos and Psiloglou 2006; Psiloglou et al. 2009):

$$DSVI_{ijk} = DE_{ijk} / DE_{jk} \tag{2}$$

where:

$DSVI_{ijk}$ the index value for day i of week j of year k,

DE_{ijk} the electricity consumption for the particular day i in weak j in year k, and

DE_{jk} the mean daily electricity consumption for week j of the year k.

Figure 3 depicts the variation of DSVI according to the day of the week.

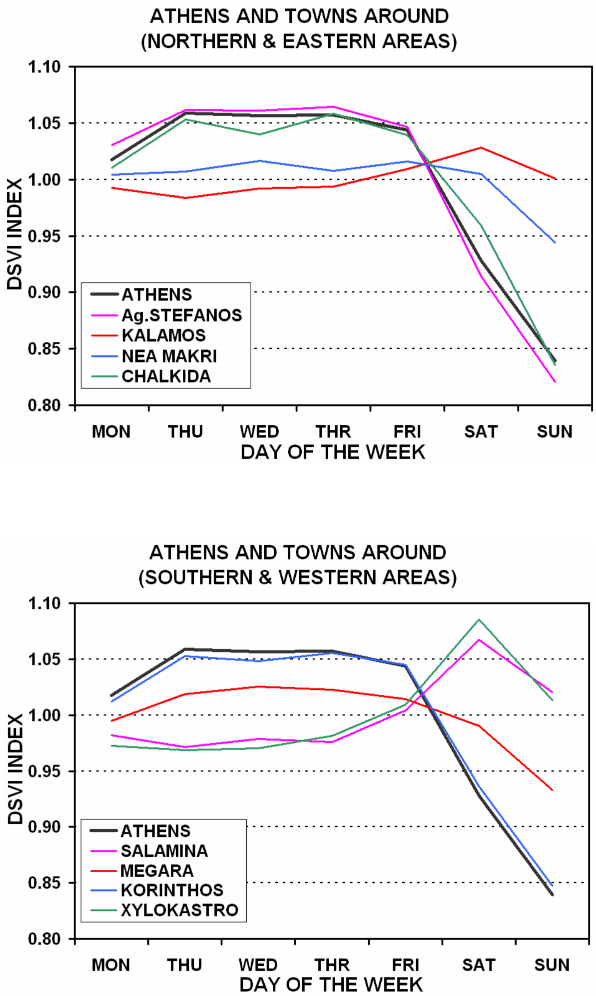


Figure 6. Daily seasonal variation index (DSVI) of electricity consumption, for eight locations around Athens, Greece, for the period 2005-2011. The DSVI index for Athens is also included for comparison.

It is clear in most areas that electricity consumption is significantly lower during the weekends (especially on Sundays) due to the reduced economic activities this period. Lower levels of consumption are also present on Mondays compared to the other days of the week because of the inertia caused by the reduced economic activities during the weekends.

Moreover, Figure 3 indicates that in the cases of Salamina, Kalamos and Xylokastro, electricity consumption increases during weekends with a peak in electricity consumption on Saturdays. This reflects the fact that an additional number of people visit the location from other areas, hence increasing the demand on this day.

Hourly seasonal variation index (HSVI)

Given that for the eight selected locations, our database include fine electricity consumption data (hourly values), the hourly seasonal variation index (HSVI) was also calculated for all these locations, which shows the diurnal variation of electricity consumption. From

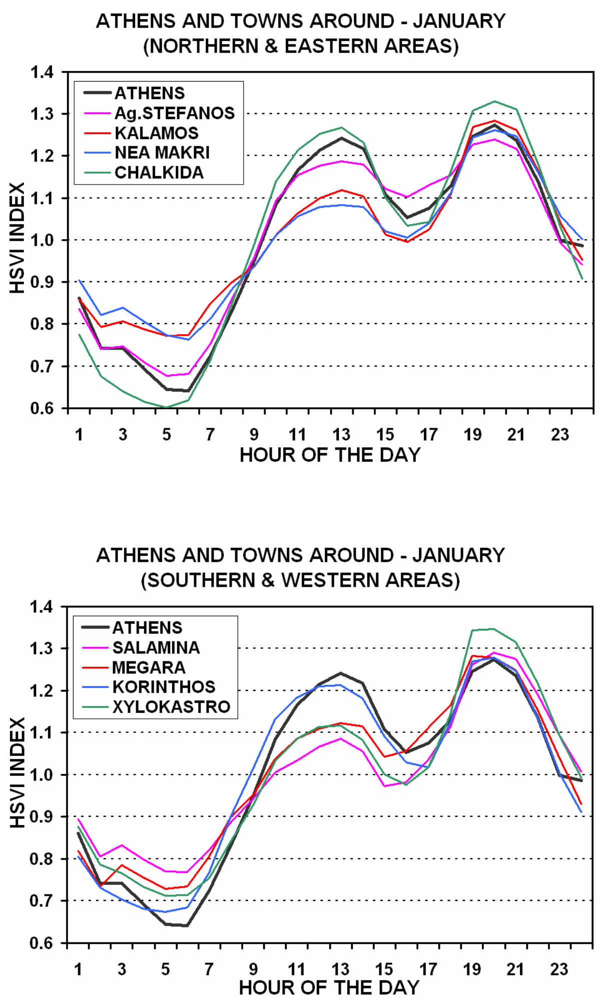


Figure 8. Hourly seasonal variation index (HSVI) of electricity consumption, for eight locations around Athens, Greece, for the period 2005-2011, for January only. The HSVI index for Athens is also included for comparison.

the hourly values, we calculated the average diurnal variation for each month (24 average hourly values each month). In this way, an average 24-hour period is available for each month, so for each year 12 such 24-hours periods are present. HSVI is therefore defined as (Giannakopoulos and Psiloglou 2006; Psiloglou et al. 2009):

$$HSVI_{ijk} = HE_{ijk} / HE_{jk} \quad (3)$$

where:

$HSVI_{ijk}$ the index value for hour i of the average 24-hours period of month j in year k,

HE_{ijk} the electricity consumption for a certain hour i in month j in year k, and

HE_{jk} the mean monthly electricity consumption for month j in year k.

In Figure 4, the hourly variation during a 24-hour period is plotted for the eight selected locations. For the greater Athens area, the behaviour of HSVI is also included for comparison (Giannakopoulos and Psiloglou 2006). It is clear that in all cases two maxima can be observed. The first maximum close to midday is due to the extensive use of electricity both for household (heating, cooking) and business (office heating, server and PC usage) needs during the working hours of the day. The second maximum is due to the use of lighting and heating/cooling using additional heaters or air-conditioners during the late afternoon and early evening hours.

It is worth noting the differences in HSVI when studying it in different seasons, most notably summer and winter. As a characteristic example we also present in Figures 5 and 6, the months of January and July.

During January (Figure 5), there are two distinct maxima in energy demand, one close to midday (due to heating, cooking or office needs) and another in the evening. The evening maximum reflects needs for extra heating and home entertainment (e.g. television) as most people stay indoors.

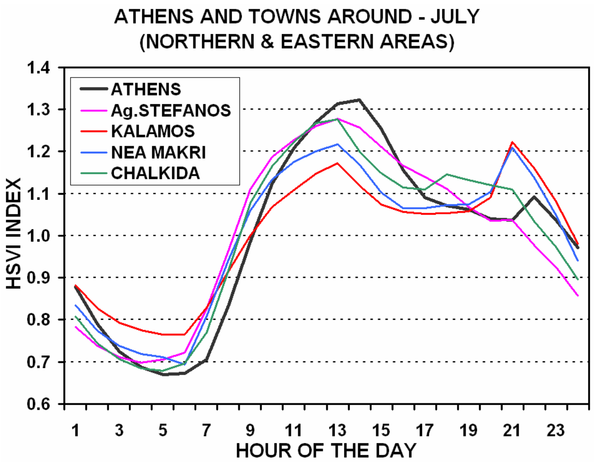
The pattern in July is different (Figure 6). Apart from the midday maximum, which occurs approximately at the same hours as the January one and is greater, the evening maximum occurs much later and is much less pronounced than the January one. Moreover, in the late afternoon/early evening hours, there is a decrease in demand which reflects the fact that most people like to stay outdoors for a dinner or other recreational activities and return home later.

4. Conclusions

This work presents a comparative study of energy demand, in terms of electricity consumption, and its diurnal, daily and monthly variations for eight locations around Athens, Greece and Athens center, seeking to identify which of these locations present increases in their electricity consumption levels during weekend and short break holidays, when inner Athens consumption levels present substantial decreases.

For all areas, Athens and towns around, energy demand peaks in winter which is associated with low temperatures while the summer peak is mainly linked to higher air temperatures requiring the use of air-conditioning. With an exception for the Athens center and Ag. Stefanos locations, the summer peak is also connected to the increase in the number of people residing in the areas close to the sea for holidays.

Regarding daily variations, most locations, including Athens center, exhibit lower energy demand levels during weekends (especially Sundays), with the exception of Salamina, Kalamos and Xylokastro where electricity levels increase on Saturday signaling the arrival of extra weekend visitors.



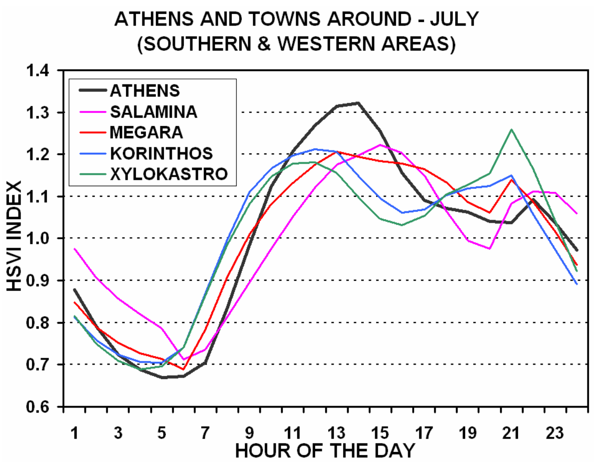


Figure 9. Hourly seasonal variation index (HSVI) of electricity consumption, for eight locations around Athens, Greece, for the period 2005-2011, for July only. The HSVI index for Athens is also included for comparison.

The hourly variation of energy demand levels has two maxima in all locations around midday and around evening, presenting some differences when studying it in different seasons, most notably summer (July) and winter (January). During January, there are two distinct maxima in energy demand, while during July the midday maximum occurs approximately at the same hours as the January one but the evening maximum occurs much later and is much less pronounced than the January one. In the late afternoon/early evening hours, there is a decrease in demand which reflects the fact that most people like to stay outdoors.

The combined characteristics of electricity consumption levels for all these locations should be taken into account during electricity conservation planning as it would be erroneous to consider that Athens consumption levels fall during weekends/holidays without taking into account the additional demand required for locations around Athens.

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An Approach to the Methodology of LCA in Buildings. An Environmental Performance of an Office Building in Greece

Mr. George XANTHAKIS[1]
Assistant Lecturer, Department of civil Engineer, ASPAITE

Ms. Panagiota PANOU
Technical Civil Engineer, Department of civil Engineer, ASPAITE

[1] Contact details of corresponding author
Tel: +30-697-2078-737
E-mail: xanthakisg@ba. aegean.gr

Address
ASPAITE, Department of Civil Engineer, Marousi, Athens, Greece

Abstract: Buildings have great impacts on the environment. Since early 1990s, the study of building sustainability has attracked the interesest of all word. A number of environmental impact assessment models were presented. LCA is a well-known tool to assess the environmental impacts of a product (according to ISO 14000 series). The paper presents the results of a detailed life cycle assessment (LCA) application to a typical dwelling in Greece. In the first part a literature review of the term Sustainability and LCA analysis is presented, making a focus especially in Buildings. An approach to the methodology of LCA analysis in buildings (according to ISO 14000 series) and an environmental performance of an office building (using software GaBi), the results and the conlussions are the second part of the paper.

Keywords: Life Cycle Assessment, Resintential Buildings, Sustainality

1. Introduction

Sustainability is adopted as the main goal for the future development of mankind. A famous definition is this of Brundland report in 1987 "Sustainable development is the development that meets the needs of present without compromisisng the ability of future generations to meet their own needs." (World Commision on Environment and DEvelopment). The same year, the World Commission on Ecoomic and Development stated that: "We remain convinced that it is possible to build a future that is prosperous, just, and secure. The ends on all countries adopting the objective of sustainable development as the overriding goal and test of national policy and international co-operation".

The construction industry can play a significant role towards sustainable development. Buildings (as a whole), from construction to their demolition, have considerable impact on environment, playing a vital role in the quality of life. Their environmental, economic and social impacts are part of a sustainable world. A new approach in building has to be presented that will calculate and try to minimize the environmental impact, protecting energy and water resources.

Life Cycle Assessment (LCA) (or Analysis) implies the identification and quantification of emissions and material consumption which affects the environment at all stages of the entire product of a life cycle, linking building products with the impact of construction. The definition of SETAC for LCA is: "LCA is a systematic way of evaluating the environmental impact of products or activities by following a 'cradle to grave' approach". LCA is the only internationally standarised environmental assesmemt method, according to the revised ISO 14040-44 (2006) and the old revision of ISO 14040-43 (1997-2000).

2. Sustainability

According to Ortiz (2008), the term sustainable development can be described as developing quality of life and allowing people to live in a healthy environment, improving the social, economic and environmental conditions for now and the future, although this claim, is not easy to operationalize. Vollenbroek (2002) described the sustainable development as a balance between the available technologies, strategies of innovation and the policies of governments. The United Nation reffered to sustainability as the guiding principle for the 21st Century, in Rio de Janeiro 1992.

The concept ''sustainable construction'' has been used (Mora, 2005) to characterize construction that includes environmental criteria in the project concept, in the way of building, maintaining and, when the time comes, of demolishing the works.

The definition of Sustainable development indicates clear links with issues as poverty, equity, environment, safety, and population control. In general, the field of Sustainable Development is subdivided into the areas of economic, environmental and social.

These areas are called pillars or dimensions of sustainability (Heijungs, 2009) and assess the sustainability of a project. A popular way of expressing the three pillars of SD is known as People, Planet, Profit (or PPP or 3P), where People represent the social pillar, Planet the environmental, and Profit the economic. At the World Summit on Sustainable Development (Johannesburg, 2002) this was modified into People, Planet, Prosperity. Changing Profit into Prosperity highlights the fact that the economic dimension covers more than the company profit. The idea of three pillars is illustrated as in Fig. 1.

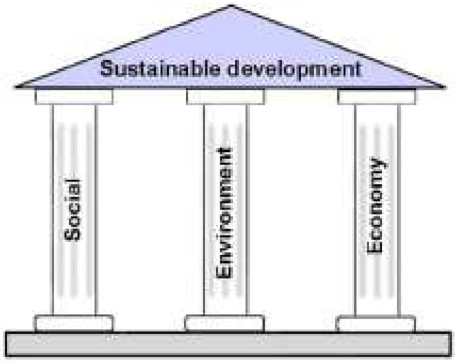

Fig. 1. A popular way of representing SD (taken from http://www.sustainability-ed. org/pages/what3 -.htm).

Given the widespread acceptance of the model (Kloepffer, 2008) it is rather straightforward to propose the following scheme for Life Cycle Sustainability Assessment (LCSA):

LCSA = LCA + LCC + SLCA, where:

Life cycle Assesment (LCA) is the SETAC/ISO environmental Life Cycle Assessment.The official definition (ISO) of LCA is: LCA is the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO, 2006). ISO (2006) defines the life cycle as the “consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal”.

Life cycle Costing (LCC)_is an 'environmental' Life Cycle Costing assessment. LCC provides a form of synopsis of the initial and consequential costs of building related decisions. These cost figures (Pelzeter, 2007) may be implemented to justify higher investments, for example, in the quality or flexibility of building solutions through a long-term cost reduction. On the other hand, LCC can be used to avoid apparent cost savings in the phases of construction, maintenance or refurbishment, which will in fact lead to substantial expenses in the phase of use.LCC developed quickly as there was already a methodological framework: economics. The main problems were to find the items to include and to estimate their values. Owing to the lack of standardisation, there are many different expressions and definitions of LCC. The result of LCC is a cost per functional unit expressed in one of the known currencies but it is different from traditional economic accounting. LCC is useful also as stand-alone assessment.

Societal LCA, (SLCA), the third pillar of LCSA, is considered to be still in its infancy, although the idea is not new. It is still in a stage, where a number of fundamental issues have not been agreed on and resolved *(Jorgensen,* 2008). One fundamental issue is which impact catergories to include in the assessment and how to evaluate these, while the perception of social impacts is also very variable, and it remains as a problem.

3. Brief History of Life Cycle Assessment

The usage of life-cycle assessment as an environmental management tool started in the 1960s in different ways and under a variety of names (Selmes, 2005). There is a confusing similarity between some of the terms that reflect different depths and types of study, especially in the literature of the early 1990s. The term life-cycle assessment has since been adopted to reflect environmental life-cycle studies. The origin of life-cycle thinking has been attributed to the US defense industry (La Greda, 1994). It has been used to consider the operational and maintenance costs of systems. This has become a costing technique known as "Life-Cycle Accounting" or "Life-Cycle Costing". The first appearance of LCA in its current modern environmental understanding was in a study held by Coca-Cola to quantify the environmental effects of packaging from cradle to grave (Hunt, 1996). The emphasis at that time was primarily on solid waste reduction, rather than on environmental emissions or energy use.

SETAC LCA advisory groups produced Guidelines for Life-cycle Assessment: A "Code of Practice" (1993) and «LCA Bible" (1996). Others LCA guidelines appeared during the 1990s, such as the Dutch guidelines on LCA (1992), and the Nordic Guidelines on Life-cycle Assessment (1995). The UN Environment Program published Direction for Life-cycle Assessment (2005) and The European Environment Agency's Life-cycle Assessment: A Guide to Approaches, Experiences and Information Sources (2005).

There were many initiatives to standardize the methodology of life-cycle assessment; the Canadian Standards Association released the world's first national LCA guideline Z-760 Environmental Life-cycle Assessment in 1994, to provide in-depth information on LCA methodology (Bardy,1996). But the most recognized standards were the ones published by the International Standards Organization ISO 14040-43.

4. The Building Environment

The building construction industry consumes about 40% of the materials entering the global economy and generates 40-50% of the global output of greenhouse gases and the agents of acid rain (Kofoworola et al., 2008). Extraction or purification of materials consumes energy, generates waste, and contributes to environmental damage with impacts such as resource depletion, global warming, acid rain, and smog.

A life-cycle approach is essential for the evaluation and improvement of the environmental performance of the construction products. There are many difficulties in conducting life cycle studies. Ideally, a complete study should include raw material acquisition, industrial refining, storage and distribution, packaging, consumption and waste management, all of which together comprise a large and complex system. The results of the LCA methodology can be implemented in order to optimize the environmental performance of the production system. LCA has been used in the building sector since 1990 and is an important tool for assessing buildings.

4.1 Application of LCA to the Construction Industry. Literature Review

As acknowledged (Blengini, 2010) in the international literature, the interest in environmental impacts of buildings in a life cycle is rapidly growing. Between 1998 and 2001, published the first worth remarking paper. (Blanchard and Reppe, 1998 –Thormark, 2001-Adalberth et al., 2001).

Since then, the literature on building LCA has focused on the two different ways:

- LCA for the building material and component combinations (BMCC) and
- The Whole Process of the construction (WPC)

4.1.1 Building material and component combinations (BMCC)

Some LCA studies explicitly dedicated to BMCC have been done during the last years. Asif et al. (Asif, 2005) studied eight construction materials for a dwelling in Scotland. The study concluded that the material used in the house with the highest level of embodied energy was concrete, at 61%. Also concrete was the material responsible for 99% of the total of CO_2 of home construction.

A new (alternative) methodology for reused materials is studied (Erlandsson and Levin, 2005), while Nie and Zuo (2003) studied the importance of investigating and applying new building materials. Koroneos and Moropoulou tried to identify keys issues associated with the life cycle of bricks (Koroneos, 2006), mortars (Moropoulou, 2006), and cement (Koroneos, 2009) produced and used in Greece.

4.2 Whole process of the construction (WPC)

When applied to the full building life cycle, LCA is divided up in three common scenarios:

- dwellings,
- commercial buildings and
- civil engineering constructions.

4.2.1 LCA for dwellings

According to Ortiz (2008): One of the first analyses during the last years on the environmental impact of the dwelling as a whole was performed by Adalberth et al. (2001). The main aim of this study was to evaluate the life cycle of four dwellings located in Sweden with different construction characteristics. Peuportier (2001) compared three types of houses with different specifications located in France. The sensitivity analysis was based on the selection of other construction materials, the type of heating energy and the transport distance of the materials. *Jian* et al. (2003) analyzed the LCA of an urban project development (District of Hyogo, Japan) calculated the emissions during construction, maintenance and operation. Arjen et al. (2006) studied the total amount of building materials which humans were exposed to, in the use phase of a Dutch home.

Life Cycle Assessment methodology is applied to a block of flats located in Barcelona, Spain, to evaluate environmental impacts during the construction Phase (Ortiz, 2009α). The aim of this project was to develop and apply several criteria for the building sector that help decision-making at the design and construction stages.

LCA has been applied within the residential building sector of two buildings, one in Spain and one in Colombia (Ortiz, 2009b). The aim of this project was to involve the environmental loads and compares operational energy during operational activities. The conclusions focus on that the final energy consumption varies from country to country due to the use of domestic technology and also there are factors that limited the energy consumption, such as availability and prices of fuels, appliances, disposal income of householders and cultural patterns.

Verbeeck (2010) presents the results of a contribution analysis of the life cycle inventory of four typical

Belgian residential buildings. The analysis shows the relative small importance of the embodied energy of a building compared to the energy consumption during the usage phase.

While in some studies (Blengini, 2010) it has been confirmed that operation energy is by far the most important contributor to life cycle impacts of conventional buildings, it has been pointed out that, especially for new and low-energy buildings, the relative weight of the remaining life cycle phases is sensibly more important.

4.2.2 LCA for commercial constructions

The first attempt on complete LCA of office buildings (Kofoworola et al., 2008) appeared in 2003. *Junnila* (2004) studied a construction of an office building of 2400 m^2. *Scheuer* et al. (2003) applied LCA to a new university building campus with a total area of 7300 m^2. The operation phase showed 97.7% consumption of the primary energy.

Koroneos (2007) presented the environmental performance of an office building in Athens, Greece, studing the construction and use phase. The use phase contributes by almost 90% to the total environmental score, while the global warming potential is the environmental impact with the largest contribution to the overall score.

A typical commercial building in Thailand is studied (Kofoworola, 2008), covering the whole life cycle (production- construction to demolition). The results showed that steel and concrete are the most significant materials in term of quantities and in their environmental impacts at the phase of manufacture. The principal contributor to impacts during use stage was emissions related to fossil fuel combustion (especially for electricity).

Also a few studies have been published on the LCA comparison of steel and concrete office buildings (Su, 2007). Lower energy consumption and environmental emissions are achieved by the concrete – framed structure on the whole life cycle.

4.2.3 LCA for engineering constructions

LCA have been used in other civil engineering projects (Ortiz, 2008,). For example, Highway constructions, Birgisdottir (2006) and Mroueh (2001)

5. LCA tools

During the last years (Haapio et al, 2008) beside generic LCA tools (LCA software applications that are not specific to the building sector), several tools specific to the building sector have been proposed. A comprehensive description and comparison of both existing general LCA tools and building-specific tools, can be found in Ortiz et al. (2009b).

Both kinds of tools are worldwide used, though they both have advantages and drawbacks.Also many authors developed their own tools, retrieving information from several sources.

There are two well-known classification systems for the environmental assessment tools. One was developed by the ATHENA Institute (Trusty, 2000), and the other by IEA Annex 31 (2001).

The ATHENA (Trusty, 2000) Institute has introduced a classification system "Assessment Tool Typology" (referred to later as ATHENA classification) which has three levels:

Level 3 is called ‘‘Whole building assessment framework or systems" and consists of methodologies such as BREEAM (UK), LEED (USA), SEDA (Aus);

Level 2 is titled ‘‘Whole building design decision or decision support tools" and uses LISA (Aus), Ecoquantum (NL), En vest (UK), ATHENA (Canada), BEE (FIN);

Finally level 1 is for product comparison tools and includes Gabi (GER), SimaPro (NL), TEAM (Fra), LCAiT (SE).

In the project IEA Annex 31 "Energy related environmental impact of buildings" the assessment tools are categorized into five classes (IEA Annex 31, 2001). The classification system is combined with the ATHENA classification system:

1. Energy Modeling software
2. Environmental LCA Tools for Buildings and Building Stocks
    - Level 1: BEES 3.0 and TEAM™
    - Level 2: ATHENA™, BEAT 2002, BeCost, Eco-Quantum, Envest 2, EQUER, LEGEP® and PAPOOSE
    - Level 3: EcoEffect and ESCALE
3. Environmental Assessment Frameworks and Rating Systems
    - Level 3: BREEAM, EcoProfile, Environmental Status Model and LEED®
4. Environmental Guidelines or Checklists for Design and Management of Buildings
5. Environmental Product Declarations, Catalogues, Reference Information, Certifications and Labels.

6. An Office Builing in Greece

A Life Cycle Assessment methodology is applied to an office building located in Greece.

6.1 Goal and Scope

The goal of this study is to estimate the environmental impacts of a small-size office building in Greece. Fig. 1 shows the layout of the studied building. Its basic parameters are shown in (Table 1). The materials used for the building structure as well as the envelope are mostly reinforced concrete and bricks.

Table 1: Basic parameters of building case study

Building parameters	*Specifications*
Levels	Ground floor and first floor
Ceiling Height	3.0 m
Service Life	80 years
Floor area	175sq.m
Structure	Reinforced concrete
Envelope	Brick
Foundation	Concrete
Walls (interior)	Brick
Floors	Cast in place concrete
Roof	Flat roof, concrete

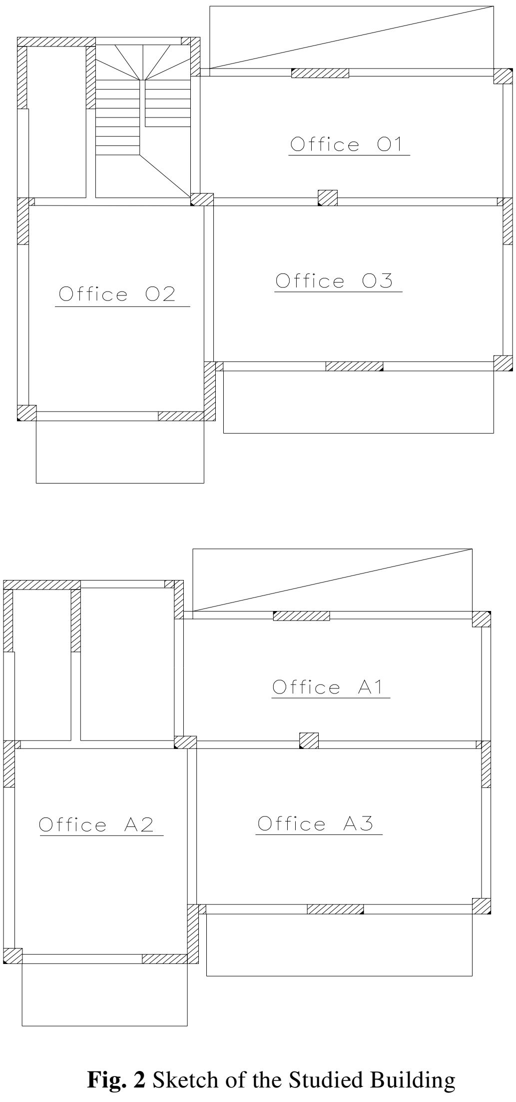

Fig. 2 Sketch of the Studied Building

6.1.1 System Boundaries

The system studied includes the entire life of the building, including:

- manufacturing of building materials and construction (Construction Phase)
- operation and maintenance (Use Phase) and
- demolition (End life Phase).

6.1.2 Functional unit

The functional unit for this estimation was defined as the unit of a 1 sq.m of the building. The case study building is a 2-story building in Greece. It cooled by centrally located HVAC equipment. Electricity from the national grid is the only operating energy used by all systems in the building.

6.2 Data origins and LCI (Inventory Analysis)

Creating the life cycle inventory (LCI) involves

- collecting data for each unit process regarding all relevant inputs and outputs of energy and mass flow,
- as well as data on emissions to air, water and land.

This Inventory Analysis includes data collection and the compilation of the data in a Life Inventory (LCI) Table. The data for each process can be described as follows: energy inputs, raw material input ancillary inputs, other physical inputs, products, co-products, wastes, emissions to air- water-soil, and other environmental aspects. The major sources of information about the types and quantities of materials and system components of the building (data for raw material input are based on the experience and the calculations of the author as a Civil Engineer. The energy inputs are based on literature review.

Before calculating the Cycle Inventory, the following three steps should be completed:

- Data Validation.Validating the collected data in a continuous process
- Relating Data to Unit Pocesses.
- Relating Data to Functional Unit.

The LCI of the Whole product system (building) is the sum of LCIs of all involved processes. An LCI requires a lot of data. Setting up inventory data can be one of the most labour- and time-intensive stages of an LCA. In order to facilitate the LCI and avoid duplication in data compilation, many databases have therefore been developed in the last decades. These include public national or regional databases, industry databases, and consultants' databases that are often offered in combination with LCA software tools.

