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[*Report (2)* on assessment methods' analysis and implementation]

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WP 11:

Report (2) on assessment methods' analysis and implementation

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Introduction

One of the three major objectives of the CASES project is to evaluate alternative policy options aiming at the internalization of external costs in the electricity sector. This objective is achieved by using appropriate assessment methods for setting up tools to be implemented in a variety of decision situations related with the internalization process.

The assessment methods considered to be the most appropriate to handle complex sustainability problems including multiple evaluation aspects are Multicriteria Decision Analysis (MCDA) and Cost-Benefit Analysis (CBA) (see D.11.1 for Guidelines on Assessment Methods). In particular, MCDA is used to develop an interactive tool for ranking alternative policy options on the basis of stakeholders' preferences (see D.11.2 for the Generic form of the MULTI-CASES tool). This tool has been used in the comparative analysis of policy instruments to produce low carbon electricity (see D.8.1) and to promote renewable energy sources (see D.9.1) with the active participation of stakeholders (see D.11.3 for the implementation of the tool and the consistency of results).

The MULTI-CASES tool was used also in the comparative evaluation of all commercially available electricity generation technologies by taking account of the degree they satisfy the social concerns reflected in the full cost estimates presented in D.6.1. This assessment procedure was also implemented in the stakeholders' workshop. Participants were namely asked to specify the relative importance of the social cost components, namely private cost and major impact categories. This policy exercise offered a valuable view on the association between MCDA and CBA and provided an alternative way of indirect monetization of non-monetized goods. Namely, the obtained technology rankings are directly comparable to those obtained on the basis of the social costs estimated in this project. Finally, an attempt is made to implement CBA for the comparative evaluation of the two sets of electricity scenarios, assuming respectively no- and full internalization of external costs (see D.1.1).

Based on the above description this deliverable consists of two parts: Part 1 presents the multicriteria ranking of technologies, identifies differences with the full cost rankings and exploits the hidden values behind the weights attached to the evaluation criteria in order to estimate the corresponding monetary equivalents of the respective non-monetized impacts. Part 2 presents the implementation of CBA in the comparative assessment of the extreme electricity scenarios constructed for all EU countries up to 2030.

1. Comparative assessment of technologies

1.1 Scoring of technologies on criteria

Full cost estimates for all commercially available technologies are obtained by summing external costs due to global warming impacts and impacts on human health, environment, crops and materials, to private generation costs [2]. The results are used to rank technologies from the cheapest to the most expensive with respect to their full social costs. The MCDA assessment procedure can provide an alternative ranking of technologies by exploiting the judgement of stakeholders for the relative importance of each particular social cost component.

External cost components are measured either in physical units (CO_2 emissions) or in monetary terms. Some additional quantitative or qualitative criteria have been added to the list in order to take account of other important decision variables not reflected in the social cost estimates. The whole list of criteria is as follows:

1. **Private cost (PR COST):** The private costs comprise investment, operation and maintenance and fuel costs and are expressed in c€/kWh. The range of values is about 25 c€/kWh, with CHP turbines being the cheapest technologies and PV panels the most expensive. The nuclear and coal/lignite technologies are generally less expensive compared to other fossil fuel technologies and most of the renewable technologies.
2. **GHG emissions (CO_2 eq):** The life cycle emissions of greenhouse gases from each technology and expressed in g/kWh of CO2 equivalents. The range of values is about 800 g/kWh, with the wind energy presenting the least emissions and lignite power plants the highest. The nuclear and other renewable technologies have generally a better performance with the exception of PVs which produce considerable emissions in other life cycle stages.
3. **External health costs (HEALTH):** They include damages to health due to emissions to air of particles, gases like NO_2, SO_2, metals and the formation of ozone. They are expressed in c€/kWh. The range of values is about 3 c€/kWh, with biogas fuel cells presenting the worst performance followed by oil condensing units and other coal condensing or CHP turbines. Wind and solar technologies have the lowest health impact, while hydro and nuclear are also very close to the minimum impact.
4. **Environmental external costs (ENV):** They include damages to ecosystems due to emissions to air, soil and water of particles, gases like NO_2, SO_2, the formation of ozone, and the emissions of metals and are expressed in c€/kWh. The range of values is here much lower (about 0.35 c€/kWh), with renewable technologies causing the least damages and biomass CHP the highest.

