Energy Policy and Development Centre (KEPA)
National and Kapodistrian University of Athens

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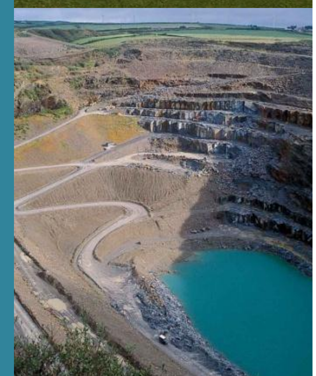

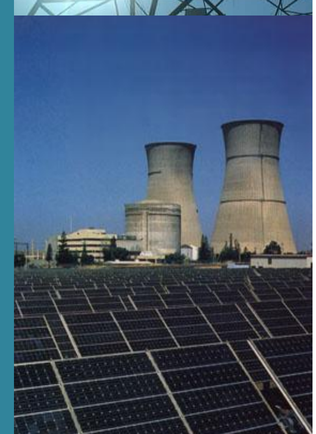


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Dear Reader,

The *"Euro-Asian Journal of Sustainable Energy Development Policy"* is the outcome of the established cooperation among scientists from Europe, Black Sea, Caspian Sea and Central Asia.

It is part of a growing cooperation in the frame of PROMITHEASnet activities. A network that includes members from sixteen countries and remains open to new participants, while its range of activities includes an Annual Scientific Conference, scientific awards, workshops, seminars and joint participation in EU financing research activities.

In addition the PROMITHEAS network disseminates relevant information through its newsletter, to more than 23,000 registered recipients from 170 countries all over the world.

In this context we do encourage scientific synergies and we invite colleagues to join us as authors, article-reviewers or even as partners in research projects.

Our continuous effort is the quality upgrade of the journal's content and to this aim we welcome your contribution.

The editor

Prof. Dimitrios Mavrakis

Дорогой читатель,

“Евро-Азиатский журнал по политике развития устойчивой энергетики” является результатом сотрудничества, налаженного между учеными из Европы, регионов Черного моря, Каспийского моря и Центральной Азии.

Он является частью растущего сотрудничества в рамках деятельности сети PROMITHEAS. Это сеть, включает в себя членов из шестнадцати стран и остается открытой для новых участников, а также спектр ее мероприятий включает Ежегодную Научную Конференцию, научные награды, совещания, семинары и совместное участие в исследованиях, финансируемых Европейским Союзом.

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Наши непрерывные усилия направлены на обеспечение качества содержания журнала, и мы приветствуем Ваш вклад для обеспечения этой цели.

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Aim and scope

The PROMITHEAS scientific journal titled "***Euro-Asian Journal of Sustainable Energy Development Policy***" is a semi-annual bilingual (English, Russian) publication addressing policy issues on energy and climate change, mainly from the Black Sea, Caspian, Central Asia and S.E. Europe regions. The aim of the publication is to motivate and encourage the scientific and research human potential of these regions to present their research work in the aforementioned areas. Thus, it is expected that the regional scientific potential will be more easily identified and able to be contacted by regional and EU energy policy and environmental stakeholders. Efforts will be made so as the journal contains articles produced through joint efforts among researchers from the regions and the PROMITHEAS network participants.

The scientific journal will also host articles and executive summaries of scientific reports and studies presented during workshops, organized by the PROMITHEAS Network, regarding energy and climate policy issues. The contents of each issue will be determined by the editorial board.

Major articles will cover a comprehensive range of topics such as:

Energy supply and geopolitics;

Strategic energy planning;

Socio-economics of hydrocarbon reserves exploitation;

Energy interconnections;

Regional Energy Market development;

Emerging hydrogen technologies;

Socio-economics of transcontinental energy corridors;

Implementation of Kyoto Protocol mechanisms;

Analysis and implementation of climate policy instruments;

RTD policies and socio-economics for new forms of energy.

Цели и задания

Научный журнал сети PROMITHEAS под названием **«Евро-Азиатский журнал по политике развития устойчивой энергетики»** является полугодичной и двуязычной (Английский, Русский) публикацией, которая уделяет основное внимание вопросам политики в области энергетики и изменения климата, в основном для регионов Черного и Каспийского морей, Центральной Азии и Юго-Восточной Европы. Целью публикации является стимулирование и поддержка научно-исследовательского человеческого потенциала этих регионов что бы представить свою исследовательскую работу в вышеперечисленных областях. Ожидается, что региональный научный потенциал будет легче идентифицироваться и заинтересованным сторонам, региональным, связаным с энергетической политике ЕС и экологии, будет легче с ним связаться. Это будет осуществляться путем включения в журнал научных статей, написанных в результате совместного сотрудничества ученых из вышеперечисленных регионов и участников сети PROMITHEAS.

Научный журнал также будет размещать материалы и краткие обзоры научных отчетов и исследований, представленных во время разных семинаров, организованных Сетью PROMITHEAS, которые касаются тем энергетической и климатической политики. Содержание каждого выпуска будет отбираться ученым советом.

Основные статьи, в меру возможностей, будут покрывать следующие темы:

- энергоснабжение и геополитика;

- стратегическое энергетическое планирование;

- социально-экономические аспекты использования углеводородных запасов;

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Pressure Swing Adsorption as an Efficient Tool for the Separation of Carbon Dioxide from Flue Gases

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Abstract: An important option for the abatement of carbon dioxide emissions is the removal of CO_2 from flue gases. This technique, known as post-combustion capture, can be realized by various methods already used in other applications. One of these methods is pressure swing adsorption (PSA), which was specifically mentioned in the IPCC Special Report as a promising emerging technology. Mathematical modelling and simulation provide a reliable and inexpensive tool to analyse the various PSA configurations that might yield high-purity CO_2. The paper presents such an approach, together with the relevant equilibrium and kinetic data and the results of extensive PSA simulations. The simulations were carried out for a three-column installation packed with zeolite molecular sieves 13X. The principal objective of the simulations was to demonstrate the practical feasibility of the proposed PSA configuration. The main result of the study is the modification of the PSA process used in the purification of flue gases by the introduction of purge with the CO_2-rich stream.

Keywords: flue gas, CO_2 abatement, pressure swing adsorption

1. Introduction

A promising technique for the removal of carbon dioxide from gas streams is pressure swing adsorption (PSA), which was specifically mentioned in the IPCC Special Report (Metz et al., 2005) as an interesting emerging option when applied to flue gases (Kikkinides et al., 1993, Na et al., 2001, Chou and Chen, 2004). However, a key problem in the design and optimization of this process is a judicious selection of a suitable adsorbent which, on the one hand, would exhibit a high CO_2 adsorption capacity and, on the other, would be selective in terms of CO_2/N_2 separations.

Therefore, the present study was at first focused on the choice of an appropriate adsorbent from a range of commercially available materials, based on extensive experimental assessment of their adsorptive properties. Then, for an adsorbent thus selected, simulations were performed for a three-column PSA installation using a model developed and verified elsewhere (Tanczyk et al., 2010). The simulations led to a number of interesting conclusions. It was found, among others, that the three-column system can yield a highly concentrated stream of carbon dioxide, with an almost complete recovery of this species.

2. Adsorption isotherms for carbon dioxide and nitrogen

The initial screening of adsorbents that might potentially be used in CO_2/N_2 separations was done for five commercially available materials: three activated carbons (BA-10, GAC CECA and Norit Vapure 612) and two zeolite molecular sieves (Molsiv 13X and Grace 13X). The equilibrium experiments were carried out using an Intelligent Gravimetric Analyser (Hiden Isochema) shown schematically in Fig. 1.

The experimental CO_2 and N_2 adsorption isotherms for the five adsorbents at 20^{o}C are shown in Figs. 2 and 3.

Based on the isotherms thus measured selectivity coefficients were calculated using the following formula

$$\alpha_{CO_2/N_2} = \frac{q^*_{CO_2}/q^*_{N_2}}{y_{CO_2}/y_{N_2}} \qquad (1)$$

Obviously, for non-linear isotherms these coefficients strongly depend on partial pressures of the two species (Warmuzinski and Sodzawiczny, 1999), Fig. 4.

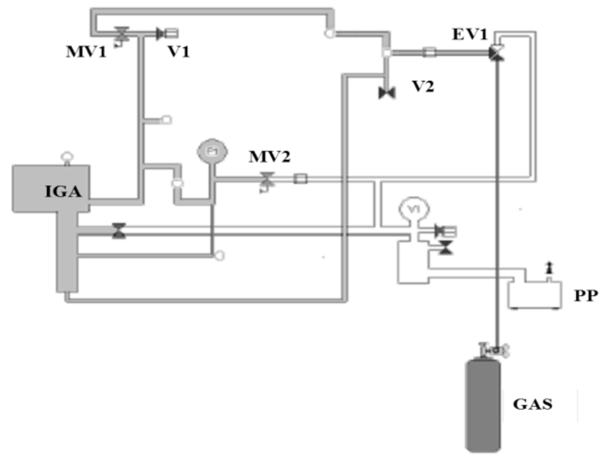

Fig. 1. Schematic representation of the measurement system (IGA – gravimetric analyser, PP – vacuum pump, GAS – gas cylinder, MV1- inlet valve, MV2 – outlet valve, EV1 – three-way valve, V1 – safety valve, V2 – inlet valve for ambient air)

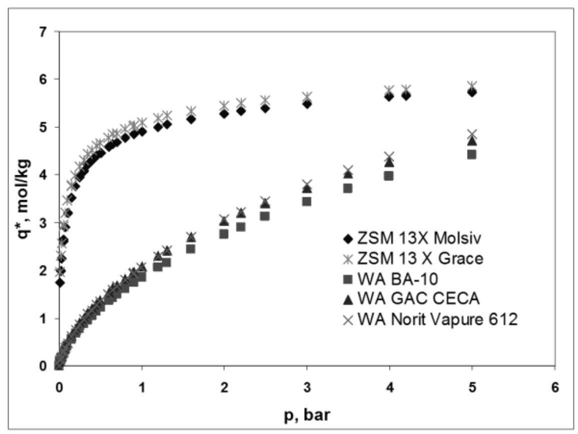

Fig. 2. Experimental adsorption isotherms for CO_2 at 20^{o}C

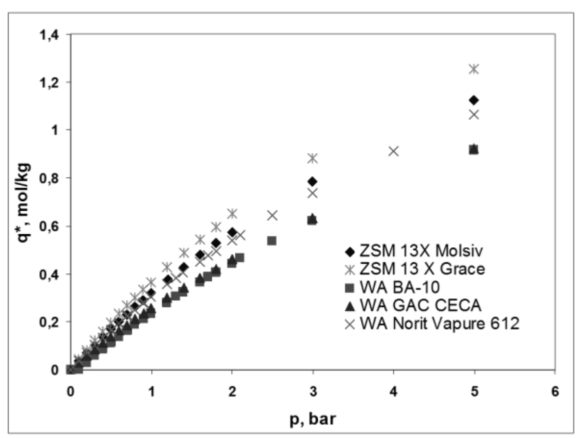

Fig. 3. Experimental adsorption isotherms for N_2 at 20^{o}C

As the experiments reveal (cf. Fig. 2, 3 and 4), ZMS Grace 13X is superior to the other adsorbents in terms of both adsorption capacity and selectivity. Consequently, it is this adsorbent that was selected for the detailed investigation of both equilibria and kinetics of CO_2 and N_2 adsorption.

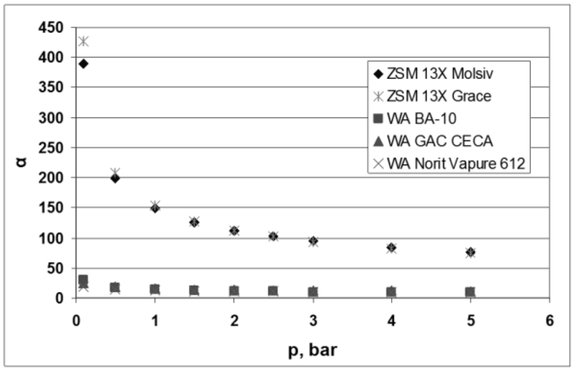

Fig. 4. CO_2/N_2 selectivities for the five adsorbents at 20°C

Adsorption equilibria were measured at 20, 40, 60 and 80oC, over a pressure range of 0-5 bar (Figs. 5 and 6).

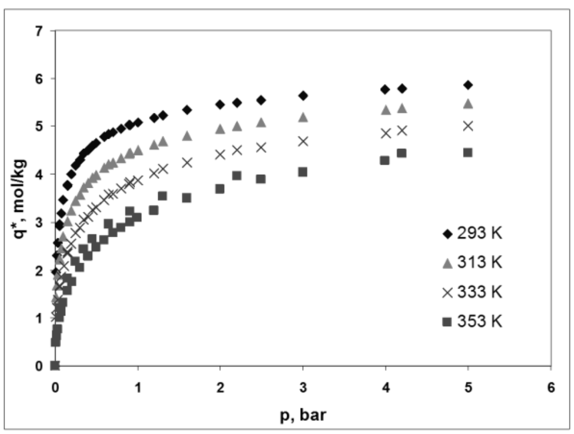

Fig. 5. Experimental equilibria for CO_2 over ZMS 13X (Grace)

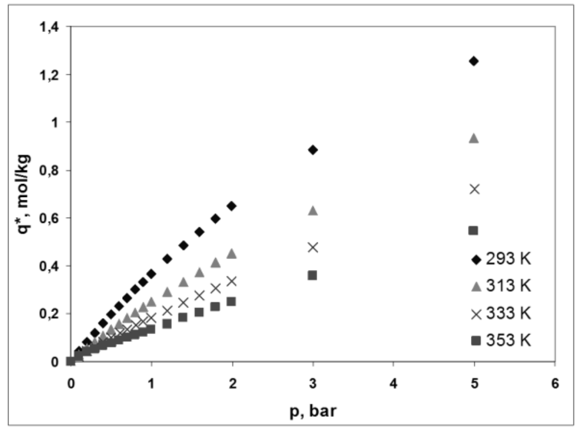

Fig. 6. Experimental equilibria for N_2 over ZMS 13X (Grace)

The equilibrium data were then correlated using the Langmuir-Freundlich equation

$$q_i^* = q_{si} \frac{b_i \, p_i^{n_i}}{1 + b_i \, p_i^{n_i}} \qquad (2)$$

3. The kinetics of adsorption

Every single point of an adsorption isotherm is measured as an uptake curve which shows the temporal approach to equilibrium. Such a curve makes it possible to determine mass transfer rate in the adsorbent pores provided certain experimental conditions are met.

The kinetics of mass transport within the pores can be quantified using diffusional time constants. For the systems analysed (i.e., CO_2 and N_2 over ZMS 13X Grace) these constants remain almost unchanged with pressure. Therefore, in simulation calculations their averaged values were used. Also, the difference between the values of this parameter for CO_2 and N_2 is only minor and is less than one order of magnitude. Hence, it is assumed that the adsorptive separation of carbon dioxide and nitrogen is controlled by their equilibrium properties rather than by the rate at which the two species move within the tortuous pores of the adsorbent.

The values of the diffusional time constants for the adsorption of CO_2 and N_2 on ZMS 13X (Grace) averaged over pressure are given in Table 1.

Table 1: Diffusional time constants for CO_2 and N_2 over ZMS 13X (Grace)

Gas	D/r^2, s^{-1}			
	20 °C	**40 °C**	**60 °C**	**80 °C**
CO_2	$9.06\cdot10^{-4}$	$1.07\cdot10^{-3}$	$1.33\cdot10^{-3}$	$1.59\cdot10^{-3}$
N_2	$4.08\cdot10^{-3}$	$4.79\cdot10^{-3}$	$4.65\cdot10^{-3}$	$4.86\cdot10^{-3}$

4. Mathematical model of the process

The main components of a dry flue gas include carbon dioxide, nitrogen and oxygen. Due to a low separation selectivity of nitrogen vs. oxygen and large adsorption capacity for CO_2 on many carbon and zeolite adsorbents, N_2 and O_2 are treated as a single component. The problem is thus reduced to the separation of CO_2 and N_2, which yields a stream of pure nitrogen and a stream of gas enriched in carbon dioxide. Based on the available literature and our own experimental and theoretical studies it is assumed that the sequence of steps in such a process can be as follows: feed with the flue gas, cocurrent depressurisation, purge with CO_2-rich stream, countercurrent depressurisation, vacuum regeneration, and, finally, pressurisation with the feed (cocurrent) or with a fraction of the N_2 stream (countercurrent). The feed, purge and vacuum regeneration steps are carried out at a constant pressure. During the other steps the pressure either increases or decreases. The direction of the cocurrent flow is the same as that of the flow during the adsorption (feed) step, while the countercurrent flow takes place in the opposite direction. It is further assumed that the process is realised in a PSA installation consisting of 2-4 columns, and the columns are packed with zeolite molecular sieves (ZMS 13X). Although the process itself is non-isothermal, thermal equilibrium prevails between the gas and the solid phase. Plug flow with axial dispersion is assumed, pressure drop over the adsorbent bed is negligible and the fluid phase is modelled as an ideal gas.

The details of the model are given in Tanczyk et al., 2010. The model was validated based on extensive experiments carried out in a two-column PSA laboratory installation for the separation of CO_2 and N_2 mixtures (Tanczyk et al., 2010).

5. Simulation studies

In conventional PSA cycles an increase in CO_2 content in the enriched gas relative to the concentration of carbon dioxide in the feed gas is 20-80%. Thus, if the initial CO_2 concentration in the flue gas is 15%, its concentrations in the enriched product are, roughly, between 18% and 27%. These are rather small numbers, despite using vacuum regeneration of the adsorbent bed. As has already been pointed out, a means to raise the content of carbon dioxide in the product is the purge with a portion of the enriched gas. The results of the numerical simulations for such a modified cycle (cf. Table 2) are shown in this chapter.

Table 2: PSA cycle in the three-bed installation. F – feed, D – depressurisation, P – pressurisation, Pu – purge, R – regeneration (vacuum), ↑ – cocurrent flow, ↓ – countercurrent flow

<table>
<tr><th>Column
Stage</th><th colspan="3">1</th><th colspan="3">2</th><th colspan="3">3</th></tr>
<tr><td>1</td><td colspan="3">F↑</td><td>D↑</td><td colspan="2">Pu↑</td><td>D↓</td><td>R↓</td><td>P↓</td></tr>
<tr><td>2</td><td>D↓</td><td>R↓</td><td>P↓</td><td colspan="3">F↑</td><td>D↑</td><td colspan="2">Pu↑</td></tr>
<tr><td>3</td><td>D↑</td><td colspan="2">Pu↑</td><td>D↓</td><td>R↓</td><td>P↓</td><td colspan="3">F↑</td></tr>
</table>

A binary CO_2/N_2 mixture (15%/85%) is separated in a three-column PSA installation (the addition of a third column leads to an almost continuous flow of the gaseous stream through the system). It is assumed that a small fraction of pure nitrogen is passed through the column undergoing vacuum regeneration to enhance the regeneration of the adsorbent. Nitrogen flow rate in this step along with the flow rate of the CO_2-enriched stream in the purge step were the only parameters varied in the calculations. The feed gas had a pressure of 1.1 bar and a temperature of 80ºC; the duration of the feed step was 120 s. The pressure during vacuum regeneration was 0.1 bar. The dimensions of the columns were the same as those in the experimental PSA system (Tanczyk et al., 2010). The performance of the installation was assessed in terms of the CO_2 content in the enriched gas and the recovery of carbon dioxide. The effect of the gas flow rate during purge and vacuum regeneration on these two parameters is shown in Figs. 7 and 8.

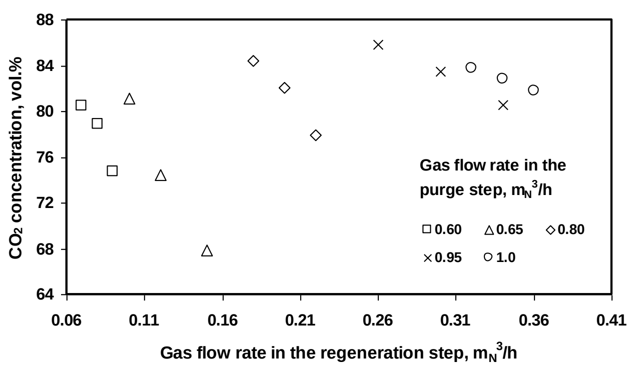

Fig. 7. Effect of the gas flow rate during the purge with CO_2 - rich stream on CO_2 product concentration

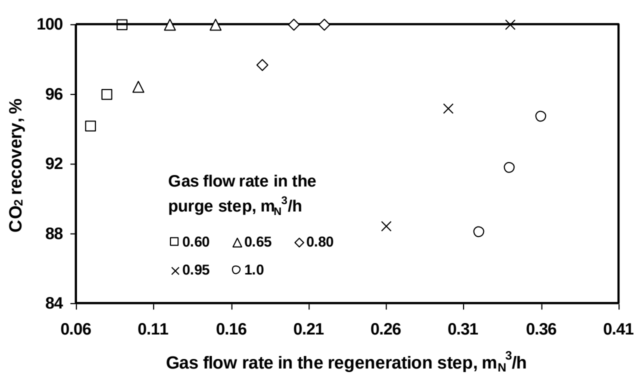

Fig. 8. Effect of the gas flow rate during the purge with CO_2 - rich stream on CO_2 recovery

As can be seen, the PSA process can enrich the 15% CO_2/85% N_2 mixture to a level of over 80% of CO_2, with a full (100%) recovery of this species. Such an efficiency can be achieved by a suitable selection of flow rates during purge with the enriched gas and vacuum regeneration. For a three-column PSA installation the maximum CO_2 content (82%) corresponds to flow rates of 0.8 and 0.2 m_N^3/h, respectively.

6. Conclusions

The mathematical model used in the simulations was successfully validated based on CO_2/N_2 separation experiments in a two-column laboratory PSA installation (Tanczyk et al., 2010). The relative discrepancy between the model predictions and experimental data were, in the majority of cases, less than 10%. Therefore, the model provides a useful tool for the analysis and optimisation of the adsorptive separation of carbon dioxide from flue gases. It has to be remembered, however, that the quality of the model strongly depends on the numerical values of the relevant equilibrium and kinetic parameters which, preferably, should be determined experimentally for each individual adsorbate - adsorbent system, as shown in Sections 2 and 3 of this paper.

