Sustainability of Electricity Generation Technologies in EU

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***Abstract*—Sustainable development is a key policy in European Union (EU). The main targets of EU energy policy are related with sustainable energy development goals. Therefore it is important to assess electricity generation technologies in terms of sustainability. The aim of this paper is to apply the multi–criteria decision support framework for sustainability assessment of the main electricity generation technologies in EU. The multi-criteria decision method MULTIMOORA was applied for the sustainability assessment of electricity generation technologies. The multi-criteria analysis conducted in the paper provided that the future energy policy in EU should be oriented towards the sustainable energy technologies are water and solar thermal ones.**

***Index Terms*—Electricity generation technologies, multi-criteria analysis, sustainability assessment.**

I. Introduction

The main EU policy documents and directives which have impact on sustainable energy development are directives promoting energy efficiency and use of renewable energy sources, directives implementing greenhouse gas mitigation and atmospheric pollution reduction policies and other policy documents and strategies targeting energy sector. Promotion of use of renewable energy sources especially biomass and energy efficiency improvements are among priorities of EU energy policy because use of renewables and energy efficiency improvements has positive impact on energy security and climate change mitigation. The directives targeting energy efficiency, renewables and climate change mitigation indicates the EU energy policy priorities: reduction of energy impact on environment, improvements in energy generation and energy use efficiencies, increase in reliability and security of energy supply, promotion of renewables use and climate change mitigation. All these directives have specific targets which can be addressed by quantitative indicators. As targets set by specific directives are related the use of interlinked indicators framework to address these targets can be useful tool for energy policy analysis and monitoring. Such tool applied by EU member states can help to harmonize EU energy policies and enhance its implementation on country level [1], [2].

New energy technologies can be considered to be an important bridge between the Europe 2020 objectives and the EU Sustainable development strategy adopted at the Goteborg European Council [3].

Indeed, the very selection of sustainable energy sources involves multiple conflicting objectives. It is therefore important to develop multi–criteria decision support frameworks for sustainable energy policy. Multi–criteria decision making (MCDM) methods are suitable to tackle energy source selection problem [1], [2], [4]-[10]. A number of the recent studies, therefore, dealt with application of MCDM in energy policy [11]-[22].

The aim of this paper is to apply the multi–criteria decision support framework for sustainability assessment of the main electricity generation technologies in EU. The main targets to achieve the aim of the paper are: to discusses the aims of EU sustainable energy policy goals and indicators; to review alternative electricity generation technologies as well as criteria for their ranking; to present MULTIMORA method applied for the sustainability assessment of electricity generation technologies; to conduct sustainability assessment of electricity generation technologies by applying MULTIMORA method based on the targets of EU sustainable energy policy.

II. EU Sustainable Energy Policy Goals and Indicators for Sustainability Assessment of Electricity Generation Technologies

The main EU policy documents and directives which have impact on sustainable energy development are directives promoting energy efficiency and use of renewable energy sources, directives implementing greenhouse gas mitigation and atmospheric pollution reduction policies and other policy documents and strategies targeting energy sector. Promotion of use of renewable energy sources especially biomass and energy efficiency improvements are among priorities of EU energy policy because use of renewables and energy efficiency improvements has positive impact on energy security and climate change mitigation. The directives targeting energy efficiency, renewables and climate change mitigation indicates the EU energy policy priorities: reduction of energy impact on environment, improvements in energy generation and energy use efficiencies, increase in reliability and security of energy supply, promotion of renewables use and climate change mitigation. All these directives have specific targets which can be addressed by quantitative indicators. As targets set by specific directives are related the use of interlinked indicators framework to address these targets can be useful tool for energy policy analysis and monitoring. Such tool applied by EU member states can help to harmonize EU energy policies and enhance

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its implementation on country level.

