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Assessment of electricity generation technologies based on social costs

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***Abstract*— The aim of the paper is comparative assessment of energy technologies in power sectors based on life-cycle social costs. The main tasks are to develop the framework for comparative assessment of energy technologies based on future carbon prices imposed on economy by post-Kyoto climate change mitigation regimes. The assessment framework allows to compare power generation technologies based on social costs. The main indicators selected for technologies assessment are: private costs and external costs of GHG emissions. The ranking of energy technologies based on total social costs allows to identify the most perspective technologies in future taking into account international climate change mitigation constraints in 2020 and 2050 and to promote these technologies by specific policy tools. The main results presented in this paper were obtained during EU financed Framework 7 project "PLANETS" dealing with probabilistic long-term assessment of new energy technology scenarios. For all policy scenarios electricity generation technologies ranking in 2020 and 2050 based on external GHG costs provides the same results as the same data on life cycle GHG emissions were applied for technologies ranking. The most competetive technology according all policy scenarios based on external GHG costs in 2020 and 2050 is biomass IGCC with CO_2 capture biomass followed by other biomass technologies. Nuclear is ranked in the middle.**

Keywords: energy technologies, comparative assessment, carbon price.

I. INTRODUCTION

Climate change is the dominating environmental concern of the international environmental political discussion of today. Therefore external costs of GHG (Greenhouse gas) emissions play the major role in penetration of new energy generation technologies in the future. The aim of the paper is to assess the main relevant future electricity generation technologies by integrating price of carbon obtained by policy scenarios run using various energy models in calculating GHG emission externalities for the main future power technologies. Such comparison and ranking of energy technologies based on total social costs covering private costs of electricity generation and external costs of GHG emissions allows identifying the most perspective energy technologies seeking to implement GHG emission restrictions targets in 2020 and 2050 imposed for energy sector by possible post-Kyoto climate change mitigation regimes.

II. CARBON PRICE DEVELOPMENTS

Within EU Framework 7 project Planets [1] aiming at probabilistic long-term assessment of future energy technologies scenarios the assessment of energy technologies was performed based on carbon price development. The policy scenarios integrating various GHG emission reduction commitments and climate change mitigation targets can provide information on carbon price developments over time frame. The policy oriented assessment of the main selected power technologies in this paper will be provided for 2020 and 2050 for the 5 regions various regions (World, OECD, Energy Exporting EEX – Russia and mid-East, Developing Asia, DevAsia, Rest of the World, ROW) covered by models (ETSAP-TIAM, DEMETER, GEMINI and WITCH) [1]. 10 policy scenarios runs were performed for 4 energy models. Two first best policy scenarios: FB-3p2 and FB-3p5 setting alternative targets after 2050: 3.2 W/m2 and 3.5 W/m2. 4 second best policy scenarios were constructed: SC1-3p2; SC1-3p5; SC2-3p2; SC2-3p5.

The commitments for second best scenarios are presented in Table I. The set of 4 variant second best policy scenarios are the same as for four second best scenarios, but with a limitation on the purchasing of carbon permits between 2020 and 2050, during which period at least 80% of abatement (defined as business usual minus the allocation) has be undertaken domestically by each region, and at most 20% of the abatement can be done with international offsets (purchase of permits).

TABLE I. GHG REDUCTION COMMITMENTS APPLIED IN POLICY SCENARIOS [2]

Regions	**Starting date of commitments**	**Commitments SC1 in 2050 comparing with year 2005**	**Commitments SC2 in 2050 comparing with year 2005**
WORLD		-28%	-26%
OECD	2015	-80%	-90%
ENERGY EXPORTING (EEX)	2025	-50%	0%
DEVELOPING ASIA (Dev. Asia)	2025	+25%	0%
REST OF THE WORLD (ROW)	2025	+55%	+100%

The ranges of global carbon price in 2020 and 2050 were obtained by 10 policy scenario runs for ETSAP-TIAM, DEMETER, GEMINI and WITCH models and they are presented in Table II [3].