Nomenclature

- b - coefficient of the Langmuir-Freundlich isotherm, $1/bar^n$
- D - coefficient of diffusion in the adsorbent pellet, m^2/s
- D/r^2 - diffusional time constant, 1/s
- i - CO_2 or N_2
- n - coefficient of the Langmuir-Freundlich isotherm
- p - pressure, bar
- q^* - adsorbed phase concentration in the pellet at equilibrium, mol/kg
- q_s - equilibrium adsorbed phase concentration at $p \rightarrow \infty$, mol/kg
- r - pore radius, m
- y - mole fraction in the gas phase
- α - selectivity

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Адсорбция Давлением в Качестве Эффективного Инструмента для Отделения Углекислого Газа от дымовых Газов

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Резюме: Важным вариантом для снижения выбросов углекислого газа является удаление CO_2 из дымовых газов. Эта техника, известная как захват после дожигания, может быть реализована разными методами уже использованы в других применениях. Один из этих методов является адсорбция давлением (АД), которая была особенно упомянута в Специальном Докладе МГЭИК, в качестве перспективной развивающейся технологией. Математическое моделирование и симуляция обеспечивают надежный и недорогой инструмент для анализа различных АД конфигураций, которые могут принести CO_2 высокой чистоты. Данная работа представляет таковой доступ, вместе с соответствующими равновесными и кинетическими данными и результатами обширных АД симуляций. Симуляции были проведены для трех колонной установки, наполненой молекулярными ситами цеолитом 13X. Основная цель симуляций является демонстрация практической осуществимости предлагаемой конфигурации АД. Главным результатом исследования является модификация АД процесса использующиеся для очистки дымовых газов при введении очищения с потоком высокого содержания CO_2.

Ключевые слова: дымовой газ, снижение CO_2, адсорбция давлением

Role of Biomass in the Energy Market of Western Balkans, Moldova and Ukraine

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Abstract: The main purpose of this work is to estimate supply from agriculture and forest based biomass in Western Balkan countries as well as in Moldova and Ukraine. A bottom up approach was employed in order to estimate the technical potential per feedstock type in each country. Forest based biomass is dominant in Montenegro, Bosnia and Herzegovina, Albania and FYROM. On the other hand, agriculture is the main source of biomass in Moldova, Ukraine, Serbia and Croatia. Currently, these countries depend heavily on fossil fuels and imports to cover their energy requirements. However, the results of this work indicate that, option for future investment in these countries. As far as heat generation is concerned, local, domestic use of wood for space heating is an important sector in all studied counties and high efficiency- low emissions modern boilers could be used to heat domestic and other public buildings. The results of this study could be used for future assessments of the economic biomass potentials and the investment opportunities for biomass exploitation in each of the under study countries, since identification, understanding and implementation of bankable bioenergy project options in the region should be included in the regional energy portfolio for the short to medium term future.

Keywords: biomass supply; energy market; Energy Community.

1. Introduction

Western Balkan countries depend heavily on fossil fuels, mainly coal and oil, to cover their energy needs. The situation is similar in Moldova and Ukraine, where natural gas is the dominant energy carrier. Furthermore, a common feature of these countries is strong dependence on energy imports. In 2008, Western Balkan countries produced on average approximately half their primary energy consumption, with energy independence ranging from 44% in Croatia to 74% in BiH. In Ukraine, energy production amounts to 60% of the primary energy consumption, while Moldova is reliant on imports for 95% of its needs [Energy Institute Hrvoje Pozar 2010; IEA 2010; Ministry of Economic Development of Montenegro 2007; National Bureau of Statistics of the Republic of Moldova 2009; NANR 2010; Statistical Office of the Republic of Serbia 2009].

With the situation described above, there is clear opportunity to reduce energy import dependency of these countries by improving energy efficiency in the production, transmission, distribution and utilization of energy and by higher energy production from renewable energy sources and other domestic resources.

Renewable energy sources are mostly undeveloped with the exception of solid biomass fuels (mostly fuelwood). According to national statistical energy data, solid biomass accounts for 10% of the domestic energy production in Western Balkans with the exception of Albania, where this number climbs to 20%. In Ukraine, solid biomass share in domestic energy production is just 0,5%. Moldova is on the opposite side, where half of the population is rural and the high prices of conventional fuels have led to a significant level of exploitation of field crop residues and prunings from orchards and vineyards. Solid biomass is the most significant domestic energy source in Moldova accounting for 70% of domestic energy production according to the national bureau of statistics.

At this point, it should be mentioned that there are significant unregistered-informal quantities of solid biomass consumed in the countries studied. These quantities are currently used mainly by the rural population for household heating, cooking and hot water preparation [FAO 2010; Savcor 2005].

The aim of this study was to estimate supply from agriculture and forest based biomass in the Western Balkan countries, namely Albania, FYROM, Montenegro, Croatia, Serbia and Bosnia and Herzegovina, as well as in Moldova and Ukraine.

2. Approach

The study employed a bottom-up approach to estimate the biomass potentials per feedstock type in each country (Figure 1). Two types of biomass potentials were considered:

Theoretical Potential: The total quantity of biomass that can be produced annually from a specific crop or waste / residue / by-product. Theoretical Potential is the quantity grown or disposed, constrained only by macro-factors such as land availability and growth yield.

Technical Potential: This considers the key issues around “practical availability” and is invariably a proportion of Theoretical Potential. Thus, calculation of Technical Potential considers factors such as other competing demands, the need for residues to stay on the land to replenish soil nutrients, etc.

Theoretical Potential can be considered a step on the way to calculating the Technical Potential. The Technical Potential provides, in a sense, the useful data, because this shows how much resource could actually be exploited. Therefore, only the technical potential is presented in this paper.

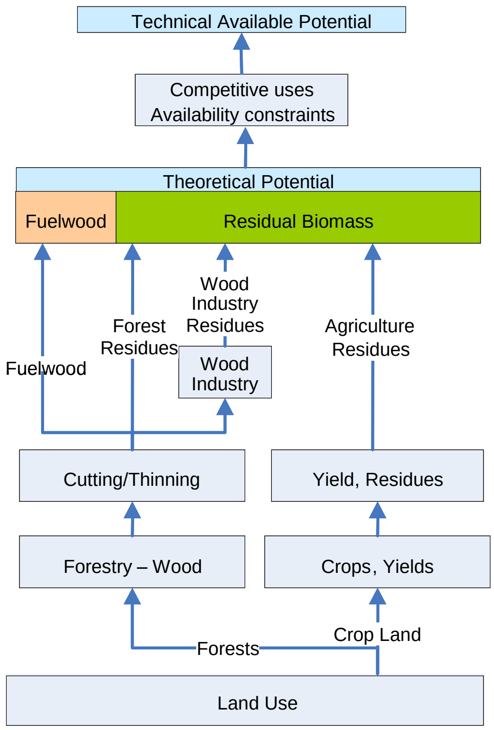

Fig. 1. Bottom up approach to estimate biomass potential.

Data sources included: official statistics from national and international governmental organisations; published and unpublished surveys and studies as well as direct communication with local experts. The reference year for all calculations was 2008.

3. Biomass Feedstocks

3.1. Agricultural based biomass

Agricultural biomass examined in this study includes field crop, arboricultural and livestock residues.

- Field crops are producing two types of field residues, i.e., dry and fresh or green residues. Green field crop residues, such as sugarbeets, potatoes, etc., are left in the field in fresh, succulent condition. These residues are usually rotting in the field and in some occasions they are used for animal feeding. That type of residues because of high moisture content, usually more than 70%, can be considered as potential feedstock for biogas applications. Dry field crop residues are derived from field crops, such as small grain cereals (wheat, barley, oat, rye, and rice), maize, oil crops (sunflower, rapeseed, etc.), etc. These residues are incorporated into the soil, burned in the field or collected and used for various purposes (animal feed, bedding, mushroom cultivation, etc.).
- Arboricultural residues are the prunings of grapes and trees such as apple trees, olive trees, pear trees, etc.
- Two main sources of livestock residues are manures and slaughter residues – the latter is not included in this study. Energy can be derived from animal manure as long as it is collected in lagoons or large tanks and can be considered feasible only in in-stall livestock systems. This precludes sheep and goats since their husbandry is extensive, making collection of manure impossible. Intensive livestock in the studied countries consists of cattle, pigs and poultry farming. Since animal manure is of a high water content, it can be digested anaerobically for the production of biogas, which can be burnt for heat or/and electricity production (AD units).

3.2. Forest based biomass

Forest based biomass includes fuelwood, forest residues and wood industry residues.

- Fuelwood is the form of wood used primarily for heat or for conversion to a form of energy.
- Forest (or logging) residues are woody biomass by-products which are created during harvest of merchantable timber. They are usually left at the logging site due to the high cost of collection and the maintenance of soil condition. Forest residues that can be used either for industrial heat or densified wood fuels (pellets and briquettes) production include tops, branches, stumps and bark.
- Wood industry residues are woody biomass by-products originating from the wood processing

as well as the paper and pulp industry. In each phase of wood processing several by-products are produced such as chips and particles, sawdust, slabs, edgings and shavings. These residues can be either used in particleboards or pulp production or used for energy purposes in industrial boilers and for densified wood fuels production (pellets and briquettes). Bark is also included in industrial residues, if industrial wood is debarked at the sawmills. Black liquor, which is a by-product of the pulp industry, can also be used for energy production.

4. Biomass supply potentials

The estimated total biomass potentials in each country are presented graphically in Figure 2.

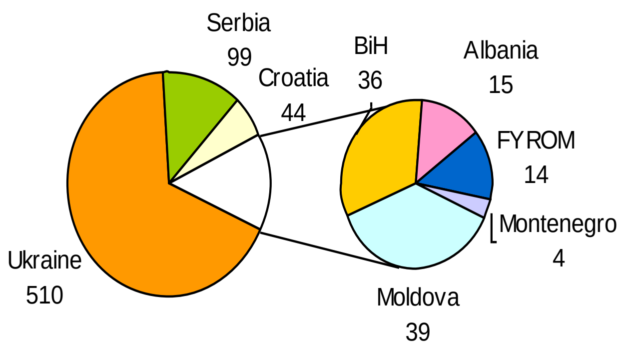

Fig. 2. Estimated biomass potentials (PJ).

Results are related with land area and land use in the under study countries. As expected Ukraine exhibits the highest potential (510PJ) and Serbia follows with 99PJ. Croatia, Moldova and BiH have similar biomass potentials of around 40PJ, while the same is true for Albania and FYROM whose potential is estimated at around 15PJ. The lowest value is found in Montenegro.

The respective contribution of each feedstock type to the total biomass potential is presented in Figure 3. Agricultural biomass is dominant in Ukraine and Moldova as well as in Serbia and Croatia. On the other hand, forest based biomass represents the highest share in Bosnia and Herzegovina, Montenegro, Albania and FYROM.

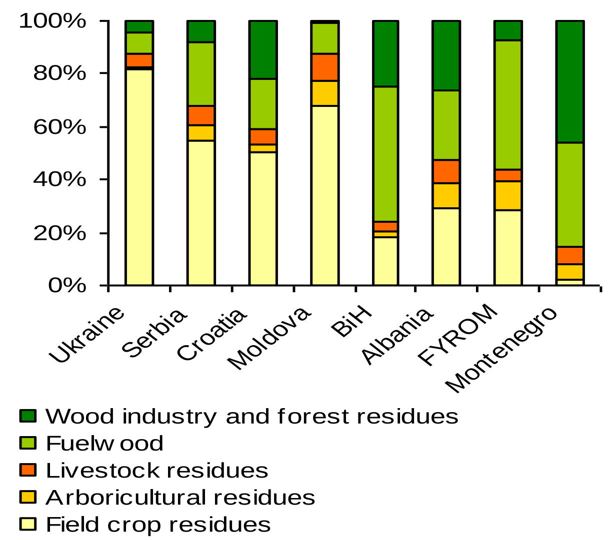

Fig. 3. Biomass contribution (per feedstock type) to the total potential in each country.

Field crop residues in Western Balkan countries derive mainly from the cultivation of maize and wheat. Oilseeds as well as sugar beet are significant biomass sources only in Serbia and Croatia, with the first category having a significant contribution to the total crop residues potential also in Moldova and Ukraine. The latter was the world's second largest sunflower seed producer in 2008. Furthermore, maize, small grain cereals and sugar beet residues have also a high share in the crop residues potential of these countries.

In the arboricultural residues category, apples and plums are the most significant sources of tree prunings, while vineyards also have significant potential in most of the countries. Olive prunings exist only in Albania, Croatia and Montenegro.

Significant quantities relative to the total potential of livestock residues are found in Moldova, Albania and Serbia. In Albania, FYROM and Montenegro livestock residues come mostly from cattle farming, while in BiH, Moldova and Ukraine cattle and poultry are dominant. Lastly, in Serbia and Croatia cattle and pig manure have the highest share.

Finally, forest based biomass comes mainly from fuelwood. However, residual biomass coming from logging activities and wood processing has a high share, which is as high as 54% of the total forest based biomass potential in Montenegro and Croatia.

5. Biomass role in the energy system

To appreciate the putative share of biomass in the energy system of the countries studied, the potentials in relation to the total primary energy supply (TPES) were estimated and are shown in Figure 4. Biomass could supply 10 to 15% of the energy needs in each country, except Moldova whose share reaches 42%.

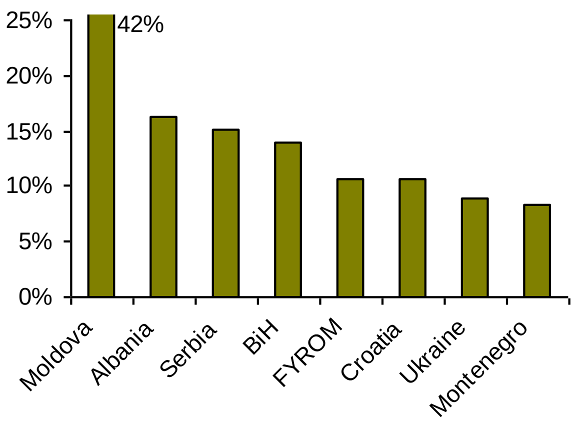

Fig. 4. Estimated biomass potentials as a percentage of each country's TPES.

Bearing in mind the above, a list of potential biomass applications in the heat & electricity markets can be identified.

An important sector for biomass use in all countries is the use of fuelwood for space heating. The use of biomass for space heating both in the residential as well as in the tertiary sector in these countries is quite high; however its use is mostly restricted to open fireplaces or inefficient old stoves. Hence there is a great potential for the use of modern, efficient biomass boilers or stoves for heating purposes in public buildings (schools, hospitals etc) as well as in the residential sector.

Furthermore, in all the countries of the former Yugoslavia apart from Croatia, power generation depends heavily on solid fossil fuels such as coal or lignite. At the same time there are numerous district heating plants that use solid fossil fuels as well. Hence there is a great opportunity for co-firing of indigenous biomass at these plants at a ratio of 5% so that there is no need for significant upgrades of the firing system.

The potential of wooden biomass may also suffice for the construction of new medium to large scale biomass only CHP units. This is particularly true in Western Balkan countries, where there is a significant potential of unexploited forest residues as well as wood industry residues.

On the other hand, the abundance of agricultural residues especially in Ukraine, Moldova, Serbia and Croatia indicates the opportunity for biogas plants and new straw fired plants, either as small scale heating units or small-medium scale CHP plants. Additionally, the vast agricultural potential in Ukraine could support in the long term the operation of large-scale straw-fired electricity plants.

6. Conclusions & Recommendations

The results of the study clearly indicate that there is a great potential for biomass utilization for energy purposes in the region studied. The exploitation of this potential can displace a large portion of the currently used fossil fuels providing significant environmental benefits and the opportunity to develop a domestic bioenergy market.

Further analysis for the investigation of the actual economically exploitable biomass potential is necessary. Specific national biomass roadmaps shall also be developed in order to set specific targets and analyse various policies and measures for achieving them. Identification, understanding and dissemination of bankable project options in the region should be a priority.

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Роль Биомассы в Энергетическом Рынке Западных Балкан, Молдовы и Украины

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Резюме: Основной целью данной работы является оценка поставок из сельского хозяйства и лесной биомассы в странах Западных Балкан, а также в Молдове и Украине. Подход "снизу вверх" был использован для того, чтобы оценить технический потенциал по типу сырья в каждой стране. Лесная биомасса является доминирующей в Черногории, Боснии и Герцеговины, Албании и Республики Македонии. С другой стороны, сельское хозяйство является основным источником биомассы в Молдове, Украине, Сербии и Хорватии. В настоящее время эти страны сильно зависят от ископаемого топлива и импорта для покрытия своих энергетических потребностей. Тем не менее, результаты этой работы показывают, что биомасса могла бы поставлять от 10 до 15% энергетических потребностей в каждой стране, особенно в Молдове, вклад биомассы мог бы достигнуть 42%. Производство электроэнергии либо через совместного сжигания в существующих электростанций или новых станций Комбинированного Тепловыделения является реальным вариантом для будущих инвестиций в этих странах. Что касается генерации тепла, то, местное, домашнее использование древесины для отопления помещений является важным сектором во всех исследуемых странах и высокой эффективности- современные котлы низкого уровня выбросов могут быть использованы для нагревания домашних и других общественных зданий. Результаты этого исследования могут быть использованны для будущих оценках экономического потенциала биомассы и инвестиционных возможностей эксплуатации биомассы в каждой из исследованных стран, поскольку идентификация, понимание и реализация экономически обоснованных вариантов проекта биоэнергетики в регионе должны быть включены в региональный портфель энергии в краткосрочной и среднесрочной перспективе.

Building sustainable biomass - to - biofuel systems: Prospect for biohydrogen generation in two EU regions

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Abstract: In this paper possibilities and roadmaps are explored, for the establishment of a technically and economically feasible, environment-friendly and sustainable, biomass-to-biohydrogen economy in Europe. The work is focused on the long range (2010-2030) potential of 2-step fermentative hydrogen generation. Current and future biomass feedstocks are assessed at EU and regional level, taking into consideration their technical suitability, cost and sustainability. The regional differences affecting policy priorities are examined by a comparative study of two EU regions, Rotterdam (NL) and Thessaly (GR). These case studies have resulted in an inventory of potential stakeholders, and the foresight of their role in 5-year segment of the considered period. The establishment of a sustainable bio-based energy system can be made possible by the appropriate synergies between stakeholders with usually diverging interests, within the frame of a common "biohydrogen culture". Some other findings follow:

- Incentives should be provided to local agro-industries and current biofuel producers for the transition from 1st to 2nd generation biofuels, including biohydrogen, with emphasis on sustainability.
- The biomass/biohydrogen potentials in these regions are quantitatively similar, but qualitatively different: in Mt/a (dry biomass), 1.5 for Thessaly (energy crops, farm residues), 1.8 for Rotterdam (agro-industrial residues, imported feedstocks), or 80 and 83 kt/a of biohydrogen, respectively. In both cases, the estimated potential can cover the expected regional H_2 demand in the next 20 years.
- The economic feasibility of such plants will require significant yield improvements, both in carbohydrate recovery and hydrogen generation rates, as well as high value-added co-product applications.

Keywords: biomass, sustainable biofuels, biohydrogen, Europe, Rotterdam, Thessaly

1. Introduction

Mapping the biological resources within specific geographical boundaries, qualitatively and quantitatively, and assessing the conditions under which they will be available, constitutes the basis for the design and sustainable operation of any biomass-to-biofuel system. Given that the role of biomass in the future energy landscape will be increasingly important **(**Van Dam et al., 2005**)**, a more accurate and "conversion technology oriented" assessment of its potential availability becomes necessary for policy making, long term planning and overall biomass-to-biofuel system design and optimization.

The research presented in this paper was carried out within the framework of EU funded Integrated Project, Hyvolution (2006-2010). The main objective of Hyvolution project is:

- the development and optimization of a 2-stage bioprocess for the generation of pure hydrogen from biomass (from this point forward to be mentioned as "Hyvolution technology"),
- the simultaneous optimization of technical, economic, environmental and social parameters of the whole biomasss-to-biohydrogen chain, and
- the exploration of the sustainable operation of the specific technology under various regional conditions within EU (Hyvolution, 2010).

It should be noted that one of the major benefits of the examined technology is its applicability at a relatively small scale (2 MW Hydrogen generation unit), which provides the flexibility and option of decentralized resource exploitation.

The carbohydrate resources from agricultural and agro-industrial sector are considered as potential feedstocks for the examined technology (Claassen et al., 1999). The overall annual hydrogen generation potential, based on the major, non forest originated, EU biomass resources, has been assessed as about 30 Mt (Karaoglanoglou et al., 2008).

The accurate estimation of the actual resource availability can take place only if the geographical boundaries of the system are kept quite limited, e.g. at regional level. Data collection at this level would provide the necessary basis for such estimation. The competition and synergies, which will be created during the implementation of the Hyvolution technology, not only with food sector but also with other biofuel/bioenergy generation options will be crucial for the feasibility and sustainability of the potential biomass-to-biohydrogen generation chains. The impact of the future plants on the natural resources, their social acceptance, which is highly dependent on their relevant effect on the local employment and economy, have to be examined regionally, as potential further incentives or constraints.

Within this framework, the present paper will provide an overview of the activities which took place, for the assessment of the prospects of the Hyvolution Technology integration, into the energy system of two EU regions, in a 20 year (2010-2030) perspective. The ultimate purpose of the whole process was to derive strategy, investment and policy hints for the development of Hyvolution technology applications in EU regions with different characteristics.

2. Methodology

Two European regions were selected in order to explore the potential logistic chains which can be built for the supply of feedstocks to biohydrogen facilities and their dependence on the regional factors.

The region selection took place, according to the criteria of Rural vs. Urban, Low vs. High income, Low vs. High innovativeness and South vs. North, and targeting at the maximum possible diversification of the two selected regions (Eurostat 2010; Pro Inno Europe, 2010):

The Region of Thessaly, Greece: As a typical low income and innovation, primary sector based region of South Europe

The Region of Rotterdam, The Netherlands: As a typical high income, highly industrialised and innovative region of North Europe

- The methodological approach which was followed, in order to collect and process data for these two regions can be summarised into three major activities:
- Desktop research, where crucial regional characteristics were identified (Figure 1), and statistical and other data were collected in a systematic way in order to have the profile of each region,
- Workshops and on-site visits to the key players in both regions,
- Scenario-based potential assessments and socio-economic analysis through the projection of the current situation into the future.