National or regional databases (Finnveden, 2009) which evolved from publicly funded projects, provide inventory data on a variety of products and basic services that are needed in every LCA, such as raw materials, electricity generation, transport processes, and waste services as well as sometimes complex products. Several national and international public databases have been released in the past, among them the Swedish SPINE@CPM database (CPM, 2007), the German PROBAS database (UBA, 2007), the Japanese JEMAI database (JEMAI, 2007), the US NREL database (NREL, 2004),the Swiss ecoinvent database (Ecoinvent, 2007) and the European Reference Life Cycle Database (European Commission, 2007a). Further databases are currently under development all over the world. Also commercially available LCA-software as Emis, PEMS, Regis, Simapro, Gabi and TEAM are used as local databases.

The LCI of the studied Office is calculated using the GaBi database

6.3 Assesing the Life Cycle Impacts (LCIA)

The Life Cycle Impact Assesment (LCIA) identifies and evaluates the amount and significant of potential environmental impacts using the LCI.The inputs and outputs are first assigned to impact categories and their potential impacts qualified

This phase consists of three mandatory elements:

- selection of impact categories,
- assignment of LCI results (classifications) and
- modeling category indicators (characterization).

Classification of the LCI results (koroneos, 2007) involve assigning the emissions, wastes and resources used to the impact categories chosen. The converted LCI results are aggregated into an indicator result, which is the final result of the mandatory part of an LCIA. *Characterization* describes and quantifies the environmental impact of the analyzed product system. After assigning the LCI results to the impact categories, characterization factors have to be applied to the relevant quantities. The characterization factors are included in the selected impact category methods like CML, TRACI, etc. Normalization, grouping, weighting (valuation) are optional steps.

In a life cycle impact assessment (LCIA), there are essentially two methods:

- problem-oriented methods (mid-points) and
- damage-oriented methods (end points)

The *mid-points approach* involves the environmental impacts associated with climate change, acidification, eutrophication, potential photochemical ozone creation and human toxicity and the impacts can be evaluated using the CML baseline method (2001*)*, EDIP 97& EDIP 2003 and IMPACT 2002+. The end points approach classifies flows into various environmental themes, modeling the damage each theme causes to human beings, natural environment and resources. Ecoindicator 99 and IMPACT 2002+ are methods used in the damage-oriented method.

In this paper, the CML baseline method (2001) is used, while the steps of normalization, grouping, and weighting (as optional steps) are skipped.

6.4 Interpretation

The last stage of ISO 14040 is the interpretation. This stage identifies significant issues, evaluates findings and formulates recommendations. The final report is the last element to complete the phases of LCA

7. Results

Analysis of the manufacturing phase and construction indicates that steel reinforcement concrete and bricks is the most significant materials in terms of their associated environmental impacts as it accounted for about 87.76% and 10,80% respectively of the global warming potential originating from the production of basic materials utilized for the building (Fig. 4). Figure 4 also presents the construction phase acidifying gases emissions. The biggest contributor to this pollutant is the steel reinforcement concrete and bricks (CO_2: 91.06%, 7.55% respectively, SO_x: 56.23%, 43.53% respectively and NO_x: 87.76%, 10.80 respectively).

The dominance of this materials could be attributed to their utilization in very large quantities as revealed by an analysis of the quantities of basic materials supplied for the construction of the building (Fig. 3) Concrete accounted for about 72.50% and 11.60% respectively of the material mass of the building. Steel is ignored as a single material- product of reinforcement concrete.

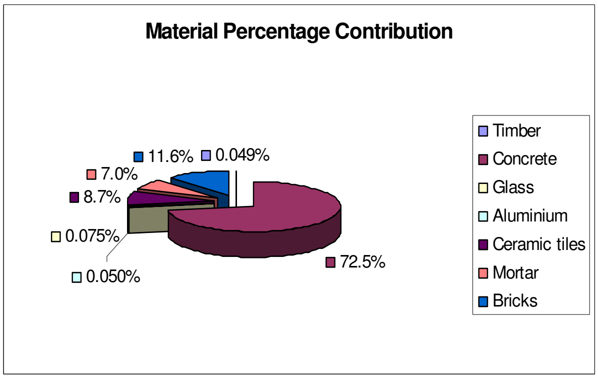

Fig. 3: Material Percentage Contribution by material mass

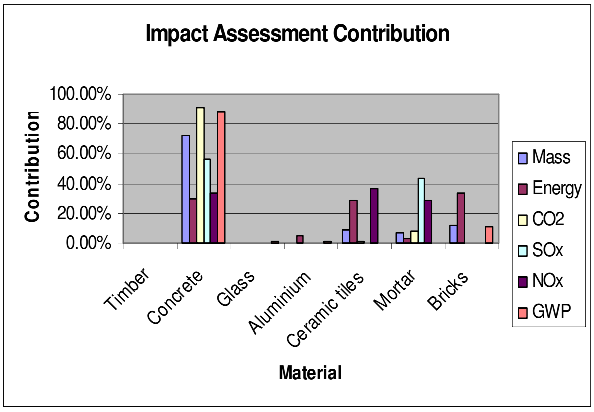

Fig. 4: Impact Assessment Contribution (Construction Phase)

Figure 5 and 6 shows the Impact Contribution (according to categories) at the phases of Use and Demolition. GWP has the greatest contribution in both phases.

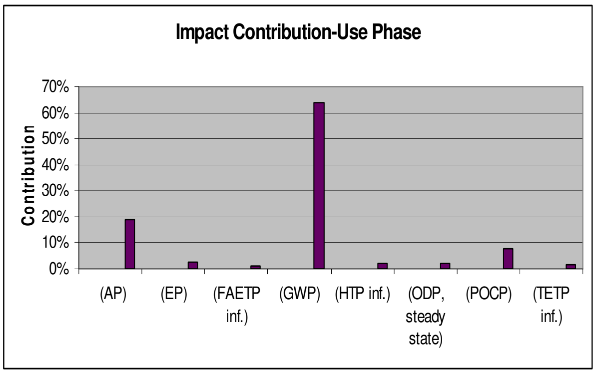

Fig. 5: The Environmental Impact Contribution of the building at Use Phase

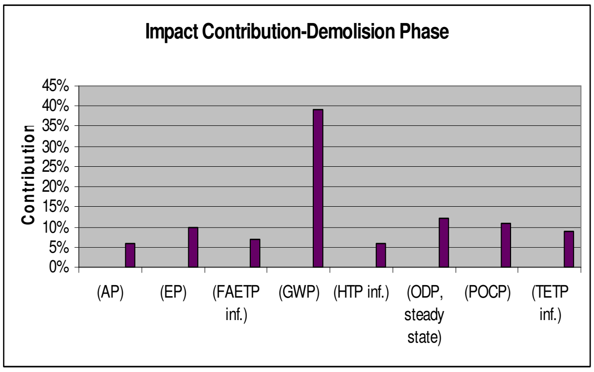

Fig. 6: The Environmental Impact Contribution of the building at Demolition Phase

The total life cycle emissions according to each life cycle stage were determined. The results showed that the use phase (operation and maintenance stage) activities account for about 65.19% of consumption energy, for about 51% of the life cycle GWP, and for about 70% of ACP (figure 7 and 7a). The construction phase (manufacturing building materials and construction) activities account for about 32.51% of consumption energy, for about 45% of the life cycle GWP, and for about 30% of ACP. The demolition phase has the smallest contribution in the environmental impacts in the life cycle of building (2.26% of consumption energy, 4% of the life cycle GWP, and almost 0% of ACP).

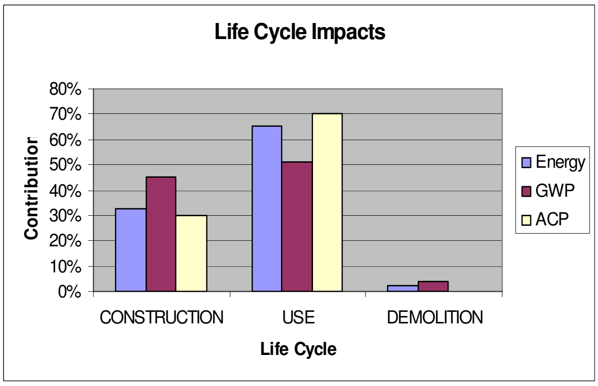

Fig. 7: The Environmental Impact Contribution of the building Life Cycle

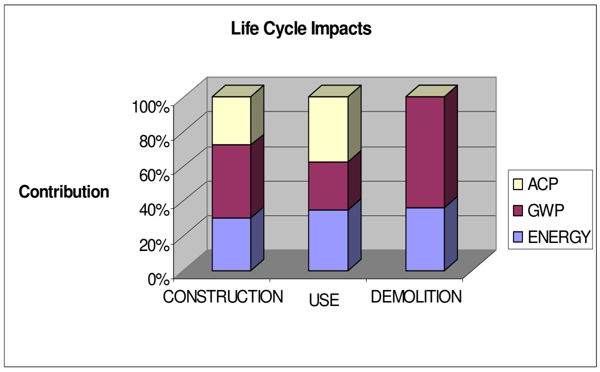

Fig. 7a: The Environmental Impact Contribution (cumulative model) of the building Life Cycle

8. Conclussions and Discussion

Humankind has no chance to survive on this planet unless a sustainable development is achieved; *sustainability* has to be established at all levels. Men have to focus to the relative modest aspect of products, including processes. Progress can be made, step by step, without direct political influence but not without the economy. Since no development can be stable at the long run without social justice, SLCA has also to be developed. LCA is well explained, and its methodologies are well established and accessible to users, but there are still many impediments to its use for buildings, and these set the research agenda for the future.

The main problem is the complicated production process of the building, and its life span which is long with future phases based on assumptions. There is little standardization within the building sector, so there is a clear lack of data inventory. Researchers are working hard to overcome this problem, but the nature of the building industry makes it difficult to have an international dataset available for all users, which can make the life-cycle assessment studies comparable. There should be an internationally accepted framework, protocol, and conversion tools based on different factors, to enable the comparison between one LCA study and another. The currently available datasets are typically not transparent, and most of them are based on local and simple materials but not components or composites. There is a need to produce accurate local datasets with the possibility to convert their results to an internationally comparable form.

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Environment – Climate Change

Ventilation Air Methane – Converting a Greenhouse Gas into Energy

Prof. Krzysztof WARMUZINSKI[1]
Director of the Institute of Chemical Engineering

Dr hab. Krzysztof GOSIEWSKI
Dr Marek TANCZYK
Dr Manfred JASCHIK
Aleksandra JANUSZ-CYGAN, M.Sc.

[1]Contact details of the corresponding author
Tel: +48 32 234 6915
Fax: +48 32 231 0318
e-mail: kwarmuz@iich.gliwice.pl

Address: Polish Academy of Sciences, Institute of Chemical Engineering, ul. Baltycka 5, 44-100 Gliwice, Poland

Abstract: Although the largest contributor to global climate change is carbon dioxide, the role of methane is substantial and is expected to rise in the coming years. One of the principal sources of anthropogenic methane emissions is coal mining, with the major share (around 70%) associated with underground ventilation. The present study explores three principal routes to deal with ventilation air methane (VAM): the use of VAM as combustion air in conventional boilers, the enrichment via membrane separation or pressure swing adsorption and, finally, oxidation in reverse-flow reactors. Each of the options is analysed in terms of the economic and technical feasibility, and its possible application in converting methane emissions into useful forms of energy. It is shown that the use of VAM as combustion air can indeed generate some profit. This depends on three basic parameters: CH_4 concentration in VAM, flow rate and distance from the boiler. On the other hand, the enrichment via membrane separation or pressure swing adsorption is by far too expensive if the concentration is to be increased to levels suitable for use in gas turbines or reciprocating engines. The most interesting technique seems to be the oxidation in reverse-flow reactors, either catalytic or non-catalytic. The latter case is discussed in more detail, and the results of extensive studies are presented which show that useful energy can be produced starting from methane concentrations as low as 0.4%.

Keywords: ventilation air methane, pressure swing adsorption, membrane separation, reverse-flow reactors

1. Introduction

Methane and coal are formed together during coalification, a process in which biomass is converted by biological and geological processes into coal. Methane is stored within coal seams and also within the rock strata surrounding the seams. Methane is released when pressure within a coalbed is reduced as a result of natural erosion, faulting or mining. Deep coal seams tend to have a higher average methane content than shallow coal seams, since the capacity to store methane increases as pressure increases with depth. Accordingly, underground mines release substantially more methane than surface mines per tonne of coal extracted. Estimates suggest that as much as 200 m^3 of methane per tonne of coal may be generated during the process of coalification. Some methane may also be generated by later biogenic action, particularly in coal seams which are relatively close to the surface. Whatever its source, most of this methane is subsequently lost by migration through the surrounding rock strata. However, undisturbed coal seams may still contain up to 25 m^3 of CH_4 per tonne of coal, adsorbed within the pore structure of the coal. This residual methane is emitted when the coal is mined and used.

Considerable amounts of methane are released into the atmosphere with coal-mine ventilation air (VAM). A single ventilation shaft may discharge several hundred thousand cubic metres of VAM per hour, and although the concentration of methane in these gas streams is rather low (usually below 1 vol.%), the emissions thus generated pose an environmental threat and lead to the loss of a potential source of energy.

The sources of coal-related methane emissions are shown in Fig.1.

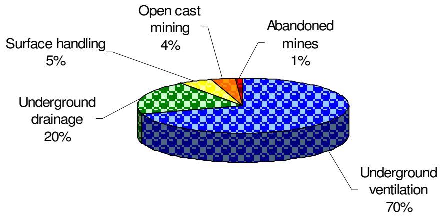

Fig.1. The sources of coal-related methane emissions

There are several ways in which methane emissions from ventilation air can be reduced. The first is to use ventilation air as the combustion air in surface installations at the mine site (Warmuzinski et. al., 2004, Warmuzinski, 2008). However, this approach is unlikely to use more than a small proportion of the total available. A second approach is to enhance the methane content in the ventilation air using one of several membrane- or adsorption-based techniques (Warmuzinski et al., 2001). Unfortunately, methane is not strongly adsorbed on any of the commercial substrates currently in use. This technique could, however, be considered as a means for obtaining a relatively small increase in concentration required for stable incineration. Finally, methane can be oxidised to CO_2 in a reverse-flow reactor, either catalytic or non-catalytic (Gosiewski et al., 2008). Simple flaring is not viable, since the concentration of methane in ventilation air is too low to support combustion. Addition of further fuel would remedy this but the overall effect would be to increase the total emission of greenhouse gases. Thermal incineration may be more practical, although the calorific value of ventilation air is typically around the minimum required for self-sustaining operation. The more recent technology of catalytic incineration could ease this by reducing the required operating temperature, although catalyst poisoning may be a problem.

The principal objective of the present study is to demonstrate in more detail the advantages and drawbacks of the various options for utilizing VAM and to assess these options in terms of both technical feasibility and economic viability.

2. The utilization of ventilation air methane in existing boilers

One of the obvious alternatives for the utilization of VAM is combustion in existing boilers situated at a reasonable distance form a ventilation shaft (Warmuzinski et al., 2004). An additional amount of energy thus introduced decreases the amount of primary fuel that would otherwise be used to carry out the combustion. The method discussed does not require any special upgrading technique or complex equipment. The principal elements of the system include a blower/compressor and an insulated pipe connecting the source to the boiler.

This mode of utilization becomes profitable once the cost of the fuel replaced exceeds the total cost of the system. Fig.2 shows the profit for different methane concentrations in VAM and different distances between the ventilation shaft and the boiler. The calculations were done for a flow rate of 565,200 m^3 (STP)/h and an optimum velocity of VAM in the pipeline (16.6 m/s).

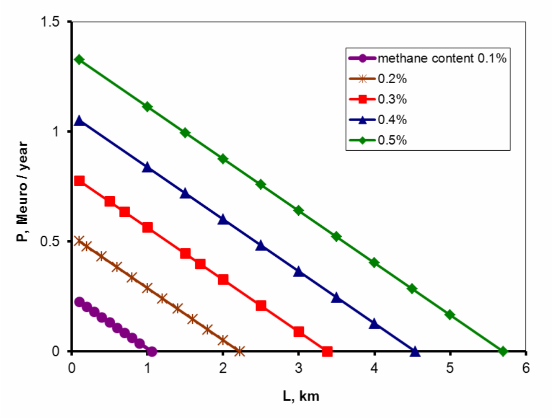

Fig.2. Profit vs. distance for the various methane concentrations in VAM

Fig.3 shows the break-even curves as VAM flow rate vs. length of the pipeline. (The discontinuity is due to a step change in the cost resulting from a step increase in the pipe thickness for diameters in excess of 2 m.) The area to the left of the curves shows parameters for which the whole exercise is actually profitable. Using such a graph is therefore a rapid and fairly accurate way for assessing the limiting values of the basic parameters involved (VAM flow rate, length of the pipeline and methane concentration) for which the use of VAM as combustion air becomes economically viable.

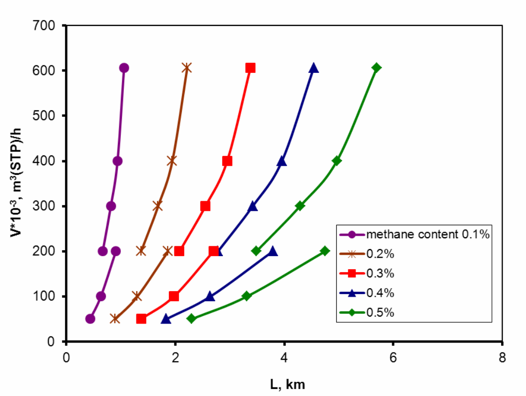

Fig. 3. Break-even curves for the utilization of VAM as combustion air

3. The enrichment of VAM via pressure-swing adsorption and membrane separation

The efficiency of heat recovery in a reverse-flow reactors strongly depends on the concentration of methane in the feed gas. As shown in Fig.4, over the range of concentrations prevailing in VAM a twofold increase in CH_4 content may raise the efficiency of a catalytic reverse-flow reactor by a factor of three. It might therefore be of interest to see whether the benefits of the enrichment outweigh the costs associated with a selected adsorptive or membrane process.

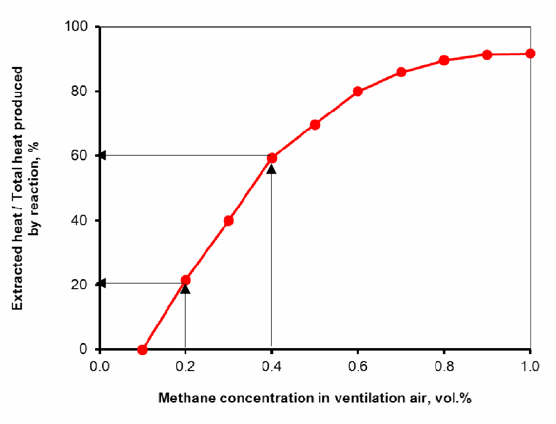

Fig. 4. Efficiency of the heat extracted as a function of methane concentration (Sapoundjiev, 2001)

The pressure-swing adsorption process is carried out in a two-column installation packed with carbon molecular sieves 5A (Warmuzinski et al., 2001). The simple pressure-swing cycle takes 26 min. to complete and includes pressurisation, adsorption, blowdown and purge. Methane is recovered as a low-pressure product during the countercurrent desorption step, and its concentration in the product is assumed to be twice that in the feed gas.

The calculations reveal that methane content in the feed over the range studied (0.25–1.5 vol.%) does not have any significant effect on the size of the installation. What really matters is the adsorption pressure—the higher the pressure, the lower the capital cost.

The operating costs include the costs of compression, maintenance and depreciation. Again, the principal parameter in terms of the cost is the pressure at which the feed leaves a compressor. Obviously, the operating costs increase with the pressure due to the increased cost of electricity. The total annual costs of the PSA enrichment as a function of the adsorption pressure are shown in Fig.5.

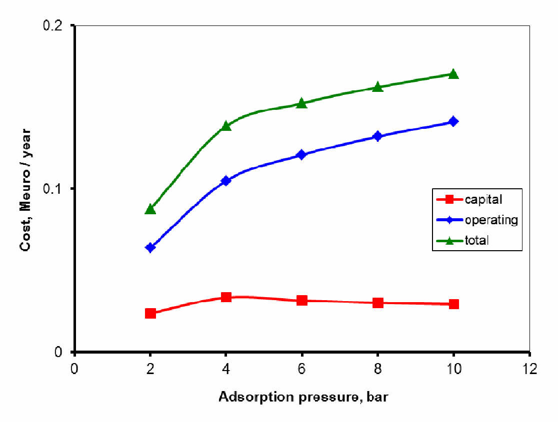

Fig. 5. Costs of PSA enrichment vs. adsorption pressure

If, however, the profit resulting from additional energy production in a reverse-flow reactor is compared with the costs incurred, it can be seen that these costs outweigh the profit by, roughly, an order of magnitude.

A survey of commercial membranes reveals that polydimethylsiloxane (PDMS) exhibits a reasonable selectivity vis-a-vis binary mixtures of methane and nitrogen. The ratio of permeation coefficients Q_{CH4}/Q_{N2} is, on the average, equal to 3.2. Our own experiments for a tubular PDMS membrane on polysulphone support yield Q_{CH4} = 7.38 x 10^{-11} kmol/m^2 s Pa and Q_{N2} = 2.21 x 10^{-11} kmol/m^2 s Pa. Thus, the ideal separation coefficient is 3.34, and it is this value that was employed in further calculations. The permeate flow rate was assumed to be equal to the flow rate of the low-pressure product in the PSA system. If, further, CH_4 concentration in VAM is 0.5 vol.% and the feed pressure is 1 bar, it is possible to calculate the membrane area necessary to effect a required separation and the associated costs for the varying permeate pressure and the methane content in the permeate. These calculations show that the total annual cost is virtually independent of the methane content in the permeate (over the range studied, 0.6–1.0 vol.%), and increases with an increase in permeate pressure (by around one third when the vacuum level increases from 33 to 250 mbar). As can be seen in Fig.6, the total annual cost, although higher than that for the PSA enrichment, is of the same order of magnitude (provided we base our comparison on the same amount of the product and the same degree of enrichment). However, the structure of the costs is totally different, with capital cost prevailing in the case of membrane separation, and operating costs predominating in pressure-swing adsorption.

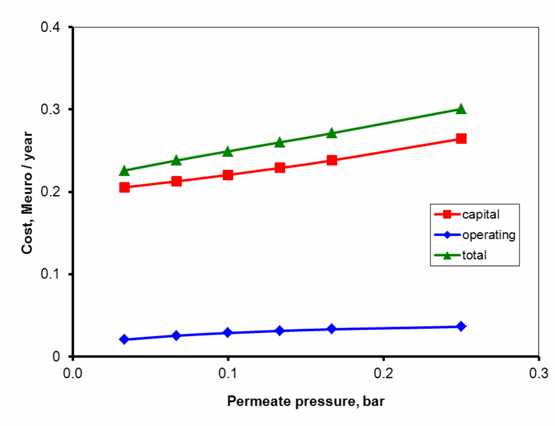

Fig. 6. Costs of membrane enrichment as a function of permeate pressure

An increase in the capital cost with increasing permeate pressure (at a constant feed pressure) is due to an increase in membrane area: if the pressure is changed from 33 to 250 mbar, the membrane area rises 1.3 times, with almost the same rise in the capital cost.

The principal conclusion is much the same as in the case of the PSA process: some profit resulting from an increased heat production in a reverse-flow reactor is only a fraction of the costs associated with the preconcentration. We have to bear in mind, however, that there is an environmental advantage, however difficult to quantify, of utilizing larger amounts of methane that would otherwise be discharged into the atmosphere.

4. Oxidation of VAM in reverse-flow reactors

An interesting option for the utilization of VAM with the simultaneous production of heat is the oxidation in reverse-flow reactors, either catalytic or non-catalytic (Warmuzinski et al., 2006). So far, the most attractive option has seemed to be that based on catalytic combustion in a CFRR (catalytic flow-reversal reactor) (Gosiewski et al., 2008). However, the large-scale implementation of this technique may prove problematic. The concentration of methane in ventilation air may reach 1% and, with the use of the manganese catalyst, the temperature of the catalytic bed may exceed 900°C for CH_4 concentrations above 0.8%, even for highly efficient removal of heat from the reactor. Thus, the relatively cheap Mn catalyst may undergo rapid destruction. If the more expensive palladium catalyst is employed, the temperature can be kept at a level lower by about 100°C. Unfortunately, the heat recovery also becomes considerably lower and the cost of the Pd catalyst leads to a payback period of almost 7 years for an industrial plant. Thus, non-catalytic reverse-flow combustors (TFRRs) offer a clear advantage over CFRRs, although materials of construction will be more expensive.

The relevant experiments were conducted in a large laboratory vessel packed with non-catalytic monolith blocs, at an inlet flow rate of 400 m^3 (STP)/h. The scheme of the experimental TFRR is presented in Fig.7.

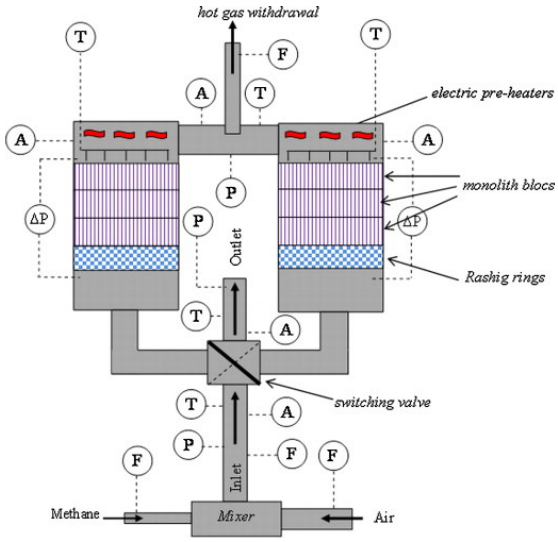

Fig. 7. Scheme of the experimental non-catalytic reverse-flow reactor

The results reveal, among others, that the cyclic steady state can be sustained for inlet methane concentrations above 0.2 vol.%. More importantly, useful energy can be produced starting from methane content as low as 0.4 vol.%. The CH_4 conversion was almost complete, and neither carbon monoxide nor nitrogen oxides were detected in the outlet gas.

5. Summary and conclusions

Large quantities of methane are exhausted into the atmosphere with coal-mine ventilation air with very low CH_4 content (0.1–1 vol.%). The global emissions of methane from this source are estimated at, roughly, 15 Mt/year. Apart from the environmental impact, this leads to considerable energy losses, as methane is a fuel in its own right. In the studies carried out in the Institute of Chemical Engineering, Polish Academy of Sciences, three principal routes for utilizing ventilation air methane were explored: using VAM as combustion air in conventional boilers, enriching VAM (via pressure-swing adsorption or membrane separation) and oxidizing VAM in reverse-flow reactors.

The use of VAM as combustion air in existing conventional boilers was analysed in terms of four principal parameters: net profit resulting from a decreased fuel consumption, concentration of CH_4 in VAM, the distance between the source and the boiler, and VAM flow rate. It is found that the use of VAM can still generate some profit for transportation distances as long as 4–5 kilometres.

A rise in methane content in the feed may considerably increase the efficiency of heat production in either CFRRs or TFRRs. Therefore, total annual costs were evaluated for the enrichment of mine ventilation air in methane using pressure-swing adsorption or membrane separation. A wide range of the operating parameters (including CH_4 concentration in the feed gas, flow rates, enrichment degree, adsorption pressure and permeate pressure) was analysed. It is revealed that the cost of the membrane separation is of the same order of magnitude as that of the PSA process. However, the structure of the costs is altogether different, with a much larger share of the capital cost and a much lower proportion of the operating cost in the case of membrane permeation. Finally, the profit resulting from an increased heat production in a catalytic flow-reversal reactor is found to only partly offset the cost of the enrichment.

Finally, both catalytic (CFRR) and homogeneous (TFRR) reverse-flow reactors were investigated. Simulations and experimental studies reveal that CFRRs are characterized by relatively high operating temperatures which may lead to a rapid deactivation of the catalyst. Therefore, non-catalytic oxidation in TFRRs was studied in more detail. The results clearly demonstrate that TFRRs can become an attractive alternative to CFRRs, provided reasonable values of the operating parameters and a suitable mode of heat withdrawal are selected.

Nomenclature

L – distance, km

P – net profit, Meuro/year

V – VAM flow rate, m^3(STP)/h

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Laser Induced Tropospheric Ozone Control

Dr. Nathanail KORTSALIOUDAKIS[1] (Corresponding Author)
Senior Researcher at Matter Structure and Laser Physics Laboratory
Tel: +30-28210-37716
e-mail: nathan@science.tuc.gr

Dr. Stelios TZORTZAKIS[2] (Co-author)
Head of Ultrashort Nonlinear Laser Interactions and Sources (UNIS) Group at IESL- FORTH

Assoc. Professor Stavros D. MOUSTAIZIS[1] (Co-author)
Director of Matter Structure and Laser Physics Laboratory

Addresses
[1] Department of Sciences - Physics Division, Technical University of Crete, Chania GR-73100, Crete, Greece
[2]Foundation of Research and Technology Hellas, Institute of Electronic Structure and Laser, P.O. Box 1527, Heraklion GR-71110, Crete, Greece

Abstract: A novel idea of controlling the ozone concentration in the troposphere by applying ultraviolet short laser pulses is proposed. The study involved: i) one experimental scheme of nanosecond pulses at 308 nm used for system calibration purposes and ii) two experimental schemes of femtosecond pulses at 248 nm by altering the conditions of beam propagation: a) linear (unfilamented) propagation and b) nonlinear (filamented) propagation. All schemes were performed in an ozone enriched atmospheric air environment under standard conditions of air pressure, temperature and humidity. The results showed ozone photolysis by femtosecond laser pulses at 248 nm is occurring about 7 times faster compared to the nanosecond pulses at 308 nm using same experimental conditions and energy amount per pulse. In addition the results are in a very good agreement both at 308 nm and 248 nm between predicted and experimental values within an uncertainty of 5% and 11% respectively. Finally the study of ozone photolysis by femtosecond pulses at 248 nm revealed a 25% faster time on ozone decomposition for the filamented scheme in comparison to the unfilamented one. This effect is believed to be due to the presence of electron density produced during the filaments formation, which accelerate the decomposition of ozone molecules by the electron impact collisions, while in the unfilamented case where only photolysis is occurred the electron density is negligible.