5. **Radionuclides external costs (RADIO):** They include damages to health due to radionuclides emissions in the life cycle of the examined technologies and are expressed in c€/kWh. Obviously, nuclear electricity has the highest cost, which is 2-3 orders of magnitude higher compared to the damage caused by most other technologies.
6. **Fatal accidents from past experience (ACC PAST):** The risk of a fatal accident using the frequency of occurrence of a severe accident in the past and the number of fatalities involved in previous accidents are depicted on this criterion. The data are derived from the ExternE project and the work done by PSI [4] and the corresponding values are expressed in fatalities/GWyear. The range of values is about 0.15 c€/kWh), with renewable technologies and nuclear energy causing the least accidents and technologies using coal the highest.
7. **Severe accidents perceived in future (ACC FUT):** The risk of severe accidents in the future is measured on a 5-level qualitative scale, where "1" denotes the poorest performance, and "5" the best performance. The distinction of technologies is the same with the previous criterion, with the only difference being the classification of nuclear and oil power plants together with coal units to the most risky technologies.
8. **Food safety risk (FOOD):** The risk that using biomass fuels will put a stress on food supply safety and food prices is taken into consideration in this criterion. A 5 level qualitative scale is utilized with "1" denoting the lowest risk and "5" the highest risk. It can be seen that all technologies receive the lowest score with the exception of the two biomass CHP units.
9. **Costs for grid connection (GRID COST):** The risk that a certain technology will induce high cost for grid connection is presented in this criterion which is measured on a 5 level qualitative scale where "1" denotes the lowest and "5" the highest cost. The worst score (5) is assigned only to the wind off-shore technology, while all technologies suitable for decentralised electricity production such as CHP and wind on-shore receive 4 and the rest of technologies 3.

Table 1 presents the evaluation matrix constructed on the basis of the above described scores. It can be seen that the main dilemma posed to energy planners and other stakeholders in the energy sector is between private costs and different external cost components. Their decision is explicitly or implicitly based on a compromise between these two major costing aspects.

Table 1: Evaluation matrix for the assessement of electricity generation technologies