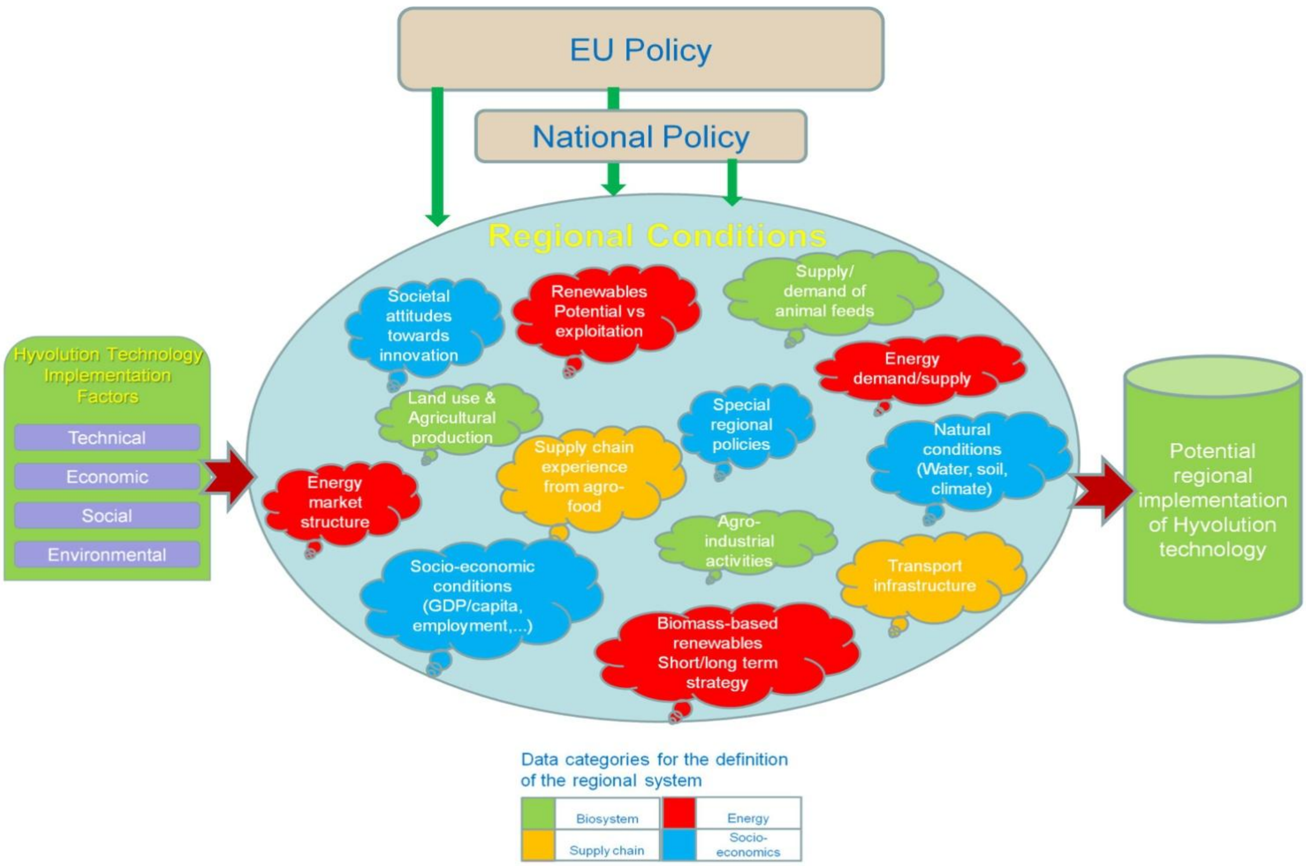

Fig. 1: Regional dimension of the implementation of Hyvolution technology

3. Results and Discussion

3.1. Desktop research - Data Collection

The regional profile of each studied region was outlined, according to the key regional factors identified in the methodology. The results of this process are presented in Table 1.

This data along with the insight already acquired, throughout the Hyvolution project, are used, first in the immediate and future potential estimation and then in the scenario development.

The application of technical, economic, social and environmental criteria lead in the identification of sugar beet juice, potato peels, barley straw and wheat bran as the most promising feedstocks for the examined technology in EU (Diamantopoulou et al., 2007; Diamantopoulou et al., 2008; Diamantopoulou, Koukios, 2010).

The biomass/biohydrogen potentials in the 2 regions are assessed to be quantitatively similar, but qualitatively different: in Mt/a (dry biomass), 1.5 for Thessaly energy crops, farm residues), 1.8 for Rotterdam (agro-industrial residues, imported feedstocks), or 80 and 83 kt/a of biohydrogen, respectively.

Table 1: Profile of two case study regions

	"Rural South":	"Industrial North":
Land use / Main Agricultural Products	- Total Agricultural Land: 490000 ha - Cotton: 150000 ha - Wheat: 110000 ha - Barley: 14000 ha - Sugar beet: 7000 ha - Fallow/pasture land/other not utilised agricultural land: 38000 ha	- Total Agricultural Land: 150000 ha - Cereals: 12500 - Potatoes: 9000 ha - Sugar beet: 4000 ha
Estimated Agricultural Income	850-2500 €/ha (40-50% coming from national or EU subsidies)	900-2500 €//ha (much higher for greenhouse agriculture)
Agro-industrial Units	2 large wheat mill units 1 large juice production unit Several small canned product units Several oil production/processing units	- oilseed crushing - grain processing - large beer breweries - potato processing facilities
Spatial Distribution of Agro-industrial Units	- 2 wheat mills are placed in Larissa and Magnesia prefectures - The juice production unit is placed in Magnesia prefecture - The rest units are distributed throughout the 4 prefectures	Main agro-industrial units are placed around the , within a 30 km radius
Potentially Available Agricultural and Agro-industrial By-products	- wheat bran - wheat and barley straw - pulp from juice industry - cake from oil industry	- wheat bran - potato steam peels - cake from oil industry
Transport Infrastructure	- a major port in Magnesia prefecture - good road network	- port (`s cheapest bunker port): the third largest port in the world - railway and road network supplying the port
Available Supply Chain Infrastructures	Already existing import (oil/oil seeds, cereals) and export (flour and other processed cereal and juice products) activities in the region	The agro-industrial units of the region are largely based on imported feedstock. The Agri-bulk handled in is about 9.5 million tones
Renewable Energy in the Region	135 MW power produced in H/E plants, and 2 biodiesel production units	- electricity production using imported wood residues(1 Mton dry wood residues) - wind energy
Biomass-based Energy Production	- 2 biodiesel production units (using imported feedstock) of 55000 tonnes total capacity - 1 bioethanol unit (from sugar beet and cereals) to be operational within 2010	- co-firing of wood for electricity - surplus of heat from oil refinery - farm scale biogas digesters - several bioethanol facilities around the port area
Population	About 750000 persons	About 1600000 persons
GDP/Capita - Employment	73.2 (considering 100 the GDP of EU25) 13% employed in primary sector	- 204 billion Euro regional product - 21% of the total employment of NL, 1.5% in primary
Special Regional Conditions - Policies	Governmental initiatives encouraging the land use change (especially from cotton to alternative crops)	Sustainable production program for all the economic sectors
Social Acceptance of Bioenergy Projects	"Thessaly Biofuel Technology Platform" along with the play a positive role in the social acceptance of biofuels	- Positive public response to "green electricity" - Negative public response to large biofuel plant projects

* Hellenic Sugar Industry announced in March 2010 that the specific project was cancelled, since they assessed that such a large plant will not be feasible and sustainable in long term.

Only a small part (5 to 10%) of this potential originates from the four most promising feedstocks (Karaoglanoglou, Koukios, 2010)

The potential plants, in the two regions, which can be based on the four most promising feedstocks are presented in Table 2 and 3.

Table 2: Mapping the landscape of potential biohydrogen units in Thessaly

Potential Feedstock	Location	Co-operation with existing or potential industrial units	Hydrogen Unit Type	Potential Capacity
Sugar beet	Larissa	Bio-ethanol Production Unit (under construction)	Add-on	>> 8000 dry t/year
Wheat Bran	Volos	Wheat Mill (locally produced and imported wheat)	Add-on	> 8000 dry t /year
Potato Steam Peels	Lamia (city close to Thessaly region)	Potato Chips Production Plant	Add-on	~ 8000 dry t/year
Barley Straw	Karditsa-Trikala	Regionally produced straw	Local stand alone	~ 8000 dry t/year

Table 3: Mapping the landscape of potential biohydrogen units in Rotterdam

Potential Feedstock	Location	Co-operation with existing or potential industrial units	Hydrogen Unit Type	Potential Capacity
Sugar beet	Rotterdam port area	Sugar production unit	Add-on	>> 8000 dry t/year
Wheat Bran	Moerdijk industrial area	Wheat Mill (mainly imported wheat)	Add-on	>> 8000 dry t /year
Potato Steam Peels	Rotterdam port area	Potato Chips Production Plant	Add-on	>>8000 dry t/year
Barley Straw	Rotterdam agricultural land area	Regionally produced straw	Local stand alone	~ 8000 dry t/year

3.2. Workshops and on-site visits

Two major on-site visits and workshops, in Thessaly (Sugar beet factory, October 2007) and in Rotterdam (Port area, May 2009) were carried out.

Furthermore, numerous communications and on-site visits took place, to:

- academics, farmers and biofuel (biodiesel) production companies in Thessaly
- potential feedstock providers (Meneba mills, Farm Frites, etc.), already existing or under construction biofuel plants and the port authority in Rotterdam

Some crucial feasibility and sustainability issues, and key stakeholders were identified throughout this process. The degree of involvement of these stakeholders on the implementation of Hyvolution technology differs, for each region and 5 year sub-period in a 20 year perspective. An assessment of this involvement can be seen in Table 4.

3.3. Scenario-based analysis

An attempt for the identification of the main priorities, bottlenecks and driving forces in each of the 5 year sub-periods, also took place. The positive or negative developments in these issues will lead in the "Best case" or "Worst case" scenarios for Hyvolution technology, respectively.

The outline of such a roadmap to the future application of Hyvolution Technology in both regions is presented in Figure 2a, b.

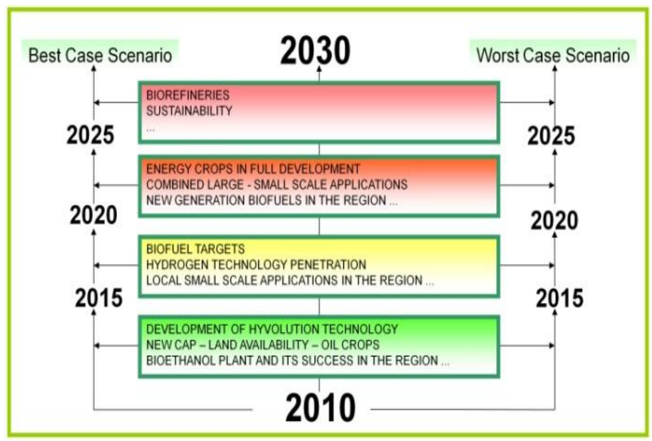

Fig. 2a: Roadmap to Hydrogen through Hyvolution technology in Thessaly

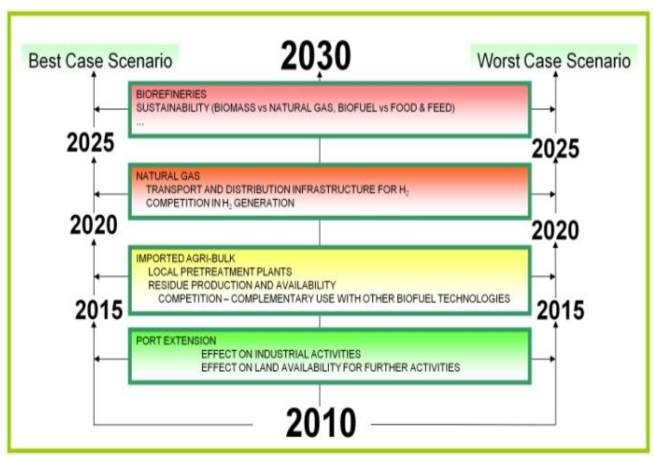

Fig. 2b: Roadmap to Hydrogen through Hyvolution technology in Rotterdam

3.3.1. Future Hydrogen generation potential in Thessaly

The prospects of the future hydrogen generation potential of the region will highly depend on the land use change which is expected to take place due to the new Common Agricultural Policy (CAP) of EU. Under this perspective, 3 scenarios for the future land use, for the period 2010-2020, were considered assuming, in the meantime, that the agricultural yield will have an improvement for all the crops, equal to 1%/year [EEA, 2006]:

- Minimum energy crops scenario: 1/3 of current set aside land used for sugar crop cultivation
- Medium energy crops: Starting from 1/3 of current set aside land in 2010, and ending to 2/3 in 2020, to be used for sugar crop cultivation
- Maximum energy crops: Starting from 1/3 of current set aside land in 2010 and 0% of current cotton land, and ending to 2/3 of set aside land and 70% of cotton land in 2020, to be used for sugar crop cultivation.

Table 4: Key Socio-economic actors and their involvement 2010-2030

	THESSALY				ROTTERDAM			
Key actors	2010-2015	2015-2020	2020-2025	2025-2030	2010-2015	2015-2020	2020-2025	2025-2030
Farmers	*	***	**	**	*	*	*	*
Local society	*	**	***	**	**	**	**	**
Existing biofuel industry	**	**	**	*	**	***	**	*
Existing food industry	*	***	**	*	**	***	**	**
Feed and fodder sector	*	**	**	**	*	**	***	**
Transport	*	*	**	**	*	**	***	***
Distribution	*	*	***	***	*	**	**	**
End-use	*	*	**	***	*	**	**	***
Technology research and development	***	**	*	*	***	**	*	*
EU policy	***	**	**	**	**	**	**	**
National policy	*	**	***	**	***	**	**	**
Hyvolution by-product market	*	*	**	***	*	*	**	**

Stakeholders' involvement	
*	simple involvement
**	significant role
***	key (dominant) actor

It should be also noted that the transition from the current agricultural land use to the future energy crop agriculture can take place only under certain conditions. The farmers' income expectations will play a major role in this process. Under the current conditions the land use change, for the replacement of cotton cultures, should lead in a gross margin generation about 400 Euro/ha in order to provide the necessary incentives to the farmers (LMC, 2007).

Moreover, the effect of the improvements in the refining and conversion technologies (especially for starch and lignocellulosics) was examined in a multiple scenario basis, starting from the currently obtained efficiencies and assuming future technology improvements, in order to assess the hydrogen generation potential from selected feedstocks in the region. (Fig. 3a, b)

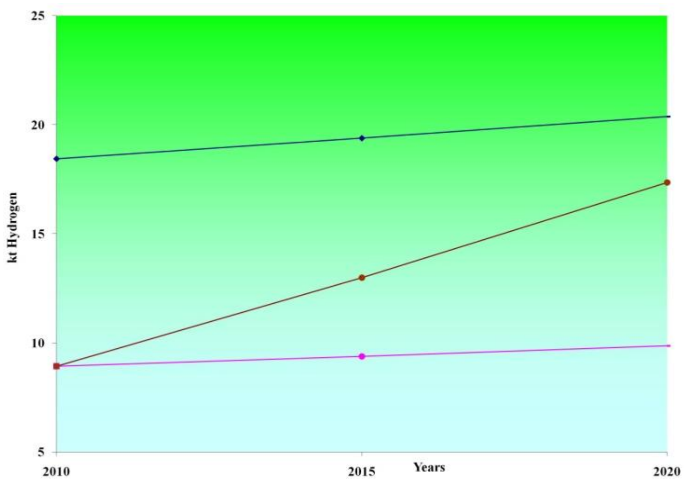

Fig. 3a: Effect of technology efficiency on minimum energy crops scenario

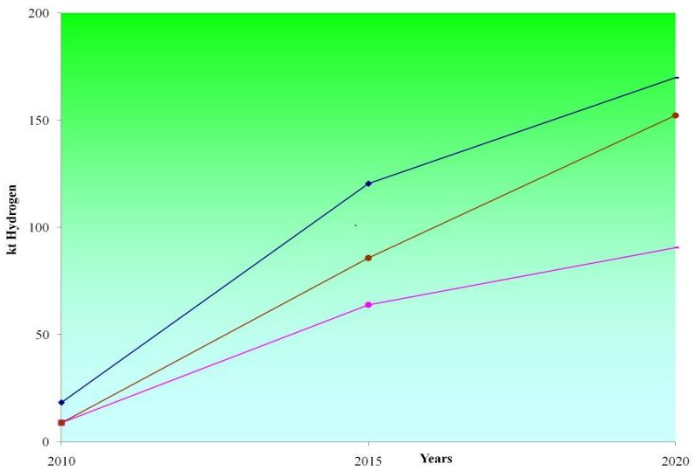

Fig. 3b: Effect of technology efficiency on maximum energy crops scenario

3.3.2 Future Hydrogen generation potential in Rotterdam

The region attracts a lot of industrial activities and it will do it even more in the short/medium term future, due to the expansion of the port area. However, the main limiting factor for the region will be the land availability for new industrial units and any other activity (e.g. agriculture).

The price of agricultural land is particularly high for growing energy crops in the region (29-68 kEuro/ha depending on the type of land). Consequently, the main feedstock for short-medium term future will be by-products from agro-processing industry, especially wet products, which are less useful for other purposes:

- Wheat processing: wheat bran (Meneba)
    - Potato processing: potato steam peelings (Cosun/Aviko, Mccain)
    - Beer breweries: spent brewery grains (Heineken, others)

The future "supply side" Hydrogen generation potential, through Hyvolution technology, for the region, was based on the total agribulk handled by the regional industrial units, and the future prospects of its development.

Table 5: Supply-side scenarios

Scenarios	Annual increase in agribulk handled in industries of port area	Available by-products/residues for hyvolution	Carbohydrate recovery	Hydrogen conversion *
1	3%	10%	30%	100%
2	3%	10%	70%	100%
3	3%	10%	30%	50%
4	3%	10%	70%	50%
5	6%	10%	30%	100%
6	6%	10%	70%	100%
7	6%	10%	30%	50%
8	6%	10%	70%	50%
9	3%	15%	30%	100%
10	3%	15%	70%	100%
11	3%	15%	30%	50%
12	3%	15%	70%	50%
13	6%	15%	30%	100%
14	6%	15%	70%	100%
15	6%	15%	30%	50%
16	6%	15%	70%	50%

* 100% conversion = 0.1 t hydrogen from 1 t carbohydrates

Several scenarios, considering the agro-industrial development and Hyvolution technology efficiency, were developed in order to map this potential. The parameters considered for each scenario are presented in Table 5.

The outcome of these scenarios along with the respective demand-side scenarios are presented in Fig. 4.

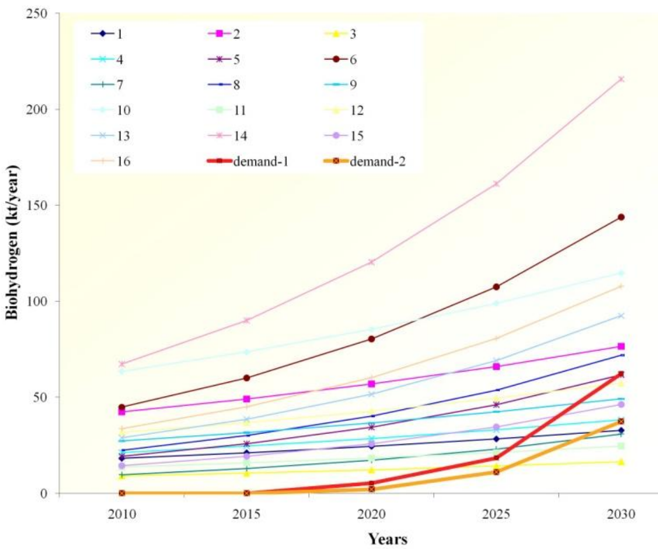

Fig. 4: Supply and demand of Hydrogen in Rotterdam

The direct connection of the feedstock availability with the development of the food sector (agribulk handled and residues produced due to the pretreatment practices) in the region should be underlined.

Although, the Hydrogen generation potential through the Hyvolution technology from the feedstock supply side can be within a wide range (10-65 kt/year in 2010 and 15 to 220 kt/year in 2030), due to the high degree of uncertainties, it can be observed that most of the supply side scenarios provide the necessary potential to fulfil the respective demand assessment.

4. Conclusions

4.1. General remarks for both regions

- The future success and sustainable application of the examined technology is a function of the positive or negative progress of the issues identified and analysed in this paper. The respective priorities of each 5 year period should be monitored and the targets should be re-assessed in order to succeed in an optimised integration of the hyvolution technology in the EU's future energy map.
- It is assessed that the transition from first generation to second generation biofuels and biohydrogen will play a crucial role for the land and infrastructure availability in both examined regions. Motives should be provided, especially to the local agro-industries and current biodiesel producers of the regions for this transition, as long as simultaneous improvement of the overall biofuel sustainability indices is achieved.
- Although the current refining and conversion technology can provide the necessary hydrogen potential, the economic feasibility of such plants will require the yield improvement and value added co-product applications.
- In a fully bioenergy integrated energy future, the competitive biofuel applications will further decrease the availability of the feedstocks. As a consequence, simultaneous research on the improvement of the hydrogen production efficiency and on the enrichment of the techno-economically suitable feedstock portfolio should be carried out.
- There will be diverse effects of existing biofuel production plants on the development and domination of Hyvolution technology:
    - Positive, in the "start-up" phase, providing the necessary infrastructure for pilot or small scale production
    - Possible negative effect in further development phase due to land use competition
    - "Success stories" of first generation biofuels will improve the social acceptance of biofuels and will create a "bio-society" culture which will facilitate the integration of Biohydrogen generation into the existing energy system.
- The land need for the reactor of the photochemical fermentation (currently 60ha for an 8000 dry tonne/year biomass plant capacity,

estimation for 10 ha after process optimisation) is a further concern especially for Rotterdam case where the land availability is already limited. This obstacle probably could be by-passed using otherwise unused areas (which primarily was water). In the case of Thessaly the availability of lower quality and non utilised agricultural land is estimated to provide the necessary land source in the start-up phase.

- The prospects of imported feedstock utilisation in biohydrogen generation plants is expected to play a crucial role in the future hydrogen economy especially in the case of Rotterdam, where the agricultural land availability for dedicated energy crop production is also extremely limited. Furthermore, this option would exploit the major strategic advantage of the region, the port infrastructure, which already supports import activities for large amounts of agri-bulk products, in the framework of the current industrial activities. As far as Thessaly region is concerned, the imported feedstocks will not be the key player for the full scale implementation of Hyvolution applications, given the current and estimated future land availability. However, they are expected to have an indirect effect, especially in the case of wheat milling residues, since the operation of already existing wheat milling plants is highly dependent on the imported (either from other Greek regions or from other countries) feedstocks. The future of this sector will affect the relevant by-product generation (wheat bran) in the region and its consequent availability for energy applications.
- Despite the potential feedstock availability for Biohydrogen generation:
    - 70% of biofuels is expected to be first generation biofuels in 2020. This situation will limit significantly the actual feedstock availability (especially in the energy crop category) for Hyvolution Technology at this time period
    - The Hydrogen distribution and end use technology will still be capable to support a small contribution of Hydrogen in regional and national energy balance

4.2. "Thessaly" Case

- The current hydrogen generation potential from the 4 selected feedstocks in Thessaly region can cover the expected from the literature annual Hydrogen-from biomass demands of the region for the period 2010-2020 (even without any energy crop use and assuming that all the biomass-hydrogen will come from Hyvolution technology).
- The energy crop cultivation scenarios, even the most conservative ones, increase the potential significantly, increasing the importance of Thessaly in the future hydrogen economy, as well. According to the assumed "maximum energy crops" scenario in the region, 2.5 to 4.7% of the expected transport sector energy needs [EC - DG for Energy and Transport, 2007] (or 1.0 to 1.9% of the expected overall energy needs) of Greece in 2020 can be covered by the "Hyvolution" Hydrogen which will be produced in the region.
- The social impact assessment of cotton culture replacement, in Thessaly, by energy crops should also consider the impact of this situation on the secondary sector, the cotton gin plants of the region, which employ a large number of labourers (about 200 permanent and 600 seasonal).