On 10 January 2007 the Commission adopted an Energy and climate change package, calling on the Council and European Parliament to approve: an independent EU commitment to achieve a reduction of at least 20% in the emission of greenhouse gases by 2020 compared to 1990 levels and the objective of a 30% reduction by 2020, subject to the conclusion of a comprehensive international climate change agreement; a mandatory EU target of 20% renewable energy by 2020 including a 10% biofuels target. This strategy was endorsed both by the European Parliament and by EU leaders at the March 2007 European Council. The European Council invited the Commission to come forward with concrete proposals, including how efforts could be shared among Member States to achieve these targets. This package is the reply to that invitation. It comprises a set of key policy proposals that are closely interlinked. They include: (1) a proposal amending the EU Emissions Trading Directive (EU ETS); (2) a proposal relating to the sharing of efforts to meet the Community's independent greenhouse gas reduction commitment in sectors not covered by the EU emissions trading system (such as transport, buildings, services, smaller industrial installations, agriculture and waste); (3) a proposal for a Directive promoting renewable energy, to help achieve both of the above emissions targets. Other proposals that are also part of the package include a proposal for a legal framework on carbon capture and storage, a Communication on the demonstration of carbon capture and storage and new guidelines for environmental state aid.

The EU Green paper on European Strategy for Sustainable, Competitive and Secure Energy (SEC (2006) 317) sets the main priorities for EU energy strategy: competitiveness of the EU economy, security of supply and environmental protection. These objectives should help to address central policy concerns such as job creation, boosting overall productivity of the EU economy, protection of the environment and climate change.

The Commission’s Green Paper on energy efficiency COM (2005) 265 stresses the importance of energy efficiency improvement for the controlling of demand growth and security of supply. According to estimates, the economic potential for improving energy efficiency in 2010 for all sectors combined is 20% of the total annual primary energy consumption of the current level. There are several directives aiming to implement Commissions Green Paper on energy efficiency: 2006/32/EC Directive on energy end-use efficiency and energy services, 2002/91/EC Directive on the energy performance of buildings and 2004/8/EC Directive on the promotion of cogeneration.

The 2006/32/EC Directive on energy end-use efficiency and energy services sets the targets for EU member states to reduce final energy consumption by 9% during the nine year period until 2015 and proposes set of measures to achieve these targets: voluntary agreements, white tradable certificates, energy service obligations, energy audits etc.

2002/91/EC Directive on the energy performance of buildings sets target to realize a savings potential of around 22 % by 2010 for energy used in heating, air – conditioning, hot water and lighting. The main measures proposed for achieving this target are: improved standards, certification of buildings and information on energy consumption in buildings disclosure, subsidies form EU structural funds for energy efficiency improvements in public buildings, the incentive billing of residents of the buildings, soft loans for energy efficiency improvements in multi-flat buildings etc.

2004/8/EC Directive on the promotion of cogeneration based on a useful heat demand in the internal energy market aims to increase energy efficiency and improve security of supply by creating a framework for promotion and development of high efficiency cogeneration of heat and power based on useful heat demand and primary energy savings taking into account the specific national circumstances especially climate and economic conditions. The strategic goal of EU-15 is to double the share of electricity produced by combined heat and power pants (CHP) by 2010. The different mechanisms can be applied to support cogeneration at the national level, including investment aid, tax exemptions or reductions, green certificates and direct price support schemes, information disclosure etc.

White Paper for a Community Strategy and Action Plan on renewable energy sources COM (97) 599 final states that member states should formulate indicative targets contribute to the ambitious indicative target of doubling the overall share of renewables in the EU by 2010. It sets an indicative target of 12% for the contribution by renewables to the total primary energy consumption within EU by 2010 and contains a strategy and action plan to achieve this target. Pursuant to the White paper on Renewables the Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market was passed in 2001. It adds the indicative target contribution of 22.1% by renewables-based electricity to total EU electricity consumption in year 2010. The main measures foreseen in directive: Feed-in prices for electricity produced from renewables, green tradable certificates, competitive bidding processes, voluntary agreements, generation disclosure rules, green electricity purchases, subsidies and soft loans for renewables projects etc.