TABLE II. GLOBAL GHG PRICE IN 2020 AND 2050 EUR (2005)/METRIC TONNE OF $CO_{2\ EQ.}$

Fuel or energy type	2020	2050
FB-3p2 scenario	21-89	176-573
FB-3p5 scenario	13-52	89-297
SC1-3p2 scenario	3-21	107-248
SC1-3p5 scenario	3-44	110-289
SC2-3p2 scenario	3-14	110-229
SC2-3p5 scenario	3-13	110-268
VAR1-3p2scenario	0-14	111-192
VAR1-3p5 scenario	3-13	110-238
VAR2-3p2 scenario	0-13	105-164
VAR2-3p5 scenario	3-11	105-203

Further the policy oriented power and transport technologies assessment will be performed for various policy scenarios (10 scenarios) for 2020 and 2050 time frame and for various regions by calculating external costs of GHG emission using data on carbon price development over time and space obtained by various models (Table II).

III. LIFE CYCLE GHG EMISSIONS AND PRIVATE COSTS OF FUTURE ELECTRICITY GENERATION TECHNOLOGIES

Climate change is the dominating environmental concern of the international environmental political discussion of today. The range of direct GHG emissions from combustion and total life cycle GHG emissions per technology were calculated in kg/MWh. Further this data will be used for external costs calculation of power generation technologies using carbon price data (EUR/tCO2) produced by various models for various policy scenarios, regions and time frames [4] (Table III).

TABLE III. LIFE CYCLE GHG EMISSIONS OF THE MAIN ENERGY TECHNOLOGIES IN POWER SECTOR [1]

Fuel or energy type	**Direct CO_2 emissions from combustion**		**Life cycle CO_2 emissions**		**Average value, of life cycle GHG emissions kg/MWh**
	kg/GJ	**kg/MWh**	**kg/GJ**	**kg/MWh**	
Nuclear	2.5÷30.3	9÷110	2.8÷35.9	10÷130	65
Oil	126.9÷300.7	460÷1090	137.9÷331.0	500÷1200	850
Natural gas	96.6÷179.31	350÷650	110.3÷215.2	400÷780	590
Hard coal	193.1÷262.1	700÷950	206.9÷344.8	750÷1250	1000
Hard coal IGCC with CO_2 capture	*52.4÷60.7*	*190÷220*	*38.6÷46.9*	*140÷170*	*155*
Large scale wood chips combustion	-	-	21.0÷23.0	76.0÷83.3	79.6
Large scale wood chips gasification	-	-	6.0÷8.0	21.6÷29.0	25.3
Large scale biomass IGCC (Integrated gasification combine cycle) with CO_2 capture	*-139.4÷-143.5*	*-505÷-520*	*-35.9÷-41.4*	*-130÷-150*	*-140*
Large scale straw combustion	-	-	62.0÷70.0	223.2÷252	237.6
Biomass (wood chips) CHP large scale	-	-	6÷10	21.6÷36.0	28.8
Biomass (wood chips gasification) CHP small scale	-	-	3÷6	10.8÷21.6	16.2

As one can see from information provided in Table III the biomass wood chips gasification technologies have the lowest life cycle GHG emissions followed by the wood chips CHP large scale. Hard coal technologies have the highest life cycle GHG emissions followed by oil and natural gas technologies. Biomass technologies with CO_2 capture have negative life cycle GHG emissions. Especially high negative GHG emissions are during combustion processes of Biomass IGCC with CO_2 capture. The private costs in EURcnt/kWh are based on the Average Levelised Generating Costs (ALLGC) methodology [5]. (Table IV).

TABLE IV. LONG-TERM PRIVATE COSTS OF POWER GENERATION TECHNOLOGIES (2030-2050), EUR/MWH

Fuel or energy type	**Costs, EUR/MWh**		**Average private costs, EUR/MWh**
	Min	**Max**	
Nuclear	24	42	33
Oil	79	100	90
Natural gas	53	60	57
Hard coal	21	44	33
Hard coal IGCC with CO_2 capture	40	43	42
Large scale wood chips combustion	35	38	37
Large scale wood chips gasification	42	49	46
Large scale biomass IGCC with CO_2 capture	57	60	59
Large scale straw combustion	44	48	46
Biomass (wood chips) CHP large scale	37	60	49
Biomass (wood chips gasification) CHP small scale	37	60	49