4.3 "Rotterdam" Case

- The supply and demand site scenarios showed that the hydrogen demand of the region can be easily covered by the feedstock availability from the regional agro-industrial units, under the conditions that the continuous future development of these units is secured and that the techno-economic feedstock suitability issues for a larger number of potential Hyvolution feedstocks are solved.

- The feasibility and sustainability of the add-on to potato unit hydrogen plants will depend on:
    - The competitiveness of bio-hydrogen against natural gas
    - The reduction of CO_2 emission due to less transport movements
    - The potential to sell the CO_2 credits earned
    - The reliability of the biohydrogen plant (no malfunctions) since long-term storage of the by-product is not desired/possible
    - The exploitation of the co-products and effluents of the $BioH_2$ facility
    - The assessment of other impacts of the bio-hydrogen plant, such a nuisance and safety regulations, and the local environment/habitat
- Given that one add-on hydrogen conversion plant may not be able to be fully supplied with potato steam peelings as feedstocks, the feasibility of using other industrial by-products in a multi-feedstock hydrogen plant should be assessed.

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Создание устойчивых систем биомассы-в-биотопливо: Перспективы генерации биоводорода в двух регионах ЕС

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Резюме: В данной работе исследоваются возможности и дорожные карты для создания технически и экономически осуществимой, экологически чистой и устойчивой, биомассы-в-биоводород экономики в Европе. Работа сфокусирована на долгосрочный (2010-2030) потенциал 2-х ступенчатой ферментативной генерации водорода. Нынешние и будущие сырья биомассы оцениваются на уровне ЕС и региональном уровне, учитывая их техническое соответствие, стоимость и устойчивость. Региональные различия, влияющие на политические приоритеты рассматриваются сравнительным исследованием двух регионов ЕС, Роттердама (НЛ) и Фессалии (ГР). Эти тематические исследования привели к инвентаризации потенциальных заинтересованных сторон, и предвидению их роли в 5-летний сегмент рассматриваемого периода. Создание устойчивой энергетической системы на биооснове может быть возможным благодаря подходящей синергии между заинтересованными сторонами у которых обычно различные интересы, в рамках общей «культуры биоводорода». Следуют некоторые выводы:

- Стимулы должны предоставляться местным агропромышленным предприятиям и нынешним производителям биотоплива для перехода с 1-ой на 2-ую генерацию биотоплива, в том числе биоводород, уделяя особое внимание на устойчивость.

- Потенциалы биомассы/биоводорода в этих регионах количественно похожи, но качественно иные: на Mt/a (сухая биомасса), 1,5 для Фессалии (энергетический урожай, сельскохозяйственные осадки), 1.8 для Роттердама (агропромышленные осадки, импортные сырья), или 80 и 83 kt/a биоводорода, соответственно. В обоих случаях, оцениваемый потенциал может покрыть ожидаемый региональный спрос H_2 в ближайшие 20 лет.
- Экономическая осуществимость таких установок потребует значительного улучшения урожая, в темпах углеводного восстановления и генерации водорода, а также применения совместных продуктов с высокой добавленной стоимостью.

Ключевые слова: биомасса, устойчивое биотопливо, биоводород, Европа, Роттердам, Фессалия

An Overview of Wave Energy Devices.

Case Study: Wave Energy in Agios Efstration, the First Greek Green Island

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Abstract: Wave energy is a renewable source, which has not yet been exploited to a large extent. So far the main focus of wave energy conversion has been on the large wave energy resources of the great oceans on northern latitudes (Diamantaras et al., 1995; Bernhoff et al., 2003). However, large portions of the world potential wave energy resources are found in sheltered waters and calmer seas, which often exhibit a milder, but still steady wave climate (Soerensen et al., 2009). Examples are the Baltic Sea, the Mediterranean and the North Sea in Europe, and ocean areas closer to the equator (Bernhoff et al., 2003). The wave energy contribution from sheltered waters has been little investigated, but there have been many attempts to successfully convert the irregular wave energy into electricity (Glendenning, 1978; Thorpe, 1992; 1998; Boud, 1999).

This paper presents an overview of some of the main developments in wave energy and their potential implementation to Agios Efstratios, the first Greek green island, in the Aegean sea. It concentrates on devices for which new data have been produced since 2009. It presents the technical characteristics of each device and their economical valuation, which includes the capital cost, operation and maintenance cost, payback period, cost of electricity and life cycle.

The methodology, which is followed, consists of two parts. In first part, it is examined the technical characteristics of the device and if it is efficient in the specific location. It is taken into consideration the wave height, depth of water, wind velocity and the annual output. If the device is efficient and productive, then we continue in the second part of the methodology, where the economic characteristics are examined examined. If a device meets the requirements then it is appropriate for implementation in the island.

The review methodology indicates that wave energy could become a useful source of energy. The results show that wave energy is already economically competitive and has good prospects of being commercially competitive with further Research and Development (R&D). In Agios Efstratios only a restrictive number of the examined devices could be implemented, due to the shallow water and the small wave power. However, the more promising offshore devices are still at the assessment stage.

Keywords: wave energy, economical valuation, green island

1. Introduction

Nowadays the need for new energy sources became more urgent. Traditional methods of energy production are contributing to serious environmental problems. Renewable energy sources could provide a solution to the problem, as they are inexhaustible and have less adverse impacts on the environment than fossil fuels.

There are many types of renewable energy that can replace the use of fossil fuels (e.g. oil and coal). Nowadays, the most widespread exploitable renewable energy sources are wind and solar. Wave energy is one of the most promising sources, as demonstrates a relatively high power density. Wave power generation is not currently a widely employed commercial technology although there have been attempts at using it since at least 1890 (Miller, 2004).

The energy from waves alone could supply the world's electricity needs. Wave energy contains roughly 1000 times the kinetic energy of wind (Kumar, 2007). Wave energy varies as the square of wave height whereas wind power varies with the cube of air speed. Water being 850 times as dense as air results in much higher power produced from wave averaged over time. The total power of waves breaking on the world's coastlines is estimated at 2 to 3 million megawatts.

The theoretical global ocean energy resource is estimated to be on the order of (IEA, 2007):
* 2.000 TWh/year for osmotic energy,
* 10.000 TWh/year for ocean thermal energy (OTEC),
* 800 TWh/year for tidal current energy, and
* 8.000 – 80.000 TWh/year for wave energy.

This theoretical potential is several times greater than the actual global electricity demand, and equivalent to 4000 –18000 MToE (million tons of oil equivalent).

In some locations, the wave energy density can average 65 megawatts per mile of coastline (Wave Energy, 2010). In the Mediterranean basin, the annual power level off the coasts of the European countries varies between 4 and 11 kW/m, the highest values occurring in the area of the south-western Aegean Sea (Clement et al., 2002). This area is characterized by a relatively long fetch and high wind energy potential. The entire annual deep-water resource along the European coasts in the Mediterranean is of the order of 30 GW, the total wave energy resource for Europe resulting thus to 320 GW (Clement et al., 2002). The problem is how to harness wave energy efficiently and with minimal environmental, social, and economic impacts.

Even though ocean waves is a substantial energy source, with no fuel costs, a high power density and high utilization over the year, wave energy conversion is often neglected on technological grounds. There are numerous suggestions on how to convert wave energy into electricity in the literature. Some of these are currently being tested in different parts of the world. The broad majority of these approaches use interfaces to match the low speed reciprocal wave motion to a conventional electrical generator (Leijon et. al., 2006).

Across Europe there is a significant ambition to develop ocean energy, notably in the countries on the Atlantic arc (UK, Ireland, France, Spain and Portugal). In recognition of the widespread interest in developing the wave and tidal energy industry across Europe, the European Commission has provided a total of €58.3 million over the past nine years to develop the industry.

The scope of this paper is to asses twenty-eight (28) wave energy devices and their potential application in Agios Efstratios, the first Greek green island. The devices are evaluated based on the location's characteristics, the capital cost, the electricity cost and the payback period. In section 2 it is presented the state of the art. Section 3 describes the methodological framework that is applied for the evaluation of the wave energy devices, while section 4 is referred to data collection. Section 5 presents the case study of Agios Efstratios – if the wave energy device is applicable and if it is, the profit of the productivity of each device. Section 6 concludes the paper.

2. State of the art

There are three approaches to capturing wave energy: floats or pitching devices, oscillating water columns (OWC), and wave surge or focusing devices; energy collection devices can be placed either on the shoreline, near the shoreline, or offshore (Wave Energy, 2010).

Shoreline devices have the advantage of relatively easier maintenance and installation and do not require deep water moorings and long underwater electrical cables (Wave Energy, 2010). The wave energy is less on the shoreline but this can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or defraction.

Nearshore devices are situated in 10-25metres of water near the shore. The most common device for this situation is the oscillating water column (OWC). Offshore devices are situated in deep water, with typical depths of more than 40metres. The incidence of wave power at deep ocean sites is three to eight times the wave power at adjacent coastal sites. A range of devices are being trialed for offshore use. Experience of constructing shoreline devices has been poor, with extended schedules and difficulties in providing adequate temporary construction works, (e.g. protection of personnel from waves).

The wave energy converting device placed on the sea bed may be completely submerged, it may extend above the sea surface, or it may be a converter system placed on an offshore platform. The visual impact of a wave energy conversion facility depends on the type of device and its distance from shore. Onshore or nearshore devices could change the visual landscape from one of natural scenery to industrial.

Shoreline and near-shore OWCs were identified in five countries: Scotland, Australia, India, Japan and Portugal (the Azores) (The Carbon Trust, 2005). Of these, presently operational shoreline units are built out of concrete, but steel has been proposed for near-shore devices. All structures have been bespoke designs for particular locations, with the collector geometry a function of the local water depth and wave climate.

3. Methodological Framework

In order to design the methodological framework that is applied in this paper, it is used as base the Methodology for Economic Appraisal that proposed by Thorpe (1999), with some changes, as it is taken into consideration other aspects such as characteristics of location, wave energy machine's lifetime and payback period. The new methodological framework is presented in Figure 1 and described below.

The clearest and simplest measure of the commercial viability of wave energy is probably the predicted cost of electricity produced by a wave energy station in terms of p/kWh (Thorpe, 1999). Although some of these aspects are common to all devices and, as such, can be discussed in general terms under appraisal methodology, other aspects are device-specific.

<u>First Step:</u> Site Selection

Wave energy can be considered as a concentrated form of solar energy. Winds are generated by the differential heating of the earth. As they pass over open bodies of water they transfer some of their energy to form waves (Southgate, 1987). Clearly, the amount of energy transferred, and hence the size of the resulting waves, depends on the wind speed, the length of time for which the wind blows and the distance over which it blows (Thorpe, 1999).

Also, as concern the site selection, it should be taken into consideration and other location characteristics, such as the depth of water, wave height and the distance from the coast.

If the location is appropriate for installing a wave energy device, then it is examined the device selection (second step). Also, if the device is not applicable to the site, there are two options: either to select another place, or to select another device.

Second Step: Device Selection

If the device is appropriate for the selected place, then they are examined the annual output, the cost of electricity, the cost of capital, the operational and maintenance (O&M) costs, the payback period and finally the profit of the investment. If the profit satisfies the investor, then the wave energy device is appropriate for applying in the selected location; if there is loss or the profit is low, it is examined again the site and device selection.

Electrical Output

• *Available Wave Power*. The amount of wave energy available for capture has a strong influence on the amount of energy any device can generate. It is a function of location, water depth and local sea bed topography.

• *Captured Wave Power*. The efficiency with which a particular device captures wave power is a function of the sea state. Most devices have been tested in wave tanks to determine this aspect of their performance. In those cases where no such data are available, theoretical analysis had to be used. The applicability of such data to the performance of full size devices in real seas is one of the most important areas of uncertainty in this research.

• *Maximum Annual Output*. The amount of energy delivered to the grid from a particular device in a given sea state depends on the losses in the power chain (turbines, generators, rectifiers, transformers, transmission lines etc.). Data exist on the relative losses as a function of power level and rating of electrical equipment but often the performance of mechanical plant had to be estimated from theoretical assessments.

• *Actual Annual Output*. The amount of energy predicted by the above calculation assumes that the wave energy scheme functions continuously (i.e. without failure). In practice there will be periods of reduced output due to breakdown and maintenance.

O&M Costs: Good maintenance procedures are essential if any energy technology is to perform successfully. However, in addition to this planned maintenance there will be other, unscheduled outages due to component failure. Therefore, any estimation of annual O&M costs has to encompass both these aspects. This assessment evaluates three main components of O&M costs (cost of spares, repair cost, operational costs).

Capital Cost: The capital cost can broken down into: the cost of the generation device itself (materials, components and labour in manufacturing and fabrication processes); the costs associated with installing it (deployment); the costs of keeping it on station (foundations or moorings); and the costs of connecting it to the grid (electrical cables and switchgear). Some of these costs are more dominant than others, and the relative distribution of cost centres varies between different device concepts and site locations.

Annual Costs: There are three main factors, which make up the annual running cost of any power station: fuel, repayment of capital costs and payment of recurrent costs such as insurance and O&M. The annual sum involved in repayment of the capital cost of a wave power scheme can be assessed in a number of ways. The approach adopted in this review was that used in previous appraisals, namely amortisation of the capital costs over the complete lifetime of the scheme using various discount rates.

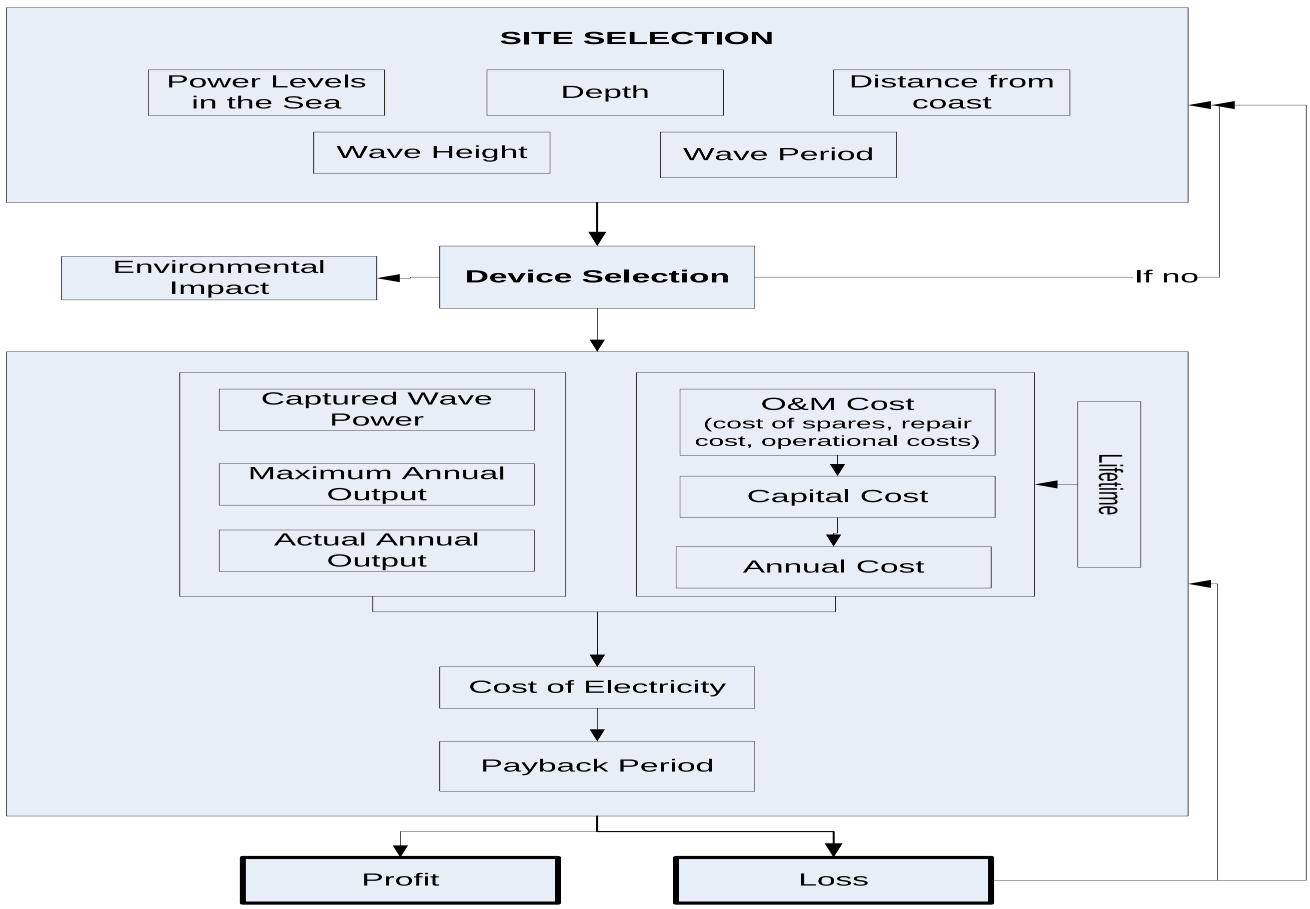

Fig. 5: Methodological Framework

4. Data Collection

The aim of this paper is to examine the technical and economic characteristics of a wide range of wave energy devices. It's examined the technology of wave energy devices and their characteristics, and their commercial use. Moreover, the devices are evaluated based on the costs of construction, the operational and maintenance costs, the payback period, the lifecycle. In order to have all these details of the wave energy devices, the manufacturer companies or research units were called to complete a form referred to the above characteristics. Ten out of thirty five companies that we conducted returned the form completed. For the rest devices their web sites were used in order to extract information. For more details about the wave energy devices, please, see Kamargianni, 2009.

5. Analysis

Case Study: Agios Efstratios, the first Greek green island

5.1. Agios Efstratios

Agios Efstratios is a small island with 250 residents, located between Lesvos and Lemnos, to which it belongs administratively, while it is the most isolated island in the Aegean sea. The geographical coordinates are 39° 27'N 24° 58'E. The island is shaped like a triangle with unequal the hypotenuse to the West and an area of 49,6 km^2. The climate is arid, with little rainfall during the winter months and long, hot summers. The landscape is mostly rocky, with scarce and low vegetation.

Athens News Agency (2009) reported that, on 4 June 2009, at a two-day international conference in Athens on "Climate Change and Challenges for the Future Generations" under the patronage of UNESCO, Agios Efstratios would soon become the country's first "green" island, entirely powered by renewable energy sources (RES), while its residents relying on solar and wind generated energy and moving around the island on bicycles and in electric cars. A €10 million project would be implemented by 2010. Agios Efstratios, could serve as a global model for 100% reliance on RES. Also, the island is included in the European Union's Natura 2000 network of nature protected areas.

Main characteristics of Agios Efstratios' electricity demand for 2008 were (Figure 2; Ministry of Development, 2009):

- Maximum Electricity Demand: 200 kW (mean), 270 kW (maximum);
- Minimum Electricity Demand: 70 kW (mean)
- Annual Electricity Demand: 1020 MWh;
- Mean Electricity Demand per day: Figure 2 (winter and summer);
- Expected RES Output : +150% base year 2008 (power and energy).

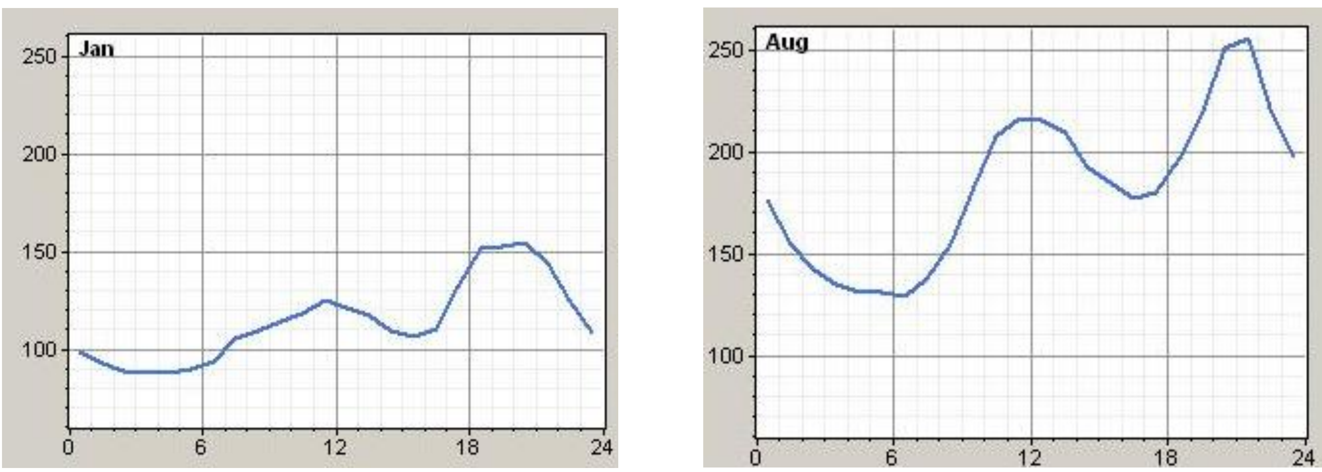

Fig. 2: Mean Electricity Demand in kW per day – January and August 2008

5.2. Agios Efstratios' Characteristics

Agios Efstratios has an average wave height of 0.7m. Specifically, accordingly to each season, the wave height is: 0.7m in autumn, 1.1m in winter, 0.7m in spring and 0.4m in summer (Fig. 3). Sea depth is shown in Fig. 4.

The wave height is small enough to implement most of the wave systems that analysed below. But there are some wave energy devices, which could be applied and be profitable.