The draft Directive promoting heating and cooling from renewable energy sources was put forward. The purpose of directive is to promote renewable heating & cooling. The EU target: 20% of heat & cold from renewables by 2020. National binding targets should be established by technology. National support mechanisms should be putted in place including green tradable certificates for heat produced from renewables, Feed-in prices for heat produced from renewables etc. Removal of administrative barriers, reliable statistics and monitoring of results are necessary.

In the EU, bio-energy resources such as forestry and agriculture crops, biomass residues and wastes already provide around 5% of all energy and 65% of renewable energy. And the potential of bio-energy is huge. In the EU it has been estimated that it could be capable of supplying more than 235 Mtones of oil equivalent in 2020 without environmental damage. The EC acknowledges this potential and adopted the European Biomass Action Plan in December 2005 to ensure that biomass plays an increasingly important role in our energy mix in view to meet our 2010 renewables target. Also important is to mobilise our agricultural and forestry sectors. It is necessary to make such resources available for energy use while ensuring that conflicts between the different types of biomass are avoided. Therefore Member States are encouraged to develop their national biomass action plans and to subsequently exchange information and best practices for better utilisation of wood resources. Countries such as Finland, Sweden and Austria successfully use some of their wood supply for energy. A key factor in these countries has been co-ordination between forest owners; energy, wood-processing, harvesting and logistical industries; and public authorities. This might be an example to follow in many Member States where better co-ordination is still needed, both at national and regional levels.

In 2007, the EC proposed an European Strategic Energy Technology Plan which will address the development of second generation biofuels to become fully competitive alternatives to hydrocarbons. The Plan will consider how to better coordinate existing resources, how to use them in a more targeted and focused manner and where to invest more. An EU Strategy for Biofuels adopted on 2006 aims to further promote biofuels in the EU and developing countries, ensure that their production and use is globally positive for the environment and to prepare for the large-scale use of biofuels by improving their cost-competitiveness and support for market penetration by scaling up demonstration projects and removing non-technical barriers. The exploration of the opportunities for developing countries for the production of biofuel feedstock and biofuels is also proposed in the strategy.

2003/30/EC Directive on the promotion of the use of biofuels or other renewable fuels in transport (RF Directive) sets that Member States must ensure by end of 2005 a 2 % minimum proportion of biofuels of all gasoline and diesel fuels sold on their market. In longer term the target is to achieve a share of 5.75 % of biofuels for transport in the total amount of fuels in Europe by 2010 and 20 % by 2020. The main measures foreseen in directive include: excise, VAT, pollution and other tax exemptions for biofuels, financial (subsidies or soft loans) assistance for the processing industry and the establishment of a compulsory rate of biofuels for oil companies etc.

All these directives and policy documents described above have positive impact on greenhouse gas emission reduction and achieving of Kyoto target. EU has ratified Kyoto Protocol committing itself to 8% greenhouse gas emission reduction in the period 2008-2012 from the 1990. Equally the New Member States are determined to meet their individual targets under the Kyoto Protocol. Baltic States have the same target as EU-15.

Therefore the main targets of EU energy policy which can be addressed by selecting the appropriate indicators are: to increase security of energy supply, promotion of renewable energy sources and cogeneration and increase of end-use energy efficiency. All these policies have positive impact on greenhouse gas emission reduction which is also the priority issue of EU energy policy; however the positive impact on other sustainable energy development targets is not so obvious and needs to be assessed.

In addition there are several EU environmental policy goals related to sustainable energy development, i.e. air pollution reduction set by EU Thematic strategy on Air Pollution and National emission ceilings, Large combustion source directives which do have impact on greenhouse gas emission increase in member states therefore the contradiction between these policies can be noticed.