Alternatives	Acr	PR COST	CO2eq	HEALTH	RADIO	ACC PAST	ACC FUT	ENV	FOOD	GRID COST
nuclear power plant	NUC	2.653	13	0.190	0.1452	0.001	4	0.015	1	3
heavy oil condensing power plant	OIL CL	7.194	208	2.390	0.0017	0.132	4	0.213	1	3
light oil gas turbine	OIL GT	9.681	435	1.853	0.0019	0.132	4	0.174	1	3
hard coal condensing power plant	COA CL	3.203	751	1.548	0.0012	0.157	4	0.186	1	3
hard coal IGCC without CO2 capture	COA IGCC	3.495	694	0.930	0.0011	0.157	4	0.105	1	3
hard coal IGCC with CO2 capture	COA IGCC CCS	4.150	154	1.042	0.0013	0.157	4	0.118	1	3
lignite condensing power plant	LIG CL	2.135	817	1.134	0.0005	0.157	4	0.130	1	3
lignite IGCC without CO2 capture	LIG IGCC	2.778	786	0.934	0.0005	0.157	4	0.094	1	3
lignite IGCC with CO2 capture	LIG IGCC CCS	3.351	106	1.051	0.0005	0.157	4	0.106	1	3
natural gas combined cycle without CO2 capture	GAS STAG	4.519	395	0.563	0.0002	0.085	2	0.077	1	3
natural gas combined cycle with CO2 capture	GAS STAG CCS	5.875	110	0.620	0.0002	0.085	2	0.086	1	3
natural gas, gas turbine	GAS GT	6.563	620	0.864	0.0002	0.085	2	0.124	1	3
hydropower, run of river 10MW	HYD S	7.229	13	0.198	0.0002	0.001	1	0.016	1	3
hydropower, run of river <100MW	HYD M	4.519	9	0.142	0.0001	0.001	1	0.011	1	3
hydropower, run of river >100MW	HYD L	4.519	8	0.127	0.0001	0.001	1	0.010	1	3
hydropower, dam (reservoir)	HYD DAM	7.350	15	0.245	0.0002	0.001	2	0.020	1	3
hydropower, pump storage	HYD PMP	7.350	14	0.251	0.0002	0.001	2	0.020	1	3
wind, on-shore	WIND ON	6.019	10	0.142	0.0005	0.001	1	0.007	1	4
wind, off-shore	WIND OFF	6.143	7	0.173	0.0004	0.001	1	0.006	1	5
solar PV, roof	PV ROOF	25.140	56	0.479	0.0022	0.001	1	0.032	1	3
solar PV, open space	PV OPEN	20.829	108	1.082	0.0028	0.001	1	0.064	1	3
solar thermal, parabolic trough	SOL TH	11.969	8	0.105	0.0002	0.001	1	0.007	1	3
natural gas CHP with extraction condensing turbine without CO2 capture	CHP GAS	4.225	366	0.527	0.0002	0.085	2	0.072	1	4
natural gas CHP with extraction condensing turbine with CO2 capture	CHP GAS CCS	5.450	101	0.574	0.0002	0.085	2	0.079	1	4
hard coal CHP with extraction condensing turbine without CO2 capture	CHP COAL	0.945	674	1.406	0.0011	0.157	4	0.167	1	4
hard coal CHP with extraction condensing turbine with CO2 capture	CHP COAL CCS	1.468	119	0.805	0.0010	0.157	4	0.092	1	4
natural gas combined cycle CHP with backpressure turbine	CHP GAS STAG	4.134	424	0.612	0.0002	0.085	2	0.083	1	4
hard coal CHP with backpressure turbine	CHP COAL BP	0.503	741	1.555	0.0012	0.157	4	0.183	1	4
biomass (straw) CHP with an extraction condensing turbine	CHP STRAW	4.751	69	1.691	0.0029	0.085	2	0.360	2	4
biomass (woodchips) CHP with an extraction condensing turbine	CHP WOOD	3.791	57	0.639	0.0028	0.085	2	0.078	2	4
MCFC (natural gas)	MCFC NG	7.300	184	1.958	0.0018	0.085	2	0.167	1	3
SOFC (natural gas)	SOFC	7.080	127	0.664	0.0005	0.085	2	0.069	1	3
MCFC (biogas)	MCFC BIO	7.824	326	3.196	0.0269	0.085	2	0.241	1	3

1.2 Multicriteria ranking of technologies

The Multi-CASES Tool was used to derive the preferences of the stakeholders participating to the CASES workshop held on April 2008. Table 2 shows the average weights derived by means of two weighting methods (RATIO method and LEVEL method, both described in D.11.3) as calculated from the individual sets of weights produced by the 30 participating stakeholders. The deviation of individual weights from these average values does not exceed 3%, although 20% of stakeholders present a mean deviation from average weights > 5%.

Table 2: Average weights of evaluation criteria

RATIO Method		**LEVEL Method**	
External health costs	19%	External health costs	16%
Private cost	17%	GHG emissions	14%
GHG emissions	16%	Private cost	14%
Environmental external costs	12%	Environmental external costs	12%
Radionuclides external costs	9%	Radionuclides external costs	10%
Costs for grid connection	9%	Food safety risk	10%
Food safety risk	8%	Severe accidents perceived in future	9%
Severe accidents perceived in future	7%	Costs for grid connection	8%
Fatal accidents from past experience	4%	Fatal accidents from past experience	7%

It can be seen that the LEVEL method produces less dispersed weights due to the different preference elicitation approach followed. However, in both weighting methods health impacts are at the top of the list with about 18%, followed by the private cost and CO_2 emissions receiving both around 15%. All other criteria receive lower weights of around 10%, with past accidents presenting the lowest weight of approximately 5%.