Fig. 3: Mean Wave Height (left to right: Autumn, Winter, Spring, Summer)

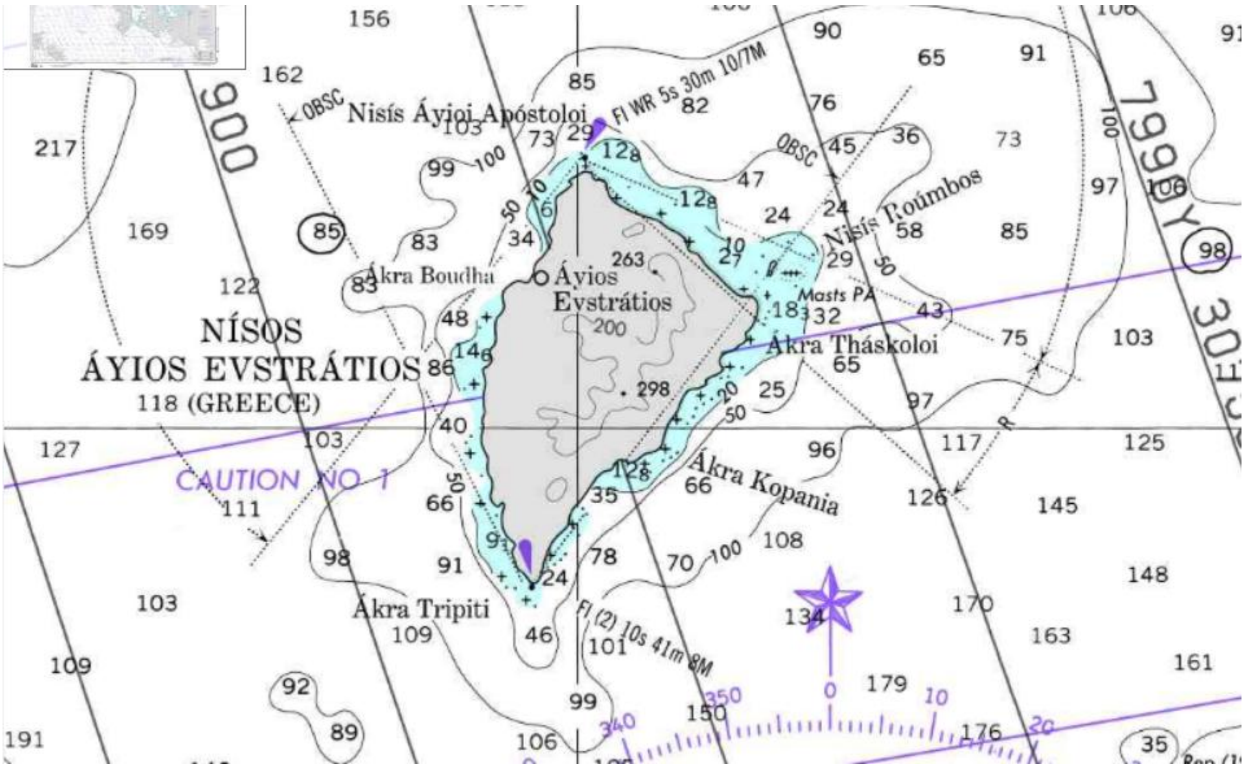

Fig. 4: Sea Depth of Ag. Efstratios (Source: http://www.nauticalchartsonline.com/)

5.3. Analysis

As it is already said, in order to evaluate a wave energy device, we take into consideration both the characteristics of the selected site and of the selected device as well.

Table 1 shows the results from each system's evaluation, when the selected site is Agios Efstratios. Having in mind that the project's budget is €10 million and focuses more on solar and wind energy we assume that the maximum amount that could be allocated in wave energy is up to €1 million and in doing so we divided the capital cost into: High (more than €3 millions), Medium (€1-3 millions), Low (less than €1 million). The Cost of Electricity takes the prices: High (more than 0.20 €/kWh), Medium (0.10-0.19 €/kWh) and Low (less than 0.09 €/kWh), as the mean cost of electricity in EU is 0.03-0.08 €/kWh.

The devices discussed in this section are evaluated on behalf of the criteria that are referred in Section 3 (Methodological Framework). After the assessment the devices that satisfy both the First and the Second step of the Methodology and both Low capital cost and Low cost of electricity are approved for installation in Agios Efstratios, while the others are declined. In this point it is worthwhile to refer that in some cases not all details were available in order to evaluate the devices and knowing only one characteristic that was not satisfying we declined the device.

Table 1: Valuation of Wave Energy Devices

Wave Energy Device	**Site Selection: Agios Efstratios** Mean Wave Height: 0,7m (min 0,4m during the summer) Mean Wave Period: 4,4sec. Sea Depth: maximum 170m Wave Power: 20kW/m	**Economic Valuation**	
		(√) Approved	**(×) Declined**
SHORE BASED			
1. LIMPET	Requires areas exposed to strong wave energy (more than 50 kW/m) Capital cost: €1.54 million (Medium) The device does not satisfy the First step.		×
2. WECA	Requires areas exposed to strong wave energy (more than 40 kW/m) Immature technology. Not applicable.		×
3. Mighty Whale	Sea depth: 40m. Capital cost: €13.5 million (High)		×
4. SARA MWEC	Ideal for areas with high wave energy capacity (more than 30 kW/m) Capital cost: €400,000 (Low)		×
5. MAWEC	Capital cost: €480,000 (Low) Electricity output: 10 kW/m (Wave Height: 0,6cm, Wave Period: 0,9sec – collects 75% of wave energy -> electricity output 16%) (Low)		×
6. Oceanlinx	Ideal for the oceans, not for the Aegean sea. Location characteristics: Wave Height: 2m, Wave Period: 0,7sec.		×
7. Sperboy™	Sea depth: 50m Electricity output: 100 kW per hour Capital cost: €600,000 (Low) Cost of electricity: 0.06 €/MWh (Low) Payback period: 6 years Proposed location: SE of the Island	√	
8. WaveMaster	Requires areas with high wave height (more than 5m) Capital cost: €190,000 (Low)		×
2. ABOVE WATERLINE WITH OVERTOPPING			
1.SSG	Requires areas with high wave height (4m) Capital cost: €420,000 Cost of electricity: 0.25 €/kWh (High) Payback period: 15 years		×
2.Wave Dragon	Sea depth: 6m (output = 0,4kW/m) Not appropriate for the site, as the mean wave height is low.		×
3. ABOVE WATER			
1. LabBuoy	Ideal for the selected location. Electricity output: 200 kW per hour Capital cost: €550,000 (Low) Cost of electricity: 0.07-0.09 €/kW (Low) Payback period: 8 years Proposed location: SE of the Island	√	
2. SDE	Electricity output: 150 kW per hour Capital cost: €600,000 (Low) Cost of electricity: 0.02-0.06 €/kWh (Low) Payback period: 3 years The most ideal for the selected site.	√	
3. WET EnGen™	Requires areas exposed to strong wave energy (more than 20 kW/m) Not Applicable to the selected site. Capital cost: €530,000 (Low)		×
4. Wave Star©	Ideal for areas with more than 2m wave height. Cost of Electricity: 0.33-0.8 €/kWh (Low) Lifetime: 50years / Maintenance every 10 years		×

5. AquaBuoy	Ideal for open seas with high wave power, not for the Aegean sea.		×
6. Manchester Bobber	Requires areas with wave height up to 8m. Sea Depth: 30-60m		×
7. CETO™	Ideal for the oceans, where wave height is more than 4m. Sea Depth: 15m Capital cost: €5 millions (High) Cost of electricity: 0.084 €/kWh (Low) It can be used to produce fresh water through reverse osmosis.		×
8. SyncWave™	Requires areas with high wave energy capacity (oceans). Cost of Electricity: 0.03-0.05 €/kWh		×
9. Power Buoy®	Ideal for open seas.		×
10. OWEC®	Ideal for open seas and oceans.		×
11. FWEPS	Its construction depends on the characteristics of the selected site. Capital cost: €990,000 (Low) => 10 mW output power will be assembled out of a great number of 10 kW devices. Electricity cost: 0.08 €/kWh (Low) Payback period: 5 years	√	
12. Brandl Generator	Designed for areas with high wave energy capacity (esp. fo North and Baltic seas) Electricity Cost: 0.033 €/kWh Profit: 8% of capital cost per year Payback Period: 10 years		×
13. WaveBlanket	Requires areas with wave power between 30-70kW		×
4. ABOVE WATERLINE WITH HYDRAULIC PTO			
1. Pelamis P-750 WEC	Designed for areas with high wave power (55kW/m) Capital cost (for one unit): €4.43 million (High) Electricity cost: 0.11 €/kWh (Medium)		×
2. DEXA	Distance from coast: 16km Capital cost: €2.68 million (Medium) Cost of Electricity: 0.068 €/kWh (Low)		×
3. Crestwing	Immature technology. It is estimated to deliver the final device in 2014. Capital cost: €12 million Est. Electricity cost: 0.13 €/kWh		×
4. McCabe Wave Pump	Wave Height: 7m (not appropriate for Agios Efstratios) Capital cost: €780,000 Electricity cost: 0.08 €/kWh (Low)		×
5. Floating Wave Generator	Its construction depends on the characteristics of the selected site. Electricity cost: 15kW per hour Capital Cost: €7,000 (Low) Cost of Electricity: 0.034 €/kWh Payback Period: 40 days	√	
5. BOTTOM MOUNTED			
1. Oyster™	Available for oceans. Sea Depth: 10m / 500m from the shore Capital cost: €1.200.000 (Medium)		×
2. WaveRoller	Wave Period: High Capital cost: €3 million (Medium) Cost of Electricity: 0.044 €/kWh (Low) It was tested in Crete but the efficiency was relatively low		×
3. bioWAVE™	Not enough information in order to evaluate.		×

6. Conclusions

Last decades, the technology of wave energy devices has improved significantly, but still is lacking behind compared to other RES devices.

The construction of a wave energy device is usually too expensive and the cost of capital in order to apply them in a site is quite high. Moreover, the payback period is quite long, as in most cases is more than 12 years. Also, the O&M costs are too high.

On the other hand, the environmental impact is low as in the most of them are used only environmental friendly materials. Also, they provide minimal obstruction for marine life.

In conclusion:

- In order to maximize the profit of such an investment, it should be taken into consideration not only the selected site, but the proper device, with the maximum output as well.
- The cost of electricity is usually bigger than this of other RES. The mean cost of electricity in EU is €0,030-0,080/kWh, whereas the mean cost of electricity for wave energy is €0,06-0,10/kWh
- The wave power in Greek seas is low and the majority of the wave energy devices that analyzed above, are inappropriate, with low output. But further research is needed in order to design wave energy devices for areas with lower wave power density.
- A further investigation and evaluation of the wave energy devices could take place for other Greek areas with higher wave power than Agios Efstratios, such as the Ionian sea and Crete.
- Wind and solar energy devices are more productive and more profitable than wave energy in Greece.
- Although, wave energy can provide big amounts of electricity, the technology is still immature. Further R&D is needed in order wave energy to become commercially competitive.

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Обзор Устройств Энергии Волн. Тематическое Исследование: Энергия Волн в Айос Ефстратиос, Первый Греческий Зелёный Остров

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Резюме: Энергия волн- возобновляемый источник энергии, который еще не эксплуатировался в значительной степени. До сих пор, основное внимание преобразования энергии волн было уделено энергетическим ресурсам больших волн великих океанов на северных широтах (Diamantaras et al., 1995; Bernhoff et al., 2003). Однако большие части мировых потенциальных энергетических ресурсов волн находятся в защищенных водах и более спокойных морей, которые часто проявляют более мягкий, но все же устойчивый волновой климат (Soerensen et al., 2009). Примерами являются Балтийское море, Средиземное и Северное моря в Европе, и океанские области ближе к экватору (Bernhoff et al., 2003). Контрибуция энергии волн от защищенных вод была мало исследована, но было много попыток для успешного преобразования нерегулярной энергии волн в электричество (Glendenning, 1978; Thorpe, 1992; 1998; Boud, 1999).

В данной работе представлен обзор некоторых основных разроботок в волновой энергии и их потенциальное осуществление на первом греческом зеленом острове Айос-Эфстратиос в Эгейском море. Она концентрируется на устройства, новые данные для которых были произведены с 2009 года. В ней представлены технические характеристики каждого устройства и их экономическая оценка, включая в себя капитальные затраты, расходы по эксплуатации и обслуживанию, срок окупаемости, стоимость электроэнергии и жизненный цикл.

Методология, которая применяется, состоит из двух частей. В первой части, рассматриваются технические характеристики устройства и если оно считается эффективным в определенном месте. Принимаются во внимание высота волны, глубина воды, скорость ветра и годовая производительность. Если устройство окажется эффективным и продуктивным, мы продолжим рассматривать экономические характеристики во второй части методологии. Если устройство соответствует требованиям, то оно подходит для осуществления на острове.

Обозрение методологии указывает, что энергия волн может стать полезным источником энергии. Результаты показывают, что энергия волн уже является экономически конкурентоспособной и имеет хорошие перспективы стать коммерчески конкурентоспособной с дальнейшим исследованием и развитием (И & Р). На Айос-Эфстратиос может быть осуществлено всего лишь ограниченное количество рассматриваемых устройств, вследствие мелкой воды и маломощных волн. Однако, более многообещающие морские устройства находятся еще на стадии обложения.

Ключевые слова: энергия волн, экономическая оценка, зеленый остров

Structure of Electricity Balance of Romania for the year 2020, Established Based on Optimal Primary Energy Resources Using the Multi-criteria Analysis Model

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Abstract: The main objective of this work was the creation of a multi-criteria model analysis for the optimal electricity balance of Romania in terms of primary energy mix used for electricity generation. The paper is part of a comprehensive thesis named "Contributions to the Elaboration of Strategies Regarding the Sustainable Development of the Romanian Energy Sector". This topic was chosen by considering two reasons: on one side, the need of a better elaboration of strategies for the energy sector development by using dynamic methods sensitive to legislative changes, and, on the other side, the need of taking into account both technical and economic elements as well as the environmental factors when elaborating the strategies for the energy sector sustainable development on medium and long term. The software "Eclipse" (based on the Java platform) is used to achieve a multi-criteria analysis of optimal electricity balance for Romania in year 2020. The software has a large database for the environment (fuel life-cycle analysis for each life-cycle stage), technical and economical points of view. It allows numerous changes of parameters and the results can be viewed in real time. The software allows also the user to conduct many simulations and interpretations of data that can be used in establishing the energy sector development strategy.

Keywords: sustainable development, life cycle analysis, multi-criteria model

1. Introduction

In this article the authors explain how to build a multi-criteria model and the results of using it for analysing the optimal electricity balance in Romania up to 2020, from the point of view of primary energy mix used to produce electricity.

To elaborate the model we started from the establishment of the electricity demand of a given year and then we created alternative scenarios to cover it. For each analyzed primary energy source (natural gas, coal, uranium, biomass, wind energy, large or small hydro) the life cycle analysis (LCA) was applied for the environmental component. An inventory of the identified main pollutants for each primary energy source and scenario was developed. Also an impact analysis was done through which the indicators for each impact class were calculated.

In order to perform the technical and economic analysis, we started to determine the installed power required to produce a certain quantity of electricity for each primary energy source considered. Costs of investment and operating, cost of fuel and finally, total expenditure were calculated. The economic recovery cost was used as main criterion so as to select the optimal scenario.

Through this model the user can identify the optimal scenario for covering the electricity demand (balance) under environmental and technical/ economic point of view.

2. How to create a multi-criteria model

The multi-criteria model was first developed using Excel. This allowed designing the multi-criteria model in a simple manner. The steps performed in model design and the obtained results are presented in the following sections.

2.1.Defining objectives and the field of study

2.1.1. Defining objectives

The main objective of the analysis was to develop a multi-criteria model that might lead to optimal load of the electricity balance of Romania (in terms of primary resources used for electricity generation) in 2020, in terms of environmental, technical and economic criteria.

2.1.2. Coverage of electricity demand in 2020

- The way for establishing the electricity demand:

The program allows setting the electricity demand every year. For this particular case, we will determine the particular needs of electricity in 2020. It has been defined taking into account the primary and final energy scenarios realized in other work using the MAED model (model analysis of energy demand). The MAED model, as it was built realized six possible scenarios for primary energy and final energy. Of the scenarios made, for further development we chose the scenario under which the final electricity consumption in 2020 will be 6.3 million toe (73.3 TWh). The total electricity demand was calculated as the sum of the final electricity consumption, ancillary services consumption in networks and was obtained (taking into account specific documents for each parameter) value of 85 TWh in 2020 perspective.

- How to cover of electricity demand (the preparation of scenarios):

To meet demand the electricity (85 TWh) we have established different scenarios that would achieve the electricity balance of different loading. In this article presents eight scenarios that coverage 85 TWh. The program enables by the user creating and other scenarios. In making these scenarios we considered technological restrictions (conditions imposed) the various international engagement assumed by Romania, and some programs being implemented with government support.

Thus, as regards the nuclear chain it was considered that alongside the two groups in operation at Cernavoda will be completed two other groups with similar characteristics. In the period 2010 - 2020 we will install an additional gross power of 1,400 MW in nuclear groups and a total energy production of 11 TWh gross.

Energy delivered into the system (net production) in these two groups will then be about 10.1 TWh. The total net production of nuclear energy of all four groups will be 20.2 TWh.

The Energy Strategy aims to build a fifth nuclear power, but this will be done in an unspecified future. Putting it into operation will take place with certainty beyond 2020. Under these conditions it has not been established to develop a nuclear scenario electricity generation. It was considered that developing nuclear energy is the same in all scenarios.

In achieving scenarios we considered retirement program groups of the National Power Generation System established.

Nuclear groups and small hydro power will not be retirement.

Another restriction relates to compliance the engagement governmental to achieving an production of 38% of gross electricity consumption from renewable sources.

According to the above gross electricity consumption in 2020 was estimated at 81 TWh.

We have thus achieved an output of 30.8 TWh of electricity from renewable energy sources. Thermal energy is obtained by difference.

Under these conditions the imposed structure of electricity generation is as follows:

Table 1 – The structure imposed on electricity production

Total production, including	**85 TWh**
- **nuclear**	20.2 TWh
- **renewables**	30.8 TWh
- **thermo**	34 TWh

Renewable energy sources considered are: large hydro, small hydro, energy from biomass and wind energy. The program enables the user to use other renewable sources. Thermo energy is studied for coal and natural gas. The program enables also the use fuel oil.

By combining the ways of producing electricity from renewable sources and thermo resulted eight scenarios and the quantities of electricity made by each chains within each scenario are presented in Table 2.

Table 2 – The amount of electricity carried by chains in the scenarios (TWh)

Energy chains	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Uranium	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
Large hidro	25	25	25	25	25	25	15.4	15.4
Small hidro	0	0	1.2	1.2	0.5	0.5	0	0
Biomass	5.8	5.8	4.6	4.6	0	0	15.4	15.4
Energy wind	0	0	0	0	5.3	5.3	0	0
Coal	17	25.5	17	25.5	17	25.5	17	25.5
Natural Gas	17	8.5	17	8.5	17	8.5	17	8.5

- The technological solutions and life cycle stages:

From the variety of technological solutions from the literature we retained the following for the production of electricity taking into account the different primary energy sources:

- For natural gas (an inferior caloric power of 50,000 [kJ/kg]) as a technical solution gas-steam combined cycle without postcombustion with an efficiency of 55% was chosen.
- For coal (coal with an inferior calorific power of 27,000 [kJ/kg]) a technical solution was chosen circulating fluidized bed combustion with supercritical parameters, with an efficiency of 45%.
- For uranium nuclear power generation technology is considered that is based on the concept of CANDU reactor, which operating with indigenous natural uranium. The efficiency for production of electricity through this chain is 35.5%.
- For biomass (an inferior calorific power 12,300 [kJ/kg]) we chose as a technical solution for the stationary fluidized bed combustion, with an efficiency of 30%.

- For the production of hydro energy in large plants using the Pelton turbine and hydropower production in small plants using the Kaplan turbine.
- Propeller-type turbines are used horizontal shaft mounted in "wind farms" to produce electricity from wind.

For each life cycle stage related to energy chain we established the efficiency and were calculated masses of fuel needed at every stage. For the stages of construction and demolition for the power plant we did not considered the efficiency. These values are approximate. The program enables the user to change the values for the stages effiency and fuels with different compositions, which lead to other inferior calorific powers.

2.1.3. Defining the field of study

First we established the field of study of each energy chain that will be part of the energy scenarios. Then, field study was realized for each scenario separately. Given that the functional unit is defined on the basis of three units: the function, time and product is considered as the functional unit: Romania's electricity needs in 2020 (85 TWh).

All scenarios are compared to this year's level. In conclusion, it will select the energy scenario which will cover energy needs with minimal environmental impact and minimum cost of production.

For each scenario, electricity demand coverage in 2020 (85 TWh), we have made detailed study fields. For example the diagram shows the results for scenario 5 (results from the analysis, Fig. 1).

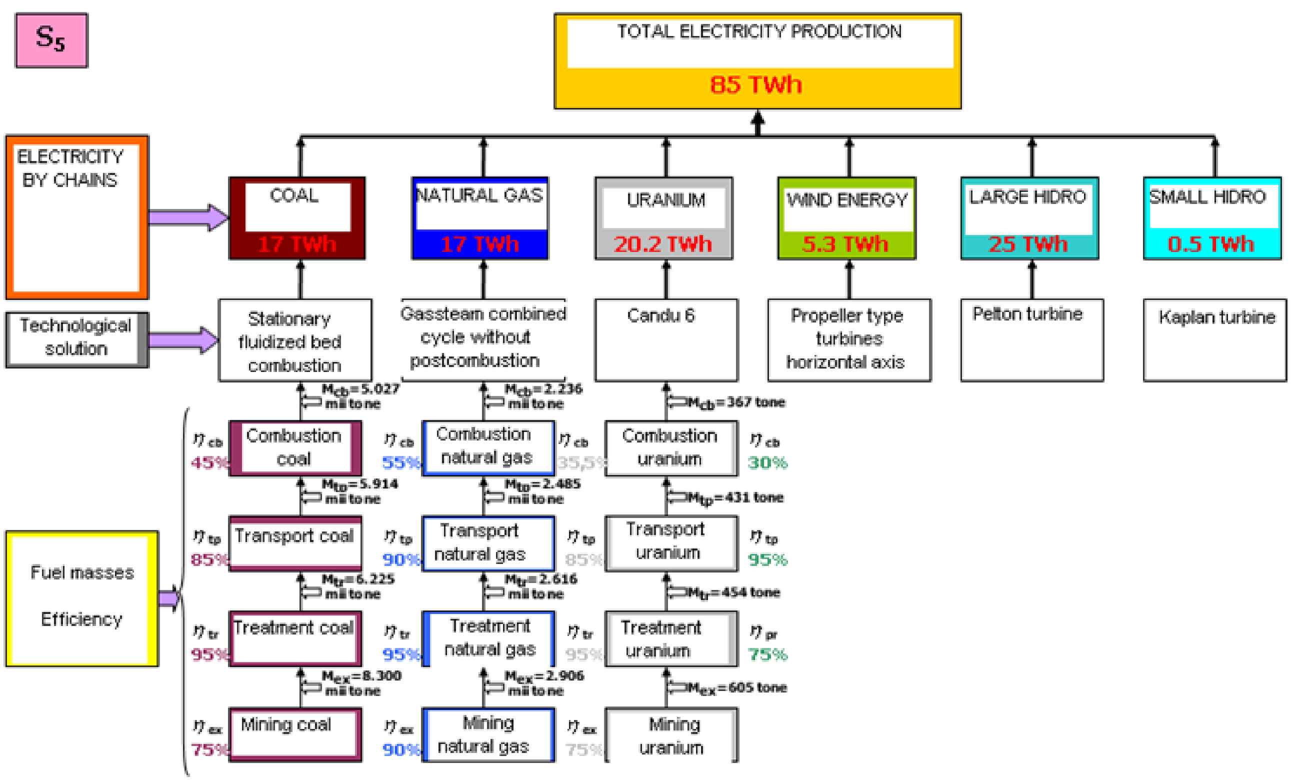


Fig. 1 – The field of study for scenario 5

2.2. Inventory Analysis

First for each life cycle stage of each energy chains the emissions were calculated, and ultimately resulted in the emissions for each scenario. After establishing the Functional Unit (FU) at one TWh and the efficiency for the stages, starting from the inferior calorific power of each fuel, we calculated the mass of fuel required at each stage relative to FU. Reference Unit (RU) in this study represents the amount of fuel required at each stage to produce one TWh of electricity.