These results allow us to propose a new method based on the nonlinear propagation of ultrashort laser pulses under filamentation formation for tropospheric ozone control.

Keywords: Climate Change, Atmospheric Pollution, Tropospheric Ozone Control

1. Introduction

Global warming and ozone layer depletion are the major examples that mankind has severely influenced the Earth's climate and environment, mainly achieved by an unintended consequence of the unreasonable use of fossil fuels. But, what if scientists could alter the weather on purpose?

Purposeful local weather modulations, as well as broader attempts to "geo-engineer" climate change, are topics that are being intensively debated - most of time with a lot of skepticism-within the scientific community and to some extent among the public due to its relation with conspiracy theories and military applications aspect.

Despite the criticism, such a possibility could imply invaluable economic and social consequences. For example, imagine if modern technology could be used to format rain clouds in drought-stricken areas by cloud water condensation, or to attenuate a monsoon and thus reduce a flood in a certain area by using the reverse technique or even reduce pollutants, like CO, NO_x and O_3 emissions, above highly polluted urban areas. These examples show the high impact that could have and the benefits for agriculture, food growth and public safety.

The advent of ultrashort laser pulses and the discovery of self-guided ionized filaments (Braun et al,1995) opened new perspectives in the domain of weather modulation.

In very recent research studies (Kasparian et al, 2012; Henin et al, 2011; Petit et al, 2011; Rohwetter et al 2010) a mechanism of laser-assisted water condensation is suggested, using field experiments which conducted under various atmospheric conditions, in order to demonstrate that laser filaments can induce water condensation and fast droplet growth up to several μm in diameter in the atmosphere as soon as the relative humidity exceeds 70%.

Following the philosophy of this rather radical approach, we are proposing the idea pollution regulation by reducing the tropospheric ozone (O_3) concentration applying ultraviolet laser pulses under filamentation, causing ozone photodissociation (photolysis). State of the art, mobile lasers units like e.g. *Teramobile* (Méchain et al 2005; Rairoux et al 2000; Wille et al 2002; Kasparian and Wolf, 2008) are easily transferred in the area of interest above the source of pollution, in order to detect and (why not?) control tropospheric pollution.

Tropospheric ozone is a global air pollution problem and an important greenhouse gas. Although not a new issue, ground level ozone remains one of the most pervasive of the global air pollutants, with impacts on human health, food production and the environment. At the global scale, ozone pollution is highest in Central Europe, Eastern China, and the Eastern USA. In Europe, the highest ozone levels occur in Central and Southern Europe. High ozone levels also occur in the tropics and are often associated with biomass burning.

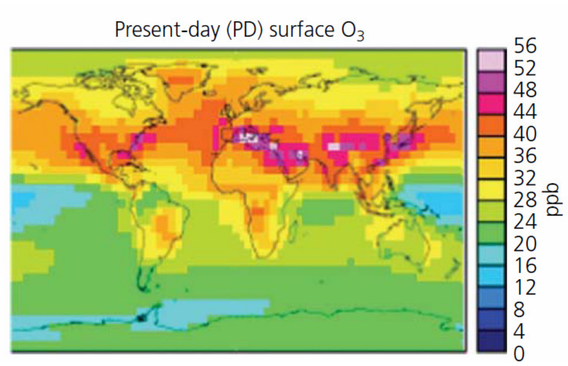

Figure 10: Multi-model mean surface layer annual mean O3 (ppb) is presented for the present day (PD). *Source: The Royal Society Science Policy Report 2008: "Ground-level ozone in the 21st century: future trends, impacts and policy implications"*

For the above reasons, our work was focused on tropospheric ozone as it has been denoted as one of the most harmful forms of pollution, causing respiratory problems especially above highly populated urban environments with massive traffic and heavy industry activities (Rappengluck et al, 2004). This pollutant is difficult to regulate, mainly because it is not emitted directly into the air. Instead, it forms in the atmosphere when nitrogen oxides and volatile organic compounds react in the presence of sunlight. Thousands of anthropogenic sources contribute to tropospheric ozone, including exhaust of transportation media and chemical solvents. Emissions from natural sources also play a role. Understanding tropospheric ozone photochemistry dynamics (Matsumi and Kawasaki, 2003) and its role on the catalytic cycle of other environmental pollutants such as CO, NO_x, CH_4, e.t.c., is in great interest of environmental sciences. Due to its local formation above areas such as motor highways or industry plants, the photodissociation of ozone by conventional means is a rather difficult, expensive (e.g. using air filters) and sometimes unsafe procedure (e.g. airborne spread of chemical substances). Therefore, the idea of a cost effective, public-safe technique in order to achieve local appliance of ozone photodissociation is under consideration and table top ultrafast lasers is a proposed solution. The spectral region that this could be effective is in the UV (190-330 nm) as it can be seen in Figure 11, since ozone can be easily photolysed there.

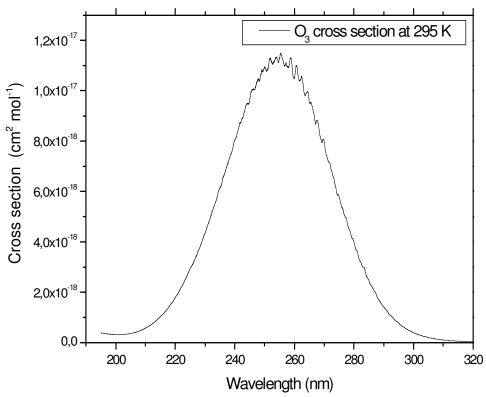

Figure 11: Absorption spectrum of ozone in the ultraviolet region (Data retrieved from the work of Malicet et al 1995)

Laser sources that can be used for photolysis purposes in this specific spectral region are excimer lasers such as KrF at 248 nm and XeCl at 308 nm. The pulse duration of these lasers vary from short (nanosecond - 10^{-9} sec) to ultrashort (femtosecond - 10^{-15} sec). As the pulse goes shorter, the intensity increases (> 10^{11} W/cm^2) and also electronic density (>10^{15} cm^{-3}) getting relatively high (Tzortzakis et al, 2001), and therefore a higher photolysis rate meaning faster ozone photodissociation. Another very important advantage of ultrashort laser pulses is the long propagation distance (up to a few km) of a focused beam due to the nonlinear phenomenon of filamentation, which is the key factor on propagating a laser beam to the troposphere (Rairoux et al, 2000; Kasparian and Wolf, 2008).As described in the work of Wille et al,2002, the idea of high intensity ultrashort laser pulses propagation in the atmosphere was tested as a unique and powerful tool concerning the detection and the monitoring of different pollutants in the atmosphere. Study of tropospheric ozone is conducted since early 1970s as described in the study of Crutzen, 1973: ozone formation in the troposphere takes place via sunlight photodissociation on nitrogen dioxide (NO_2). The nitrogen dioxide is split up into an excited oxygen atom O (^{1}D) and nitric oxide (NO) by the photolysis. The rate of photodissociation is strongly dependent on the sunlight intensity and cannot take place during nighttime (Figure 12).

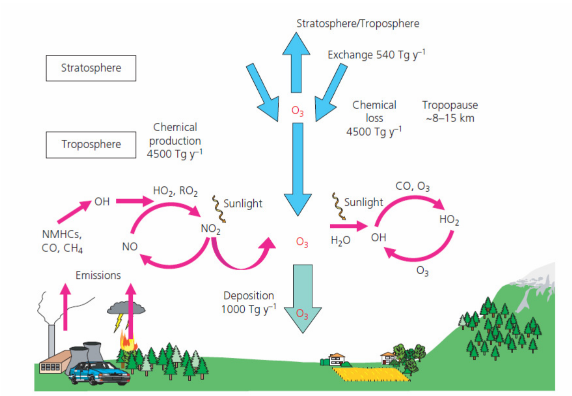

Figure 12: Formation of tropospheric ozone

The photodissociation of ozone in the troposphere is achieved by ultraviolet photolysis mostly in the Hartley bands for λ<310 nm with almost 90% efficiency and in the Huggins bands for λ>310 nm with 10% efficiency (Sarwaruddin Chowdhury, 1998). The most efficient reaction where the ozone molecule splits into molecular oxygen (O_2) and excited atomic oxygen $O(^1D)$ is describing by the following reaction:

$$O_3 + h\nu\ (\lambda < 310\ \text{nm}) \Rightarrow O(^1D) + O_2(^1\Delta_g)$$

This reaction is responsible for the production of OH radical via the rapid reaction of $O(^1D)$ with water vapor and since this is the primary oxidant in the troposphere, accurate values of both ozone and OH radical concentrations and its correlated reaction processes with the other species (such as NO_x, CO, etc), are critical components of any model of tropospheric photochemistry. In our work, a laboratory study of ozone photochemistry including photolysis by pulsed laser using a 308 nm nanosecond laser and a 248 nm femtosecond laser was conducted. The 308 nm experiments were conducted mainly for calibration purposes. The experimental data and its fitting curves seem to agree well. Such information will lead to better understanding of this important pollutant and potentially assist in efforts to reduce it, by applying modern laser technology.

2. Experimental procedure

In order to study the photolysis of ozone, a laboratorial atmospheric simulator apparatus was built. The simulator was able to monitor in real time the variation of ozone concentration due to photolysis by applying ultraviolet laser pulses. The ozone was generated by a commercial electric discharge ozone generator (Anseros COM-SD-30 Ozone Generator). The apparatus of the simulator is described on Figure 13.

Ozone was produced by the electric discharge generator at atmospheric pressure and it was circulated at a flow rate of 4 lt/min into a closed circuit to reach in the detection area. The detection chamber was built by a 100 cm long, 1.4 cm in diameter quartz tube, sealed by quartz windows. The ozone concentration was measured by the well-defined optical absorption technique using the *Beer – Lambert* law. The measurement was obtained by using a pre-calibrated Hg lamp (Oriel Instruments, Hg-calibration lamp pencil-like, model 6035) at the wavelength of 253.65 nm and a XUV phototube (Hamamatsu XUV phototude, solar blind, model R765) which is almost monochromatic to that wavelength.

Due to very low signal (a few μV), a preamplifier was also used and the final signal was measured by a lock-in amplifier (Stanford Research Systems, Lock-in Amplifier model SR-510). Signal and data acquisition was possible by an output port of the lock-in amplifier which was connected with a laptop via RS-232 serial port. By this procedure both online monitoring of ozone concentration and data storage was achieved. The laser photolysis was accomplished by propagating the laser beam through the quartz tube. The measurement of ozone concentration via absorption signal was made in a direction perpendicular to the long axis of the quartz tube as it can be seen in Figure 13. For the implementation of the proof of concept lab experiments were performed into 2 different wavelengths in UV: 1) with a 308 nm nanosecond laser for calibration purposes and 2) with a 248 nm femtosecond laser. For this reason experiments conducted in 2 different locations with 2 different laser systems: at 1) Matter Structure and Laser Physics Laboratory – Technical University of Crete (TUC), Chania, Crete, Greece with a commercial Lamda Physik EMG 102 MSC XeCl (308 nm) excimer laser with pulse duration 20 ns FWHM, 1-20 Hz rep. rate and average energy 12 mJ/pulse and at 2) Ultraviolet Laser Facility, Institute of Electronic Structure and Laser, Foundation for Research and Technology- Hellas (FORTH) –

Heraklion Crete, Greece with a hybrid femtosecond excimer (KrF) oscillator-amplifier system in conjunction with a dye laser (Szatmari and Schafer, 1989) is used.

It produces linearly polarized pulses at 248 nm with duration of 450 fs and energy up to 10 mJ at a repetition rate of 1-10 Hz. The laser system consists of a double–chamber Lambda–Physik Excimer laser and an ultra–short dye laser system. The XeCl Excimer laser oscillator beam pumps a series of dye lasers to produce a sub–picosecond green (496 nm) laser pulse.

These pulses are frequency doubled in a nonlinear BBO crystal and amplified twice in the KrF cavity of the excimer laser. The final laser beam had a rectangular profile of 26 mm x 8 mm and a full divergence angle of 0.15 mrad.

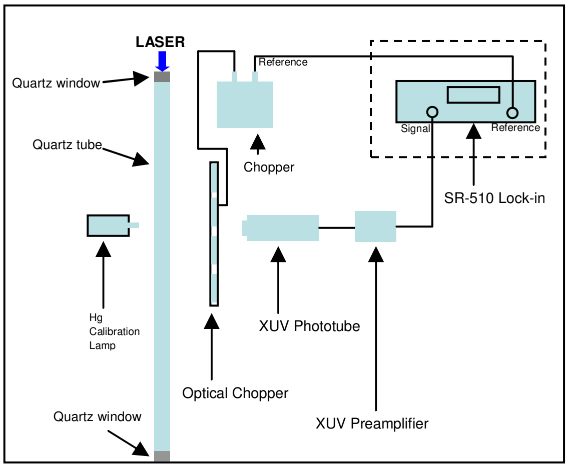

Figure 13: Simulator apparatus

3. Discussion - Results

The experiment apparatus was at first built at TUC for the first series of experiments and then it was transferred to FORTH for the second series of experiments.

3.1 Estimation of Ozone Photolysis Rate

The photolysis rate J_λ, is wavelength depended and proportional to cross section σ_λ (cm^2), quantum yield φ_λ and spectral radiation intensity I_λ (photons/sec cm^2): $J_\lambda = \sigma_\lambda \times \varphi_\lambda \times I_\lambda$.

In the below table (

Table 20) we calculated the estimated values of the ozone photolysis rate for both experimental setups. In the calculation of photolysis rate the effect of the relative humidity was taken into account. The relative humidity was varying from 50% to 60% according to measured values from room hydrometer. This gives a factor of 80% to 85% of loss of total produced ozone concentration due to the reaction of ozone with water vapor according to the specifications of the manufacturer of ozone generator (Figure 14).

Table 20: Estimated ozone photolysis rate for the experiments of this work

λ (nm)	**σ_λ (cm^2) x 10^{-20}**	**φ_λ**	**Pulse duration (sec)**	**E (mJ /pulse)**	**I_λ (photons /sec cm^2)**	**J (sec^{-1})**
248	1020 [235]	0.94 [236]	450 x 10^{-15}	4	4.41 x10^{16}	**4.65 x10^{-2}**
308	18.5 *	0.79 *	20 x 10^{-9}	12	1.64 x10^{17}	**3.55 x10^{-3}**

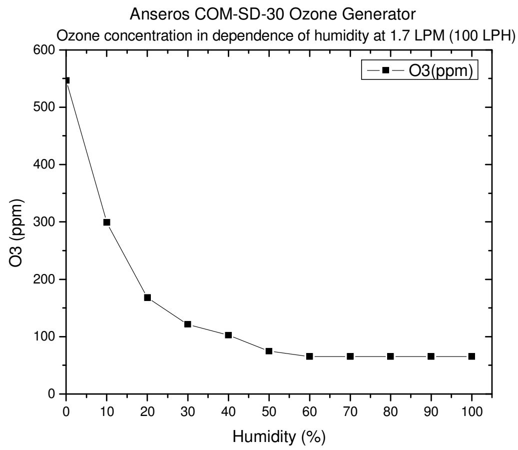

Figure 14: Ozone concentration in dependence of humidity

3.2 Photolysis at 308 nm

In Figure 15, the ozone photolysis at 308 nm experimental measurements and the best fitting curve is depicted. It can be clearly seen the results agree well. In y-axis the ozone concentration is normalized in order to compare with initial value at 3.2 x10^{16} mole/cm^3. The total time for the decomposition of ozone for the specific volume is about 1800 sec with pulse repetition rate at 10 Hz, average energy of 12 mJ/pulse. In addition, the photolysis rate from the experimental date is found to be: J_{O3}(308 nm)=3.38 x10^{-3} sec^{-1}. This gives a 5% uncertainty compared to the theoretical calculations (see

[235] Sarwaruddin Chowdhury, 1998
[236] Atkinson et al, 2004

Table 20), which shows a very good agreement in the data compared with estimated values.

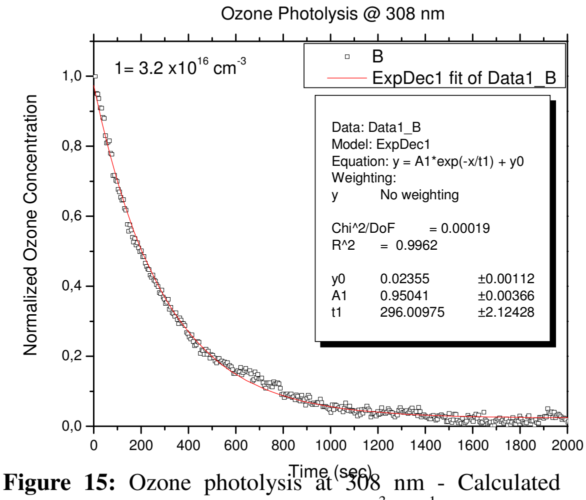

Figure 15: Ozone photolysis at 308 nm - Calculated photolysis rate: J_{O3}(308 nm)=3.38 x10^{-3} sec^{-1}

The relatively long time of ozone decomposition by laser photolysis at 308 nm can be explained theoretically by the small efficiency of the reaction (about 1%) of photolysis as well as of small absorptivity of ozone at the spectral region of 300-310 nm as it can be seen in Figure 11.

3.3 Photolysis at 248 nm

In this scheme, the photolysis of ozone was carried out by applying laser pulses at 248 nm. The experimental conditions (apparatus and initial concentrations) were similar to the case of 308 nm photolysis which was used for system calibration. The repetition rate of the laser was 10 Hz, and the energy was measured about 4 mJ/pulse. In this setup we studied: 1) the ozone photolysis by the unfilamented (unfocused) beam, and 2) the photolysis by the filamented beam. In the first case the laser beam was propagated in to the chamber without any focusing while in the second case the laser beam was focused by a lens of *f=+5 m* in order to achieve its nonlinear focus and filamentation conditions which occurs during propagation in non-linear media.

The filamentation is a result of the dynamic interplay between Kerr self-focusing and ionization-driven defocusing and it is well described physical process in the literature (Tzortzakis et.al., 2000). The term filamentation has been adopted as it describes well the spatial confinement of the self-guided laser beam over distances that extent well beyond the characteristic Rayleigh length.

In Figure 16 it can be shown the ozone photolysis at 248 nm experimental data in both focusing conditions (unfilamented and filamented) at pulse repetition rate of 10 Hz and energy of 4 mJ/pulse and its best fitting curves.

The time needed for the total destruction of ozone due to laser photolysis is about 250 sec at the unfilamented case and 200 sec and the filamented case which gives a factor of about 7 times faster than the photolysis at 308 nm and in addition a factor 25% faster time at 248 nm between the filamented and the unfilamented case.

Another noticeable difference between 308 nm and 248 nm photolysis is the curve shape. At 308 nm the experimental data were fitted by an exponential decay function but at 248 nm (both cases) the data were fitted by a sigmoid function (slogistic1) which is a typical function for autocatalytic reactions.

The autocatalytic behavior of ozone at 248 nm is well described in the literature (Slanger et al, 1998; Bao et al, 1995) and it is explained as follows: Although 248 nm radiation falls 0.12 eV short of the energy needed to dissociate O_2 large densities of ozone can be produced, even from unfocused 248 nm KrF excimer laser irradiation.

The process is initiated through weak two-photon O_2 dissociation, which results in a small amount of O_3 being generated. As soon as any O_3 is present, it strongly absorbs the 248 nm radiation and dissociates to vibrationally excited ground state O_2 (among other products), with a quantum yield of 0.1 to 0.15. During the laser pulse, a portion of these molecules absorb a photon and dissociate, which results in the production of three oxygen atoms for one O_3 molecule destroyed. Recombination then converts these atoms to O_3, and thus O_3 production in the system is autocatalytic. The phenomenon becomes stronger due to the presence of already formed O_3 generated from ozone generator.

The photolysis rates at 248 nm (both cases) are calculated by best fitting curve analysis and found to be: J_{O3} (248 nm-unfilamented)=4.11 x10^{-2} sec^{-1} with an uncertainty of 11% approximately, compared with estimated value (see

Table 20) and J_{O3} (248 nm-filamented)=3.01 x10^{-2} sec^{-1}. The latter result gives a factor of 25% faster photolysis at the filamented case which is a strong indication that this is due to filamentation effect.

In particular it is believed that the formation of electron plasma density which occurs during filamentation is the main mechanism behind this factor of 25% of faster photolysis. The electron plasma formation is order of 10^{11} e^-/cm^3 according to measurements of the laser system (Tzortzakis et al, 2001) which it may be low but it is enough to initiate electron impact reactions of ozone destruction.

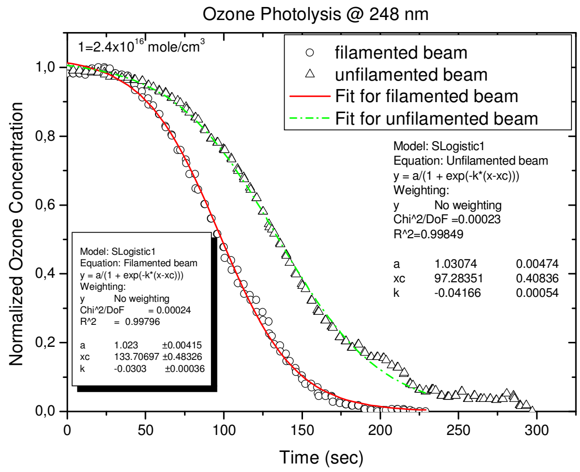

Figure 16: Ozone photolysis at 248 nm- The concentration of ozone in autocatalytic reactions cycle follows the logistic function which is used here for best fitting curve.

4. Conclusions

In this study, a new idea of reducing the concentration of tropospheric ozone by means of laser photolysis is investigated. Due to the local formation of ozone in the troposphere above highly polluted urban areas there is a lack of control in a global way. In the present work, ozone photolysis was carried out by applying ultraviolet laser pulses at wavelengths of 308 nm and 248 nm.

The results showed that ozone photolysis by laser pulses at 248 nm is occurring about 7 times faster compared to the 308 nm using same experimental conditions and same order of energy amounts per pulse which is verified by the cross section difference at these wavelengths. In addition the results are in a very good agreement both at 308 nm and 248 nm between predicted and experimental values within an uncertainty of 5% and 11% respectively. Finally the study at 248 nm revealed a 25% faster time of ozone decomposition for the filamented scheme compared to the unfilamented one. This effect is believed to be due to the presence of electron density produced during the filamentation formation, which accelerate the decomposition of ozone molecules by the electron impact collisions, compared to the unfilamented case where only photolysis is occurred and the electron density is negligible.

This work indicates that the above described method can be used for ground based applications in order to achieve local photolysis of tropospheric ozone. In particular, the present work showed that using nonlinear propagation scheme; more effective ozone photolysis can be achieved by means of faster time of decomposition by a factor at least 25% than the normal conditions of beam propagation. This factor can be increased by optimizing the laser system (high energy amount, shorter duration e.t.c.).

With these results, it can be claimed that having the appropriate laser system, is possible to control tropospheric ozone formation by laser photolysis. This can be achieved in real conditions by local appliance from a mobile laser unit with the proper characteristics.

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Determinants of GHG emissions from urban ground transportation: review on a sample of European cities

Edoardo CROCI
Research director, IEFE Bocconi (Corresponding Author)

Tel: +39-02-58-36-3814
Fax: +39-02-58-36-3890
e-mail: edoardo.croci@unibocconi.it

Address
IEFE - Centre for research on energy and environmental economics and policy, Bocconi University. Grafton Building, Via Roentgen 1, 20136 Milan, Italy

Co-authors:
Sabrina MELANDRI, environmental engineer
Tania MOLTENI, research fellow, IEFE Bocconi
Olha ZADOROZHNA, research fellow - IEFE Bocconi, Kyiv Economic Institute

Abstract: The responsibility of cities to global GHG emissions has rapidly grown in recent years and so their role in climate change mitigation policies. Emissions per capita differ considerably among cities. This difference depends on specific local features: climate, urban form, demographic features, economic activities in place, technology, mobility and housing infrastructures and prices, income and lifestyles of city residents and users. Mobility is one of the main activities generating urban GHG emissions. The mode and length of movements and the carbon efficiency of fuels and engines in motorized movements determine emissions. The purpose of this paper is to explore the socio-demographic, economic and spatial determinants of GHG emissions from urban mobility. The analysis is limited to European cities. A sample of 24 cities is taken into account. The analysis makes use of available data to evaluate through a linear regression the relevance of a set of variables in causing emissions.Results show that population density has a significant negative correlation with emissions, confirming previous literature. Relative prices of transport modes also appear to be among the most relevant determinants. The results provide relevant information to policy-makers in order to define and implement effective mitigation plans and measures.

Keywords: cities, GHG emissions, urban transport

1. Introduction

The role of cities in climate mitigation policies has grown in recent years and has consequently received more attention in economic literature. Households and companies located in cities consume relevant amount of energy for their everyday activities and needs, which give rise to GHG emissions. Furthermore, they consume and import several services and goods, whose production gives rise to emissions also outside the urban area.

GHG inventories of cities usually report emissions produced within a defined boundary applying a "territory principle": GHGs are assigned to the location where gases are emitted (e.g. location of fuel combustion or consumption). In specific cases, an "activity principle" is applied and GHGs are assigned to the location where the activity generating emissions takes place, even if gases are emitted outside the defined activity boundary (e.g. emissions from imported electricity are allocated to the city). A relevant issue in the inventorying process is thus to identify the spatial area and the activities that should be included or not in the estimation (Bader and Bleischwitz, 2009).

Most of published urban inventories focus mainly on emissions from energy uses in several activity sectors. Emissions embedded in products and services consumed within a city – i.e. emissions generated along their complete life cycle: production, use and disposal - are more rarely included in urban inventories, because of the complexity of methods and scarcity of data.

UN-Habitat (2011) highlights that, since no unique definition of city and no globally accepted standards to allocate emissions to cities are available, figures about the contribution of cities to global emissions should be considered with caution. Reporting the results of an estimation based on the location of emissions production, they suggest that cities are probably responsible for 30-40% of anthropogenic GHG emissions. According to other sources, the contribution of all urban areas to global emissions, including also towns and other urban settlements, is in the range 40-70% (Walraven, 2009, in UN-Habitat, 2011).

Inventories show that levels of urban emissions per capita can differ considerably in the world, from 2 to 30 tCO_2eq (Dodman, 2009; Kennedy et al., 2009; Sovacool and Brown, 2009). Differences in emissions levels depend on specific local features: climate conditions, urban form, demographic features, economic activities in place, state of technology, mobility and housing infrastructures and prices, income and lifestyle of city residents and users (UN-Habitat, 2011; Croci et a., 2011).

Climate determines the energy needs to heat and cool buildings throughout the year. Urban morphology is related to the city's shape and compactness, which have an influence on energy efficiency in buildings and transportation. Urban economy contributes to shape the overall GHG emissions of a city, according to the typologies of activities in place (e.g. service oriented city vs. manufacturing city). The availability of specific infrastructures, such as district heating network, metro lines and other mass transportation systems provides a low carbon alternative for heating and mobility. The prices of different fuels and transportation modes have an influence on local emissions, according to the price elasticity of demand of consumers. Income has an influence on the quantity and typology of consumption, also in terms of its carbon content. According to their lifestyle, personal habits and also age, citizens and city-users have different consumption and travel habits, which impact energy use and emissions.

The paper focuses on GHG emissions of European cities from transportation. Urban mobility is currently a relevant issue in European policies on climate change and urban environment. This is due not only to the impact of this sector on GHG emissions, but also to its implications on quality of life. At European level, urban transport is responsible for about 23% of total CO_2 emissions from transport, of which 70% are due to passenger cars and 27% to goods transport vehicles (EC, 2011). But the sector is also responsible for most of air pollution emissions, and for high levels of congestion and noise which impact health and wellbeing of citizens and city-users. Reducing GHG emissions therefore generates also other environmental and non-environmental co-benefits: for this reason, the theme becomes important in the agenda of urban policies.

Passenger transport, in particular, offers interesting options to abate emissions: estimates suggest that emissions could be abated up to 88% in comparison to an unchanged policy scenario, if the following measures were applied: fuel efficiency standards (44% of reduction), decarbonisation of energy supply (42%), spatial planning and shift to non motorized modes and public transit (2%) (EC, 2011).

The purpose of this analysis is to explore the determinants of GHG emissions from urban transport. We make use of available data at European level to evaluate through a linear regression a set of variables and to determine their relevance in influencing emissions. A sample of 24 European cities is considered. Urban emissions reported under the "Covenant of Mayors", a voluntary commitment signed with the European Commission, are put in relationship with socio-demographic, economic, infrastructural and geographical data from the Urban Audit, a European database on cities (Eurostat, 2010).