The average global scores calculated by using average weights are shown in Fig. 1. It can be seen that the impact of the weighting method on the global score and consequently on the final ranking of the technologies is very low, leading to no significant changes in their rank order, especially for the top and bottom ranked technologies.

One can distinguish at least three groups of technologies. The group of the best performing technologies, achieving a score higher than 0.9, includes practically all hydro units and wind on-shore. In the second best group are placed technologies with average global score between 0.8 and 0.9, among which wind off-shore, gas and nuclear units and PVs. The third group includes mostly innovative technologies using fossil fuels, and fuel cells, while the worst performing group includes conventional oil and lignite power plants, and CHP using straw or coal, all presenting a global score lower than 0.6.

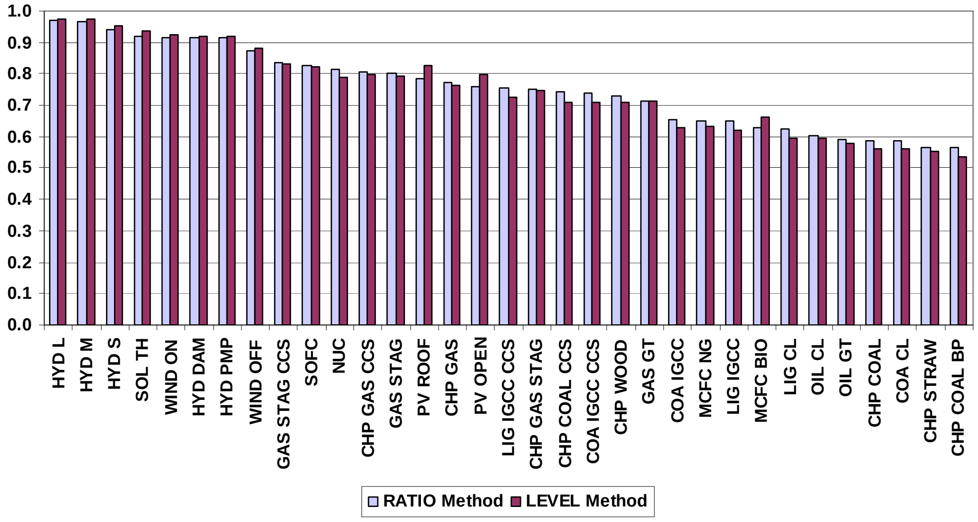

Figure 1: Average global scores of electricity generation technologies

The above classification of technologies is quite representative for the whole group of stakeholders. Fig. 2 shows for how many stakeholders a technology appeared among the top 10 and the top 5 technologies (by using the RATIO method). It can be seen that consensus is very high for most types of hydro power plants and wind on shore. On the other side, individual results can differ significantly from the average, since for example, Lignite IGCC or CHP Coal, both with CCS, are placed twice in the top 10 list, though their average ranking position was only 17 and 19, respectively.