In its Thematic Strategy on Air Pollution (COM 2050 446 final), the European Commission outlined the strategic approach towards cleaner air in Europe and established environmental interim targets for pollutants contributing to acidification, eutrophication and the formation of ground-level ozone in year 2020 compared to year 2000 levels. As one of the main policy instruments, the Thematic Strategy announced the revision of the Directive on National Emission Ceilings (2001/81/EC) with new emission ceilings that should lead to the achievement of the agreed interim objectives. In the meantime European Commission started the process to develop national ceilings for the emissions of the relevant air pollutants. The EU global goal in 2020 would make for SO_2 - reduction by 87%, for NO_X - reduction by 50%, for PM2.5 by 41%, for NH_3 - by 25% and for VOC - by 46% compared to 2000. The main EU legislation for pollutants contributing to acidification, eutrophication and the formation of ground-level ozone relevant to energy production sector are Large Combustion plant directive (2001/80/EC), Sulphur Content of Liquid Fuels Directive (1999/32/EC), and National emission ceilings directive (2001/81/EC) etc.

The results of energy sector modeling applied in Lithuania indicated that implementation of these atmospheric pollution limiting directives would have impact on greenhouse gas emission increase in Lithuania.

2001/81/EC Directive on national emission ceilings for certain atmospheric pollutants sets since 2010 the national emission ceilings for SO_2, NO_X, VOC and NH_3 which are very close to the limits of the same pollutants established by Gothenburg protocol to Long Range Transboundary Air Pollution Convention. This directive was implemented in Lithuania on 25 September 2003 by The Decree of the Minister of Environment No 468 On the approval of national emission ceilings for SO_2, NO_X, VOC and NH_3 emissions. The following national emission ceilings were set for Lithuania: for SO_2 – 145 thou t, for NO_X – 110 thou t, for VOC – 92 thou t and for NH_3 – 84 thou t.

Directive 1999/32/EC relating to a reduction in the sulphur content of certain liquid fuels (Sulphur directive) is to ensure that as from 1 January 2004 the heavy fuel oil (HFO) used within territories of EU Member States do not exceed the sulphur content of 1,00 % by mass. The requirement do not exceed the sulphur content of 1% shall not apply to HFO used in (large and small) combustion plants where the emissions of sulphur dioxide from the plant are less than or equal to 1700 mg/Nm^3 and for combustion in refineries, where the monthly average of emissions of SO_2 averaged over all plants in the refinery shall not exceed 1700 mg/Nm^3. According the requirements of EU Directive 88/609/EEC it is possible to burn HFO with a sulphur content exceeding 1% if it is co-combusted with either natural gas or with biomass. Thus, HFO - having a sulphur content of 2.2% - can be used by large combustion plants if it is co-combusted with at least 55% natural gas or 55% biomass (in terms of energy input).

In this case, the concentration of SO_2 in the flue gas will be kept below 1700 mg/Nm^3.

In addition since 2008 the new norms for SO_2 emission will be established for large combustion plants based on Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plans (LCP Directive).