The paper is structured as follows:

1) In the first part, emissions from urban transport are decomposed in key factors and some underlying determinants of these factors are commented.

2) In the second part, a model for emissions from urban transport is presented

3) In the third part, data sources are presented

4) The final part is dedicated to the discussion of results.

2. Decomposition of emissions from urban transport

GHG emissions from ground transport at city level depend on the amount of transport demand of residents and city users and the modes through which this demand is satisfied. Grazi and van den Bergh (2008) highlight four "mechanisms of change" concerning GHG policies in the transport sector, which could be activated through specific measures: (1) transport volume carried out within the city, expressed in trips or kilometers travelled; (2) the modal split, that is the composition of traffic between freight and passenger transportation and the extent to which different modes are employed to move goods or are chosen by people to travel (3) energy efficiency of motorized modes according to the technological features of the operating vehicle fleet and (4) fuel types used, each characterized by different carbon contents.

Several identities can be used to describe emissions from ground transport. Each identity highlights factors that contribute directly or indirectly to energy use and GHG emissions from transport (Darido et al., 2009).

Identities (1) and (2) have been chosen for discussion in this paper. They represent emissions as a product of factors and show key differences between passenger and freight transport.

$$Et_{passengers} = \sum_{i=1}^{f} \sum_{j=1}^{m} (T_j \times L_j \times lf)_i \times EF_{ji} \quad (1)$$

$$Et_{freight} = \sum_{i=1}^{f} \sum_{z=1}^{n} VKT_{zi} \times EF_{zi} \quad (2)$$

Where:

T_j = number of passengers' trips with "j" mode

L_j = average length of a single trip with "j" mode (passengers km)

lf = load factor of "j" mode (n. passengers/vehicle)

EF_{ji} = emission factors of "i" fuel with "j" mode (gCO_2/vehicle km)

i = 1, … 6

1 = gasoline

2 = diesel

3 = LPG

4 = electricity

5= other

6 = no fuel

j = 1, … 6

1 = foot

2 = bicycle

3 = subway/rail

4 = bus (and related sub-categories)

5 = passenger car (and sub-categories)

6 = motorcycle (and sub-categories)

VKT_{zi} = kilometres travelled by freight vehicles of "i" fuel and of "z" mode (vehicle km/inhabitants)

EF_{zi} = emission factors of "i" fuel with "z" mode (gCO_2/vehicle km)

z = 1,…3

1 = light duty vehicles (and sub-categories)

2 = heavy duty vehicles (and sub-categories)

3 = rail

Both equations have the same structure: they are composed by the product of transport activity (kilometres travelled) and the specific CO_2 emission factor of vehicles/mode used to perform the travel.

For passenger transport, demand is represented by two factors, which taken together represent the overall transport volume generating emissions: the number of trips and the average trip length. Each mode is characterized by a specific average trip length, which can vary according to the typology of user (e.g. commuters commonly perform longer trips than city residents) and to the kind of mode (e.g. trips made with non-motorized modes are usually shorter than motorized trips). Furthermore, specific urban features can contribute to incentivize shorter or longer trips, such as the extent of the city area and its spatial organisation. For motorized modes, in addition to factors representing transport demand, technological features are highlighted in the equation through emission factors, which are different according to vehicle categories and to fuels consumed.

For freight, transport volume is represented by vehicle kilometres travelled, resulting from the number of freight vehicle trips for the length of trips. As for passenger transport, several conditions can influence the patterns of goods within the city and determine the average trip length of goods vehicles (e.g. city dimension, urban form, localization of commercial activities and warehouses). As well as private motorized vehicles, freight vehicles are characterized by a specific emission factor according to vehicle category and fuel used.

Several urban features can have an influence on each or both of these two key factors used to estimate emissions (transport activity and the average emission factor of each transport mode). These urban features can refer to urban population (demographic, socio-economic features), urban economy, to city's location and form, to features of urban transport infrastructures and transport modes available in the city. These features can be considered as the main "determinants" of urban transport emissions and, since they are strictly interlinked, they need to be jointly analysed. Each of them is briefly summarized in the following section and some results from previous literature are presented.

Demographic and socio-economic features of population

Socio-demographic trends in Europe show that population is ageing, that women have longer life expectancy and that the average size of families is declining (Gerőházi et al., 2011). These trends have an impact on GHG emissions from transport that must be explored, since age, gender and family structures influence personal mobility patterns and the choice of travel modes.

The quantity, typology and length of trips we perform change with age. It could be supposed that young people and adults make more trips than elderly people, because they perform everyday journeys to the study or workplace, whereas old-aged people stay more frequently at home. Furthermore, the number of impairments that can affect mobility grows with age (Tacken, 1998).

Also the choice of transport mode is influenced by several variables (i.a. accessibility, comfort, safety, price) whose importance can differ according to age and gender. For example, low accessibility and low comfort can be obstacles for older people using public transportation. Perceived unsafeness can induce women not to use transit after dark. These conditions can favour car use, which is often seen as a mode that can ensure higher safety and flexibility of use (Li et al., 2012).

Considering income, increases in average income are usually connected with a rise in car ownership, but ownership rates are not necessarily associated with car use (Gerőházi et al., 2011). This suggests that other conditions, specific to the city (urban density, infrastructure, user cost of transport modes) can have a strong impact on travel decisions and need to be investigated.

Several works have explored the relation between socio-economic characteristics and mobility patterns. A recent paper by Barla et al. (2011) focuses on greenhouse gas emissions from urban travel in the Quebec City area and takes into consideration, among other variables, the impact of individual and households characteristics on different emission levels. The study finds that GHG emissions from urban travel differ depending on the gender of the responder (female produce 25% less emissions than males), age (emissions peak in the range 35-49 years old and decline after 65 years old), family structure, professional status and income level (average emissions per respondent seem to increase with income, household size and employment).

Urban form

The relation between urban form and travel has been analysed extensively. Several authors have compared travel data of cities worldwide and found a correlation between city density and reduced energy consumption for travel. However, when socio-demographic variables are included in the analysis, land-use looses part of its significance (Van de Coevering and Schwanen, 2006).

Newman and Kenworthy (1989) were among the first to address the density-travel nexus. Their study compared travel data from 32 cities of Europe, North-America, Australia and Asia, and found that population density is strongly and negatively correlated with energy used for transport. As highlighted by Van de Coevering and Schwanen (2006), their work has been criticized because of the lack of multivariate analysis and of control for variables that have an influence on the amount of travel (fuel prices, economic situation, demographic structure). The sample was later expanded to 46 cities (Kenworthy and Laube, 1999), and to 84 cities (Kenworthy, 2003), confirming the relevance of urban density on containing energy use. A following analysis by Van de Coevering and Schwanen (2006) on data used by Kenworthy and Laube showed that urban form is indeed relevant for metropolitan travel-patterns, but also socio-demographic, housing and history-related variables are statistically significant.

Several authors have highlighted that it is not density per se that reduces transport activity in terms of transport and length of trips, but it is rather the spatial distribution of places (jobs, dwellings, services) within the city. Bertaud (2004) shows how density distribution can affect the average length of trips in cities with the same average density. He also shows how dense cities are incompatible with the use of private cars, since limited availability of space generates a competition between land uses. He remarks that public transport needs high densities to be financially feasible, because a certain amount of potential customers must be located within the catchment area of each station or stop in order to justify the investment in infrastructure.

Commuting

The presence and density of workplaces and services in cities, both large and medium-sized, attracts people from the surrounding urban area, determining the flow of in-commuters and consequently a rise in transport activity within the city area. These commuting flows can take different forms according to how workplaces/services/amenities and housing are distributed within the city and according to the city's form itself (sprawled urban areas generate longer commuting trips to reach city's places). In European cities, commuting patterns are complex and they are often not limited to trips from periphery to the centre; the localization of jobs and commercial activities in the urban fringe also generates a out-commuting flow, which contributes to traffic and congestion (ECOTEC, 2007).

Commuter modality differs significantly between European cities, and this has important implications for emissions. Cities in United Kingdom show relevant share of car use in commuting (80%), and in other countries such as Italy and Belgium the share of cars arrives to 60%. On the contrary, in the new Member States public transport is highly used for commuting. Historical reasons are behind this peculiarity, such as the rigid planning distinction between urban and rural areas realized in these countries and the greater importance given to transit infrastructure discouraging private consumption in planned economies; this trend is now being reversed by increasing suburbanization and affluence, which drives a wider uptake of car use (ECOTEC, 2007).

Public transport infrastructure

The availability of a good network of public transport should incentivize citizens and city-users to prefer transit to their private cars. This incentive effect does not only depend on "quantitative" features of the network (length of the network, number of lines) but also on the quality of the network and its perceived quality by customers. Poudenx (2008) attributes the failure of certain policies limiting car use to the insufficient level of quality of transit services which are proposed as alternative to the private mode.

UITP (2010) underlines that public transport customers have relevant expectations from transit services in terms of quickness, safety, affordability, reliability, cleanness and availability of accessible and comprehensible information on travel options. Policies that enhance service quality targeting some of these aspects, for example improving connections and reliability of time schedules, providing innovative services such as bike-and-ride or park-and-ride, investing in weather protection for stops and improvement of stations, have proven to be successful in increasing the share of transit (see for example cases described by Poudenx, 2008).

Relative price of transport modes

Prices affect travel demand in a significant and complex way. Changes in prices can regard and impact each component of travel: the number of trips, their destination and path, mode, travel time, type of vehicle, parking location and duration (Institute for Transport Studies, 2004). Furthermore, price sensitivity is influenced by several factors, such as (1) the type of price change, that determines which travel component is affected by the variation in price (e.g. fees on the vehicle; fuel price; fixed toll; congestion charging; parking fees; transit fare); (2) the type of trip and of traveler (commuting vs. occasional trips; weekday vs. weekend trips; urban high-peak period vs. low-peak period trips); (3) the quality and relative price of travel alternatives (routes, modes, destinations); (4) the time period (short vs. long term); and finally (5) how specifically or generically transportation is defined (VTPI, 2011).

With his milestone work, McFadden (1974) showed the relevant relations between prices and urban travel. According to his analysis, car travel demand increases when car costs for users fall, income rises and prices and waiting time for public transportation rise. Viceversa, he showed how car travel demand decreases with an increase in car costs for users and how they generate a higher demand for public transportation.

3. Methodology

Several variables, namely socio-demographic, economic, physical and spatial variables, have a significant influence on mobility patterns and emissions. In this paper they are jointly analyzed, making use of homogenous urban data. However, due to the small size of available dataset (24 cities) only a subset of variables is considered for the analysis[237].

The model of emissions from urban transport considered in the paper takes the following form:

E = f (Density, Incommuters, PTRelativePrice, GDP, Age-Mobility)

Where

"E" are CO_2 emissions from ground transport per inhabitant (tCO_2)

"Density" is the number of residents per unit of land area ($inhab/km^2$)

"Incommuters" is the amount of commuters the city attracts for its workplaces (proportion of incommuters of persons employed in the city)(%)[238]

"PTRelativePrice" is the relative price of public transportation to private transportation (Cost of a monthly ticket for public transport (for 5-10 km) / price of 1 litre of gasoline + cost of 1 hour parking in the city centre + fee of 1 entrance in the congestion pricing zone, if present)

"GDP" is the Gross Domestic Product of the NUTS3 region per inhabitant in PPS[239] (€)

"Age-Mobility" is the percentage of residents that we consider having low mobility on total population (residents aged > 65 years + residents aged < 14 years / total resident population) (%)

Checking normality of all variables, it came out that population density is non-normally distributed. For this reason, this variable was tested also in logarithmic form (see in the list of regressions performed below: Model 1 and 2).

Correlation tests were performed among all variables to verify if they are correlated between themselves, in order to eliminate possible bias. Results are shown in the following matrix:

[237] Given the relevance of public transport features (quantity, quality) in influencing urban mobility, we tried to include in the regressions a variable related to public transport supply (namely the density of public transport network). Results showed a very high correlation of public transport density with population density. This was a predictable result, because, as highlighted by Bertaud (see page 4 of this paper) investments in public transport supply need high population densities to be financially feasible. Because of this high correlation value, the variable PT density was not included in final regressions.

[238] It should be noted that the variable "Incommuters" is used here as a proxy of city's attractiveness. Emissions generated by commuters are already included in ground transport emissions estimated by cities in their emissions inventories.

[239] Purchasing Power Standards (definition by Eurostat: PPS is a common currency that eliminates the differences in price levels between countries allowing meaningful volume comparisons of GDP between countries. The conversion to PPS is based on national purchasing power parities which are also regularly calculated by Eurostat).

Figure 1. Correlation matrix for all variables

	tco2pc	density	incomm~s	ptrela~e	gdp	agemob~y
tco2pc	1.0000					
density	-0.4223	1.0000				
incommuters	0.2140	0.2863	1.0000			
ptrelative~e	0.4777	-0.0703	0.5126	1.0000		
gdp	0.2082	-0.2070	0.1041	0.2503	1.0000	
agemobility	0.1211	0.0715	-0.1034	-0.0849	-0.2905	1.0000

Results show a moderate correlation between PTRelativePrice and Incommuters (0.5126), so it was decided to test their significance jointly (in the same regression, see Model 1 and 2) and then individually (in separate regressions; see Model 3 and 4).

Since emissions values used in the regressions include also emissions produced by commuting trips performed within the city, we supposed that the variable "Incommuters" could be endogenous. For this reason, we performed an endogeneity test to verify this supposition. Its results suggest that the variable Incommuters shows a low degree of endogeneity. However, this result could be due to the small sample size, so further tests shall be performed in future research with a larger dataset.

There are some studies that suggest GDP might be related to CO_2 emissions in a non-linear way (see Galeotti et al., 2006, for an extensive literature review on the topic). Therefore, we performed a test of non-linear relationship, including GDP^2 into the model and then testing joint significance of GDP and GDP^2. The test results show no support for non-linearity hypothesis. For this reason it was decided not to include GDP^2 into the models.

The following regressions have been performed:

Model 1.

$E_1 = \alpha_1 + \beta_1$ Density $+ \gamma_1$ Incommuters $+ \eta_1$ PTRelativePrice $+ \delta_1$ GDP $+ \zeta_1$ Age-mobility $+ \varepsilon_1$

Model 2.

$E_2 = \alpha_2 + \beta_2$ ln Density $+ \gamma_2$ Incommuters $+ \eta_2$ PTRelativePrice $+ \delta_2$ GDP $+ \zeta_2$ Age-mobility $+ \varepsilon_2$

Model 3.

$E_3 = \alpha_3 + \beta_3$ Density $+ \gamma_3$ PTRelativePrice $+ \eta_3$ GDP $+ \delta_3$ Age-mobility $+ \varepsilon_3$

Model 4.

$E_4 = \alpha_4 + \beta_4$ Density $+ \gamma_4$ Incommuters $+ \eta_4$ GDP $+ \delta_4$ Age-mobility $+ \varepsilon_4$

All of the models are estimated using OLS.

3. Data

Emissions data were extracted from documents submitted by Local Governments for their compliance with the Covenant of Mayors[240] initiative. Since standardized urban emissions data are not available yet at the international level, it was decided to refer to a wide-scale emissions reporting scheme which could give a sufficient amount of data to support a quantitative approach. At European level, the CoM is giving a significant impulse in the direction of urban CO_2 reporting and emissions reduction planning. Covenant signatories cities are expected to develop and implement Sustainable Energy Action Plans (SEAPs) grounded on Baseline Emissions Inventories (BEIs), which they commit to regularly update and monitor.

Data regarding explanatory variables were extracted mainly from the Urban Audit[241] database, apart for

[240] Launched in 2008 by the European Commission, the Covenant recognizes the role of local governments in the global challenge against climate change and commits city mayors to go beyond the so called "20-20-20" targets related to the reduction of CO_2 emissions, energy efficiency and energy saving, and the increase of energy use from renewable sources. At this purpose, cities are expected to develop set of actions in several relevant fields (Sustainable Energy Action Plans, SEAPs). The participation in the initiative has grown exponentially in 3 years; nowadays, more than 4.000 local authorities from the 27-Member States, and some non EU-countries as well, are part of the Covenant. Of these, more than 1.600 have submitted a SEAP. The CoM initiative provides non-binding recommendations on the compilation of SEAPs and BEIs in order to ensure flexibility to participating cities, allowing for different approaches and methodologies to be used for the estimation of city emissions and the elaboration of emission reduction measures. According to the CoM guidelines, emissions from private passenger and freight transport are reported together. For this reason it was not possible to disaggregate emissions data into the two categories.

[241] The Urban Audit is a comprehensive data collection process taking place since the 2000s, after a pilot phase conducted in the late 90's, targeted at providing comparative information on selected urban areas in Member States of the European Union and the Candidate Countries. Several aspects related to quality of life are considered in the process, in brief: demography, social aspects, economic aspects, civic involvement, training and education, environment, travel and transport, information society, culture and recreation. Data collection takes places every three years and an annual collection is foreseen for a limited set of variables The first collection (2003/4) has been carried on 258 participating cities; the second (2006/7) regarded 321 cities from the 27 Member States and 36 additional cities in Norway, Switzerland and Turkey; the third collection (2009) will be completed in 2011

some data related to the relative price of public transportation[242].

Table 2. Emissions per capita (tCO_2 or tCO_2eq) of the sample cities

City name	Unit	tCO_2/p.c.	Year
Bruxelles	CO_2eq	0,80	2007
Aarhus	CO_2eq	1,65	2007
København	tCO2eq	0,87	2005
Hamburg	tCO2	2,52	2007
Frankfurt am Main	tCO2eq	2,44	2005
Stuttgart	tCO2	1,76	2005
Bremen	tCO2	2,84	2005
Hannover	tCO2eq	1,72	2005
Nürnberg	tCO2	2,06	2004
Freiburg im Breisgau	tCO2eq	1,79	2005
Karlsruhe	tCO2	2,18	2007
Barcelona	tCO2eq	0,65	2008
Dublin	tCO2	2,33	2006
Milano	tCO2	1,09	2005
Torino	tCO2	0,82	2005
Genova	tCO2	0,81	2005
Bologna	tCO2	1,34	2005
Rīga	tCO2	1,00	2005
Amsterdam	tCO2	0,68	2006
Lisboa	tCO2	2,96	2002
Porto	tCO2	1,99	2004
Stockholm	tCO2	1,11	2005
Bergen	tCO2eq	1,69	2007
Kristiansand	tCO2eq	2,07	2006

Reference year for emissions values differs among cities because each city government has elaborated autonomously its emissions inventory. The recommended baseline year within the Covenant of Mayors is 1990. If 1990 data are not available, the Local Authority can make use of data referred to subsequent years, provided that data are sufficient and reliable (JRC, 2010).

4. Results

Table 2. shows OLS results obtained from the four Models.

Model 1. shows that population density and the relative price of public transportation are significant. Density is negatively related with emissions, whereas public transport relative price is related with a positive sign.

These results are confirmed also in Model 2, which expresses population density in a logarithmic form to deal with the non-normality of standard errors, and in Model 3, which excludes the variable "Incommuters" from the regression.

Model 4. excludes the variable "PTRelativePrice", in order to verify the relative strength of this variable in relation to "Incommuters". Results of this model show that Density is again significant and negative, and Incommuters is now significant, with a positive relation with emissions.

Looking at the results per variable, the significance of population density and of public transport relative price stand out as the most robust result. These two variables are significant in all the regressions performed, the former with a negative sign and the latter with a positive sign.

Considering density, the analysis confirms that cities with a compact built environment generate lower levels of emission from transport activity, as highlighted in previous literature. Considering public transport relative price, the positive sign of its relation with emissions can be explained by the modal shift towards motorized modes induced by an increase of the relative price of transit.

"Incommuters" is significant only in Model 4., where the variable "PTRelativePrice" is not included, showing a positive relation with emissions. This result could be driven by the endogeneity issue or a relatively high correlation between these variables, which must be further investigated with a larger sample size. Further research is also needed to explore the modal share of commuters and how much this can influence transport emissions.

(http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban; http://www.urbanaudit.org/).
Within the Urban Audit, data are collected at four spatial levels: the Core City, according to the administrative definition; the Larger Urban Zone, which is an approximation of the functional urban zone which has its centre in the city; the Kernel, a special zone created for specific capital cities for which the use of the Core City level does not provide a unit comparable with other cities in the database; the Sub-City district, a subdivision of the city based on population criteria (for reference: Eurostat (2010). In the paper, data referred to the Core City level has been used, to ensure consistency with emissions data which refer to the administrative boundaries of the Local Authority.

[242] For a few cities, data on the average cost of a monthly ticket were unavailable in the Urban Audit database, so they have been integrated with data of the transit operators; data on congestion charge fees are published by the congestion scheme operator; fuel prices are from the Market Observatory for Energy of the European Commission (http://ec.europa.eu/energy/observatory/oil/bulletin_en.htm).

Table 3. Results of the four models

Emissions	**1**	**2^**	**3**	**4**
Density	-0.0097829**	-0.2625735**	-0.0085154**	-0.0113338***
	(-2.30)	(-1.89)	(-2.18)	(-2.61)
Incommuters	0.0063904	0.0082482		0.0136749*
	(0.78)	(0.90)		(1.90)
PTrelativeprice	1.660789*	1.729968*	2.08595**	
	(1.65)	(1.65)	(2.49)	
GDP	0.0040853	0.0030136	0.0042752	0.0073311
	(0.37)	(0.26)	(0.40)	(0.66)
Agemobility	5.393491	4.148327	5.067956	5.684471
	(1.20)	(0.89)	(1.15)	(1.21)
constant	-0.9767535	-0.1707032	-0.8560822	-0.6414465
	(-0.59)	(-0.09)	(-0.52)	(-0.37)
#Observations	24			

^ In Model 2. Density is expressed in logarithmic form.
Note: ***- 1% significance level; ** - 5% significance level; * - 10% significance level
t-statistics in parenthesis

Conclusions

Several studies have explored the determinants of urban emissions from mobility and of their main components: travel demand and modes employed to satisfy such demand. Our paper makes use of data available at European level to analyse jointly the relevance of several determinants related to socio-demographic, economic and physical features of cities in influencing emissions values. The small size of the sample limited the study to consider only a subset of variables, which were tested in four different models.

The main results of the analysis confirm the relevant and negative correlation of population density with transportation emissions, even considered jointly with other explanatory variables, as ensued from previous studies published in literature. Results also highlight the significance of the relative price of public transportation to private transportation and how an increase in such a relative price can have an upward effect on emissions. For the other variables included in the models, GDP, Incommuters and Age-Mobility, no relevant results seem to emerge from the regressions.

Further research will need to be done with larger samples of cities, in order to confirm the significance of these results and to expand the set of explanatory variables.

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Estimation of defects in induction machine using of current space vector locus

Dr. Astrit BARDHI[1]
Lecture at Automation Department

Prof. Dr. Ymer LUGA
Professor at Automation Department

Prof. Ass. Myrteza BRANESHI
Professor at Electrotechnic Department

Msc. Alfred PJETRI
Lecture at Automation Department

[1] *Contact details of corresponding author*

Tel: +355-42-238-60
Fax: +355-42-238-60
e-mail: asibardhi@gmail.com

Address
Automation Department, Faculty of Electrical Engineering, Polytechnic University of Tirana (UPT), "Sheshi Nënë Tereza", Nr. 4,
Tirana, Albania

Abstract: In industry, a pivotal role is played by induction machines resulting in a strong demand for their respective reliable and safe operation. Faults and failures of induction machines can lead to excessive downtimes and generate large losses in terms of maintenance and revenues. Nowadays, experts are performing numerous researches to reduce both unexpected failures and maintenance cost by detecting faults during the machine activity operations. In this matter, measurements and monitoring must be performed during on-line conditions. In order to accurately identify the stator winding damage, we have used the stator currents, which are easily monitored. The space vectors locus of stator current provides the possibility to detect faults in induction machine. To confirm our theoretical analysis with experimental data, an induction machine was re-winded at laboratory to have some winding outputs in order to simulate different shorted turn of phase winding. The obtained theoretical and experimental results show coherence amoung each other.
Keywords: Induction machine, turn shorted of winding, current space vector

1. Introduction

Induction motors, mainly due to their low cost, ruggedness, controllability, ability and low maintenance have become one of the most critical components for today's electric utilities and process industries. A motor failure, in such utilities, can result in the shutdown of a generating unit or production line. Upon such conditions, researches are focused on monitoring of on-line induction machine operation. The induction machine on line estimation and detection of abnormal electrical and mechanical conditions indicating a system failure can be avoid by minimizing potential hazardous effects. In recent years, monitoring of induction motors has become very important to reduce maintenance costs and prevent unscheduled downtimes. Therefore, there has been a substantial amount of research to provide induction motors, new condition monitoring techniques. The failure of induction machine during operation can be fail due to normal ageing, assembling problem, operating mode, cooling conditions environment varieties or combination of a variety of faulty mechanisms.

In the survey reports by EPRI [EPRI, 1982], Thorsten & Dalva [Thorsen, O.V., 1999] found that 37% of motor failures have been by stator winding failures, 10% by rotor failures, 41% by bearing failures and 12% by miscellaneous failures. It should notice that failure emphasis's (defects) classification depends on operating mode and environmental conditions.

Stator winding failures such as inter-turn short circuits and magnetic circuit, which can cause by a combination of thermal, electrical, mechanical and environmental stresses that act on the stator [Tavner P.J., 2008], are found to be an important percentage of motor failure. Moreover, the stress in insulation of stator winding is increased in induction machines which are supplied by electronic inverter.

Winding stator faults usually start as inter-turn short circuits. In fact, the primary or main cause of the stator faults is insulation degradation which leads to inter-turn short circuits. The resultant short circuit between the copper turn causes a significant circulating current that flows in the coil, leading to a isolation rapid deterioration and induction machines failure. Turn failure tend to be very destructive, and involve burning of insulation and localized melting of the copper conductors [Tavner P.J., 2008]. Shorted turns in the stator winding belong to this class of faults in the first stage often may have a negligible effect on the performance of the machine (e.g., rotor speed, phase current or efficiencies etc.), but their presence may eventually lead to a catastrophic failure [Thorsen, O.V, 1999].

Rotor faults occur during manufacture stage also, through defective case casting of die cast rotors, poor jointing in the case of brazed case and welded end rings. Such faults result in a high resistance causing overheating and impaired cage strength at high temperatures. As a consequence, cracking can than occur in the rotor bar which usually take place at the cage end rings when the bars are unsupported by the rotor core [Tavner P.J., 2008]. During the induction machine operation, particularly when the machine operation in intermittent periodic duty mode, electrical, mechanical or thermal troubleshoots, can be present. In this case, the initially currents are six-seven times as nominal current and the motor running time is very short. High amount thermal energy is resulting to rotor bars cracking [Xhoxhi N., 1989].

Base on literature survey data can be concluded that stator and rotor winding faults are approx. 50% of generally of induction machine defects [Bornnett, H., 1992, Nandi S, 2005]. For this reason, during the last years, the performed studies are predominantly focused how the on line monitoring of stator and rotor faults of induction machine under operation can be performed. In this matter, the subject of on line detection of inter-turn short circuits in the stator windings of three-phase induction motors has been addressed by several researchers [Thomson, W.T. 1999]. We can mention different monitoring proposed by researchers as the monitoring of axial leakage flux [Penman J., 1994], the spectral analysis of motor line current [Joksimovic, 2000], partial discharging testing [Sendding, H.G., 1989], the monitoring of zero component of motor line current [Briz, F., 2005], the monitoring of frame vibration [Li, W., 2004], the monitoring of positive and negative impedance [Kohler J.L., 2002], the monitoring of instantaneous of power [Legowski S.F. 1996]. In order to on line estimate of the rotor bar broken several methods as the spectral analysis of motor line current [Thomson, W.T. 2001], the monitoring of instantaneous torque [Bellini, A., 2001], the monitoring of frame vibration [Thorsen, O.V, 1999], injection of low frequency signal [Ho, S.L., 1998], the monitoring of axial flux [Jarzyna, W., 1995] are proposed.

The aim of this article is to present another potential fault detection method which is based on the analysis of space vector locus of the stator line currents of induction machine. In normal condition operation the space vector locus of induction machine represents a circle with the radius that depends on the motor load. In case of induction machine stator winding faults such as single-phasing, stator-winding inter-turn short-circuits, the space vector locus is represented by an ellipse, whose major axis orientation is aligned to the faulty phase. In case of rotor defects as cracked bars or ring damage, the negative sequence of rotor currents induces in stator line currents with lower and upper twice-slip-frequency sidebands around the fundamental frequency. The space vector locus of motor current line is represented with a thicker circle while its monitoring requires no extra equipments and is easy to use by operators. To confirm our theoretical analysis with experimental data at the Laboratory of "Electrical Machine" of Electrical Engineering Faculty of our University, an induction machine is re-winded to have some winding outputs in order to simulate different turn to turn short of phase winding. To simulate rotor faults two rotor bars of an induction machine have been cutter. The data obtained from experiments confirm very well with analytical analysis developed in this paper.

2. Space vector locus of stator line current

Initially, the work of induction machine working under normal conditions is analyzed. Space vector locus of motor line currents in stationary reference frame is represented by a perfect circle. Then, we will analyze the induction machine in faulty case (e.g., inter-turn shorted or rotor bars damage). The space vector locus of motor line currents under the faulty conditions is different from one in normal conditions.