As one see from information provided in Table IV the cheapest technologies in long-term perspective are: nuclear and hard coal technologies followed by large scale biomass combustion and biomass CHPs. The most expensive technologies in terms of private costs are: oil and natural gas technologies. Therefore the energy technologies having the lowest life cycle GHG emissions are not the most expensive but not the cheapest one in terms of private costs. Therefore the ranking of technologies in terms of competitiveness would highly depend on the carbon price implied by various policy scenarios integrating specific GHG emission reduction commitments taken by countries and set climate change mitigation targets.

IV. Ranking of Future Electricity Generation Technologies Based on Carbon Price Developments

The ranking of 11 main future electricity generation technologies for 2020 and 2050 based on external costs of GHG emissions and private costs for more strict first best policy scenario is presented in Fig. 1 and Fig. 2.

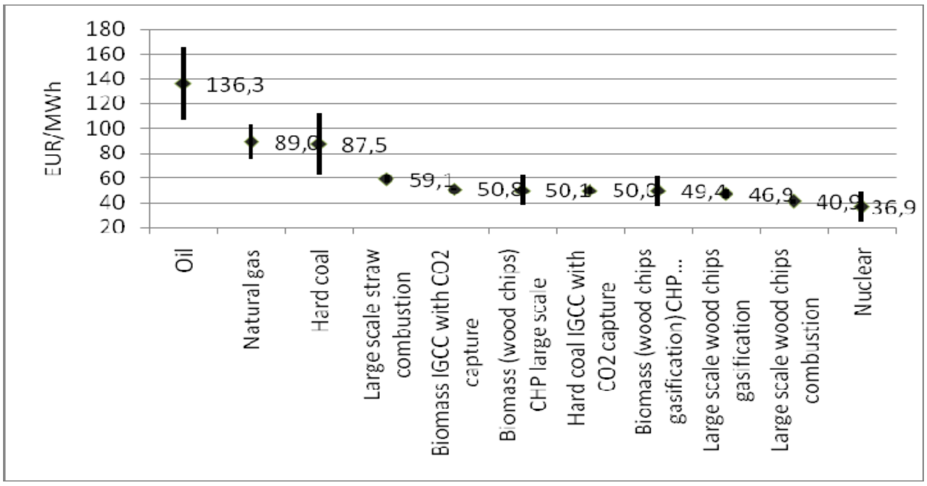

Figure 1. The range of social costs of electricity generation in 2020 according the first best policy scenario FB-3p2.

As one see from Fig. 1 because of large uncertainties related with life cycle GHG emission and private costs of power generation technologies the ranking of electricity generation technologies is quite complicated however from Fig. 1 is obvious that the best electricity generation option in 2020 is nuclear following by large scale wood chips combustion and other biomass technologies. Oil based technologies are the least attractive following natural gas and coal technologies. The most expensive biomass based technology in 2020 is large scale straw combustion technology. Hard coal with CO_2 capture technology is ranked in the same order like most biomass based technologies including biomass with CO_2 capture.

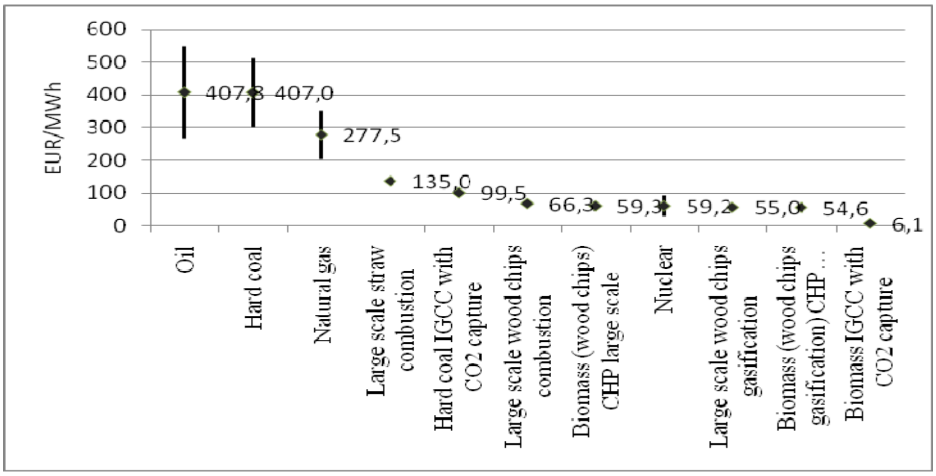

Figure 2. The range of social costs of electricity generation in 2050 according the first best policy scenario FB-3p2.