TABLE I: INDICATORS SELECTED FOR EU ENERGY POLICY ANALYSIS

Indicators	**Subtheme**	**Directive or policy document**	**Target**	**Date for achievement**
Energy efficiency				
End-use energy intensity of GDP	Energy efficiency	Directive 2006/32/EC on end-use efficiency and energy services	To reduce by 9% the current level (2006)	2016
Energy saved in buildings	Energy efficiency	2002/91/EC Directive on the energy performance of buildings	22% of energy used in buildings	2010
Savings of primary energy supply	Energy efficiency	The Commission's new Green Paper on energy efficiency COM (2005) 265	20% from year 2005 level	2020
The share of CHP in electricity production	Energy efficiency	2004/8/EC Directive on the promotion of cogeneration national energy strategy	Double the current share	2010
Promotion of renewables				
The share of renewables in primary energy supply	Renewables	The White Paper on renewable sources	12%	2010
The share of renewables in electricity generation	Renewables	Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market	22,1% (7% for Lithuania)	2010
The share of renewables in heat production	Renewables	Proposal for Directive promoting the renewable heating and cooling	25%	2020
The share of renewables in fuel used in transport	Renewables	2003/30/EC Directive on the promotion of the use of biofuels or other renewable fuels in transport	2% 5.75% 20%	2005 2010 2020
The share of renewables in final energy	Renewables	EU energy and climate package: (COM(2008) 30 final)	20%	2020
Security of supply				
Energy independency	Security of supply	The EU Green paper on European Strategy for Sustainable, Competitive and Secure Energy	50%	2030
Emission reduction				
Greenhouse gas emissions (CO_2 emissions from energy sector)	Climate change	Kyoto protocol	Reduction by 8% of year 1990 level Reduction by 20% of year 1990 level	2008-2012 2020
SO_2 emissions, NO_x emissions, VOC emissions, NH_3 emissions SO_2 emissions, NO_x emissions, VOC emissions, NH_3 emissions	Acidification and eutrophication	Gothenburg protocol NEC directive 2001/81EC	Reduction by 35%, 30 %, 11% 0% comparing to 1990 level, Reduction by 87%, by 50%, by 46% by 41% compared to 2000 level	2010 2020

Besides that the implementation of all these directives and policy documents targeting specific but interrelated sustainable energy development targets described above and measures foreseen in these directives would interact with each other and this interaction is necessary to evaluate and address in setting harmonized reinforcing each other energy policies and achieving synergy effect implemented measures. Therefore before the implementation of policies and measures the evaluation of these policies impact on sustainable energy development targets needs to be addressed. The multi criteria decision aiding analysis would allow assessing impact of various energy technologies on sustainable energy development targets imposed by various EU policy documents. Sophisticated modelling tools (General Equilibrium Modelling, Partial Equilibrium Modelling including just energy sector etc.) can be used to assess the impact of various policies on sustainable energy development targets set by directives and Green papers described above.

The aims of EU directives targeting sustainable energy development were summarized in Table I. The security of supply, energy efficiency improvements, promotion of renewable, reduction of greenhouse gas and other atmospheric pollutants emissions are the major targets of EU energy policies. Based on EU energy policy analysis the selected indicators were grouped by 4 priority areas established by EU energy policy: increase of energy efficiency, use of renewables, increase of energy security and greenhouse gas and other atmospheric emission reduction (Table I).

Table II presents the full set of indicators covering economic, environmental, and social aspects for long-term sustainability assessment of energy technologies. The proposed indicator framework addresses the EU energy and environmental policy priorities and the three dimensions of sustainable development. Seeking to assess electricity generation technologies based on EU energy policy targets presented in Table I the indicators for long–term sustainability of the energy technologies are presented in Table II.

TABLE II: INDICATOR SET FOR LONG-TERM SUSTAINABILITY ASSESSMENT OF ELECTRICITY GENERATION TECHNOLOGIES

Acronym	Indicator	Units of measurement	Information sources
Economic dimension			
PR COST	Private costs	EUR cnt/kWh	[23], [24]
AVAILAB	Average availability (load) factor	%	[25]
SECURE	Security of supply	Point	[26]–[28]
GRID COST	Costs of grid connection	Point	[23], [24]
PEAK LOAD	Peak load response	Point	[26]–[29]
Environmental dimension			
CO_2eq	GHG emissions	kg/kWh	[23], [24]
ENV	Environmental external costs	EUR cnt/kWh	[23], [24]
RADIO	Radionuclide external costs	EUR cnt/kWh	[23], [24]
HEALTH	Human health impact	EUR cnt/kWh	[23], [24]
Social dimension			
EMPL	Technology-specific job opportunities	Person-year/kWh	[29]
FOOD	Food safety risk	Point	[23], [24]
ACC PAST	Fatal accidents from the past experience	Fatalities/kWh	[29]
ACC FUT	Severe accidents perceived in future	Point	[23], [24]