2.1. *Space vector locus of stator line currents in normal condition*

Assuming symmetrical three-phase operation in the steady state, the three-phase winding is symmetrical and the feed by sinusoidal supply with frequency f_1. In steady state, through stator winding flow a symmetrical three phase currents with the same frequency f_1. The stator phase currents will produce a resultant forward magnetic field, rotating at synchronous speed

$$\Omega_1 = 2\pi n_1 = \frac{2\pi f_1}{p} = \frac{\omega_1}{p} \quad (1)$$

where Ω_1 and ω_1 are angular speed of magnetic field in geometric radians per second and electrical radian per second respectively, n_1 is the synchronous speed of magnetic field, in revolution per second and p is the number of pole pairs. The magnetic flux created by currents passing in stator winding induces an electromotive force (EMF) and currents in the rotor bars with frequency sf_1, where s is motor slip. The rotor currents which flow in each of rotor bars are given by [Maliti, K.C., 2000]:

$$i_{b,m} = I_b \cos\left(s\omega_1 t - m\phi\right) \quad (2)$$

where $i_{b,m}$ is the instantaneous value of the current of m-bar of rotor, $\phi = 2\pi p/Z_r$ is the angle between two neighbour rotor bars, Z_r is number of rotor slots, m is a integer 0, 1, 2, . . ., $Z_r - 1$ and I_b is amplitude of the currents through rotor bars. Each of rotor bars will produce a magnetic field with magneto-motive force (MMF) [Sribovornmonkol, Th., 2006]

$$f_{b,m} = WI_b \cos\left[s\omega_1 t - m\phi\right]\cos\left[\theta - m\phi\right] \quad (3)$$

where $f_{b,m}$ is MMF of m rotor bar and θ is air gap of induction machine in radians. The resultant MMF created by all rotor bars currents at an angle θ can be expressed as:

$$f_r\left(\theta, t\right) = \frac{Z_r}{4} I_b \cos\left(\theta - s\omega_1 t\right) \quad (4)$$

From Eq. (4), the resultant MMF created by rotor currents is rotated in the direction of stator MMF with angular speed $s\omega_1$, related to rotor frame. The angular speed of rotor MMF, $\Omega_2^{(1)}$, related to stator frame is:

$$\Omega_2^{(1)} = s\Omega_1 + \Omega = \Omega_1 \quad (5)$$

From Eq. (5) it is obvious that magnetic fields of the stator and rotor are rotated with same angular speed, forming thus air-gap magnetic field. The interaction between air-gap flux and rotor bars currents creates a constant electromagnetic torque. The instantaneous values of phase currents of induction machine working under normal conditions can be expressed as follows:

$$\begin{aligned} i_{sA}(t) &= I_m \cos(\omega_1 t + \phi) \\ i_{sB}(t) &= I_m \cos(\omega_1 t + \phi - 2\pi/3) \\ i_{sC}(t) &= I_m \cos(\omega_1 t + \phi - 4\pi/3) \end{aligned} \quad (6)$$

where I_m is maximum value of a phase current. The space vector of stator currents $\overline{i_s}$ in stationary reference frame (fixed to the stator of the induction machine) can be obtained by the following expression [Vas, P., 1993]:

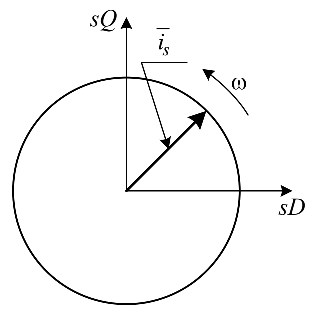

Fig. 1. Space vector locus of stator line currents of induction machine working under normal conditions in stationary reference frame.

$$\overline{i_s} = \frac{2}{3}[i_{sA}(t) + a i_{sB}(t) + a^2 i_{sC}(t)] = \overline{I_1} e^{j\omega_1 t} \quad (7)$$

where $\overline{I_1}$ is space fazor of stator current and 1, a, a^2 are unit vectors in the direction of magnetic axes of stator phases [$a = \exp(2\pi/3)$]. From Eq. (7), the space vector locus of motor line currents working under normal conditions in stationary reference frame has a perfect circular shape with the center at the origin with radius equal to amplitude of current, I_m. Fig. 1 shows the space vector locus of induction machine working under normal conditions.

2.2. *Space vector locus of stator line currents in case of broken rotor bars*

In this section the effect of broken rotor bars to space vector locus of stator line currents is analyzed. In previous section, it is assumed that induction machine is fed by symmetrical three-phase voltage with frequency f_1 and in stator winding flow symmetrical three phase currents with same frequency. Magnetic flux created by the stator currents induces an EMF at rotor bars with frequency sf_1. The damage of rotor bars cause asymmetry on the rotor circuit, therefore, through rotor winding will flow an asymmetrical current system. Magnetic field created by rotor currents can be analyzed by symmetrical components. The positive sequence of rotor currents creates a magnetic field similar with symmetrical rotor (no faults). The rotor currents of negative sequence with frequency sf_1 creates a magnetic field which is rotated in opposite direction of the rotor with angular speed $\Omega_{22}^{(2)} = -s\Omega_1$ related to rotor reference frame. The angular speed of rotor MMF of negative sequence, $\Omega_{21}^{(2)}$, with respect to the stator frame is:

$$\Omega_{21}^{(2)} = -s\Omega_1 + \Omega = \left(1 - 2s\right)\Omega_1 \quad (8)$$

The MMF of negative sequence of rotor currents induces EMF with frequency $f_{brb} = (1 - 2s)f_1$ at stator phase windings. This induced EMF, causes at stator winding a current with same frequency. The instantaneous values of stator phase currents of induction machine working with rotor broken bars can be expressed as follow:

$$\begin{aligned} i_{sA}(t) &= I_m \cos(\omega_1 t + \phi) \\ &\quad + I'_m \cos[(1-2s)\omega_1 t + \phi'] \\ i_{sB}(t) &= I_m \cos(\omega_1 t + \phi - 2\pi/3) \\ &\quad + I'_m \cos[(1-2s)\omega_1 t + \phi' + 2\pi/3] \\ i_{sC}(t) &= I_m \cos(\omega_1 t + \phi - 4\pi/3) \\ &\quad + I'_m \cos[(1-2s)\omega_1 t + \phi' + 4\pi/3] \end{aligned} \tag{9}$$

where I'_m is maximum value of $(1 - 2s)f_1$ harmonic amd ϕ' is its phase angle. The space vector locus of motor line currents in this case in stationary reference frame can be expressed by:

$$\begin{aligned} \overline{i}_s &= \frac{2}{3}[i_{sA}(t) + a i_{sB}(t) + a^2 i_{sC}(t)] \\ &= \overline{I}_1 e^{j\omega_1 t} + \overline{I}'_1 e^{-j[(1-2s)\omega_1 t]} \end{aligned} \tag{10}$$

Eq. (10) shows, that in the case to rotor bars damage, the space vector locus of stator line currents contain an extra component which rotates in negative sense with angular speed $(1 - 2s)\omega_1$. The amplitude of extra component depends on by motor load and the numbers of broken rotor bars. Usually the rotor of induction machine is constructed by a large number bars, thus the current amplitude of negative sequence is very small compare to item positive sequence ($\overline{I}'_1 \ll \overline{I}_1$). In this manner, the space vector magnitude of phase currents is pulsating with $(1 - 2s)f_1$ frequency. Therefore, the space vector locus of stator line currents in stationary frame represent by a thicker circle, as is shown in Fig. 2. In case of constant motor load the width of circle depend on by number of damaged rotor bars. The interaction between the fundamental magnetic field of the stator with negative sequence of rotor current, produces pulsating torque with frequency $2sf_1$ [Williamson, S., 1982]

The pulsating torque will cause speed fluctuations of the rotor. Due to speed oscillation, in the stator winding of induction machine, side band components around the fundamental frequency have been induced. The frequency of the side band components corresponds to:

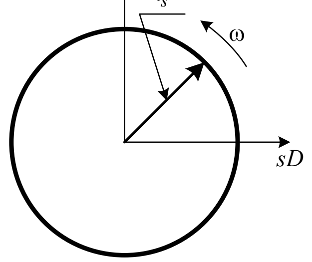

Fig. 2. Space vector locus of induction machine working under damage rotor bars in stationary reference frame.

$$f_{brb,s} = (1 \pm 2ks) f_1 \tag{11}$$

where $f_{brb,s}$ are the side band frequencies due to broken rotor bars and k is an integer 1, 2, 3, ...

2.3. *Space vector locus of stator line currents in case of stator winding damage*

In this section the effects of the inter-turn shorter circuit fault in shape of space vector locus of stator line currents are analyzed. Again, it is assumed that induction machine is supplied by a three-phase voltage system and rotor circuit is symmetric. The cases of inter-turn short circuit of stator winding are shown in Fig. 3 such as (a) between turns of the same winding, (b) between phase winding to ground and (c) between turns of different phases.

Due to shorted circuit, in the stator winding through shorted turns will flow currents which are several times higher than of rated motor current. Referring to Fig. 3(a) additional to line current I in shorted turn will flow the current I_k. This current is named as circulation current. The currents that flow in the shorted windings also produce MMF, which is opposite to the main MMF produced by the phase winding [Stavrou, A., 2001]. When a short circuit take place, the phase windings have less number of turns and so produce less MMF. Shorted turns in the stator winding belong to that class of faults that may often have a negligible effect on the performance of the machine but the presence of which may eventually lead to a catastrophic failure [Joksimovic G., 2000].

Magnetic field created by inter-turn shorted affects not only the phase damage but the other two phases due to the mutual induction. Therefore the phase currents of induction machine with damage stator winding are asymmetric. To estimate how the damage of stator winding affects in the motor line current the fault at phase A is supposed. The line current in phase A, i_{sA} is

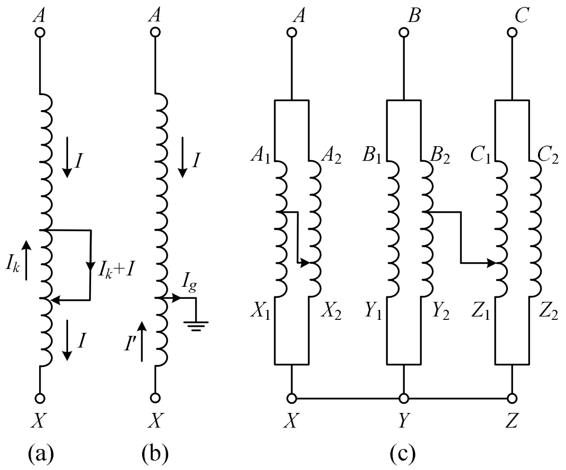

Fig. 3. The cases of inter-turn short circuit of stator windings of induction machine.

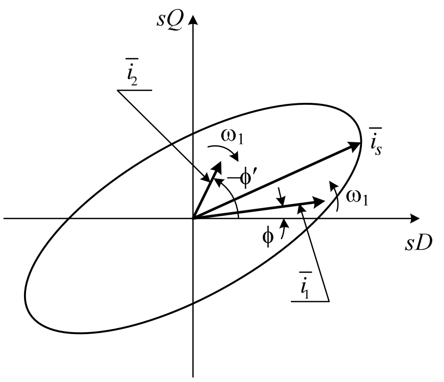

Fig. 4. The space vector locus of stator line currents in case of stator winding fault in stationary reference frame.

$$i_{sA} = \frac{1}{R_s}\left(u_{sA} - \frac{d\psi_{sA}}{dt} \right) \quad (13)$$

where R_s and ψ_{sA} are resistance and magnetic flux of healthy part of the phase winding. The current of faulty phase increases due to two reasons: active resistance of phase is smaller than in case of normal conditions and magnetic flux of damage phase is smaller than in the case of normal conditions. Thus the phase currents in case of inter-turn shorted faulty are different with each other, that means phase currents contain the positive and negative components. The stator line currents can be expressed as follow:

$$\begin{aligned} i_{sA}(t) &= I_m^{(1)} \cos(\omega_1 t + \phi) + I_m^{(2)} \cos(\omega_1 t + \phi') \\ i_{sB}(t) &= I_m^{(1)} \cos(\omega_1 t + \phi - 2\pi/3) + I_m^{(2)} \cos(\omega_1 t + \phi' + 2\pi/3) \\ i_{sC}(t) &= I_m^{(1)} \cos(\omega_1 t + \phi - 4\pi/3) + I_m^{(2)} \cos(\omega_1 t + \phi' + 4\pi/3) \end{aligned} \quad (15)$$

where $I_m^{(2)}$ is amplitude of negative sequence of current and ϕ' is phase angle of negative sequence. The space vector locus of stator line currents of induction machine with inter-turn shorted circuit in the phase winding A can be written as:

$$\overline{i_s} = \frac{2}{3}[i_{sA}(t) + a i_{sB}(t) + a^2 i_{sC}(t)] = \overline{i_1} + \overline{i_2} \quad (16)$$

where:

$$\overline{i_1} = \overline{I_1} e^{j\omega_1 t}$$

$$\overline{i_2} = \overline{I_2} e^{-j\omega_1 t}$$

and $\overline{I_1}$ is the space phasor of the positive sequence current, $\overline{I_2}$ is space phasor of negative sequence current. The space vectors $\overline{i_1}$, $\overline{i_2}$ rotate with angular speed ω_1 but in the opposite direction. Because of the negative sequence, the space vector locus of stator line currents can show some distortion as an elliptical shape as in Fig. 4. The magnitude of major axis of ellipse depends on the degree of damages and its orientation is aligned to the faulty phase. In case of single phasing of induction machine during operation, the space vector locus of stator line currents is represented by a straight line which is perpendicular with magnetic axis of opened phases.

Table I. induction machines data

P_n kW	n_n rpm	U_n V	I_n A	cos □$_n$	f_n Hz
1.47	1430	220	3.3	0.84	50
3	1410	220	6.9	0.82	50

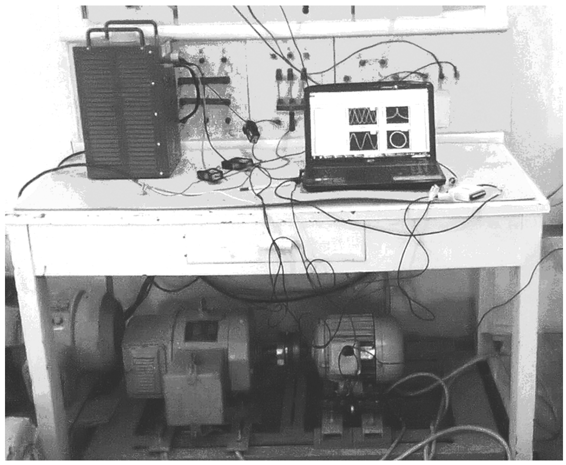

Fig. 5. Experimental setup stand.

3. Experimental results

In order to confirm the above theoretical analysis of induction machine faults, a series of experiments are performed. The objects of the experiment are two squirrel cage induction machines. The data of induction machines are listed in Table 1. Induction machines are loaded by DC generators.

The supply voltage of both induction machines has been effectuated by a three phase balanced supply through a 3-phase variable auto-transformer. LabView software is used to visualization space vector locus of stator line currents, spectral analysis of stator current and instantaneous of phase currents.

3.1 *Induction machine working under normal condition*

The Fig. 5 shows the experimental stand for normal working conditions at the “Electrical Machine” Laboratory of Polytechnic University of Tirana. Space vector locus, spectral analysis and waveform of the stator currents for this case are showed in Fig. 6. The spectrum of stator currents as expected, contain only fundamental harmonic with frequency 50 Hz.

The space vector locus of stator line currents is a circle and the waveform of stator line currents are symmetrical, as expected. The radius of circle is equal with amplitude of stator line currents.

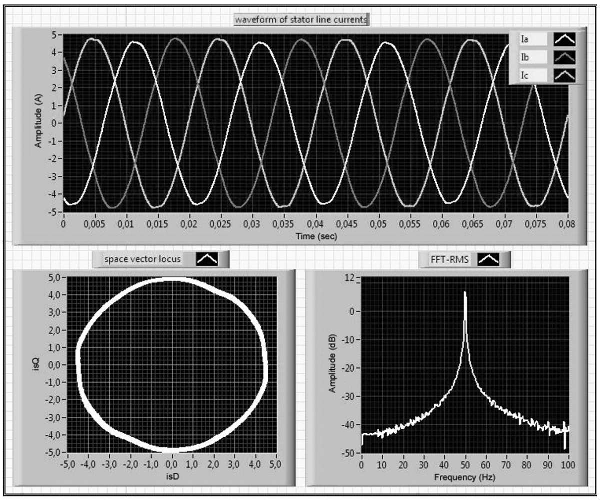

Fig. 6. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents of induction machine for the case of normal condition.

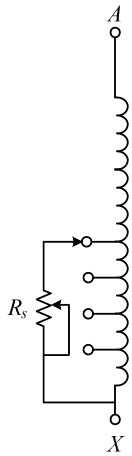

Fig. 7. The modification of the stator windings to have accessible several tapings.

3.2 *Induction machine working under faulty stator winding*

The Stator windings are modified to have accessible several tapings that can be used to simulated inter-turn short circuits, with a different number of turns and different locations along the stator windings. To protect the stator windings of the motor from overheating due to the high short-circuit currents, at all of the experimental tests, reducing the circulation current is performed by connecting an external resistance in series with inter-turn shorted, as shown in Fig. 7.

The experiment is performed with induction machine loaded at rated power and defects in stator windings. The spectrum, space vector locus and waveform of stator line currents, in the case of 7.5% inter-turn shorted and circulation current 5 A, are shown in Fig. 8. From this figure we can see that, the space vector locus is represented by an ellipse and the phase current are not symmetrical.

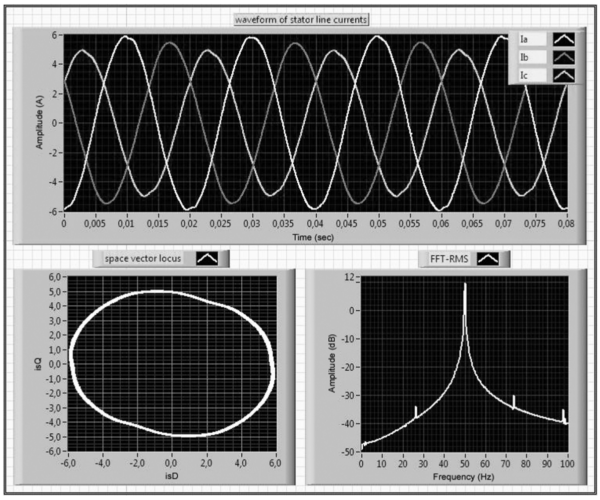

Fig. 8. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents of induction machine for the case of fault in stator windings.

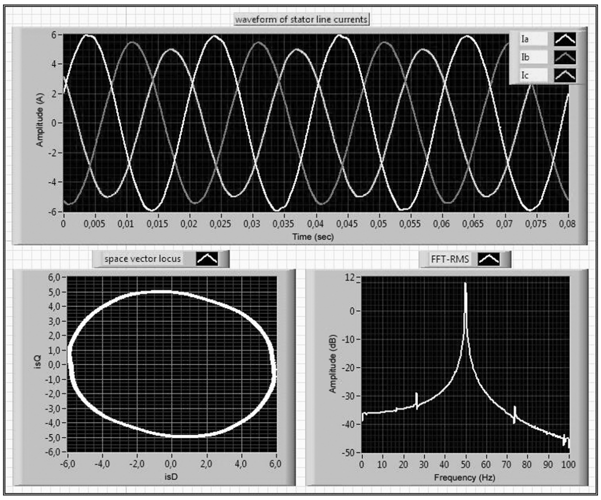

Fig. 9. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents of induction machine for the case of galvanic contact of inter-turn shorted of stator windings.

Fig. 9 represents the same experimental results as in Fig. 8, but with galvanic contact of inter-turn short circuit. The shape of space vector locus of stator line currents is more elliptical. In this case the circulation currents are about ten times of rated motor current.

It should be note that the differences in rotor speed of induction machine, in case of faulty stator winding with normal condition, are not significant. The spectrum, space vector locus and waveform of stator line currents in case of inter-turn shorted between different stator winding phases, are shown in Fig. 10.

Figs. 8 to 10 shows the elliptical shape of space vector locus depend on by degree of winding damages.

3.3 *Induction machine working under broken rotor bars*

Two rotor bars at laboratory induction machine, were cut definitely. The induction machine with broken rotor

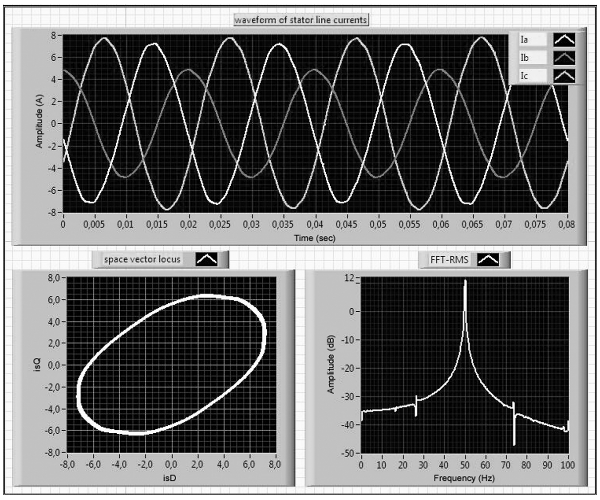

Fig. 10. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents of induction machine for the case of inter-turn shorted of different phases of stator windings.

bars is experimented with different load. The spectrum,

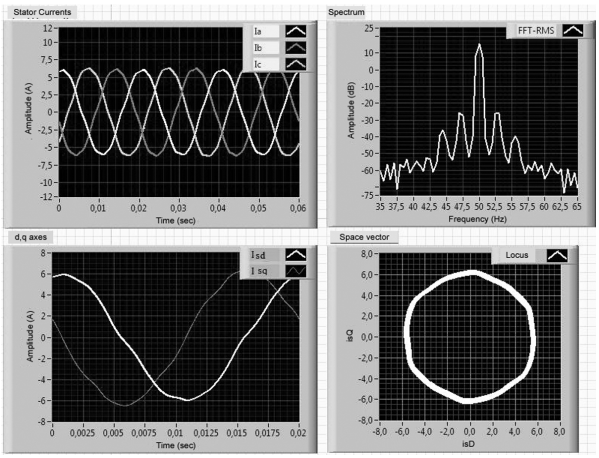

Fig. 11. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents for the case of broken rotor bar of induction machine working at half of rated power.

waveform and space vector locus of stator line currents are shown in Fig. 11 for motor loaded with half of nominal power. As shown by Fig. 11 in the spectrum of stator current sidebands harmonics are appeared and space vector locus of stator line currents is circle with thicker width compare to the item of induction machine, working under normal condition as resulted from theoretical analysis.

In Fig. 12 are represented the same quantities as in Fig. 11 but for motor loaded at nominal power. The space vector locus of stator line currents is presented once

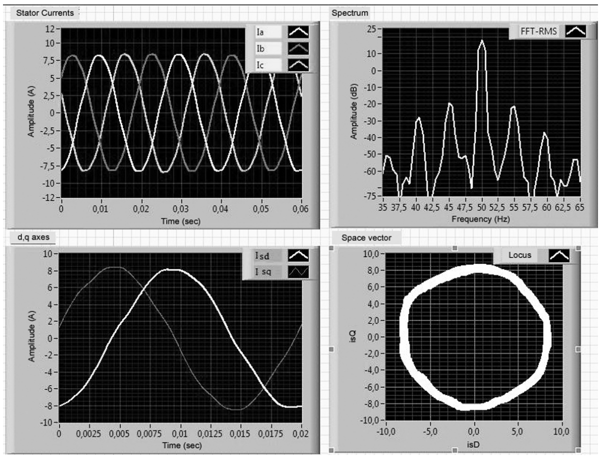

Fig. 12. Experimental data of the spectral analysis, waveform of stator currents and space vector locus of stator line currents for the case of broken rotor bar of induction machine working at rated power.

again by a thicker circle whereas the amplitude of side bands harmonic are increased, this means that width of circle depends on the degree of rotor bar damages and motor load.

4. Conclusion

In this paper we have demonstrated a simple method for detection of rotor bars faults and inter-turn shorted at induction machine stator windings. The method is based on space vector locus of stator line currents. The space vector locus in case of the machine working under normal condition is a circle. The circle radius depends on the motor load.

The space vector locus of stator line currents in case of inter-turn shorted of stator winding is represented by an ellipse. The major axis of ellipse depends on the number of inter-turn shorted of stator winding. In case of failure (opened) phases during operation or single phasing of three phase induction machine the space vector locus of stator line currents is represented by a straight line.

The space vector locus of stator line currents in case of broken rotor bars is a circle, but its width is thicker than in normal condition. The thicker of space vector locus depend by number of broken rotor bars and by motor load.

The stator phase currents can be monitored without interfering on the motor regime, by using spectrum analyzer and space vector locus we can detect rotor bars and inter-turn stator winding faults of induction machine at early stage.

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Speed Estimation of Induction Motors With Rotor Slot Harmonics

Msc. Alfred PJETRI[1]
Lecture at Automation Department

Prof. Dr. Ymer LUGA
Professor at Automation Department

Prof. Ass. Myrteza BRANESHI
Professor at Electrotechnic Department

Dr. Astrit BARDHI
Lecture at Automation Department

[1] Contact details of corresponding author
Tel: +355-42-238-60
Fax: +355-42-238-60
e-mail: alfredpjetri@yahoo.com

Address
Automation Department, Faculty of Electrical Engineering, Polytechnic University of Tirana (UPT), "Sheshi Nënë Tereza", Nr. 4,
Tirana, Albania

Abstract: Nowadays, an increasing trend in using of sensorless speed control of induction motor electrical drives is observed. In these systems, the estimation of the rotor speed without using a mechanical speed sensor is necessary. This paper presents a simple and robust method of sensorless rotor speed estimation of induction motors. The method is based on the spectral analysis of voltage waveform between neutral point of stator windings and neutral point constructed by three-phase resistive network. Some harmonics of voltage waveform are from rotor slots and depend on the number of slots and rotor speed. Extracting of these harmonics, make possible the estimation of the rotor speed of induction motor. To verify the accuracy of the proposed method, the rotor speed, based on rotor slot harmonics, is compared with other techniques of speed measurements. The results of experiments are in good agreement with each other.

Key Word: Induction motors speed identification, rotor slot harmonics, rotor speed estimation, spectral analysis.

1. Introduction

Induction motors for variable speed drives have been widely used in many industrial applications. For accurate torque control and precise operating speeds in the control of induction motor electric drives, more sophisticated techniques are necessary. These techniques employ high speed digital signal processors and control techniques based on the estimation or the identification of speed and other machine states. Speed estimation is an issue of particular interest. The speed measurement in adjustable induction motor speed drives is performed using conventional techniques such as d.c. tachogenerator, a.c. tachogenerator, opto-electronic or electromagnetic speed transducers that are mounted in rotor shaft. D.c. tachogenerator is a separately excited d.c. generator. It is well known that in d.c. tachogenerator the armature voltage is proportional with angular rotor speed of motor. In this manner it is easy to determine the angular speed of motor. For measuring the angular speed of motor the use of a.c. tachogenerator is possible. An a.c. tachogenerator is a two phase squirrel cage induction machine and these phases are in space quadrature. These two phases are called the main and the auxiliary winding. The main winding is supplied by an a.c. voltage with constant magnitude and constant frequency, generally the base frequency and the magnitude of voltage induced in the auxiliary winding when the rotor of a.c. tachogenerator is rotating at specific speed, it is proportional to the angular rotor speed. So it is possible to determine the angular speed. Optical encoders are widely used in position control in electrical drives. Generally an encoder is constructed by a low inertia disc, transparent segments rotates between a led device and a light detector to pulse light. An encoder converts the angular position or speed of motor shaft to an analog or digital code. Decrypting of this code gives us the angular position or speed of the motor shaft. Electromagnetic resolver is becoming increasingly popular for measuring the rotor position, due to their more rugged construction and higher operating temperatures, when compared to encoders. The resolver has two stator windings, cosine and sine windings, which are in space quadrature and the rotor winding. In conventional resolver there is a wound rotor, the air gap is cylindrical and the rotor winding is supplied by a sine wave reference voltage through slip rings and brushes. It should be noted that it is also possible to generate digitally the sine reference voltage using a counter, a read only memory programmed with sine function and a digital analog converter. When the rotor of resolver rotate and the rotor winding is supplied by sine reference voltage in the stator cosine and sine windings are induced the voltages. The two output signal voltages of the resolver can be sampled, and by using analog digital conversion they can be converted into digital signals. When these signals are divided to each other and after some mathematical calculation the rotor position is obtained.

Using a mechanical speed sensor increases the cost of the control system, gives errors in speed detection as a result of mounting, vibration and the ingress of contaminant and reduces the system reliability. Commercially available speed measurement devices are mounted in rotor shaft and require direct contact with the rotor shaft of the motor and are often inaccurate and unreliable after long time use. Thus, measuring rotor speed without a mechanical sensor is essential on induction motor drives. In some cases induction motors, even when accessible, do not provide an exposed shaft due to their mounting configurations. Also in some applications, speed control needs to be implemented without modification of the existing mechanical arrangement. For example, many compressors used in air conditioning, refrigeration and washing machines equipment are coupled to the motors inside a shield compartment, thus preventing motor speed measurement by all commercially available tachometers. All these problems can be overcome by using sensorless speed estimation. Sensorless speed estimation permits the speed identification to be done remotely, even some distance from the motor. All that is needed is access to the motor power supply terminals. This could even be at the control centre situated remotely. The proposed technique of sensorless speed estimation is a very safe method. Therefore sensorless speed detection is highly desirable in electric drives. The rotor angular speed and instantaneous rotor position determination are essential in sensorlees induction motor electric drives. Many control and estimation strategies for induction motor drives are based on electrical equivalent circuit models of the motor. In many cases, the model is a steady-state equivalent circuit model, but for high performance drives, a transient model of the motor is required. Many schemes based on simplified motor models have been divided to sense the speed of the induction motors from measured terminal quantities such as voltage and current.