Inventory of air emissions was realised on ecosystems air, water and soil on each stage for each chain separately. Emissions for each chain were taken from literature reference. The unit is g/kWh.

The stages of construction and demolition power plant chains of natural gas, coal, uranium and biomass were considered equal in terms of emissions.

Each scenario is designed to produce 85 TWh of electricity.

The inventory analysis was performed for each scenario, the emissions are reported according to the contribution of each chain in producing electricity. The total emissions of each scenario are presented in Table 3.

Table 3 – The pollutants for each scenario (thousand t/scenario)

Emissions	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
CO_2	28,363	32,939	28,828	32,831	28,358	32,361	29,692	33,695
CO	16.473	14.610	16.263	14.401	15.408	13.546	18.053	16.191
NO	0.721	0.363	0.721	0.363	0.721	0.363	0.721	0.363
NH_3	2.224	2.883	2.182	2.841	2.020	2.679	2.562	3.221
CH_4	90.687	64.898	90.661	64.872	90.061	64.272	89.977	64.188
NO_2	82.082	102.867	81.096	101.881	77.149	97.934	89.682	110.467
Dust	162.971	239.166	162.931	239.127	162.649	238.844	163.044	239.240
Formaldehyde (CH_2O)	0.145	0.073	0.145	0.073	0.145	0.073	0.145	0.073
COD	1.209	0.641	1.208	0.640	1.203	0.636	1.217	0.650
SO_2	123.727	177.447	123.346	177.065	121.775	175.495	126.587	180.306
N_2O	0.780	0.634	0.756	0.610	0.664	0.518	0.968	0.822
Lead	0.058	0.031	0.058	0.031	0.058	0.031	0.059	0.031
Arsenic	0.003	0.004	0.003	0.005	0.003	0.005	0.003	0.005
Barium	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
Chromium	0.005	0.007	0.005	0.007	0.005	0.007	0.005	0.007
Cobalt	0	0.001	0	0.001	0	0.001	0	0.001
Copper	0.002	0.004	0.002	0.004	0.002	0.004	0.002	0.004
Molybdenum	0.001	0	0	0	0	0	0	0
Nickel	0.004	0.006	0.004	0.006	0.004	0.006	0.004	0.006
Selenium	0.007	0.011	0.008	0.011	0.007	0.011	0.007	0.011
Vanadium	0.007	0.010	0.007	0.010	0.005	0.010	0.007	0.010
NH_4	0.399	0.597	0.399	0.597	0.399	0.597	0.399	0.597
Hydrogen Chloride (HCl)	1.229	1.229	0.984	0.984	0.039	0.039	3.183	3.183
Hydrogen Fluoride (HF)	0.004	0.004	0.004	0.004	0.004	0.004	2.413	2.413
Nitric acid	0.002	0.002	0.002	0.002	0	0	0.006	0.006
Isopren	123.172	123.172	97.732	97.732	0	0	326.692	326.692

In quantitative terms, the air emissions are much higher than those in water and soil ecosystems. The main pollutants in the scenarios are: CO_2, dust, SO_2, NO_2, CH_4, CO, NH_3 and N_2O. Although the values for other pollutants are insignificant, however, impact assessment should be realized to determine their influence on the environment.

Regarding the maximum values of the main pollutants in each scenario the following aspects are distinguished:

- In terms of carbon dioxide, dust particles, sulphur dioxide, nitrogen dioxide, scenario 8 (biomass-coal scenario) has the largest amount of emissions.
- For carbon monoxide, methane the maximum values are recorded in scenario 1 (large hydro-gas scenario, 90.7 thousand t/scenario) and scenario 7 (biomass-gas scenario, 16.2 thousand t/scenario).

2.3. Impact Analysis

Table 4 shows a comparison between the calculated impact indicators for each scenario.

Table 4 – The impact indicators for each scenario

Impact indicators	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
ADP[t equivalent Sb]	272,738	300,524	250,785	278,572	167,510	195,297	448,360	476,147
GWP [thou. t equivalent CO_2]	31,083	35,516	30,968	35,401	30,457	34,890	31,883	36,316
AP [t equivalent SO_2]	193,074	271,128	192,055	270,110	187,938	265,993	200,846	278,900
POCP [t equivalent ethylene]	143,316	146,533	115,534	118,751	8,792	12,009	365,544	368,761
EP [t equivalent PO_4^{3-}]	11,760	15,044	11,617	14,901	11,047	14,331	12,867	16,151
HTP [thou. t equivalent 1,4-dichlorobenzene]	817.495	997.400	816.181	996.087	810.817	990.722	827.372	1.007
FAETP [t equivalent 1,4-dichlorobenzene]	13,171	18,141	13,171	18,141	13,175	18,145	13,165	18,135
MAETP [t equivalent 1,4-dichlorobenzene]	837,555	590,985	875,604	590,989	837,580	591,009	837,480	590,910
TETP [t equivalent 1,4-dichlorobenzene]	5,744	6,601	5,744	6,601	5,744	6,602	5,744	6,601

According to available data we can make some observations:

- In terms of the impact indicator "Abiotic Depletion Potential" (ADP), scenario 8 presents the highest value (equivalent to 476,147 t Sb) versus the lowest value recorded for the scenario 5 (equivalent to 167,510 t Sb).
- In terms of the impact indicator "Global Warming Potential" (GWP), the highest value scenario is also found in scenario 8 (36,316,272 tonnes CO_2 equivalent), and the lowest in scenario 5 (30,456,539 tonnes CO_2 equivalent).
- Regarding the indicator "Acidification Potential" (AP), maximum and minimum values obtained in this study are equivalent to 278,900 tons SO_2 (in scenario 8) and 187,938 tons SO_2. (in scenario five).
- Regarding the indicator "Photochemical Ozone Creation Potential" (POCP), the values obtained in this study vary greatly. The minimum recorded in scenario 5 (8,892 tons are equivalent ethylene), and the maximum scenario 8 (equivalent to 368,761 tons ethylene).
- In terms of the impact indicator "Eutrophication" (EP) the scenario 8 presents the highest value (equivalent to 16,151 tons phosphate), while the minimum value is found in the scenario 5 (equivalent to 11,047 tons of phosphate).
- Analyzing the impact indicator "Human Toxicity Potential" (HTP), we conclude that the EP as the indicator, the maximum value presents in the scenario 8 (approximately equivalent to 1,007 kt 1,4 DCB) and the minimum value in the scenario 5 (equivalent to 811 kt 1,4 DCB).
- The "Freshwater Aquatic Ecotoxicity Potential" (FAETP) shows the maximum (equivalent to 18,135 t 1,4 DCB) in scenario 8, and the

minimum value in scenario 7 (equivalent to 13,165 t 1,4 DCB).

- The "Marine Aquatic Ecotoxicity Potential" (MAETP) has maximum value equivalent to 875,604 t DCB 1,4 in scenario 3 and the minimum value is recorded in the scenario 8 (equivalent to 590 910 t 1,4 DCB).
- For indicator “Terrestrial Ecotoxicity Potential” (TETP) scenarios 1, 3, 5 and 7 presents the minimum value of about 6 kt 1,4 DCB equivalent and scenarios two, four, six and eight presents the maximum to about 7 kt DCB 1,4 equivalent.

2.4. Technical and economic analysis

Starting from the amount of electricity produced we determined for each chain the power installed in each scenario for 2020. Taking into account the duration of the investment, the duration of exploitation and the duration of the study, were determined the investment costs, operating costs, fuel costs, resulting the total expenses. We used three cost scenarios eco-taxes. The table below shows the total expenditure eco-tax. It is worth mentioning that the scenario with the highest required total expenditure is scenario 7. The software allows the user to modify the values considered for eco-taxes.

Table 5: The total expenditure with eco-taxes for the energy chains and for the scenarios [million Euro].

Total expenditure without/with ecotax	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Total expenditure without ecotax	4,397	4,305	4,005	3,913	2,500	2,408	7,531	7,439
Total expenditure with minimum ecotax	4,658	4,629	4,264	4,235	2,753	2,723	7,804	7,774
Total expenditure with medium ecotax	5,389	5,525	4,996	5,132	3,450	3,586	8,559	8,695
Total expenditure with maximum ecotax	7,745	8,616	7,335	8,206	5,720	6,592	11,044	11,915

The economic cost recovery (Table 6) was chosen as the criterion of selection the technical and economic scenarios. This indicator is appropriate for these types of scenarios created, each producing the same amount of electricity.

This indicator represents the minimum price at which electricity can be sold so as to cover all economic costs over the lifetime.

Table 6: The economic cost recovery for the scenarios [Euro/MWh].

Economic cost recovery (ECR)	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
ECR without ecotax	65.7	65.4	61.3	60.9	43.8	43.4	101.4	101.1
ECR with minimum ecotax	69.2	64.3	64.8	46.7	46.7	47.2	104.7	105.1
ECR with medium ecotax	79.9	73.0	75.3	55.2	55.2	57.6	113.6	116.0
ECR with maximum ecotax	116.4	100.7	111.7	82.1	82.1	93.1	143.0	154.0

Note that the minimum value for the cost of recovery scenarios are recorded in scenario 5 (43.8 Euro/MWh) and scenario 6 (43.4 Euro/MWh). Both have very similar values.

The software allows the changing of values for the duration of study and for the discount rate.

2.5. Multi-criteria Analysis

The previous performed steps allowed us to obtain information about energy chains used to create scenarios. Further, we will achieve global comparison between scenarios.

Evaluations were normalized after each criterion and were established in the class memberships good/low.

We obtained the normalized matrix (Table 7), based on which energy scenarios were evaluated against the set of criteria to finally obtain a global evaluation of energy scenarios.

Table 7: The normalized matrix.

CRITERIA	**S_1**	**S_2**	**S_3**	**S_4**	**S_5**	**S_6**	**S_7**	**S_8**
Ecologial								
ADP [t equivalt Sb]	0.573	0.631	0.527	0.585	0.352	0.410	0.942	1.000
GWP [thou. t equivalent CO_2]	0.856	0.978	0.853	0.975	0.839	0.961	0.878	1.000
AP [t equivalent SO_2]	0.692	0.972	0.689	0.968	0.674	0.954	0.720	1.000
POCP [t equivalent ethylene]	0.389	0.397	0.313	0.322	0.024	0.033	0.991	1.000
EP [t equivalent PO_4^{3-}]	0.728	0.931	0.719	0.923	0.684	0.887	0.797	1.000
HTP [thou. t equivalent 1,4-dichlorobenzene]	0.812	0.990	0.810	0.898	0.805	0.984	0.821	1.000
FAETP [thou. t equivalent 1,4-dichlorobenzene]	0.726	1.000	0.726	1.000	0.726	1.000	0.726	0.999
MAETP [thou. t equivalent 1,4-dichlorobenzene]	0.957	0.675	1.000	0.675	0.957	0.675	0.956	0.675
TETP [thou. t equivalent 1,4-dichlorobenzene]	0.870	1.000	0.870	1.000	0.870	1.000	0.870	1.000
Technical and Economic								
Investment expenses (thou. Euro)	0.928	0.979	0.937	0.988	0.949	1.000	0.854	0.905
Operating expenses (thou. Euro)	0.942	0.972	0.938	0.969	0.925	0.956	0.970	1.000
Fuel expenditure (thou. Euro)	0.563	0.548	0.508	0.494	0.299	0.284	1.000	0.985
Exonomic recovery cost without cost to emissions of CO_2, SO_2 nd NOx (Euro/MWh) (at "a"=discount rate=8%)	0.856	0.886	0.842	0.871	0.771	0.801	0.971	1.000

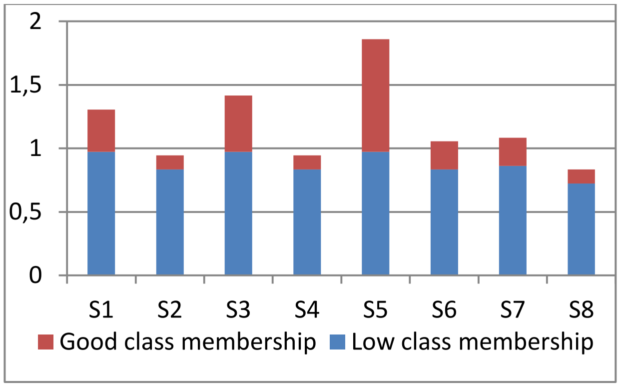


Fig. 2: The evaluation of energy scenarios using environmental criteria.

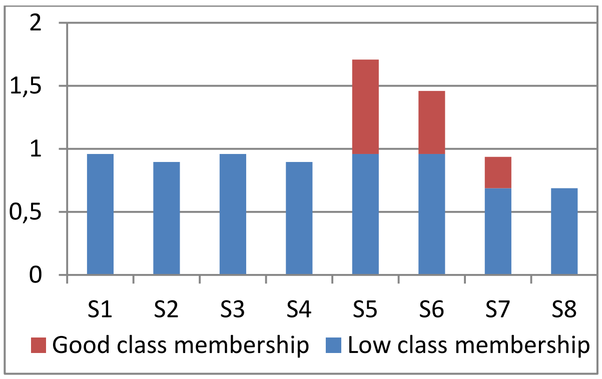


Fig. 3: The evaluation of energy scenarios using economic and technical criteria.

Normalization was performed for each value of this criterion in relation to the maximum value of that criterion.

Referring to the environmental criteria, scenario 5 received the highest value and is considered the best scenario, while scenario 8 is the worst scenario (Fig. 2).

Regarding the technical and economic criteria, scenario 5 presents the highest value and is, therefore, the best scenario. The program also selects other two scenarios as the best scenario (scenario 6, with a value close to that of Scenario 5 and Scenario 7 with a lower value) (Fig. 3).

The evaluation results were represented by families of criteria set by a radar chart (Fig. 4).

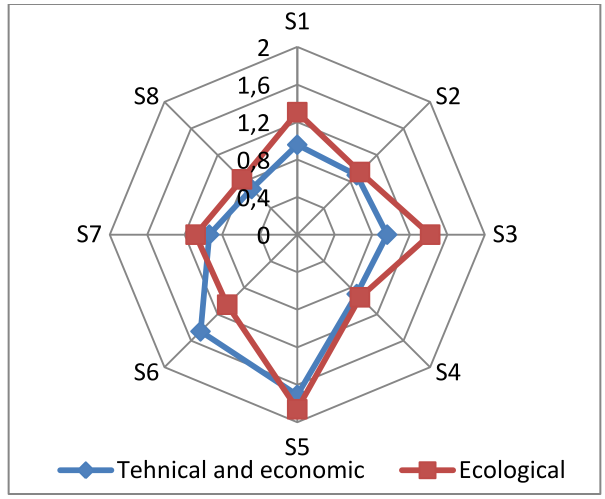


Fig. 4: The global assessment of energy scenarios.

Observe the diagram above that scenario 5 has the highest values recorded in terms of family environmental criteria. In terms of family economic and technical criteria, scenario 5 is the optimal scenario. We require that the solution always chosen to have maximum value under environmental criteria, since an environmental criterion is the decisive criterion in selecting the optimal scenario.

2.6. Sensitivity analysis and robustness analysis

The sensitivity analysis was performed taking into account both the change in the objective indicators (share of families of criteria etc.) and subjective indicators of change (fuel prices, introduction eco-taxes, the discount rate).

The robustness analysis revealed that the chosen solution (scenario 5) remains the best because the optimal loading scenarios depending types of primary sources of energy is achieved at about the same proportion.

3. The structure and the results obtained with multi-criteria model using "Eclipse"

In the previous chapter has presented the multi-criteria model as was done in Excel. Transposition was done in the "Eclipse" program (using Java) in order to quickly select an optimal energy scenario in detail using other values, where modification is done in a long time and with lower performance. Eclipse software offers attractive graphical interfaces and a database creating a multi-criteria model that can be enriched by providing greater opportunities for simulation and interpretation of different data loads.

The developed multi-criteria model consists of five modules, named after the steps necessary to use the software (and have been detailed in part 2 of article in the creation phase of the model), as follows:

Module 2 "Scenarios" makes covering different amounts for each scenario with electricity of each scenario with power produced from primary energy sources to 2020 (year of study in the article), but also for any desired year. The program developed allows the user to use for simulation other scenarios, which it creates.

Viewing this module is done in Fig. 6.

Module 3 "Life cycle analysis" is very detailed and contains all the analysis done by applying the methodology LCA.

In the next window we present the inventory analysis and the impact assessment on all scenarios (Fig. 7).

The software allows the user to choose different fuel composition and other specific efficiency for each stage of the respective chains, but also using other reference values for emissions. Graphic comparisons can be made in terms of chains (total emissions of CO_2, CO_2 emissions without, Fig. 8), comparisons in terms of an impact indicator, but comparisons between chains (from the point of view of all indicators, except the "Global Warming Potential, in Fig. 9).

1. Establishment of electricity demand;
2. Scenarios;
3. Life Cycle Analysis;
4. Powers, technical and economic calculations;
5. Evaluation scenarios.

These modules are added to a home page, from which the user has direct access to the modules listed above. Module 1 "Establishment of electricity demand" is shown in Fig. 5.

Module 4 "Powers, technical and economic calculations" is detailed (Fig. 10), and was described in part 2 of the article.

Module 5 "Evaluation scenarios" made global comparison (ecological, technical and economic) for the scenarios achieved. You can compare any scenarios between them.

This module is based on the evaluation matrix that includes ecological and techno-economic indicators for each scenario. Matrix is then made to normalize the values of the evaluation matrix (Fig. 11). We calculated the class membership of good/low on environmental criteria categories, namely technical and economic (Fig.12, fig.13).

In the final I realized the global evaluation of scenarios both families of criteria, ecological and techno-economic. Evaluation is possible in the form of graphic (Fig. 14).

We can make comparisons between scenarios (graph) in terms of recorded emissions and in terms of impact of each indicator assigned to a scenario. (Fig. 15).

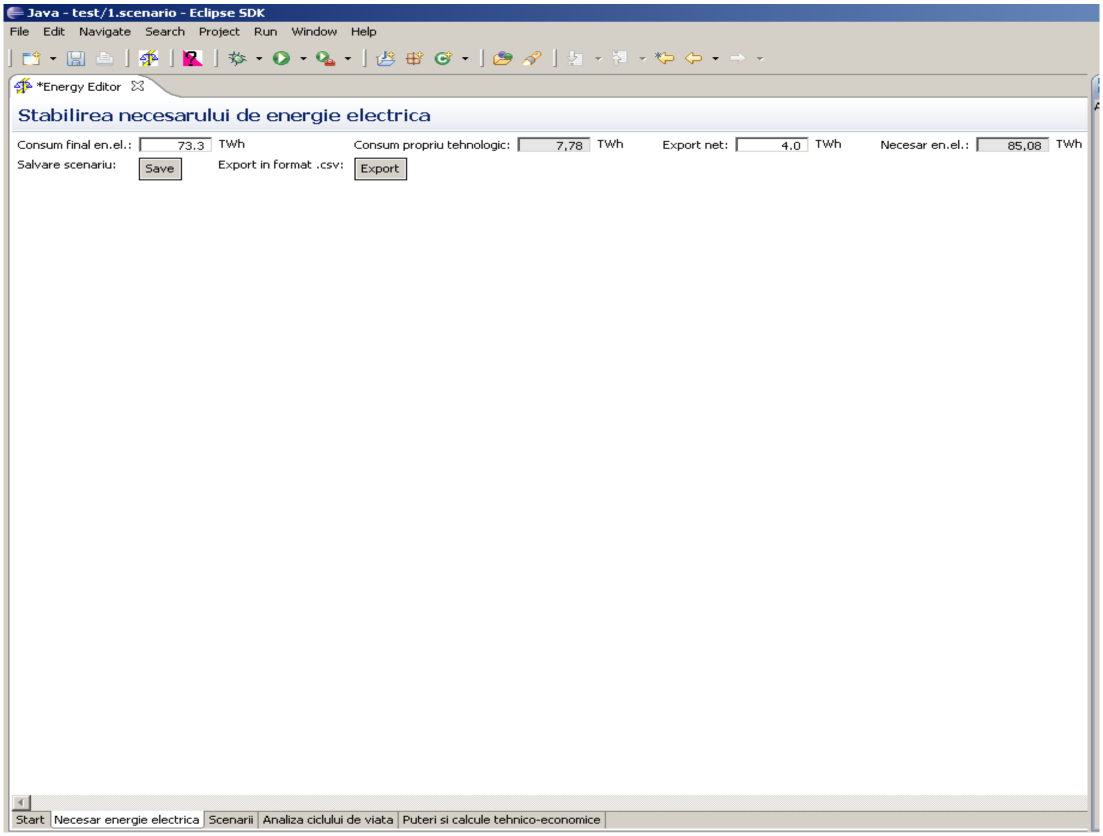


Fig. 5: Module 1 "Establishment of electricity demand"

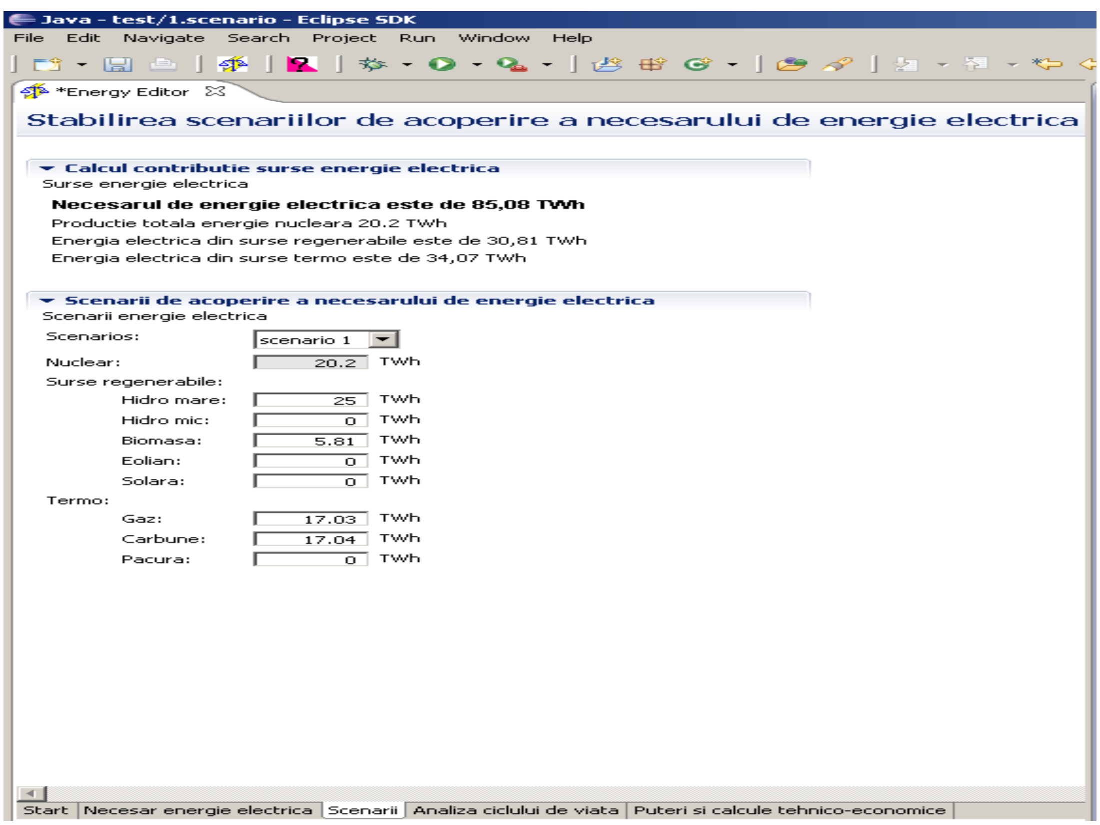


Fig. 6: Module 2 "Scenarios".