The Economic dimension in sustainability assessment of energy technologies is very important as energy supply cost is the main driver for energy technologies penetration in the markets. There are 6 indicators selected to address economic dimension of sustainability assessment in electricity and heat sector: private costs, fuel price increase sensitivity, average availability factor, costs of grid connection, peak load response, security of supply. The most important indicators are: private costs, availability factor and costs of grid connection. The main environmental dimension indicators for energy technologies assessment are: GHG emissions, environmental external costs, radionuclides external costs, severe accidents perceived in future and fatal accidents from the past experience. Additional environmental indicators are land use and solid waste. The main social indicators selected for electricity technologies assessment in this report are technology-specific job opportunities, human health impact, food safety risk and work related fatalities per accident. The most important indicators applied in almost all studies for technologies assessment are: external health costs and technology specific job opportunities.

Table III summarizes electricity and heat generation technologies which will be assessed in terms of the previously described sustainability assessment indicators framework.

TABLE III: ELECTRICITY AND HEAT GENERATION TECHNOLOGIES SELECTED FOR MULTI–CRITERIA SUSTAINABILITY ASSESSMENT

Technologies and types of power plants			Acronyms
Electricity production			
Nuclear		EPR	NUC
Fossil fired power plants	oil	heavy oil condensing PP	OIL CL
		light oil gas turbine	OIL GT
	coal	condensing PP	COA CL
		IGCC	COA IGCC
		IGCC PP with CO2 sequestration	COA IGCC CCS
	lignite	condensing pp	LIG CL
		IGCC	LIG IGCC
		IGCC pp with CO2 sequestration	LIG IGCC CCS
	gas	combined cycle	GAS STAG
		combined cycle PP with CO2 sequestration	GAS STAG CCS
		gas turbine	GAS GT
Hydropower	run of river	<10 MW	HYD S
		<100 MW	HYD M
		>100 MW	HYD L
	dam		HYD DAM
	pump storage		HYD PMP
Wind	on shore		WIND ON
	off shore		WIND OFF
Solar PV	roof		PV ROOF
	open space		PV OPEN
Solar thermal			SOL TH
Electricity and heating production (CHP)			
CHP with an extraction condensing turbine	gas	CC	CHP GAS
		CC PP with CO2 sequestration	CHP GAS CCS
	coal	PP	CHP COAL
		IGCC PP with CO2 sequestration	CHP COAL CCS
CHP back pressure	gas		CHP GAS STAG
	coal		CHP COAL BP
Biomass CHP with an extraction condensing turbine	straw		CHP STRAW
	wood chips		CHP WOOD
Fuel cells	natural gas	MCFC	MCFC
		SOFC	SOFC
	bio gas	MCFC	MCFC BG

There are 13 the long-term sustainability indicators consisting of 5 economic indicators (private costs, grid costs, availability factor, peak load response and security of supply), 4 environmental (environmental external costs, radionuclides external costs, human health related external costs, GHG emissions), and 4 social indicators (technology-specific job opportunities, food safety risks, fatal accidents from the past and severe accidents perceived in the future). Respective rows describe each of 33 electricity production technologies under consideration.

III. MULTIMOORA METHOD

In this paper for sustainability assessment of electricity generation technologies the MULTIMOORA method was applied. The MULTIMOORA method was developed by Brauers and Zavadskas [1], [18]-[20].

MULTIMORA method was employed for prioritization of the electricity generation technologies. MULTIMORA originated from Multi-Objective Optimization by Ratio Analysis (MOORA) method introduced by Brauers and Zavadskas [18] on the basis of previous research. The same authors [19], [20] extended the method and in this way it became more robust as MULTIMOORA (MOORA plus the full multiplicative form).

The MULTIMOORA method begins with a response matrix X, where its elements x_{ij} denote i^{th} alternative of j^{th} objective (i=1, 2, …, m and j=1, 2, …, n). The method consists of three parts, viz. the Ratio System, the Reference Point approach, and the Full Multiplicative Form.