There are several techniques based on motor mathematic model such as field orientation technique which is generally called in the literature as “vector control”. In sensorless vector control, rotor speed is estimated by using voltage or current model of the induction motor [Holtz J. 2006, Holtz J. 2003, Vas P. 1998]. Briefly, rotor flux vector is obtained indirectly by integrating the induced voltage which can be measured by sense coils or phase voltage. However, the accuracy of rotor speed estimation is mainly dependent on the accuracy of integration that is also out on the motor parameter and usually fails at low speeds [Vas P. 1998]. In the following rotor position detection without a direct position component (sensorless) voltage, current and flux measurement sensors may be utilized. An alternative way to improve the measurement accuracy at low speed is achieved by injecting a high frequency carrier signal with frequency which is generally higher and independent of the fundamental excitation frequency [Holtz J. 2006]. On the other hand, these methods either need a modification in the applied pulse-width modulation signals or more generally need an inclusive redesign of the inverter circuitry hardware. Another disadvantage of signal injection has been to generate cogging torques especially at small sized machines.

One of the more recent techniques in speed estimation based on the mathematic machine model is the Model Reference Adaptive System (MRAS). In this technique the induction motor is used as the reference and a vector-controlled induction motor model is used as the adjustable model [Shinde S.N. 2012, Finch J.W. 2008, Vasic V. 2001]. This model is adjusted to drive the error in speed between the two models to zero. The method uses the synchronous reference frame in the model. In order to obtain an accurate dynamic representation of the motor speed, it is necessary to base the calculation on the coupled circuit equations of the motor. In this technique of speed estimation, the induction motor is modelled based on a state-space model of the machine using two axis variables. This may be done in the stationary or synchronous frames, both having been used widely. Since the motor voltages and currents are measured in the stationary reference frame, it is convenient if the motor equations are also in the stationary reference frame. With complete knowledge of the motor parameters and variables like the resistance, inductance, poles, electrical angular speed, stator voltages and current, the instantaneous speed of the rotor can be estimated on a closed-loop basis from the equations of the machine.

This method of speed detection has disadvantages because of its dependence on machine parameters. The frequency dependence of the rotor electrical circuit parameters, non-linearity of the magnetic circuit and temperature dependence of the stator and rotor electrical circuits all have an impact on the accuracy of the observer and hence the speed estimation. At high frequencies and no-load conditions these errors are usually quite negligible. However, the speed accuracy is generally sensitive to model parameter mismatch if the machine is loaded, especially in the field-weakening region and in the low-speed range [Vas P. 1998]. The parameter contributing to this variation are, rotor resistance variation with temperature, stator resistance variation with temperature, stator inductance variation due to saturation of the stator teeth's.

A total different way to estimate rotor speed can be achieved by using rotor slot harmonics. If a symmetrical three-phase induction motor is supplied by a system of symmetrical three-phase voltages, the air gap flux will contain space harmonics. Some of these harmonics space are due to the non sinusoidal spatial distribution of the stator winding, and there are also slots harmonics produced by variation of the reluctance due to the stator slots and there are also harmonics which are due to the slots of the rotor [Vas P. 1993, Boldea I. 2002, Sadarangani C. 2000, Kaikaa M.Y. 2006]. The latter can be utilized for the detection of the angular slip frequency and the angular speed of the motor. The variation of the air gap reluctance due to rotor slot openings modulates the fundamental air-gap flux. This modulation can be observed either from the flux of the machine via a sensing coil, as from phase voltages of a current controlled machine, as from phase currents of a voltage controlled machines. In the literature the harmonics caused by rotor slots are generally called rotor slot harmonics. Speed estimation methods based on the rotor slot harmonics analysis are popular because they do not depend on the machine electrical parameters knowledge [Vas P. 1993, Boldea, I. 2002, Sadarangani C. 2000, Kaikaa M.Y. 2006, Keysan O. 2010]. Rotor slot harmonics are relatively small in magnitude compared to the magnitude of fundamental excitation and its harmonics. The frequency of the rotor slots harmonics is directly related with the number of rotor slots and the rotor speed. Thus, knowing the number of rotor slots and the frequency of rotor slots harmonics, the rotor speed can be estimated [Vas P. 1993, Boldea I. 2002, Sadarangani C. 2000, Kaikaa M.Y. 2006, Keysan O. 2010, Nandi, S. 2003]. It is observed that previous studies always use spectral estimation techniques to determine the frequency of rotor slots harmonics. The spectral estimation technique is mainly based on Fast Fourier Algorithm (FFT).

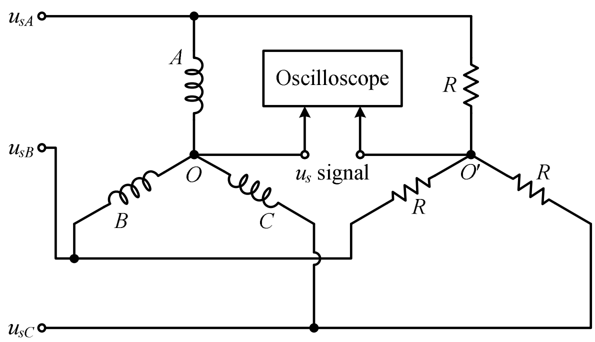


Fig. 1 Signal measurement for rotor slot harmonics analysis.

In this paper we present a simple and robust method to estimate the speed of induction motors which is based on spectral analysis of electrical quantity such as voltage between neutral point of stator windings and neutral point constructed by three-phase resistive network [Vas P. 1993]. This voltage is not zero because of motor parameters and geometry asymmetry. Air gap magnetic flux of induction motors, due to the slots in the stator and rotor magnetic circuit, will contain not only fundamental but also higher harmonics [Vas P. 1993, Boldea I. 2002, Sadarangani C. 2000, Kaikaa M.Y. 2006, Keysan O. 2010, Nandi S. 2003]. The order of these harmonics depends on the number of slots in the stator and rotor as well as the rotor rotational speed of induction motor. The air gap flux variation caused by rotor slot generates rotor slot harmonics in the stator current. Unfortunately it can be quite difficult to detect these harmonics in the stator current due to their low amplitude comparing to the fundamental stator current harmonic [Vas P. 1993]. To overcome this problem we use to monitor the voltage waveform between the neutral point 0 of the stator winding and the neutral point 0′ constructed by the three-phase resistive network as it is shown in Fig. 1. Harmonic of air gap magnetic flux due to the rotor slots will induce in stator winding an electromotive force (e.m.f.) which frequency is depend by rotor rotational speed [Vas P. 1993]. The determination of this voltage frequency allows us to find the induction motor rotor angular speed, when the rotor slots number is known. The determination of this frequency is done by Fast Fourier spectral analysis of voltage waveform between the neutral point 0 of the stator windings and the neutral point 0′ of resistive network by using of oscilloscope.

2. Calculation of magnetic field in induction machines

2.1. *Magnetomotive force in induction machines*

Air gap magnetomotive force (m.m.f.) of induction machines is created as a result of currents passing in the windings of stator and rotor. Due to spatial distribution around air gap of stator and rotor windings, in the resultant m.m.f., except of fundamental harmonic will exists space harmonics [Vas P. 1993, Boldea I. 2002, Sadarangani C. 2000, Kaikaa M.Y. 2006, Keysan O. 2010].

Taking into consideration a three-phase induction machine with p pole pairs and q number of coils for pole and phase, and indicating air gap periphery with θ, m.m.f. of stator winding of induction machine can be calculated as following [Vas P. 1993, Boldea I. 2002]:

$$F_s(\theta,t)=\sum_{\upsilon=1}^{\infty}\hat{F}_{s,\upsilon}\cos\left(\upsilon p\theta-\omega_1 t-\varphi_1\right) \quad (1)$$

where

$$\upsilon=6k\pm1, \quad k=0,\ 1,\ 2,... \quad (2)$$

and $\hat{F}_{s,\upsilon}$ is the harmonic amplitude of order υ. The harmonic amplitude can be calculated as [Holtz J. 2006]

$$\hat{F}_{s,\upsilon}=\frac{3\sqrt{2}}{\pi}\frac{qN}{\upsilon}k_{p\upsilon}k_{y\upsilon}I_1, \quad (3)$$

where, N is the number of conductors in one coil, ω_1 angular electric speed of fundamental harmonics, φ_1 initial phase of stator current, I_1 stator phase current, $k_{p\upsilon}$ distribution winding coefficient for the harmonics order υ, $k_{y\upsilon}$ pitch coil coefficient for the harmonics order υ. The angular mechanical speed of the harmonics order υ can be calculated with the expresion below

$$\omega_\upsilon=\frac{\omega_1}{\upsilon p}=\frac{\omega_1}{\left(6k\pm1\right)p} \quad (4)$$

Harmonics of angular speed that are with positive sign (e.g. 7, 13, . . .) create waves that rotate in the same direction with the fundamental harmonic wave, while harmonics with negative sign (e.g. 5, 11, . . .) create waves that rotate in the opposite direction with the fundamental harmonic wave.

In the rotor winding, due to the magnetic field created by the stator winding, will pass a current which except of fundamental harmonic will contain higher harmonics. In this manner, m.m.f. of rotor winding can be expressed as a sum of two components. The first component represent m.m.f. created from fundamental harmonic of rotor current and can be calculated with the following expression [Vas P. 1993, Boldea I. 2002]

$$F_{r,1}(\theta,t)=\sum_{\mu=1}^{\infty}\hat{F}_{r,1}\cos\left(\mu_1 p\theta-\omega_{\mu,1}t-\varphi_\mu\right) \quad (5)$$

where

$$\mu_1=k\frac{Z_r}{p}+1, \quad k=0,\ \pm1,\ \pm2,..., \quad (6)$$

$\hat{F}_{r,1}$ is the harmonic amplitude of order μ_1

$$\hat{F}_{r,1}=\left(-1\right)^{\mu}\frac{3\sqrt{2}}{\pi}\frac{qN}{\mu}\xi_1\xi_\mu I_1\cos\varphi_1 \quad (7)$$

Z_r is the number of rotor slots, μ_1 space harmonic of rotor, φ_1 initial phase for respective harmonics, □$_1$ distribution rotor winding coefficient, ξ_μ pitch coil coefficient of rotor. Angular speed $\omega_{\mu,1}$ of air gap magnetic field created from m.m.f of rotor winding, due to fundamental harmonic of rotor current in the stationary reference frame (stationary reference frame is fixed in stator) can be calculated with the following expression

$$\omega_{\mu,1}=\left(\frac{\omega_r}{p}+\frac{s\omega_1}{\mu_1 p}\right)\mu_1 p=\omega_1\left[1+\frac{kZ_r\left(1-s\right)}{p}\right] \quad (8)$$

where s is induction motor slip and ω_r is the electric angluar speed of rotor.

The second component of rotor m.m.f. is created from higher harmonics of rotor current. This component is given by the expression

$$F_{r,2}(\theta,t)=\sum_{\mu=1}^{\infty}\hat{F}_{r,2\mu}\cos\left(\mu_2 p\theta-\omega_{\mu,2}t-\varphi_\mu\right) \quad (9)$$

where

$$\mu_2=k\frac{Z_r}{p}+\upsilon, \quad k=0,\pm1,\pm2,... \quad (10)$$

$$\hat{F}_{r,2,\mu}=\left(-1\right)^{\mu}\sqrt{2}I_{r\upsilon}\frac{\upsilon}{\mu}\xi_\upsilon \quad (11)$$

$I_{r\upsilon}$ is the rotor current amplitude of harmonics υ, ξ_υ distribution rotor winding coefficient for harmonics υ.

Resultant air gap m.m.f. of induction motor is equal to the sum of m.m.f stator winding and the m.m.f. of rotor winding [Vas P. 1993, Boldea I. 2002]. Thus from expressions (1), (5), and (9), the resultant m.m.f. of induction machine result

$$\begin{aligned}F(\theta,t)&=F_s(\theta,t)+F_{r,1}(\theta,t)+F_{r,2}(\theta,t)=\\&=\hat{F}_1\cos\left(p\theta-\omega_1 t-\varphi_1\right)\\&+\hat{F}_{6k+1}\cos\left[\left(6k+1\right)p\theta-\omega_1 t-\varphi_1\right]\Big|_{k=1,2,3...}\\&+\hat{F}_3\cos\left[\left(Z_s-p\right)\theta-\omega_1 t-\varphi_1\right]\\&+\hat{F}_4\cos\left[\left(Z_s+p\right)\theta-\omega_1 t-\varphi_1\right]\\&+\hat{F}_5\cos\left[\left(Z_r-p\right)\left(\theta-\omega_r t\right)+s\omega_1 t\right]\\&+\hat{F}_6\cos\left[\left(Z_s+p\right)\left(\theta-\omega_m t\right)-s\omega_1 t\right]\end{aligned} \quad (12)$$

From expressions (12) it can be see that the resultant air gap m.m.f. of induction machine contains a number of harmonics which are due both windings and the stator and rotor slots of induction machine.

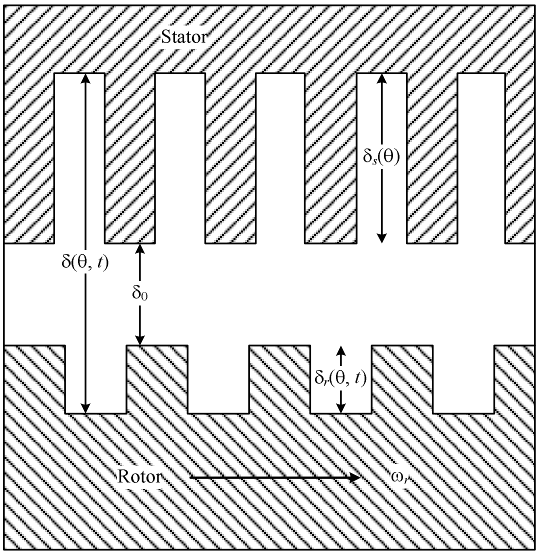


Fig. 2 Air gap of induction machines.

2.2. *Calculation of air gap specific magnetic conductivity in three-phase induction machines*

Air gap specific magnetic conductivity in three-phase induction machines can be calculated by studding the air gap of induction machine, which is variable due to slots of the stator and rotor. In Fig. 2 it is shown a schematically view of one sector of air gap in induction machines. For analyze simplicity the slots of stator and rotor are accepted to have rectangular shape [Boldea I. 2002, Sadarangani C. 2000]. In this case for air gap of induction machine we have

$$\delta(\theta,t)=\delta_s(\theta)+\delta_r(\theta,t)+\delta_0 \qquad (13)$$

where δ_0 represent the constant air gap and it is the air gap of induction machine when the rotor and stator are without slots (with smooth surface), $\delta_s(\theta)$ depends from the angle θ and represents the depth of the stator slots, $\delta_r(\theta, t)$ depends from the angle θ and from the time t and represents the depth of the rotor slots. The air gap of stator teeths is periodic function with period $T_s = 2\pi/Z_s$. In the same manner the air gap of rotor teeths is periodic function with period $T_r = 2\pi/Z_r$. The reference frame fixed in rotor φ, and reference frame fixed in stator can be related to each other with the expresion $\varphi = \theta - \omega_r t$, where $\omega_r = d\theta_r/dt$ is the angluar speed of rotor. Air gap specific magnetic conductivity can be expressed as

$$\begin{aligned}\lambda(\theta,t)&=\frac{\mu_0}{\delta(\theta,t)}=\frac{\mu_0}{\delta_s(\theta)+\delta_r(\theta,t)+\delta_0}\\&=\frac{\mu_0}{\delta_0}\frac{1}{k_{c1}k_{c2}}+\sum_{k=1}^{\infty}\lambda_{1,k}\cos(kZ_s\theta)\\&+\sum_{m=1}^{\infty}\lambda_{2,m}\cos\left[mZ_r(\theta-\omega_m t\right]\\&+\sum_{k=1}^{\infty}\sum_{m=1}^{\infty}\lambda_{1,2,k\pm m}\cos\left[\left(kZ_s-mZ_r\right)\theta-mZ_r\omega_m t\right]\\&=\lambda_0+\lambda_s+\lambda_r+\lambda_{r-s}\end{aligned} \qquad (14)$$

where k_{c1}, k_{c2} are Carter coeficient [Boldea I. 2002] which takes into account the geometric dimensions of stator and rotor teeth and the state of the magnetic core, while ω_m is the mechanical speed of rotor $\omega_m = \omega_r/p = (1-s)\omega_1/p$. As can be seen from the expression (14) air gap specific magnetic conductivity in three-phase induction machines is the sum of four components:

1. First component λ_0 is constant and represent air gap specific magnetic conductivity of induction machine when the air gap is smooth (without slots).
2. Second component λ_s represents the influence of the stator slots.
3. Third component λ_r represents the influence of the rotor slots and the rotor speed.
4. Fourth component λ_{r-s} takes into account the influence both from stator and rotor slots.

2.3. *Air gap flux density of induction machines*

Air gap flux density of induction machines can be can be expressed as a product of air gap specific magnetic conductivity (14) with resultant m.m.f. (12).

$$\begin{aligned}B\left(\theta,t\right)&=\lambda\left(\theta,t\right)F\left(\theta,t\right)\\&=\left(\lambda_0+\lambda_s+\lambda_r+\lambda_{r-s}\right)\left(F_s+F_{r,1}+F_{r,2}\right)\end{aligned} \qquad (15)$$

If we develop the expression (15) and take into account only the fundamental harmonics, then air gap flux density can be expressed as

$$\begin{aligned}B\left(\theta,t\right)&=\hat{B}_1\cos\left(p\theta-\omega_1 t\right)\\&+\hat{B}_5\cos\left(5p\theta+\omega_1 t\right)+\\&+\hat{B}_7\cos\left(7p\theta-\omega_1 t\right)\\&+\hat{B}_{1-s}^{(+)}\cos\left[\left(Z_s-p\right)\theta+\omega_1 t\right]+\\&+\hat{B}_{1-s}^{(-)}\cos\left[\left(Z_s+p\right)\theta-\omega_1 t\right]\\&+\hat{B}_{1-R}^{(+)}\cos\left[\left(Z_r-p\right)\left(\theta-\omega_m t\right)+s\omega_1 t\right]\\&+\hat{B}_{1-R}^{(-)}\cos\left[\left(Z_r+p\right)\left(\theta-\omega_m t\right)-s\omega_1 t\right]\end{aligned} \qquad (16)$$

where $\hat{B}_1, \hat{B}_5, \hat{B}_7, \hat{B}_{1-s}^{(+)}, \hat{B}_{1-s}^{(-)}, \hat{B}_{1-R}^{(+)}, \hat{B}_{1-R}^{(-)}$ are the amplitude of the corresponding harmonics. As we mentioned before, the indexes (+) and (–) showing positive and negative waves created due to slots in the stator and rotor. The expression of air gap flux will be similar with air gap flux density.

$$\begin{aligned}\Phi(\theta,t) = {} & \hat{\Phi}_1 \cos(p\theta - \omega_1 t) \\ & +\hat{\Phi}_5 \cos(5p\theta + \omega_1 t) + \\ & +\hat{\Phi}_7 \cos(7p\theta - \omega_1 t) \\ & +\hat{\Phi}_{1,s}^{+} \cos\left[(Z_s - p)\theta + \omega_1 t\right] + \\ & +\hat{\Phi}_{1,s}^{-} \cos\left[(Z_s + p)\theta - \omega_1 t\right] \\ & +\hat{\Phi}_{1,r}^{+} \cos\left[(Z_r - p)(\theta - \omega_m t) + s\omega_1 t\right] \\ & +\hat{\Phi}_{1,r}^{-} \cos\left[(Z_r + p)(\theta - \omega_m t) - s\omega_1 t\right]\end{aligned} \tag{17}$$

where $\Phi_\upsilon = B_\upsilon S_\upsilon = B_\upsilon S_1/\upsilon$ and S_1 represents surface periphery belonging to a pole of fundamental harmonic.

2.4. *E.m.f. induced in stator winding*

From the expression (17), it can be noticed that the air gap magnetic flux contains several harmonics. Each harmonics of air gap flux will induce in the rotor and stator windings corresponding e.m.f. [Vas P. 1993], which for one phase can be expressed

$$\begin{aligned}u_{sA} = \frac{\partial \hat{\Phi}}{\partial t} = {} & \hat{U}_1 \cos(p\theta - \omega_1 t) \\ & +\hat{U}_5 \cos(5p\theta + \omega_1 t) + \hat{U}_7 \cos(7p\theta - \omega_1 t) \\ & +\hat{U}_{1,s}^{(+)} \cos\left[(Z_s - p)\theta + \omega_1 t\right] \\ & +\hat{U}_{1,s}^{(-)} \cos\left[(Z_s + p)\theta - \omega_1 t\right] \\ & +\hat{U}_{1,r}^{(+)} \cos\left[(Z_r - p)(\theta - \omega_m t) + s\omega_1 t\right] \\ & +\hat{U}_{1,r}^{(-)} \cos\left[(Z_r + p)(\theta - \omega_m t) - s\omega_1 t\right]\end{aligned} \tag{18}$$

where $\hat{U}_1$ is the amplitude of main component of e.m.f., $\hat{U}_{1,s}^{(+)}$, $\hat{U}_{1,s}^{(-)}$ dhe $\hat{U}_{1,r}^{(+)}$, $\hat{U}_{1,r}^{(-)}$ are the amplitudes of positive and negative components due to slots in the stator and rotor. As it is seen from the above expression, the first component of the voltage varies with same frequency of the voltage source, while the second and third components are the five and seventh haarmonics due to distributed winding of stator. The other components of phase voltage are due to slots in stator and rotor. Other phase voltage respectively phase *B* and *C* can be obtained from expression (18) with the difference that they are displaced by 120° dhe 240° electric deegre from phase *A*.

3. Theoretical analysis of rotor slot harmonics

From the expression (18) it can be noticed that e.m.f. induced in stator winding, except the fundamental harmonic and its multiples, contains other harmonics because of rotor slots [Vas P. 1993]. If the instantaneous stator phases voltages are summed together then it is obtained

$$\begin{aligned}u_s = {} & u_{sA} + u_{sB} + u_{sC} = \\ & = \frac{1}{2} k_{\upsilon 1} (N_r\omega_r + \omega_1)\left\{1 + 2\cos\left[2(N_r+1)\frac{\pi}{3}\right]\right\} \\ & \times \cos\left[(N_r\omega_r + \omega_1)t - (N_r+1) f_{h1}\right] \\ & + \frac{1}{2} k_{\upsilon 2} (N_r\omega_r - \omega_1)\left\{1 + 2\cos\left[2(N_r-1)\frac{\pi}{3}\right]\right\} \\ & \times \cos\left[(N_r\omega_r - \omega_1)t - (N_r-1) f_{h2}\right]\end{aligned} \tag{19}$$

where $k_{\upsilon 1}$, $k_{\upsilon 2}$, f_{h1}, f_{h2} depend on the electromagnetic and mechanical structure of the induction machine and N_r is the number of rotor slots per pole pairs ($N_r = Z_r/p$) [Holtz J. 2006]. From above expression it is clear that the form os u_s voltage is sinusoidal one. If in the expression (19) N_r is a natural number, then

$$u_s = 0 \tag{20}$$

for $N_r = 3N$, $N = 1, 2, \ldots$

$$\begin{aligned}u_s = {} & \tfrac{3}{2} k_{\upsilon 1} (N_r\omega_r + \omega_1) \\ & \times \cos\left\{(N_r\omega_r + \omega_1)t - (N_r+1) f_{h1}\right\}\end{aligned} \tag{21}$$

for $N_r = 3N - 1$, $N = 1, 2, \ldots$

$$\begin{aligned}u_s = {} & \tfrac{3}{2} k_{\upsilon 2} (N_r\omega_r - \omega_1) \\ & \times \cos\left\{(N_r\omega_r - \omega_1)t - (N_r-1) f_{h2}\right\}\end{aligned} \tag{22}$$

for $N_r = 3N + 1$, $N = 1, 2, \ldots.$

Thus from the expression (19) it can be seen that if N_r is a natural number , except for a multiple of three, then to voltage waveform u_s it is detected only one component of slot harmonics [Vas P. 1993]. The fundamental slot harmonic frequency of voltage waveform u_s can be expressed as

$$\begin{aligned}f_s & = \frac{N_r\omega_r \pm \omega_1}{2\pi} \\ & = \frac{\left[N_r(1-s) \pm 1\right]\omega_1}{2\pi} \\ & = \left[\frac{Z_r(1-s)}{p} \pm 1\right] f_1\end{aligned} \tag{23}$$

where s is the slip of the induction motor. From the expression (23) it can be seen that the rotor slot harmonic frequency depends only on f_1 and s. If in expresion (23) N_r is not a multiple of three then the frequency f_s can be detected by spectral analysis of voltage waveform u_s between neutral point of stator windings and neutral point of three-phase resistive

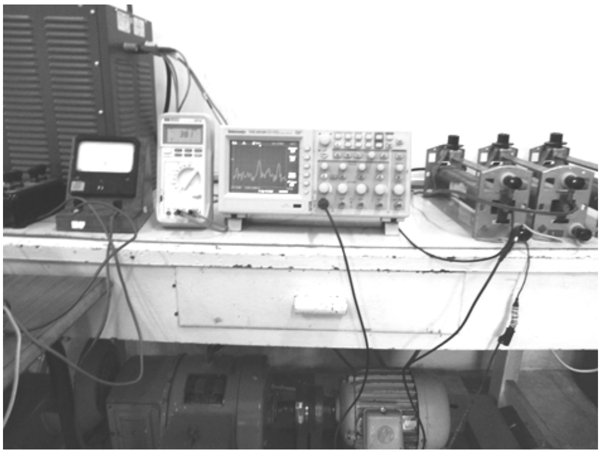


Fig. 3 Eksperimental setup stand.

network, Fig. 1. In this manner the rotor speed of induction motor is obtain as following [Vas P. 1993]

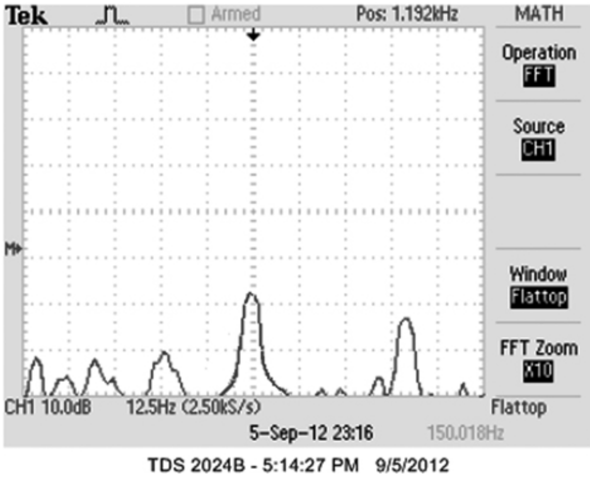
Table 1. Induction motor rated data

P [kW]	*N* [rpm]	*U* **[V]**	*I* [A]	cos □	***F*₁** **[HZ]**
3	1430	380	6.9	0.82	**50**

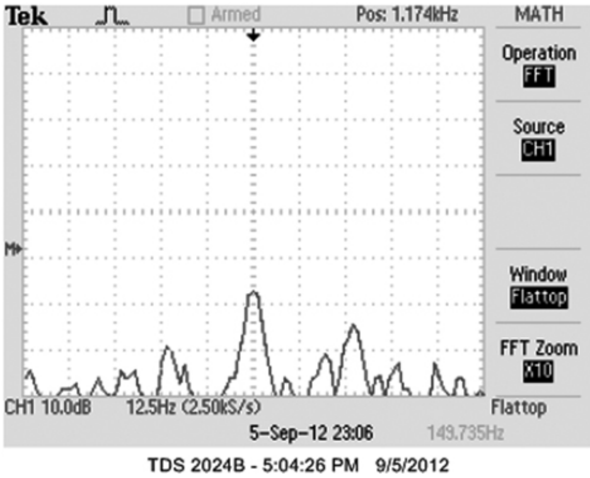
$$n = 60\frac{f_1}{Z_r}\left(\frac{f_s}{f_1} \pm 1\right), \quad [\text{rpm}] \qquad (24)$$

4. Experimental results

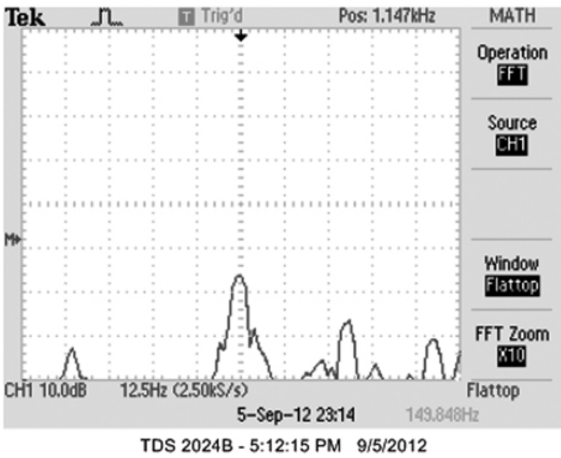
In order to verify the proposed method for speed estimation of three-phase induction motors with rotor slot harmonics based on spectral analysis of voltage between neutral point of stator winding and neutral point of three-phase resistive network, experiments have been done in electric machinery lab, Fig. 3. The experiments were carried out in a three-phase squirrel cage induction motor which parameters are listed in Tab. 1. The induction motor under consideration has the rotor slots number Z_r = 46. The induction motor was supplied by a system of symmetrical three-phase voltages with rated voltage and rated frequency f_1 = 50 Hz. Changing in the load torque of the motor was achieved using a d.c. generator which is coupled to the induction motor. As it is known changing of load torque causes changing in rotor speed of induction motor. Spectral analysis of voltage u_s, based on Fast Fourier Algorithm (FFT) was done by using an oscilloscope. In Fig. 4 are shown spectral analysis of voltage u_s for three different values of rotor speed 1492 rpm, 1469 rpm and 1430 rpm. Induction motor rotor speed values, measurement and estimated by rotor slot harmonics are shown in Tab. 2. As it can be notice from Tab. 2, the speed error is very low and what is most important is the fact that the error is independent from the motor load and temperature conditions.