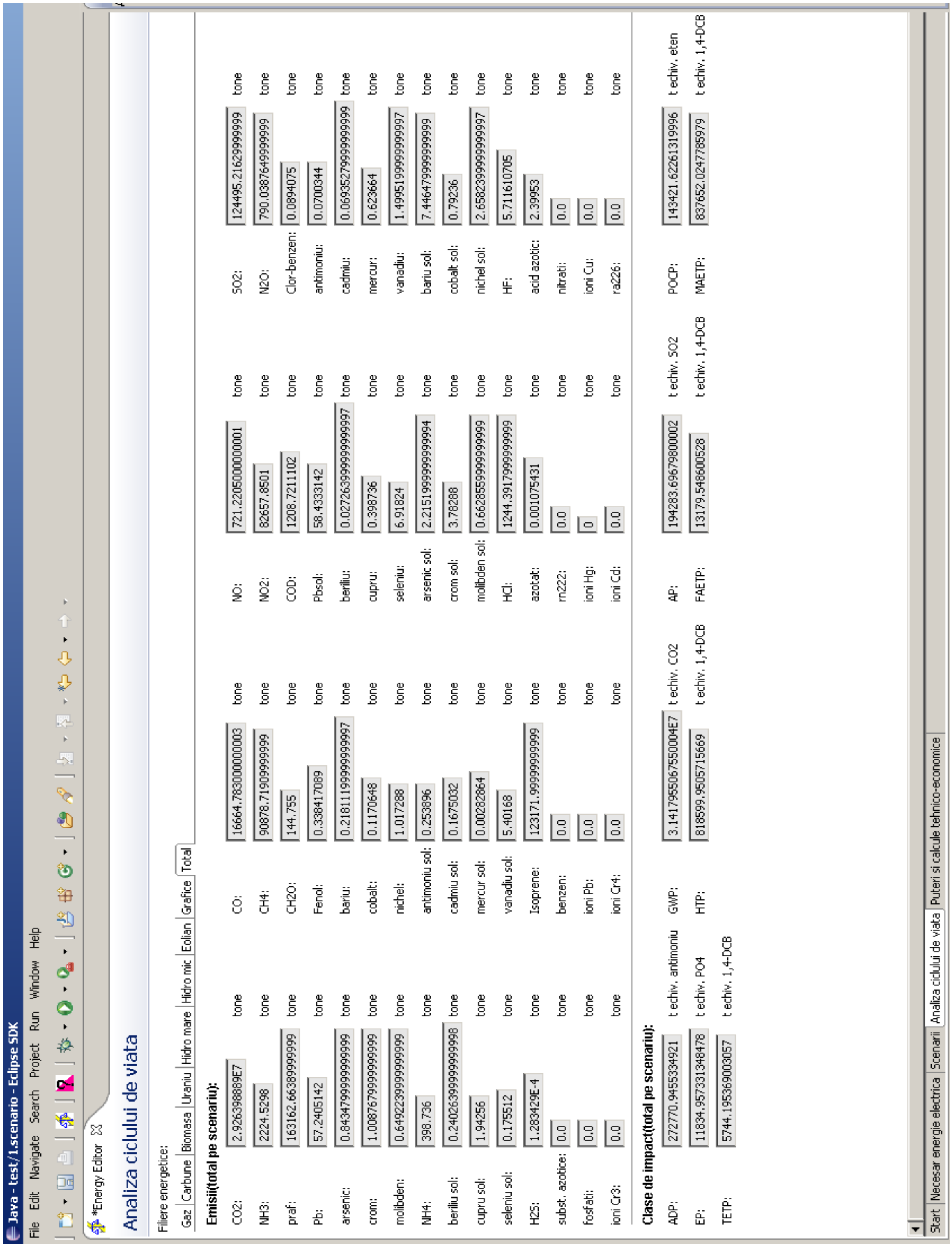


Fig. 7 – The inventory analysis and the impact assessment on all scenarios

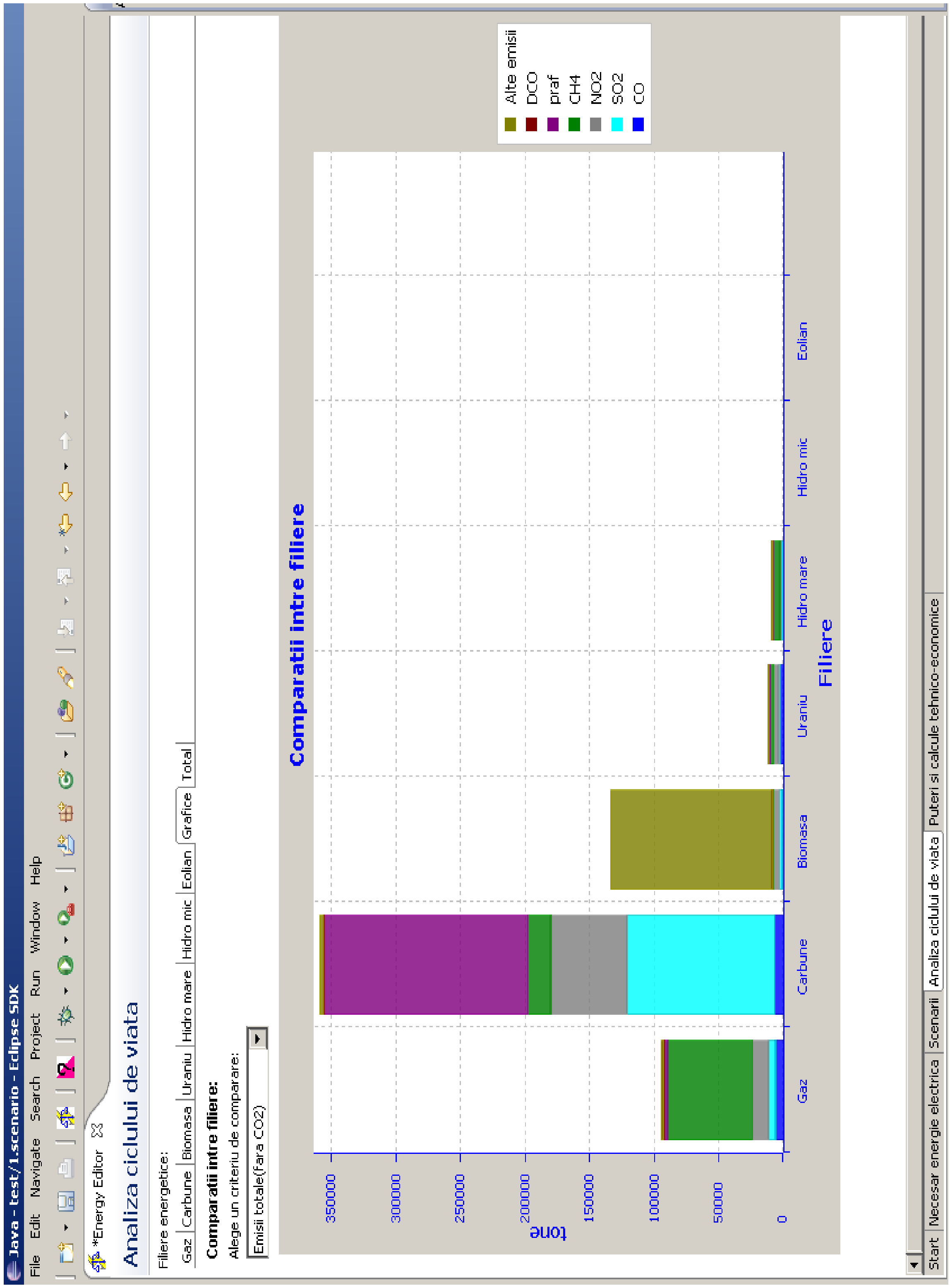


Fig. 8 - Comparison between the chains in terms of total non-CO2 emissions

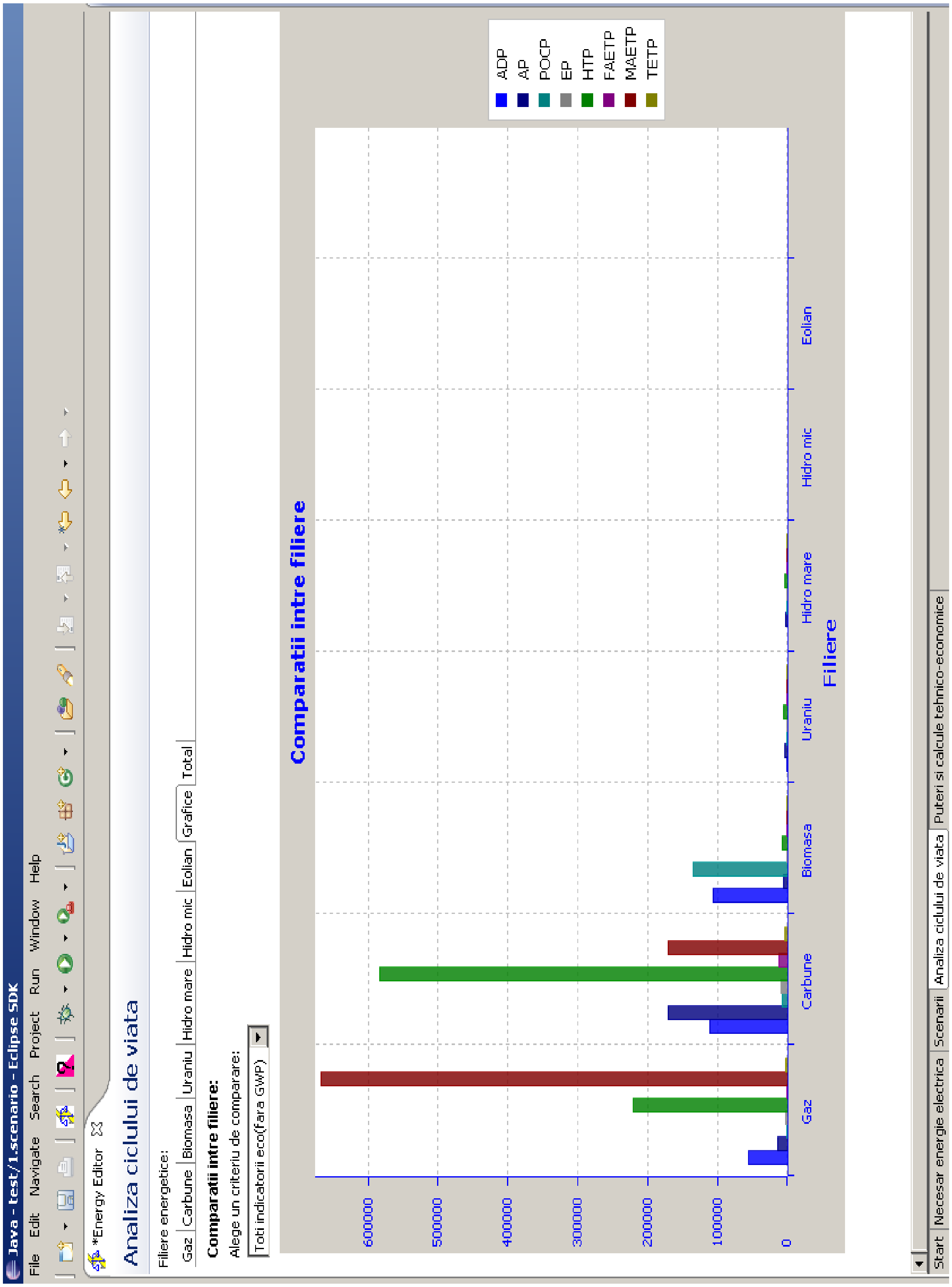


Fig. 9: Comparison between the chains in terms of impact classes, less GWP

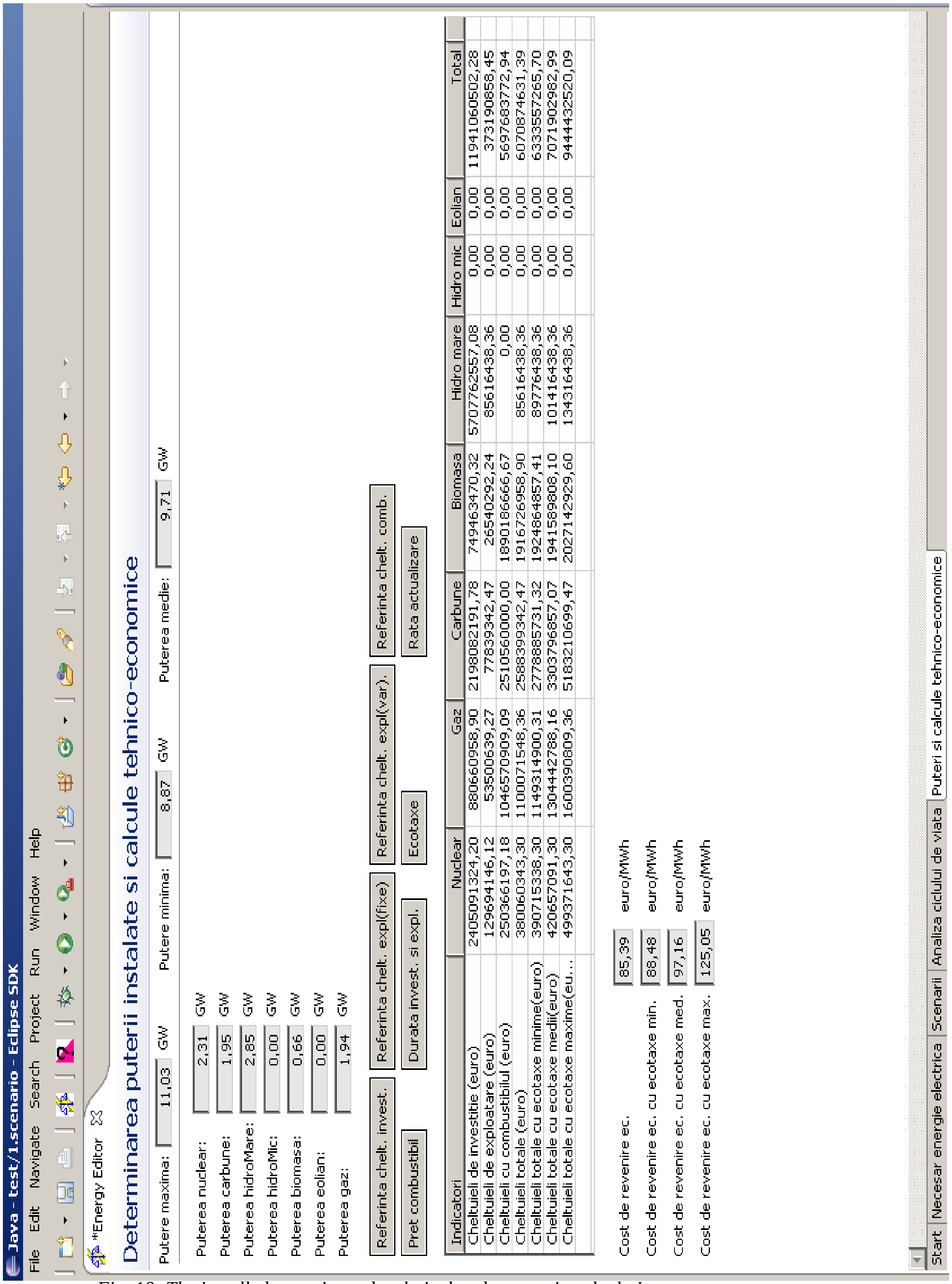
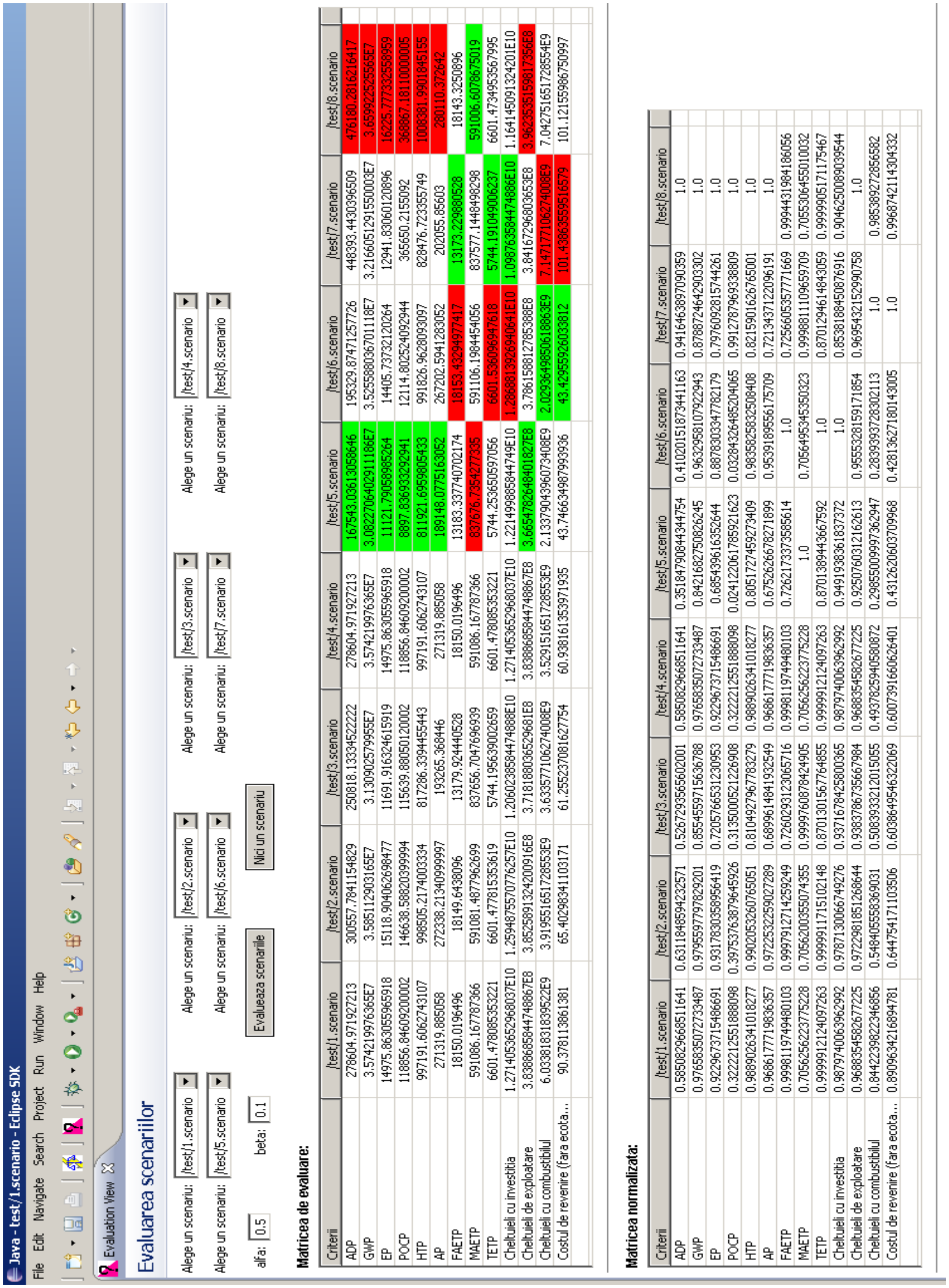


Fig. 10: The installed capacity and technical and economic calculations.