Therefore the ranking of 11 future electricity generation technologies based on total costs in 2020 and 2050 is quite different. This is related with the fact that the high carbon prices in 2050 have significant impact on technologies ranking as external costs of GHG emissions overweigh private costs of electricity generation technologies. The most competitive technologies according total costs (private and external costs of GHG emissions) in 2020 are: nuclear, large scale wood chips combustion, large scale wood chips gasification, biomass (wood chips gasification) CHP small scale, hard coal IGCC with CO_2 capture, biomass (wood chips) CHP large scale and biomass IGCC with CO_2 capture.

Total costs of these first ranked technologies are quite similar except nuclear. The less attractive technologies are: large scale straw combustion, hard coal, natural gas and oil. In 2050 the following ranking of the same electricity generation technologies based on total costs is provided: biomass IGCC with CO_2 capture, biomass (wood chips gasification) CHP small scale, large scale wood chips gasification, nuclear, biomass wood chips CHP large scale, large scale wood chips combustion, hard coal IGCC with CO_2 capture, large scale straw combustion, natural gas, hard coal and oil.

V. Conclusion

The long-term assessment of new energy technologies was performed in the paper for various long-run policy scenarios taking into account 2 main criteria: private costs (ALLGC) and external GHG emission costs. The assessment of the main selected power technologies based on external costs of GHG emissions and total costs was performed in 2020 and 2050 for the first best (FB-3p2) and second best scenarios (SC1-3p2; SC2-3p2). Scenarios with more strict targets (3.2 M/m2) were selected for technologies assessment.

11 main future electricity generation technologies were selected for technologies ranking: nuclear, oil, natural gas, hard coal including hard coal technologies with CO_2 capture and various biomass technologies (wood chips combustion, gasification, CHP, straw combustion, biomass IGCC with CO_2 capture). For all policy scenarios electricity generation technologies ranking in 2020 and 2050 based on external GHG costs provides the same results as the same data on life cycle GHG emissions were applied for technologies ranking. The most competetive technology according all policy scenarios based on external GHG costs in 2020 and 2050 is biomass IGCC with CO_2 capture biomass followed by other biomass technologies. Nuclear is ranked in the middle.

Though quite different ranking of electricity generation technologies is obtained for various scenarios and time frames the results obtained in technologies ranking based on external GHG emission costs and total costs are similar just for FB-3p2 scenario in 2050 because of very high carbon price (375 EUR/tCO_2 eq). External costs of GHG emissions in FB-3p2 scenario in 2050 overweight impact of private costs in technologies ranking.

The most expensive technology in terms of total costs for all main policy scenarios in 2020 and 2050 is oil. The most competitive technology for all scenarios in 2020 is nuclear followed by large scale wood chips combustion technologies and in 2050 - biomass IGCC with CO_2 capture followed by biomass wood chips gasification CHP small scale. The hard coal and natural gas technologies are among the most expensive for all policy scenarios. In 2050 because of the high carbon prices in all policy scenarios natural gas technologies are more competitive than coal and in 2020 coal technologies are more competitive than natural gas technologies as private costs overweight external costs of GHG emissions in comparative assessment of technologies.

The ranking of biomass technologies based on total costs is different for specific scenarios and time frames and depends on carbon price obtained by specific scenarios. Very high carbon prices make more competitive technologies having low life cycle GHG emission such as biomass IGCC with CO_2 capture and biomass wood chips gasification technologies though these technologies in terms of private costs are more expensive than other biomass technologies nevertheless the external costs of GHG emissions in high carbon price scenarios overweight the private costs in technologies ranking.

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