1492 rpm



1469 rpm



5. Conclusions and future works

The speed estimation method for induction motors, based in rotor slot harmonics is very accurate in high range speeds. This conclusion can be noticed from experimental data. Estimation of rotor speed based on this method has several advantages compared with conventional techniques. It does not need speed transducers that are mounted in rotor shaft, is not affected by the environment in which it works, it can be used for different range power induction motors and it is maintenance free. When the rotor speed is very low, the amplitude of signal voltage u_s decreases. If the amplitude of voltage u_s is to small we can not obtain a reliable signal because of harmonics noise. So it will be difficult to detect the rotor slot harmonic. This is a disadvantage of the method. To overcome this problem an extra sinusoidal three-phase signal must be injected into stator windings of the induction motors. This will be our future research.

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Evaluation of carbon capture and storage (CCS) technologies for Integrated Gasification Combined Cycle (IGCC) power plants

Assoc. Prof. Dr. Calin-Cristian CORMOS

Tel: +40-264-593833
Fax: +40-264-590818
E-mail: cormos@chem.ubbcluj.ro

Address:
Babes – Bolyai University, Faculty of Chemistry and Chemical Engineering
11 Arany Janos, RO-400028, Cluj – Napoca, Romania

Abstract: Integrated Gasification Combined Cycle (IGCC) power plants offer significant advantages compared with classical combustion-based power plants in term of lower energy and cost penalties for carbon capture and storage (CCS), utilisation of wide range of fuels (lower grade coals, biomass, wastes etc.), energy vectors poly-generation capability, plant flexibility, lower environmental impact etc. These are the main reasons for which IGCC technology received an increased interest in the last decade and have promising prospects for the future low carbon economy. The aim of this paper is to evaluate using process flow modelling and process integration techniques, the prospects for introducing various carbon capture and storage technologies into an IGCC power plant design. The CCS technologies to be investigated in the paper are ranging from more technologically and commercially mature gas-liquid absorption processes (assessed in both configurations pre- and post-combustion capture using chemical and physical solvents) to emerging carbon capture technologies like chemical looping systems. Future technology developments like hydrogen and power co-generation for increasing plant flexibility are also presented. Investigated IGCC-based power plants concepts generate about 400 MW net electricity with a carbon capture rate higher than 90 %. The paper presents in details the plant configurations, main design assumptions, process integration issues among various plant sub-systems (e.g. heat and power) and main key performance indicators (fuel consumption, gross and net power, carbon capture rate, energy penalty, specific CO_2 emissions, economic aspects etc.). A reference IGCC power plant without carbon capture will be used to benchmark the CCS power plant concepts.

Keywords: IGCC, Carbon Capture and Storage (CCS)

1. Introduction

The world is facing the challenge of reducing its greenhouse gas emissions (mainly carbon dioxide) and securing its supply of energy to satisfy the growing energy needs, while improving the competitiveness of its economy. In particular, the European Union (EU) is committed to reduce its greenhouse gas emissions by at least 20 % compared to 1990 levels by 2020 and by 85 – 90 % by 2050 (European Commission, 2008). The transition to a low-carbon society can only be realised through the acceleration of development of a diverse portfolio of low-carbon energy technologies, which, in turn, will enable the timely commercialisation and large-scale deployment of these technologies in the energy sector (IPCC, 2005; Gibbins and Chalmers, 2008; European Commission, 2009).

Currently, fossil fuels are the backbone of the European energy system, supplying more than 50% of power generation. Coal provides for about 60% of fossil fuel electricity, while natural gas provides for most of the balance (Odenberger and Johnsson, 2010). Furthermore, all projections show that fossil fuels will remain the main source for electricity generation in Europe at least in the short to medium term, despite the significant ongoing efforts to promote renewable energy technologies and energy efficiency. In this respect, carbon capture and storage (CCS) technologies applied in high-efficiency power plants represent a critical component of the portfolio of low-carbon technologies for the transition to a low carbon society since the utilisation of fossil fuels in power generation is the main source for greenhouse gas emissions (IPCC, 2005; Figueroa et al., 2008; Hammond et al., 2011).

Integrated Gasification Combined Cycle (IGCC) is one of the most promising energy conversion methods which is intensively evaluated as a potential clean technology having the highest potential to capture the carbon dioxide with the low penalties in term of energy efficiency and cost (IEA-GHG, 2003; Higman and van der Burgt, 2008; Cormos, 2012a). Through gasification, the solid fuel (either fossil or renewable) is partially oxidised to produce a combustible gas (syngas) mainly containing carbon monoxide and hydrogen. The syngas can be converted via chemical route in valuable compounds (e.g. hydrogen, methanol, ammonia etc.) or can be burn in a Combined Cycle Gas Turbine (CCGT) for power production (Gasification Technologies Council, 2012).

The present paper evaluates using process flow modelling and process integration techniques, the prospects for introducing various carbon capture and storage technologies into an IGCC power plant design. The CCS technologies to be investigated in the paper are ranging from more technologically and commercially mature gas-liquid absorption processes (assessed in both configurations pre- and post-combustion capture using chemical and physical solvents) to emerging carbon capture technologies like chemical looping systems (Fan, 2010).

Investigated IGCC-based power plants concepts generate about 400 MW net electricity with a carbon capture rate higher than 90 %. As investigated gasifier, Shell gasifier was evaluated in all cases considering its high energy efficiency. The evaluated coal-based power plant concepts analysed in this paper are the following:

- Case 1: IGCC without CO_2 capture;
- Case 2: IGCC with pre-combustion CO_2 capture using physical gas-liquid absorption (Selexol®);
- Case 3: IGCC with post-combustion CO_2 capture using chemical gas-liquid absorption (Methyl-Diethanol-Amine - MDEA);
- Case 4: IGCC with pre-combustion CO_2 capture using iron-based chemical looping.

2. Plant configurations and main design assumptions of evaluated power plant concepts

IGCC is a power generation technology in which the solid feedstock is partially oxidized with steam and oxygen (produced by an air separation unit – ASU), to generate syngas, a mixture of carbon monoxide and hydrogen. Although many types of gasifier are currently commercially available, this paper addresses one type of oxygen-blown entrained-flow gasifier which is likely to be one of the most suitable solutions for IGCC with CCS design: Shell gasifier (dry feed type with gas quench and heat recovery boiler). IGCC plant without CCS is described in literature (Higman and van der Burgt, 2008).

The first carbon capture option is based on pre-combustion capture using gas – liquid absorption (either physical absorption or chemical absorption) applied to the shifted syngas. Physical absorption using Selexol® solvent was consider taking into account the better performances compared with chemical solvents (IEA-GHG, 2003; Cormos, 2012a). Conceptual layout of a modified IGCC scheme for power generation with carbon dioxide capture using pre-combustion capture is presented in Figure 1.

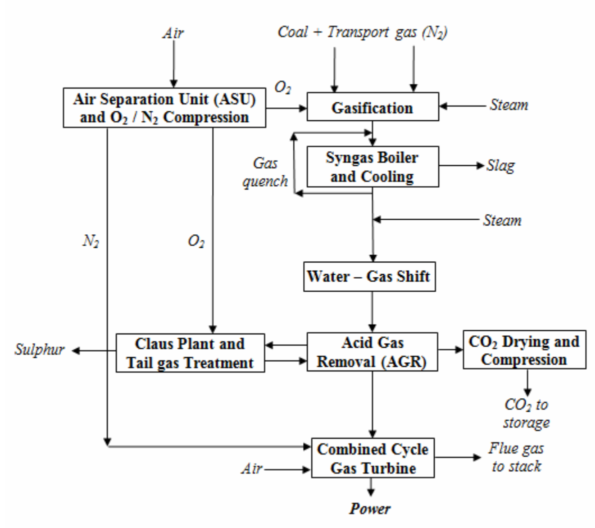

Figure 1. Conceptual layout of IGCC design with pre-combustion capture based on gas-liquid absorption

The second carbon capture option is based on post-combustion capture from gas turbine flue gases (this case is similar with conventional IGCC power plant without carbon capture, the most significant difference being the introduction of gas-liquid absorption unit at the end of heat recovery steam generator). As solvent used to CO_2 capture, activated methyl-diethanol-amine (MDEA) was used considering its performances (IEA-GHG, 2004). The conceptual layout of an IGCC scheme for power generation with carbon capture using post-combustion option is presented in Figure 2.

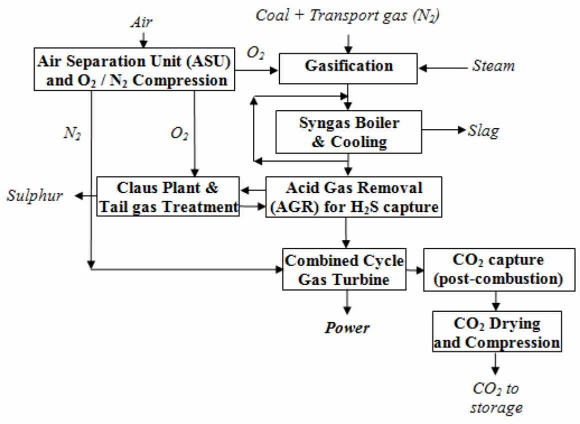

Figure 2. Conceptual layout of IGCC design with post-combustion capture based on gas-liquid absorption

The third carbon capture option is based on innovative chemical looping system - iron-based (Fan, 2010; Cormos, 2012b). In the chemical looping system, the oxygen carrier (iron oxide) is recycle between syngas reactor (where it is reduced to FeO and Fe) and steam reactor (where it is oxidised back with steam). Both cases 2 and 4 are using a hydrogen-fuelled gas turbine in contrast with cases 1 and 3 which are based on syngas-fuelled gas turbine (IEA-GHG, 2003; Cormos, 2011). The configuration of IGCC-based chemical looping system is presented in Figure 3.

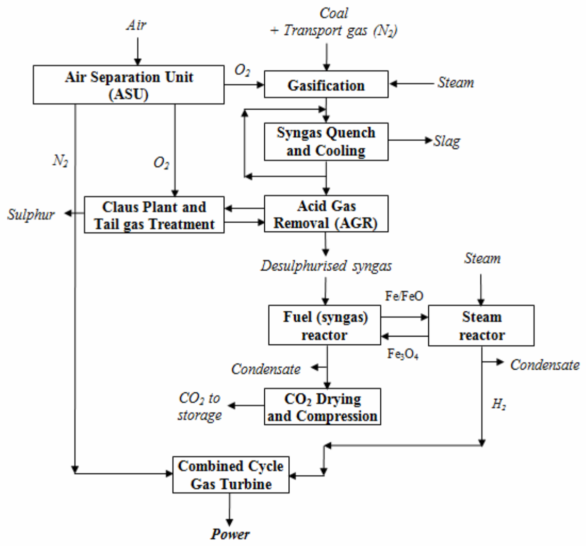

Figure 3. Conceptual layout of IGCC design with pre-combustion capture based on chemical looping

The main design assumption of all evaluated IGCC plant concepts is that they generate about 400 MW net power using one M701G2 gas turbine (334 MW net power). The steam cycle has the following parameters: HP / MP / LP pressure levels = 118 / 34 / 3 bar. The steam cycle has also a MP steam reheat. The evaluated case studies are designed to capture more than 90% of the feedstock carbon. The desulphurisation step achieves more than 99% sulphur removal. As fuel used, all cases are considering coal. The coal ultimate analysis (reported on dry base) is: 72.04% carbon, 4.08% hydrogen, 1.67% nitrogen, 7.36% oxygen, 0.65% sulphur, 0.01% chloride and 14.19% ash. The moisture content is 8.1% reported on as received base. The lower heating value (LHV) is 27804 kJ/kg dry.

The evaluated gasifier system is based on Shell design running at 40 bar pressure and a syngas quench temperature of about 800°C (in accordance with the coal characteristics). All CCS designs consider 120 bar delivery pressure of captured CO_2 stream with at least 95% purity (IPCC, 2005; De Visser et al., 2008). As storage option, the most restrictive case was considered (Enhanced Oil Recovery - EOR).

Based on the parameters and process configurations described in this section of the paper, computer simulations were conducted for all four cases. ChemCAD was used for main plant modelling and simulation and Thermoflow was used for power block related aspects. The used simulation packages have comprehensive property database, therefore most of the chemical species can be selected directly from the database. The unconventional components such as coal and ash are specified using new component module embedded in the software.

3. Technical evaluations

IGCC schemes with and without CCS were modelled and simulated using ChemCAD and Thermoflex software. Developed models were validated against industrial and experimental data. No significant differences were reported (IEA-GHG, 2003; IPCC, 2005; Higman and van der Burgt, 2008; Fan, 2010). Simulation of various coal-based IGCC plant concepts produced all data needed to assess the techno-economic performances of investigated power plants. The plant concepts were optimised by performing heat and power integration analysis (using pinch technique) for maximization of power generation (Cormos, 2010). Steam flows generated in gasification island, syngas conditioning line and water gas shift / chemical looping reactors were integrated in the steam cycle of the combined cycle gas turbine (CCGT).

As an illustrative example for Case 2 (pre-combustion capture using Selexol®), hot and cold composite curves (HCC and CCC) of hydrogen-fuelled CCGT unit are presented in Figure 4. For syngas conditioning line and water gas shift reactors, Figure 5 presents the hot and cold composite curves for the same example (Case 2).

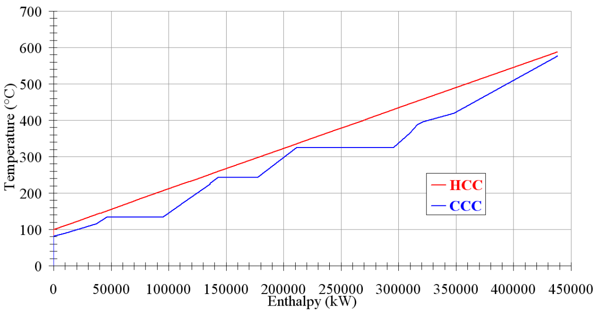

Figure 4. Composite curves for hydrogen-fuelled CCGT

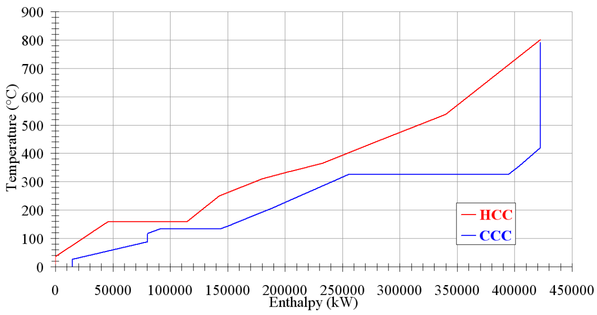

Figure 5. Composite curves for syngas conditioning & WGS reactors

As minimum approach temperature, a conservative value of 10°C was chosen. As can be noticed from Figures 4.a and 4.b, the steam flows (high, medium and low pressure) were optimised for maximisation of plant energy efficiency. Figures 6 and 7 present for the same plant sub-systems (syngas conditioning line including WGS and CCGT power block), the correspondent grand composite curves.

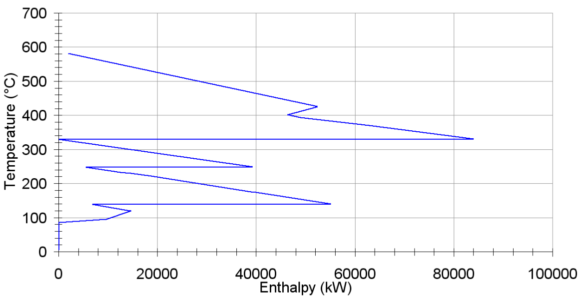

Figure 6. Grand composite curve for hydrogen-fuelled CCGT

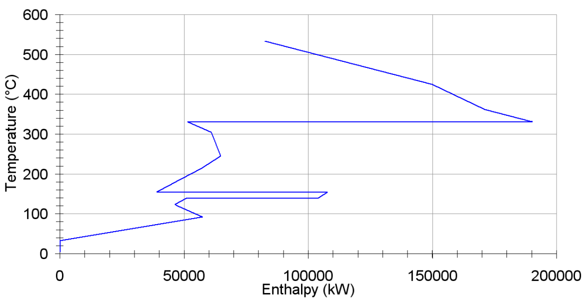

Figure 7. Grand composite curve for syngas conditioning and WGS reactors

Table 1. Key performance indicators

Plant indicator	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Coal flowrate [t/h]	147.80	165.70	148.18	162.34
Coal LHV [MJ/kg]	25.35			
Coal energy [MW]	1040.88	1166.98	1043.56	1143.28
Syngas energy [MW]	839.05	934.76	835.37	916.27
Cold gas efficiency [%]	80.61	80.10	80.05	80.14
Clean gas energy [MW]	835.41	831.92	831.95	814.31
Treatment eff. [%]	99.56	88.99	99.59	88.87
Gas turbine [MW]	334.00	334.00	334.00	334.00
Steam turbine [MW]	224.01	210.84	135.67	199.45
Expander power [MW]	0.68	0.78	1.45	1.50
Gross power [MW]	558.69	545.62	471.12	534.95
Air separation unit [MW]	39.91	44.73	39.98	43.82
Gasifier island [MW]	8.38	9.12	8.21	15.06
Acid gas removal [MW]	6.12	39.81	27.76	15.18
Power island [MW]	19.09	18.78	19.12	22.00
Total consumption [MW]	73.50	112.44	95.07	96.06
Net power output [MW]	485.19	433.18	376.05	438.89
Gross efficiency [%]	53.67	46.75	45.14	46.79
Net efficiency [%]	46.61	37.11	36.03	38.38
Carbon capture rate [%]	0.00	90.79	90.36	99.55
CO_2 emissions [kg/MWh]	741.50	86.92	90.11	3.08

As can be noticed from Figures 6 and 7 there is a significant energy recovery potential for both sub-systems of the power plant - the pockets are showing the heat recovery potential of the whole system (Smith, 2005; Botros and Brisson, 2011; Kunze et al., 2011).

The mass and energy balances resulted from simulation were then used to calculate the plant performance indicators. Table 1 is presenting the performance indicators for evaluated IGCC case studies with and without CCS.

As can be noticed from Table 1, the introduction of CCS technologies implies a significant energy penalty of about 8 – 10 net efficiency percentage points compared with the power plant without CCS. The least energy penalty for carbon capture is in the case of chemical looping. This can be explained by the fact that chemical looping unit is operating at high temperature which enables high temperature heat recovery with positive effects on overall plant efficiency (Fan, 2010; Cormos, 2012b). Another positive aspect in case of chemical looping technology is almost total decarbonisation rate (>99% carbon capture rate) of the fossil fuel used. However, significant technological developments and scale-ups are still needed for chemical looping systems to become fully commercial for large-scale applications as required in energy sector.

CCS technologies based on gas-liquid absorption (either chemical of physical solvents) exhibit lower plant efficiency but it has to be mention here that these technologies are far more commercially and technologically mature than chemical looping. Physical solvents in pre-combustion capture arrangements are implying lower energy penalty for carbon capture compared with post-combustion capture (Kohl and Nielsen, 1997; IEA-GHG, 2003; IEA-GHG, 2004) mainly due to the fact that in pre-combustion capture designs the CO_2 partial pressure is higher compared with post-combustion cases (>10 bar compared with 0.1 - 0.15 bar).

4. Plant flexibility – hydrogen and power co-generation

Plant flexibility means in the context of this article the capacity of the plant to vary the energy output in form of power and hydrogen co-generation accordingly to the instant demand from the grid whilst maintaining reasonable plant efficiency. The first question is why there is a need for plant flexibility. Generating plants which can operate only as based load units are not very attractive when operating at part load, since the ancillary power demand does not drop in proportion to the output. This is the case of IGCC power plants in which the start up times are also likely to be quite long, because of the presence of explosive gases in the gasifiers and syngas processing line. This will probably mean that it will be impossible to operate any form of IGCC in a two shift or cycling mode, where the plant has to shut down overnight, as demand falls away (Starr et al., 2007; Zhaofeng et al., 2011).

Another important factor which is putting an additional pressure for designing flexible power plant concepts is the increasing penetration in the energy sector of renewable energy sources, some of them being highly irregular in time (e.g. solar, wind). This aspect will put a significant burden to the need of plant flexibility for fossil fuel electricity supply. Therefore, the ability to vary the output from hydrogen to electricity will enable the IGCC plants to run the gasifier and processing units at full output all the time. Beside the need for plant flexibility, the main performance indicators (e.g. power and hydrogen output, electrical, hydrogen and cumulative plant efficiencies, specific carbon dioxide emissions) need to be quantified against the degree of flexibility.

For the particular case of energy conversion process evaluated in this paper (IGCC plants) the plant flexibility offers also important advantages considering the emerging hydrogen market (in view of the development and deployment of large scale hydrogen applications). For the present time, these flexible plants can operate mostly in power generation mode (with some hydrogen output used in chemical sector) but in the future, as hydrogen economy is taking off, the need for hydrogen will be growing and the plants will be operated in co-production mode without major changes (Chiesa et al., 2005; Li et al., 2012).

One of the main aims of this paper was to evaluate how the key plant performance indicators are affected against the co-production ratio. For the flexible co-production evaluated in this paper, a range of 0 to 150 MW hydrogen was evaluated, the gas turbine is gradually turned down to about 80 % from the nominal load in order to displace an energy stream of hydrogen-rich gas which can be then purified (at least 99.95 % vol.) and then send to external customers. The reason to select 80 % as turn down limit of the gas turbine is imposed by the fact that under this value the efficiency drops significantly (variable inlet guide vanes are completely closed and no control of the airflow can be made to maintain the gas turbine inlet temperature).

Considering as illustrative example the Case 4 (IGCC plant with pre-combustion capture based on iron chemical looping system), Figure 8 presents the plant concept for hydrogen and power co-generation.

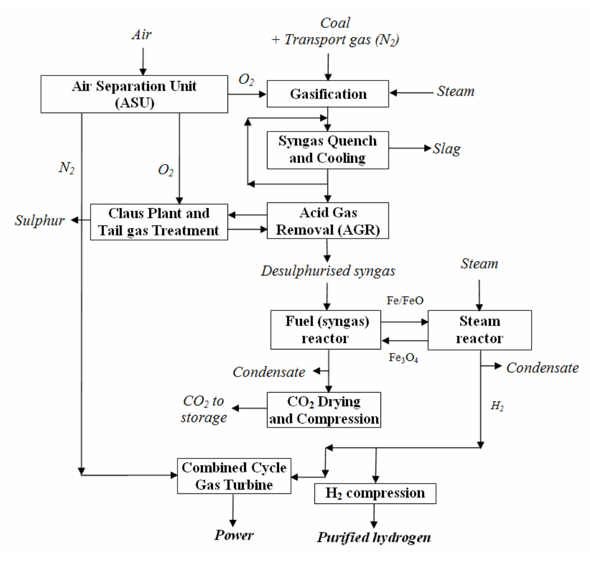

Figure 8. Conceptual layout of hydrogen and power co-generation based on IGCC design with pre-combustion capture

Table 2 presents the variation of plant performance indicators with hydrogen output for Case 4. For co-production mode, the specific carbon dioxide emissions were calculated considering the total plant energy output (power plus hydrogen).

Figure 9 presents the variation of electrical efficiency, hydrogen efficiency and overall (cumulative) energy efficiency with the hydrogen output (co-production rate).

A fact that has to be mentioned for hydrogen and power co-production mode, the overall efficiency of the plant is increasing in the situation in which the ancillary power consumption is not varying significantly (in fact the ancillary consumption is even decreasing - see Table 2). This fact is very important and attractive for plant cycling (modification of the power generated by the plant according to the demand of the electricity grid) considering that for low electricity demand the plant can produce mostly hydrogen which, compared with power, can be stored to be used either for covering peak loads or for other applications (transport, petro-chemical etc.).

Regarding the greenhouse gas emissions, specific carbon dioxide emissions are decreasing with increasing hydrogen production rate (see Table 2). This fact is also in favour of plant operation in co-production mode in addition to the aspects mentioned already. A calculation for Case 4 indicates that for hydrogen production (no net electricity output), the overall plant energy (hydrogen) efficiency is about 65% and the specific carbon dioxide emissions are about 2.5 CO_2 kg/MWh.

Table 2. Plant performances vs. co-production rate

Plant indicator	Power only	Hydrogen and power co-generation		
Coal flowrate [t/h]	162.34			
Coal LHV [MJ/kg]	25.35			
Coal energy [MW]	1143.28			
Syngas energy [MW]	916.27			
Cold gas efficiency [%]	80.14			
Clean gas energy [MW]	814.31			
Treatment eff. [%]	88.87			
Gas turbine [MW]	334.00	313.54	293.05	272.60
Steam turbine [MW]	199.45	188.99	179.71	170.39
Expander power [MW]	1.50	1.48	1.46	1.44
Gross power [MW]	534.95	504.01	474.22	444.43
Hydrogen output [MW]	0.00	50.00	100.00	150.00
Air separation unit [MW]	43.82	43.82	43.82	43.82
Gasifier island [MW]	15.06	15.06	15.06	15.06
Acid gas removal [MW]	15.18	15.18	15.18	15.18
H_2 compression [MW]	0.00	0.56	1.13	1.70
Power island {MW]	22.00	20.67	19.33	17.99
Total consumption [MW]	96.06	95.29	94.52	93.75
Net power output [MW]	438.89	408.72	379.70	350.68
Gross efficiency [%]	46.79	44.08	41.47	38.87
Net efficiency [%]	38.38	35.75	33.21	30.67
Hydrogen efficiency [%]	0.00	4.37	8.74	13.12
Cumulative efficiency [%]	38.38	40.12	41.95	43.79
Carbon capture rate [%]	99.55	99.55	99.55	99.55
CO_2 emissions [kg/MWh]	3.08	2.92	2.79	2.68

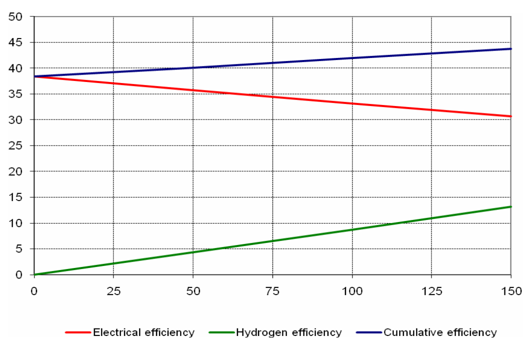

Figure 9. Variation of plant efficiency vs. hydrogen output

5. Economic aspects of IGCC plants with CCS

In term of economic aspects, the estimation of capital costs and specific capital investments were made for IGCC plant concepts without CCS and with CCS based on gas-liquid absorption (NETL, 2007; Mondol et al., 2009; Cormos, 2012a). For Case 4 (pre-combustion capture based on chemical looping), considering the existing level of experience and information of such systems (laboratory and pilot installations below 1 MW), the capital costs estimation was considered too early to be made considering the existing technological maturity of such systems.

For estimation of capital costs, IGCC-based power plant designs were divided into basic sub-systems as follow: solids handling facilities (fuel, sorbents, ash), Air Separation Unit (ASU), gasification island, syngas processing train, Acid Gas Removal (AGR), CO_2 compression and drying, sulphur removal unit (SRU) and tail gas treatment, power island and utilities & offsite units. Then equipment capital costs were expressed considering material and energy flows that equipments have to handle into the process using cost correlations (Smith, 2005; IEA, 2007; Towler and Sinnott, 2007; Cormos, 2012a).

Table 3 is presenting the capital costs and specific capital investments for Cases 1 to 3 (IGCC without CCS – reference case and IGCC with CCS based on gas-liquid absorption processes).

Table 3. Capital cost estimations

Plant indicator	**Case 1**	**Case 2**	**Case 3**
Net power output [MW]	485.19	433.18	376.05
Gross efficiency [%]	53.67	46.75	45.14
Net efficiency [%]	46.61	37.11	36.03
Capital costs [M€]	909.63	1153.47	1235.69
Capital investment [€/kW gross]	1628.15	2114.05	2622.87
Capital investment [€/kW net]	1874.80	2662.79	3285.96

As can be noticed from Table 3, introduction of CCS imply an important increase of the capital costs by 27 - 36%. The specific capital investment per kW net generated power increases with 42 - 75% (the higher figure refers to post-combustion capture option). Once again as also showed by the technical evaluation, post-combustion capture for IGCC power plants does not seems a good option.