Criterii	/test/1.scenario	/test/2.scenario	/test/3.scenario	/test/4.scenario	/test/5.scenario	/test/6.scenario	/test/7.scenario	/test/8.scenario
ADP	278604.971927213	300557.7841154829	250818.13334522222	278604.971927213	167543.03613058646	195329.87471257726	448393.4430396509	476180.2816216417
GWP	3.574219976365E7	3.585112903165E7	3.130902579955E7	3.574219976365E7	3.0822706402911186E7	3.525588036701118E7	3.2166051291550003E7	3.659922525565E7
EP	14975.863055965918	15118.904062698477	11691.916324615919	14975.863055965918	11121.79058985264	14405.73732120264	12941.83060120896	16225.777332558959
POCP	118856.84609200002	146638.58820399994	115639.88050120002	118856.84609200002	8897.836933292941	12114.802524092944	365650.2155092	368867.18110000005
HTP	997191.6062743107	998505.2174003334	817286.3394455443	997191.6062743107	811921.6959805433	991826.9628093097	828476.723355749	1008381.9901845155
AP	271319.885058	272338.21340999997	193265.368446	271319.885058	189148.0775163052	267202.5941283052	202055.85603	280110.372642
FAETP	18150.0196496	18149.6438096	13179.924440528	18150.0196496	13183.337740702174	18153.43294977417	13173.229880528	18143.3250896
MAETP	591086.167787366	591081.4877962699	837656.7047696939	591086.167787366	837676.7354277335	591106.1984454056	837577.1448498298	591006.6078675019
TETP	6601.478085353221	6601.477815353619	5744.195639002659	6601.478085353221	5744.253650597056	6601.536096947618	5744.191049006237	6601.4734953567995
Cheltuieli cu investitia	1.2714053652968037E10	1.2594875570776257E10	1.2060238584474888E10	1.2714053652968037E10	1.221499885844749E10	1.2868813926940641E10	1.098763584474886E10	1.164145091324201E10
Cheltuieli de exploatare	3.8388685844748867E8	3.8525891324200916E8	3.718188036529681E8	3.8388685844748867E8	3.6654782648401827E8	3.786158812785388E8	3.84167296803653E8	3.9623535159817356E8
Cheltuieli cu combustibilul	6.03381831839522E9	3.919551651728553E9	3.633577106274008E9	3.529151651728553E9	2.1337904396073408E9	2.0293649850618863E9	7.147177106274008E9	7.042751651728554E9
Costul de revenire (fara ecota...	90.378113861381	65.40298341103171	61.255237081627754	60.938161353971935	43.746634987993936	43.42955926033812	101.43863559516579	101.12155986750997

Criterii	/test/1.scenario	/test/2.scenario	/test/3.scenario	/test/4.scenario	/test/5.scenario	/test/6.scenario	/test/7.scenario	/test/8.scenario
ADP	0.5850829668511641	0.6311848594232571	0.5267293565602001	0.5850829668511641	0.35184790844344754	0.41020151873441163	0.9416463897090359	1.0
GWP	0.9765835072733487	0.9795597797829201	0.8554559715636788	0.9765835072733487	0.8421682750826245	0.9632958107922943	0.8788724642903302	1.0
EP	0.9229673715486691	0.9317830358956419	0.7205766531230953	0.9229673715486691	0.685439616352644	0.8878303347782179	0.7976092815744261	1.0
POCP	0.3222212551888098	0.39753763879645926	0.3135000521226908	0.3222212551888098	0.024122061785921623	0.03284326485204065	0.9912787969338809	1.0
HTP	0.9889026341018277	0.9902053260765051	0.8104927967783279	0.9889026341018277	0.8051727459273409	0.9835825832508408	0.8215901626765001	1.0
AP	0.9686177719836357	0.9722532259027289	0.6899614841932549	0.9686177719836357	0.6752626678271899	0.9539189556175709	0.7213437122096191	1.0
FAETP	0.9998119749480103	0.9997912714259249	0.7260293123065716	0.9998119749480103	0.7262173373585614	1.0	0.7256605357771669	0.9994431984186056
MAETP	0.7056256223775228	0.7056200355074355	0.9999760878424905	0.7056256223775228	1.0	0.7056495345350323	0.9998811109659709	0.7055306455010032
TETP	0.9999912124097263	0.9999911715102148	0.8701301567764855	0.9999912124097263	0.8701389443667592	1.0	0.8701294614843059	0.9999905171175467
Cheltuieli cu investitia	0.9879740063962992	0.9787130066749276	0.9371678425800365	0.9879740063962992	0.9491938361837372	1.0	0.8538188450876916	0.9046250089039544
Cheltuieli de exploatare	0.9688354582677225	0.9722981851268644	0.9383786735667984	0.9688354582677225	0.9250760312162613	0.9555328159171854	0.9695432152990758	1.0
Cheltuieli cu combustibilul	0.8442239822346856	0.548405558369031	0.5083933212015055	0.4937825940580872	0.29855009997362947	0.2839393728302113	1.0	0.985389272856582
Costul de revenire (fara ecota...	0.8909634216894781	0.644754171103506	0.6038649546322069	0.6007391660626401	0.4312620603709968	0.42813627180143005	1.0	0.9968742114304332

Fig. 11: Assessment scenarios (matrices evaluation and normalization).

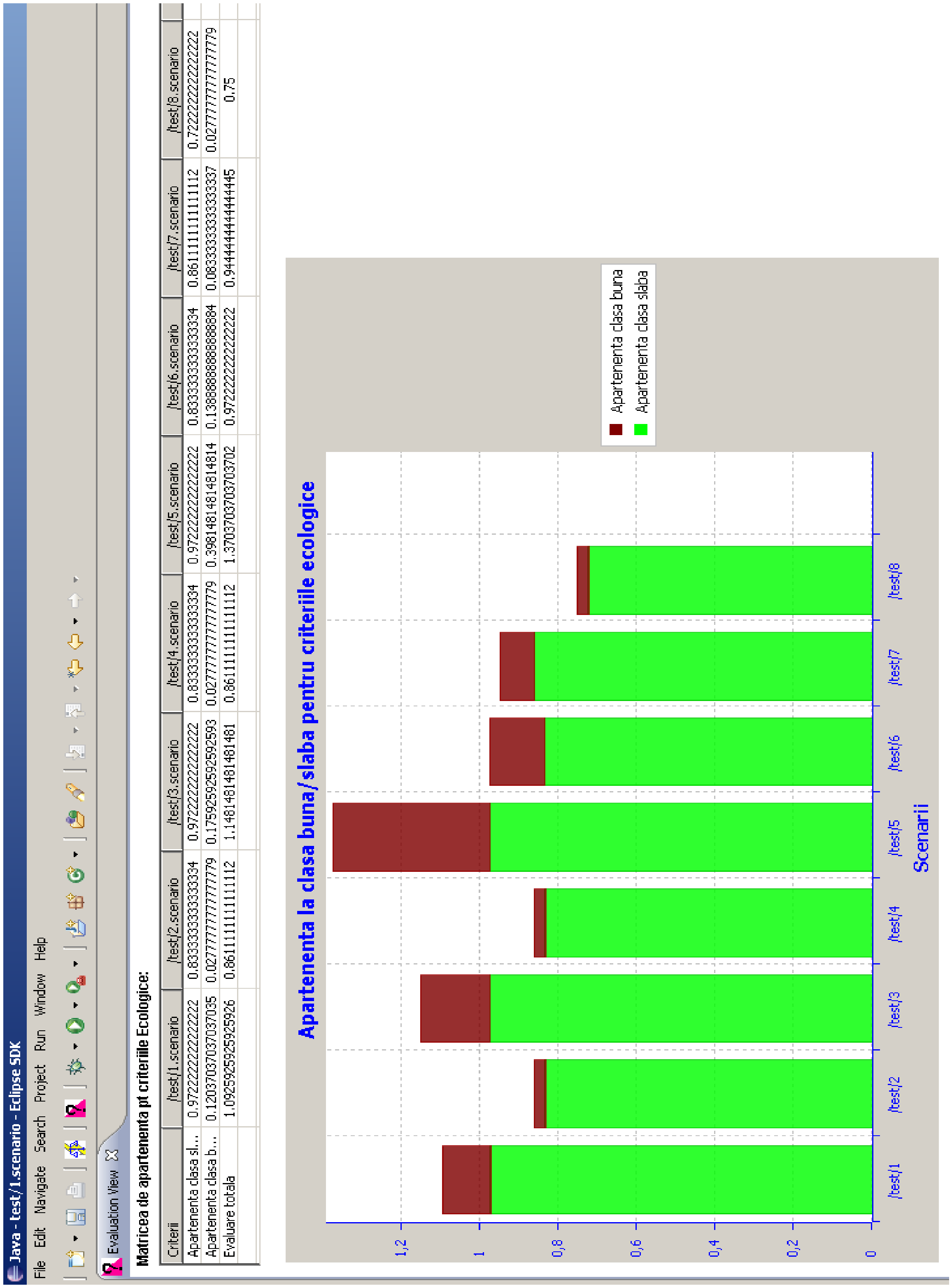


Fig. 12: Assessment scenarios (class membership good/low as ecological criteria).

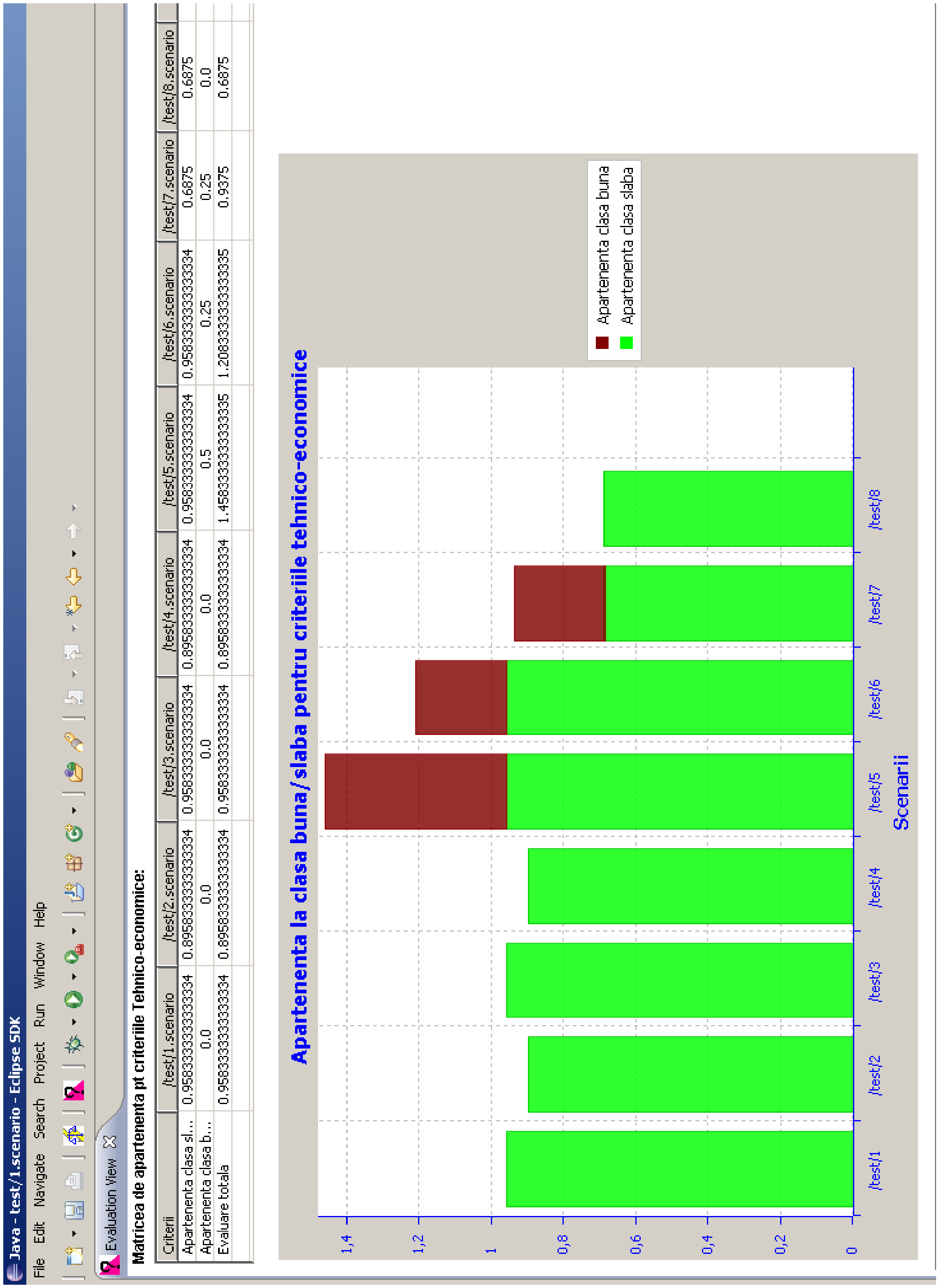


Fig. 13: Assessment scenarios (class membership good/low as economic and technical criteria).

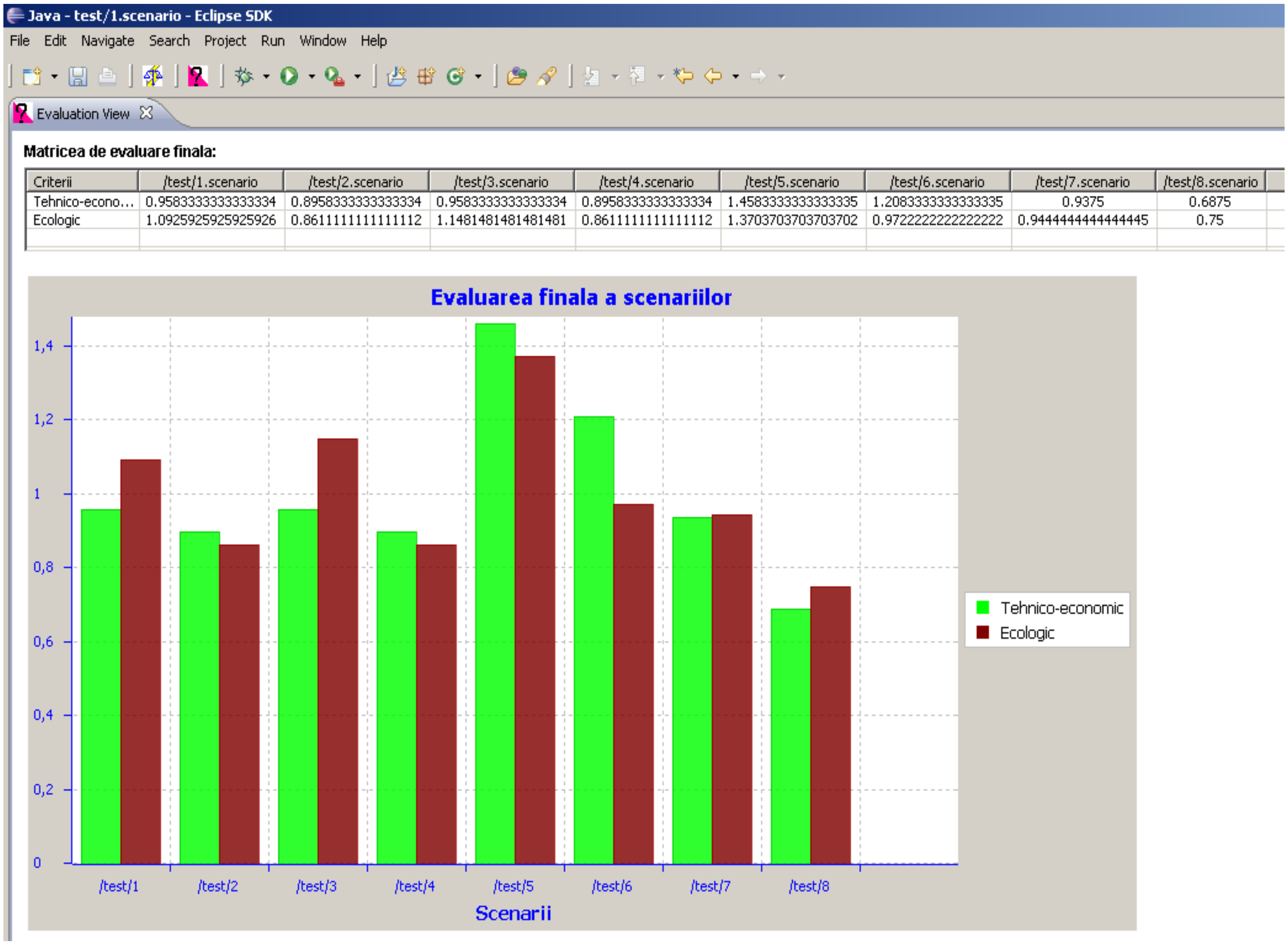


Fig. 14 - Global assessment of scenarios

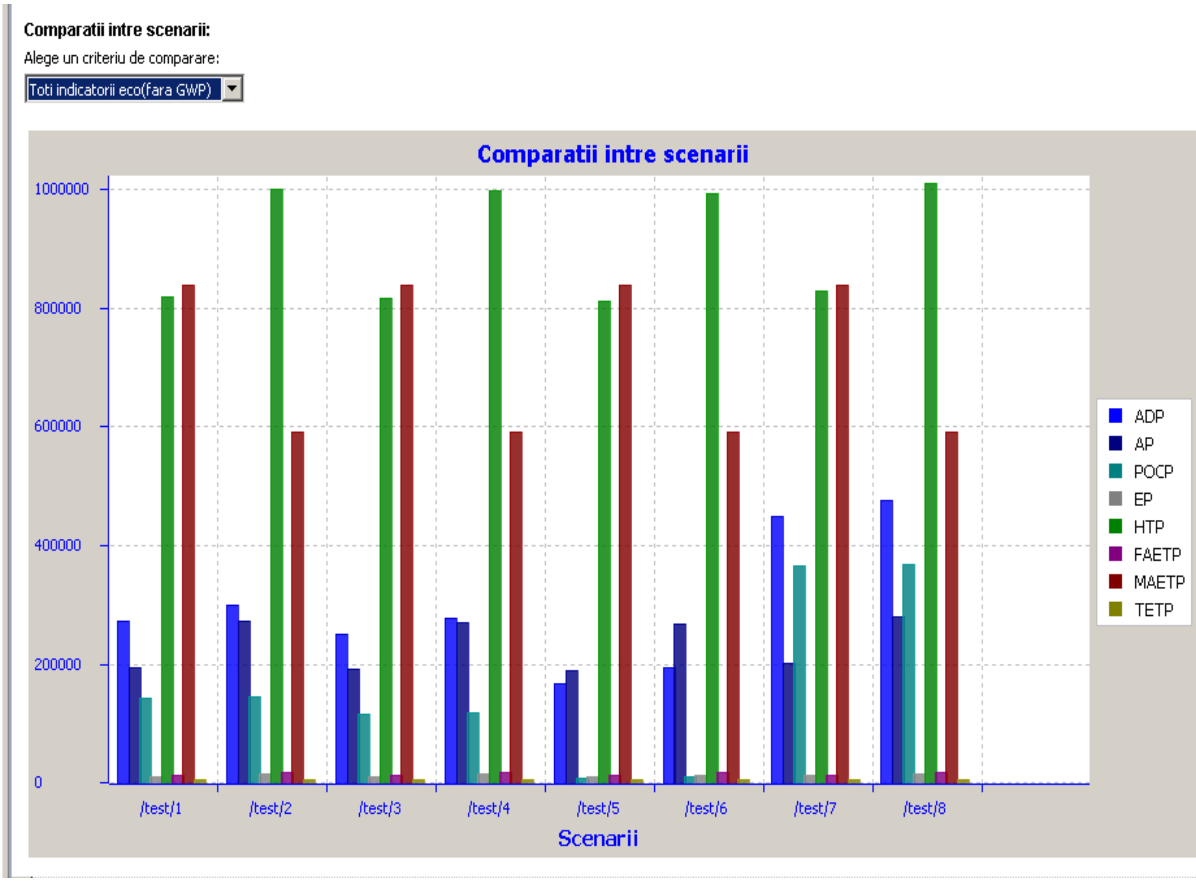


Fig. 15: Comparison between scenarios in terms of impact classes, less GWP.

4. Conclusions

- The implementation of this model enabled the identification of the optimal scenario to cover the balance of electricity in terms of environmental criteria and in terms of technical and economic criteria.
- Following analysis, scenario 5 is the optimal scenario to cover the electricity needs of 85 TWh in 2020. It was called "Wind – Natural gas Scenario". The loading of this scenario is as follows:
  - four nuclear groups, provide 20.2 TWh;
  - wind energy provides 5.3 TWh;
  - large hydro provides 25 TWh;
  - small hydro provides 0.5 TWh;
  - thermo energy is achieved in equal proportion of coal and gas, each making one 17 TWh.
- Since the software supports changes to many parameters, it allows the user to perform many simulations and data interpretation (in a very short time) that can be used in determining strategies for the energy sector development.
- The software also addressed to less initiated persons into multi-criteria model, encompassing a part of graphics makes it possible to interpret the data in an easier manner. It presents a tool that allows exporting data in Excel format.

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Структура Электроэнергетического Баланса Румынии на 2020 год, Созданная на Основе Оптимальных Первичных Энергоресурсов Используя Модель Многокритериального Анализа

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Резюме: Основной целью этой работы является создание модели многокритериального анализа для оптимального баланса электроэнергии Румынии, с точки зрения первичного энергетического баланса использующиеся для выработки электроэнергии. Данная работа является частью исчерпывающей диссертации под названием "Содействия в Разработки Стратегий в Области Устойчивого Развития Энергетического Сектора Румынии». Эта тема была выбрана по двум причинам: с одной стороны, из-за необходимости лучшей разработки стратегий развития энергетического сектора, используя динамические методы чувствительны к законодательным изменениям, а с другой стороны, из-за необходимости учитывать технические и экономические элементы, а также факторы окружающей среды, при разработке стратегий для устойчивого развития энергетического сектора на среднесрочную и долгосрочную перспективу.

Для достижения многокритериального анализа оптимального баланса электроэнергии для Румынии в 2020 году, используется программное обеспечение "Eclipse" (основанное на платформе Java). Это программное обеспечение имеет большую базу данных для среды (анализ жизненного цикла топлива для каждой стадии жизненного цикла), технические и экономические характеристики. Оно позволяет многочисленные изменения параметров и результаты могут просматриватся в реальном времени. Программное обеспечение позволяет пользователю проводить многочисленные моделирования и интерпретации данных, которые могут быть использованы для создания стратегии развития энергетического сектора.

Ключевые слова: устойчивое развитие, анализ жизненного цикла, многокритериальная модель.

PROMITHEAS Network, the origin of which is the Project Development Fund of BSEC, aims to promote scientific cooperation on the energy and climate policy issues between the countries of BSEC and EU and thus to contribute in knowledge transfer to that region, as a basic precondition for the development of human potential that will materialize policies of cooperation.

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PUT	Polytechnic University of Tirana, Albania
ESC	Energy Strategy Centre, Armenia
GPOGC	Geotechnological Problems of Oil, Gas and Chemistry, Azerbaijan
BSREC	Black Sea Regional Energy Centre, Bulgaria
TUSB	Technical University of Sofia, Bulgaria
EEC	Energy Efficiency Centre, Georgia
NOA	National Observatory of Athens, Greece
AUT	Aristotle University of Thessaloniki –Laboratory of Heat Transfer and Environmental Engineering, Greece
UA	University of Aegean – Department of Environment, Energy Management Laboratory, Greece
INEXCB-Kz	Independent Expert Consulting Board to Promote Scientific Research Activity in Kazakhstan, Kazakhstan
SRC KAZHIMINVEST	Scientific Production Firm KAZIMINVEST, Kazakhstan
PCTC-KG	Public Centre for Tobacco Control, Kyrgyzstan
IPE	Institute of Power Engineering, Moldova
ISPE	Institute for Studies and Power Engineering, Romania
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ESSUT	Eastern Siberia State University of Technology, Russian Federation
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SoDeSCo	Society for Development of Scientific Cooperation in Tajikistan, Tajikistan
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TUBITAK	Marmara Research Center, Energy Institute, Turkey
MUGLA	Mugla University, Turkey
ESEMI	Energy Saving and Energy Management Institute, Ukraine
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The Energy and Climate Change Policy Network

Energy Policy and Development Centre (KEPA)
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