The Ratio System of MOORA. Ratio system employs the vector data normalization by comparing alternative of an objective to all values of the objective:

$$x_{ij}^{*} = w_j \cdot \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (1)$$

where x_{ij}^* denotes i^{th} alternative of j^{th} objective and w_j is weight of the j^{th} criterion, $\sum_j w_j = 1$. In the absence of negative values, these numbers belong to the interval [0, 1].

These indicators are added (if desirable value of indicator is maximum) or subtracted (if desirable value is minimum). Thus, the summarizing index of each alternative is derived in this way:

$$y_i^* = \sum_{j=1}^{g} x_{ij}^* - \sum_{j=g+1}^{n} x_{ij}^* \quad (2)$$

where g=1, 2, …, n denotes number of objectives to be maximized. Then every ratio is given the rank: the higher the index, the higher the rank.

Thus MULTIMOORA summarizes MOORA (i.e. Ratio System and Reference point) and the Full Multiplicative Form. Brauers and Zavadskas [20] proposed the dominance theory to summarize the three ranks provided by different parts of MULTIMOORA.

IV. RESULTS OF THE SUSTAINABILITY ASSESSMENT OF ELECTRICITY GENERATION TECHNOLOGIES

In order to compare the 33 electricity production technologies listed in Table III against targets of EU sustainable energy policy development and sustainability criteria [23]-[25] provided in Table II the four different scenarios [26]-[29] were defined (Table IV).

TABLE IV: CRITERIA WEIGHTS UNDER DIFFERENT SCENARIOS

Criteria	Holistic approach	Economic approach	Environmental approach	Social approach
Economic indicators	0.33	0.5	0.25	0.25
Environmental indicators	0.33	0.25	0.5	0.25
Social indicators	0.33	0.25	0.25	0.5

TABLE V: THE RANKS OF DIFFERENT ELECTRICITY GENERATION TECHNOLOGIES FOR 4 SCENARIOS

Rank	Holistic approach	Economic approach	Environmental approach	Social approach
1	HYD M	HYD M	SOL TH	HYD M
2	HYD L	HYD L	HYD M	SOL TH
3	SOL TH	HYD S	HYD L	HYD DAM
4	HYD S	HYD DAM	HYD S	WIND ON
5	HYD DAM	CHP WOOD	HYD DAM	PV ROOF
6	HYD PMP	HYD PMP	HYD PMP	PV OPEN
7	WIND ON	CHP COAL CCS	WIND ON	HYD L
8	CHP WOOD	SOL TH	WIND OFF	HYD S
9	CHP COAL CCS	CHP STRAW	CHP COAL CCS	HYD PMP
10	WIND OFF	CHP COAL BP	CHP WOOD	CHP WOOD
11	SOFC	COA IGCC CCS	PV OPEN	WIND OFF
12	CHP GAS CCS	SOFC	SOFC	CHP GAS CCS
13	COA IGCC CCS	WIND ON	PV ROOF	SOFC
14	PV ROOF	WIND OFF	GAS STAG	CHP COAL CCS
15	CHP STRAW	COA CL	COA IGCC CCS	CHP STRAW
16	PV OPEN	LIG IGCC	CHP GAS CCS	GAS STAG
17	LIG IGCC	CHP GAS CCS	CHP STRAW	MCFC
18	CHP COAL BP	GAS STAG	CHP GAS	COA IGCC CCS
19	GAS STAG	PV ROOF	LIG IGCC	CHP COAL BP
20	MCFC	GAS GT	CHP COAL BP	COA CL
21	CHP COAL	MCFC	GAS GT	GAS GT
22	COA CL	CHP COAL	MCFC	MCFC
23	GAS GT	OIL CL	CHP GAS STAG	CHP COAL
24	OIL CL	CHP GAS	CHP COAL	CHP GAS
25	CHP GAS	CHP GAS STAG	GAS STAG CCS	CHP GAS STAG
26	CHP GAS STAG	PV OPEN	LIG IGCC CCS	GAS STAG CCS
27	COA IGCC	COA IGCC	COA IGCC	COA IGCC
28	OIL GT	LIG CL	COA CL	OIL GT
29	MCFC	OIL GT	OIL CL	NUC
30	GAS STAG CCS	MCFC	LIG CL	LIG IGCC
31	LIG IGCC CCS	GAS STAG CCS	OIL GT	OIL CL
32	LIG CL	LIG IGCC CCS	MCFC	LIG IGCC CCS
33	NUC	NUC	NUC	LIG CL