6. Conclusions

The present paper is investigating the prospects of various carbon capture and storage technologies to be applied into an IGCC power plant design. The investigated CCS technologies are ranging from commercially and technologically mature gas-liquid absorption processes (both in pre- and post-combustion configurations) and chemical looping systems (presently existing only in laboratory and pilot installations). One IGCC design without CCS was considered for benchmarking the carbon capture cases. The gas-liquid absorption processes exhibit an energy penalty for capturing more than 90% of the feedstock carbon of about 9 – 10 net efficiency percentages. For chemical looping case, the energy penalty is a bit lower in the range of 8 % but for almost total decarbonisation rate of the coal used.

In term of capital costs, introduction of carbon capture technologies using gas-liquid absorption implies an increase of the capital cost with about 27 - 36% and in term of specific capital investments per kW net power by about 42 - 75% (the higher figures refer to post-combustion capture option).

As a possible option to increase the IGCC plant flexibility, the case of hydrogen and power co-generation was evaluated. As main advantage of this operation mode is that during the peak hours the plant can produce only hydrogen and during the night the plant can produce mostly hydrogen that can be store to cover the peaks or to be used in other applications (transport, petro-chemical, heat generation etc.). In this way the plant operates mostly in base load, this fact having positive influence on techno-economical indicators and plant life.

As main conclusions, for the present situation the most suitable carbon capture option to be applied in an IGCC power plant considering the technical, economic and technological and commercial maturity is based on pre-combustion capture using physical gas-liquid absorption. For the future, chemical looping systems are very promising for increasing the plant efficiency but significant scale-ups and demonstration has to be done before to become fully commercial.

Acknowledgement

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Uncertainty of carbon dioxide emission factor for natural gas

Dr. Marija ZIVKOVIC [1]
Assistant professor, University of Belgrade-Faculty of Mining and Geology

Dr. Dejan IVEZIC,
Dr. Dusan DANILOVIC,
MSc. Aleksandar MADZAREVIC

University of Belgrade-Faculty of Mining and Geology
[1] Contact details of corresponding author
Tel: +381-11-3219-158
e-mail: zivkovic@rgf.bg.ac.rs

Address: University of Belgrade-Faculty of Mining and Geology, Djusina 7, Belgrade, Serbia

Abstract: Determination of carbon dioxide emitted due to combustion processes is significant task in GHG inventory preparation. The procedure is based on information about activity data and emission factors of fossil fuels. More detailed consideration of emission factor for natural gas leads to conclusion, that the uncertainty of this factor can be significant due to possible ballast component - carbon dioxide. Emission factors currently used for calculation of CO_2 emitted are determined just on the basis of carbon dioxide emitted due to oxidation of combustible carbon. The carbon dioxide -ballast component of natural gas is emitted too, and such fact can not be ignored especially for natural gas with high carbon dioxide content. Reserves of natural gas in Serbia are characterized by low heating value and high carbon dioxide content. Carbon dioxide content affects both influential parameters: mass fraction of combustible carbon and heating value, keeping the emission of CO_2 – product of combustion, at approximately 55kg/GJ, for all compositions analyzed. Therefore, ballast component-carbon dioxide must be included in estimation of carbon dioxide emitted in processes of natural gas combustion. New method for calculation of the overall emission factor for natural gas and the correlation between carbon dioxide content and percentage of emission factor increase are presented in the paper. It is shown that depending of carbon dioxide's volumetric content, emission factor can increase for more than 20%.

Key words: emission factor, natural gas, ballast content

1. Introduction

The anthropogenic influence to the climate has been proclaimed as one of the main causes of the environmental issues in the modern world. The Republic Serbia is committed to the international cooperation in the field of climate research and survey. The Republic of Serbia has no obligation to reduce greenhouse gases emission, but it is obliged to report National Communications to the UNFCCC. Also, as the candidate to European Union membership, in the negotiation process, Serbia will have obligation to reduce or to limit the emission of greenhouse gases.

As the first step in quantifying GHG emissions, The Republic of Serbia submitted First Initial National Communication to UNFCCC in 2010 (Ministry of Environment and Spatial Planning, 2010). Emissions of carbon dioxide coused by fossil fuels combustion for energy purposes in Serbia (IPCC Source Category 1) were 94.1% of the total CO_2 in 1990, while estimated carbon dioxide emission for energy purposes in 1998. were 93.7% of total carbon dioxide emitted (Ministry of Environment and Spatial Planning, 2010). Emissions of CO_2 are evaluated as the product of the quantity of the fuel sort and the corresponding carbon dioxide emission factor (IPCC, 1996).

In the structure of primary energy consumption of The Republic of Serbia in 2009, coal accounted 53%, oil 28%, natural gas 13%, while the share of renewable energy sources was 6% (IEA, 2009). Coal demand is covered by domestic production, which is not a case for crude oil and natural gas (IEA, 2009).

The Republic of Serbia does not have significant energy potential of natural gas. Share of domestic production of natural gas in previous years was between 10% and 15% (Statistical Office of Serbia 2009-2011). In addition, in many local deposits of natural gas, composition is such that it deviates from the usual, in terms of the increased content of inert components (Geology of Serbia, 1975), which reduces its calorific value and fraction of combustible carbon, boath influencing parametars for calculation of carbon dioxide emission factor.

Effect of different compositions of natural gas to pollutant emissions of vehicles was analyzed in (Karavalakis et al. 2012) and (Park et al., 2012). The results of presented studies show that, fuel properties have a clear and direct impact on fuel economy and some emissions components such as carbon dioxide.

During combustion, besides carbon dioxide product of oxidation, carbon dioxide -ballast component of natural gas is emitted too, and such fact can not be ignored especially for natural gas with high carbon dioxide content. In such case uncertainty of carbon dioxide emission factor can be significant. New method for calculation of the overall emission factor for natural gas (which include carbon dioxide emitted due to combustion process and emitted carbon dioxide ballast) and the correlation between carbon dioxide ballast content and emission factor increasing are presented in the paper.

2. Natural gas in the energetics of The Republic of Serbia

The Energy Development Strategy of the Republic of Serbia promoted natural gas as the fuel with the most dynamic growth, based on the substitution of other energy sources and increasing needs. The goal was to have a share in meeting the total energy requirements approximate those in developed countries (Ministry of Mining and Energy, 2005). Existing facilities, as well as those that will be built in the future and assessed needs of consumers in Serbia, are the basis for the constant growth of share of natural gas in primary energy consumption in Serbia.

Meny of natural gas′s deposits in Serbia characterize composition different from the usual, in terms of the increased content of inert components, which reduces its calorific value, but also causes difficulties in its combustion (Colorado et al, 2010). The compositions of natural gas in existing deposits in Serbia are presented in Table 1 (Geology of Serbia, 1975).

Table 1. Composition of natural gas in deposits discovered in Serbia, volumetric %

Gas field	methane	ethane	propane	i-butane	n-butane	pentane	higher hydrocarbons	nitrogen	Carbon dioxide
Kikinda	84,05	6,16	2,67	1,68		2,01		3,44	0,02
Plandište	89,50	0,69	0,17	0,06	0,03	0,01		9,28	0,26
Mokrin	79,78	7,55	3,43	2,45		1,14	2,20	2,3	1,15
Gospođinci	92,88	0,71	1,76	0,525	0,62			3,70	0,31
Srbobran	75,15	1,95	0,50	0,12	0,25	0,16		11,90	10,00
Kikinda-varoš	85,30	3,90	2,80	2,10				5,9	/
Begejci	97,39	0,28	0,08	0,03	0,02			2,15	0,05
Melenci	98,0							1,40	0,60
Nikolinci	70,10	0,30	0,09	0,02	0,02	0,01		26,40	3,06
Srpska Crnja Cr-1	80,80	4,64	1,04	0,31	0,30			11,10	1,54
Srpska Crnja Cr-2	79,44	4,66	1,32	0,35	0,39			11,59	1,84
Velebit	88,55	3,35	0,42	0,04	0,04			3,72	3,88
Tilva	91,12	0,34	0,18	0,06	0,07	0,07	0,08	8,00	0,08
Mramorak	85,43	0,35	0,02	0,09				14,11	
Međa	93,22	2,40	0,82	0,13	0,16	0,17		3,10	
Ada	89,35	0,80	0,57	0,12	0,16			9,00	
Miloševo	28,76	0,65	0,41	0,19				6,94	63,05
Novi Kneževac	83,06	4,28	2,17	0,74		0,36	0,25	5,00	4,14
Radičevićevo	97,15							1,95	0,90
Gornji breg	96,63	0,06	0,01	1,75				1,75	1,55
Gornji breg I	91,04	1,67	0,04	0,01				6,95	0,25
Bečej	9,30							6,70	84,00
Bečej	95,60	0,21						3,90	0,20
	65,74	0,09						2,32	31,50
Mramorak Selo	94,14	0,96	0,31	0,39				4,13	0,70
Banatsko Selo	87,44	0,57	0,33	0,17	0,30			9,07	1,12
Čantavir	76,41	2,51	0,43	0,05	0,07			7,69	12,80
Bačka Topola	82,43	1,92	0,29	0,11				11,76	3,49
Ruski Krstur	84,15	0,28	0,12	0,12				15,18	0,14
	90,24	0,21	0,11	0,05				9,28	0,11
Karađorđevo	95,48	0,62	0,55		0,18			1,48	1,25

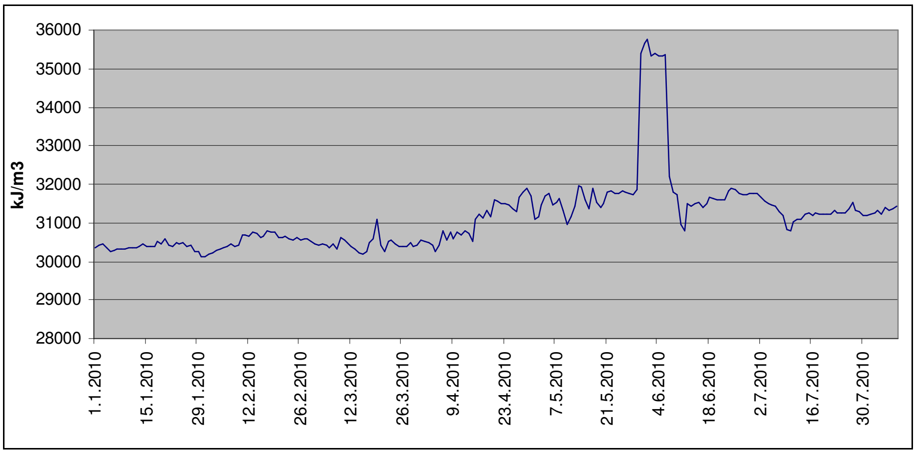

Figure 1. Lower heating value of natural gas produced in Serbia, (Kacanski, 2012)

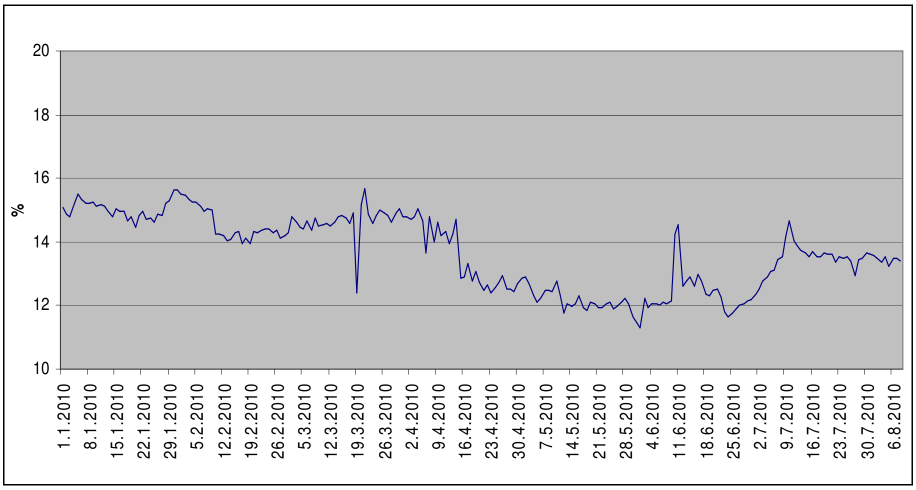

Figure 2. Ballast content of natural gas produced in Serbia-volumetric, (Kacanski, 2012)

The usual practice in Serbia, is such that the ballast components are not removed from the gas before it is used. Lower heating value of natural gas from domestic production, as well as volumetric share of ballast components, at the entrance of distribution pipeline, are presented in Figures 1 and 2 (Kacanski, 2012

Typical share of ballast component in natural gas is around 5%, and for such composition of natural gas proposed, predefined emission factor is proposed: 56,1 kg/GJ, or 15,3 tC/TJ (IPCC, 1996). Presented data of ballast content in Serbian gas (between 12 and 16%) lead to conclusion that predefined emission factor proposed for natural gas based on net calorific value can not be used for GHG inventory.

3. Carbon dioxide emission factor

All fossil fuels do not have the same contribution to carbon dioxide emissions for the same thermal effect achieved, through the energy transformation in combustion processes. Considering the different chemical compositions, different are results of emissions generated by combustion processes of different fuels, for the same thermal effect. To makepossible comparison of different fuels, a carbon dioxide emission factor (KCO_2) is introduced. It represents the mass of carbon dioxide emitted per unit of heat energy.

3.1. Carbon dioxide emission factor for natural gas - result of combustion

The emission factor of carbon dioxide as a result of combustion is determined by its definition (equation 1):

$$KCO_2 = 3{,}67 \frac{g_c}{H} \qquad (1)$$

where:

3,67 stoichiometric ratio

g_c the mass fraction of combustible carbon in the fuel.

H calorific value of the fuel [MJ/kg].

Calculation of the carbon dioxide emission factor, by this equation, for natural gas, assumes calculation of the mass fraction of combustible carbon, and calorific value per the unit of mass, based on volumetric gas composition.

Carbon dioxide emission factor for natural gas can be calculated also, without determining the mass fraction of combustible carbon, which may be easier, since the composition of natural gas is usually presented as volumetric (Equation 2).

$$KCO_2 = \sum r_i K_i \qquad (2)$$

r_i volumetric fraction of combustible component

K_i carbon dioxide emission factor of combustible natural gas′s component

The values of emission factors for the combustible components of natural gas are presented in Table 2, calculated from stoichiometric equations, assuming that combustion process is completed. For the samples of natural gas compositions measured in distribution network in Serbia presented in Table 3, carbon dioxide emission factors only as the result of combustion are calculated. The results obtained are presented in Figure 3.

Table 2. Emission factors for the combustible components of natural gas

	Carbon dioxide emission factor based on net calorific value	Carbon dioxide emission factor based on gross calorific value
	kg CO_2/GJ	kgCO_2/GJ
Methane	54,75	49,33
Ethane	60,97	55,81
Propane	63,42	58,40
n-butane	63,54	58,69
i-butane	64,36	59,43
Pentane	70,02	64,59
hydrogen sulfide	0	0

Table 3. Samples of natural gas with volumetric composition (Srbijagas, 2011)

Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Methane	97,721	94,583	85,101	83,929	80,8	79,44	76,41	82,43	87,82	92,599	87,826	88,459	84,361	94,59
Ethane	0,564	1,682	2,884	3,145	4,64	4,66	2,51	1,92	7,96	2,784	2,553	2,396	3,446	3,02
Propane	0,234	0,391	0,404	0,45	1,04	1,32	0,43	0,29	0,58	0,413	0,377	0,248	0,307	0,44
n-butane	0,04	0,113	0	0,053	0,3	0,35	0,07	0,11	0,03	0,036	0,029	0,024	0,02	0,14
i-butane	0,044	0,092	0,015	0,043	0,31	0,39	0,05	0	0	0,02	0,02	0,014	0,027	0
Pentane	0,015	0,051	0,007	0,033	0	0	0	0	0	0,006	0,008	0,008	0,012	0
Hydrogen sulfide	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	0,922	1,556	1,942	2,06	11,37	11,59	12,8	3,49	2,36	1,726	2,077	2,521	3,207	1
Carbon dioxide	0,46	1,532	9,647	10,287	1,54	1,84	7,69	11,76	1,25	2,416	7,114	6,338	8,642	0,81

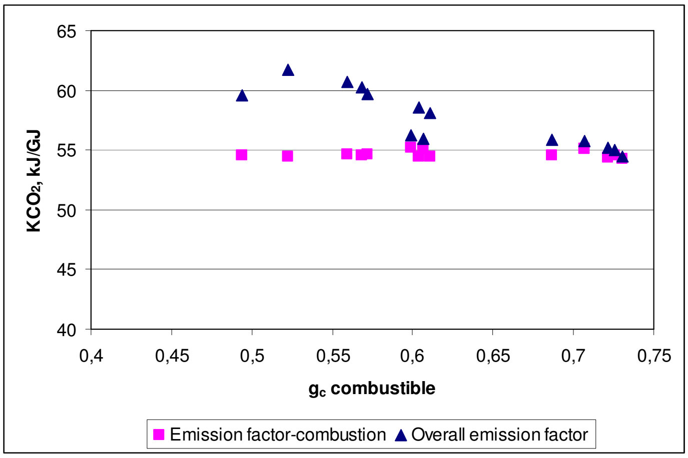

Figure 3. Carbon dioxide emission factors for natural gas

3.2. Overall carbon dioxide emission factor

In addition to carbon dioxide, which is a product of combustion and is emitted into the atmosphere, carbon dioxide which is a part of the fuel as ballast is emitted too. Due to this fact, equation 1 needs to be corrected. Corrected emission factor for natural gas is calculated based on equation 3 and contains both: carbon dioxide as product of combustion and ballast carbon dioxide:

$$KCO_2 = \frac{3.67\,gc + m_{CO_2}}{H} \qquad (3)$$

where mco_2 represents the mass of emitted carbon dioxide –ballast component.

Depending on the composition of natural gas the overall carbon dioxide emission factor will change. The results of overall carbon dioxide emission factors calculated for different gas composition samples are presented in Figure 3. Emission factors are calculated based on net calorific value of the fuel. Considering obtained results, the following can be concluded:

Carbon dioxide emission factor which is result of the combustion of combustible components is almost constant and its value is approximately 55 kg/GJ. Growth of ballast content in the fuel induce reduction of the of combustible carbon content, reduction of the mass of carbon dioxide emitted, but also induce reduction of the net calorific value of the fuel. Combination of these two influential parameters makes an approximately constant ratio of carbon dioxide emission factor, due to combustion. Calculation of the carbon dioxide emission factor, assuming only combustion, is performed using both described methods (based on equations (1) and (2)) and as a result almost identical values are obtained.

Higher value of combustible carbon content corresponds to the smaller difference between emission factors: first concerning emission as a result of combustion and second –the overall emission factor. Increase of the combustible carbon content reduces the ballast and also the mass of carbon dioxide that emitted as ballast.

Mass of carbon dioxide emitted as ballast increases with increase of carbon dioxide ballast content in natural gas, having as result significant increase overall emission factor.

Some typical cases of compositions can be analyzed based on results presented in Figure 4:

- Gas samples 1, 9 and 14 represent examples of gas with high content of hydrocarbons and negligible ballast, which makes the difference between emission coefficients negligible.
- Gas sample 8 is an example of gas with low content of hydrocarbons, and significant presence of ballast (higher percentage of carbon dioxide than nitrogen).
- Gas sample 7 is similar with sample 8 concerning hydrocarbons content in gas but compared to sample 8, nitrogen is predominant in ballast.

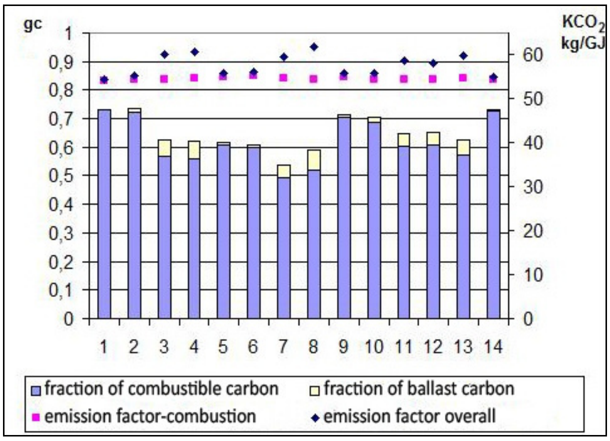

Figure 4. Fractions of carbon (combustible and ballast) and emission factors for natural gas

Diagram presented at Figure 5 shows correlation of the addition to emission factor of natural gas as a function of the mass fraction of carbon in ballast.

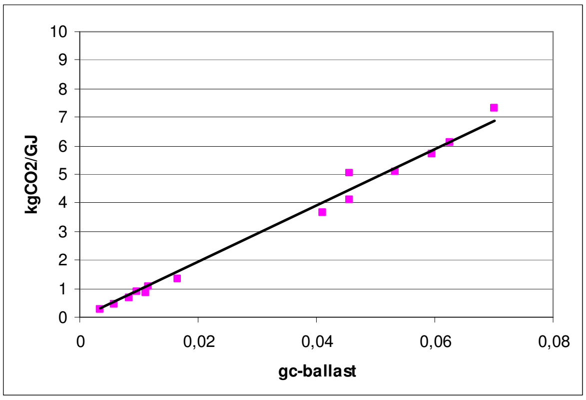

Figure 5. Correlation of carbon ballast fraction and addition to emission factor

This is an approximate linear relation, proposed with equation 4:

$$\Delta K_{CO_2} = 97{,}8\, g_{cballast} \qquad (4)$$

Small deviations are explained by the different composition of the gas. If in the addition of carbon dioxide gas ballast, exists significant amounts of nitrogen, heating value will be lower and the increase of carbon dioxide emissions coefficient will be higher.

4. Conclusion

Composition of natural gas in gas fields in exploitation can deviate significantly compared to common composition, used for carbon dioxide emission factor calculation. If ballast component, carbon dioxide, is not removed before combustion, it is emitted to atmosphere too. Therefore, ballast component must be included in estimation of carbon dioxide emitted in processes of natural gas combustion. Method for calculation of overall emission factor is presented, as well as, analyses of influence of different gas compositions to emission factors, too. The carbon dioxide emission factor which is result of the combustion of combustible components is almost constant and its value is approximately 55 kg/GJ.

Mass of carbon dioxide emitted as ballast increases with increase of carbon dioxide ballast content in natural gas, having as result significant increase overall emission factor. Based on different samples analyses, correlation between carbon ballast fraction and addition to emission factor is established. Proposed emission factor should be used in GHG inventory, in cases of combustion of natural gas with high ballast content.

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Appendix

Calculation of the overall carbon dioxide emission factor

In the most of the cases volumetric composition of natural gas is the basis for the calculation of emission factor. Based on volumetric composition, volumetric heating value of gas can be calculated (equation 4):

$$H = \sum r_i H_i, \quad \frac{MJ}{m^3} \qquad (4)$$

r - Volumetric fraction of the combustible components of natural gas [/]

H - Heating value of corresponding combustible components [MJ/m^3]

Heating value per unit of mass is calculated based on equation 5:

$$H = \frac{H\left[\frac{MJ}{m^3}\right]}{\rho\left[\frac{kg}{m^3}\right]},\ \frac{MJ}{kg} \qquad (5)$$

Recalculation of volumetric composition to the mass composition:

$$g_i = r_i \frac{M_i}{M_s} \qquad (6)$$

g_i - mass fraction of the i-th component

M_i - molecular mass of the i-th component

M_s - molecular mass of the mixture

The molecular mass of the mixture is calculated based on equation 7: $M_s = \sum r_i M_i$ (7)

Mass of 1 m^3 of ideal gas at normal conditions can be calculated from the equation of state (equation 8):

$$pV = m_s RT \qquad (8)$$

p - pressure, [Pa]

V - volume, [m^3]

m_s - mass, [kg]

$R = \frac{8315}{M_s},\ \frac{J}{kgK}$ - gas constant of natural gas

T - temperature, [K]

Mass of each component from 1m^3 is:

$$m_i = g_i m_s \ [kg] \qquad (9)$$

Mass of combustible carbon

$$mc_{g_i} = k_i m_i \ [kg], \qquad (10)$$

where k is the proportion of carbon in a combustible component. For example, for methane: $k_{CH_4} = \frac{12}{16}$.

The total mass of combustible carbon

$$mc_g = \sum mc_{g_i} \ [kg] \qquad (11)$$

The mass fraction of the combustible carbon in natural gas can be calculated based on the equation 12:

$$gc_g = \frac{mc_g}{m_s} \ [/] \qquad (12)$$

Based on the obtained mass fraction of combustible carbon, the emission factor of carbon dioxide is calculated by using the equation (1).

Mass of carbon dioxide from the ballast emitted during the combustion 1 m^3 of gas:

$$m'_{co_2} = g_{co_2} m_s \ [kg] \qquad (13)$$

Mass of carbon in the ballast:

$$mc_b = \frac{12}{44} m'_{CO2} \tag{14}$$

The mass fraction of carbon from the ballast:

$$gc_b = \frac{mc_b}{m_s} \tag{15}$$

Mass of carbon dioxide emitted from the ballast per 1 kg of fuel:

$$m_{CO2} = 3{,}67\, gc_b \tag{16}$$

Total mass of carbon dioxide emitted during combustion:

$$m_{uCO_2} = 3{,}67\, gc_g + m_{CO_2} \;\; [kg] \tag{17}$$

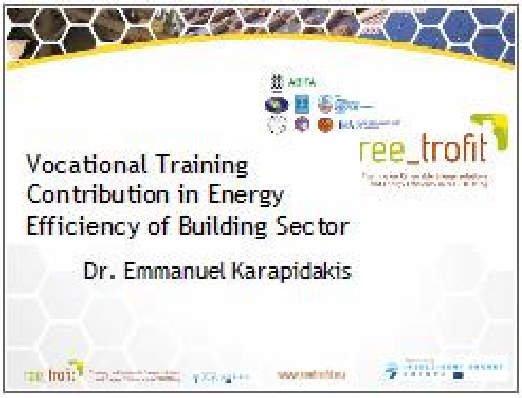
Overall emission factor:

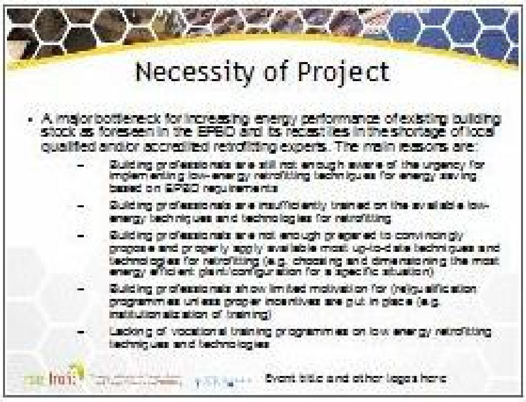
$$KCO_2 = \frac{m_{uCO_2}}{H} \tag{18}$$

Programs and Projects

Vocational Training Contribution in Energy Efficiency of Building Sector

(presented by Dr. Popi KONIDARI on behalf of Dr. Emmanuel KARAPIDAKIS)






Project Targets
• Organizing, promoting and implementing vocational training courses over 3 rolling cycles in each country with at least 18 vocational training courses qualifying more than 450 retrofitters in 6 European countries
• These retrofitters include:
• Building Professionals
• Electrical Installers
• Thermo-Hydraulic Installers
• Until now, 2 cycles have been implemented in the three major cities of Crete (Heraklion, Chania and Rethymnon) with 293 participants
Event title and other logos here


Training Course - Heraklion
Event title and other logos here

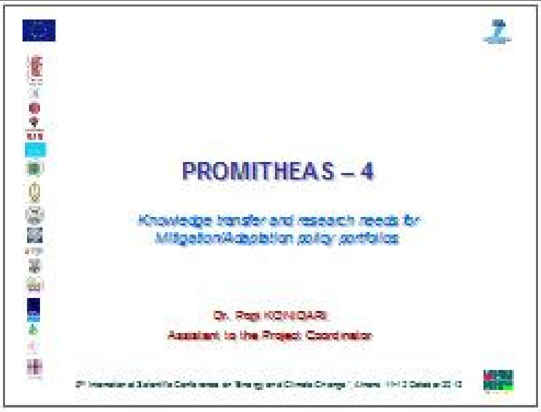

Training Course - Chania
Event title and other logos here

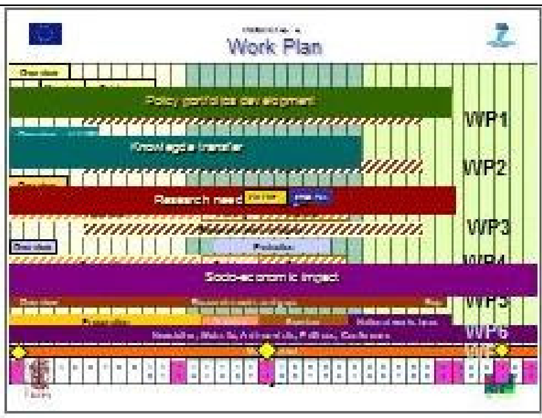

Training Course - Rethymnon
Event title and other logos here


THANK YOU!!!
Event title and other logos here

PROMITHEAS-4 - Knowledge transfer and reserach needs for Mitigation/Adaptation policy portfolios

by Dr. Popi KONIDARI






Dissemination (Socio-economic impact)
1st step: International level
Newsletter, Website, Ad hoc visits, Final Conference
Comments: BSEC-PERMIS, BSEC-BC, UN, UNAI, BSEC Ministerial Meetings (Sofia, Nafplion, Belgrade), cooperation with Lebanon and Georgia
2nd step: National level
National Workshops
3rd step: Scientific level
Special editions, Scientific papers
- 7 -


Thank you
Contact point
Dr. Popi KONIDARI