As one can note the first scenario is a holistic one, where every of the sustainability dimensions is treated as equally important. The following three scenarios put the most of significance on economic, environmental, or social factors, respectively. More specifically, weights for certain criteria were obtained by dividing indicator group's weight by the number of indicators in that group (i. e. cardinality). For instance, the five economic indicators were attributed with uniform weights equal to according to the economic approach. The decision matrix was normalized by employing (1). Thereafter (2) was applied for the Ratio System, which enabled to rank the alternatives. The procedure was repeated for each of scenario defined in Table V.

The Table V presents the results. As one can note, renewable energy sources-based technologies were the most preferable ones according to every approach. Ranking with equal significance of every sustainability dimension (i. e. holistic approach) suggests hydro power (HYD M, HYD L, HYD S) and solar thermal (SOL TH) technologies being the most sustainable. Meanwhile, the economic approach is also related with similar technologies with exception of solar thermal energy (SOL TH) which is no longer among the most sustainable technologies. At the other end of spectrum, wood and coal CHP (CHP WOOD, CHP COAL) graduated in the technology list. The environmental approach supports solar energy, hydro energy and wood CHP. Finally, the social approach suggests hydro (HYD L, HYD M, HYD DAM), solar thermal (SOL TH), and on-shore wind (WIND ON) electricity production. The results of multi-criteria assessment indicated that conventional energy technologies (oil, gas, coal, nuclear) as the most unsustainable according targets of EU sustainable energy policy.

V. Conclusion

The main EU energy policy documents and directives implementing sustainable energy policies or priorities for energy sector development are targeting energy efficiency improvements, promotion of use of renewables, increase of security of supply and greenhouse gas and other atmospheric emission reduction. All these priority areas are related and can be addressed by the interlinked framework of indicators establishing the concrete targets for monitoring progress towards implementation of the main EU directives promoting sustainable energy development;

1) The framework of indicators for addressing the priority areas and EU targets towards achievement of sustainable energy development goals allows assessing electricity generation technologies based on sustainable energy development targets.
2) The benefit of the proposed technology assessment technique for energy sector developed on the basis of MCDA MULTIMORA allows for measurement in quantitative and qualitative terms of impacts of electricity generation technologies on the main indicators of sustainability and on sustainable energy policy targets.
3) EU policy analysis performed and the main quantitative targets are presented in the framework of indicators.
4) Based on these analyses indicators for electricity generation technologies assessment were selected and integrated sustainability indices integrating these indicators were developed. Electricity generation technologies were assessed in terms of sustainability.
5) The selected energy technologies were assessed on a basis of information gathered during the projects dedicated to the long-term assessment of these technologies conducted in EU.
6) The MULTIMOORA method was employed in order to rank electricity generation technologies based on priorities of EU energy policy.
7) The multi–criteria analysis showed that renewable energy sources-based electricity production technologies are to be preferred. To be specific, hydro and solar power systems were identified as the most sustainable, whereas wood CHP and wind power remained some positions behind. At the other end of spectrum, conventional energy technologies, namely oil, gas, coal, and nuclear power, were the most unsustainable according targets of EU sustainable energy policy development and sustainability criteria provided.

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