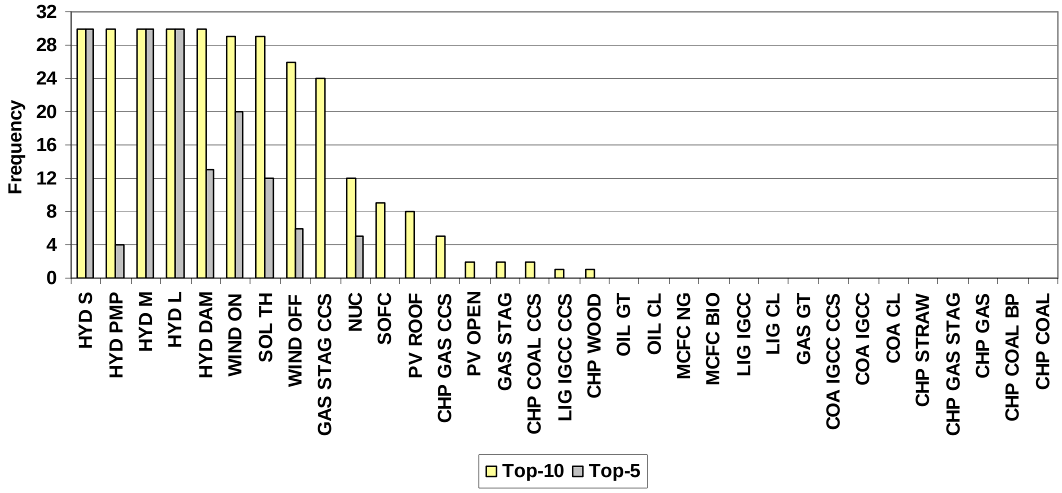

Figure 2: Number of appearances of technologies in the top 10 and top 5 places

1.3 Indirect monetization of impacts

Indirect monetization is based on the assumed equivalence of the stakeholder's relative preferences, relating the weight w_i calculated for each criterion measuring an environmental impact or other impact on non traded goods to the weight w_c of a monetary criterion (e.g. cost or profit) adequately reflecting market prices. The defined weights are considered to reflect the importance attached to the maximum improvement that can be achieved in each criterion when moving from the worst to the best score. Thus, the following identity can be assumed:

$$\frac{w_i}{IR_i} = \frac{w_c}{IR_c}$$

where, IR_i and IR_c denote the impact range (i.e. the maximum potential gain) of the physical impact i and of the cost criterion, respectively. The underlying assumption is that the value functions for all impact categories are linear, e.g. improvements in the impact level are valued the same, independent of the absolute impact level. The linearity assumption reflects neutral behaviour against risk. This is a simplifying, although a reasonable hypothesis given the limited range of impact levels under consideration. Hence, the per unit monetary equivalent of the physical impact i, mi, is calculated as:

$$m_i = \frac{IR_c \cdot w_i}{IR_i \cdot w_c}$$

It can deduced that for any pair of criteria *i/c*, the higher the ratio of weights and/or the lower the ratio of impact ranges, the higher is the per unit monetary value implicitly assigned to the physical impact *i*.

Based on the above hypothesis, the weights assigned by stakeholders during the multicriteria assessment of technologies have been further elaborated in order to reveal the hidden monetary equivalents. The analysis is restricted only to the environmental impacts taken into consideration in the full cost estimates. These criteria are measured in quantitative terms and allow for a direct comparison of the two valuation approaches [1].

The impact range of the examined criteria has been defined by excluding the most expensive technologies of PVs and Solar thermal units. It is namely considered that the impact range of 25 c€/kWh does not represent a cost difference of a realistic decision situation because of the much smaller scale of these technologies. In addition, such a cost difference could lead to extremely high monetary values for the examined environmental impacts. Table 3 shows the average monetary equivalents for each impact category, calculated by excluding the 20% of the extreme top and bottom values.

Table 3: Average monetary equivalents

Impact	RATIO Method	LEVEL Method
HEALTH	3.88	3.33
CO2eq (€/t)	120.27	119.71
ENV	23.77	24.56
PADIO	45.07	45.34

The monetary equivalent for GHG emissions is provided directly in monetary terms (€/t CO_2eq) since this criterion is measured on a physical impact scale. For the other three criteria, the calculated monetary equivalents represent a coefficient to be multiplied with the already defined monetary values. This means that for example the cost assigned to health impacts calculated through the MCDA equivalents are 3.33-3.88 times higher than the respective cost estimates defined in WP 6, depending on the weighting method used.

A general observation is that all environmental impacts have been overestimated in comparison with the value estimates shown in Table 1. This explains the obtained multicriteria rankings and the position of all renewable energy technologies on the top of the list. The calculated monetary equivalents can be used to translate the qualitative ranking shown in Fig. 1, in a quantitative ranking based on full costs. Specifically, the external cost estimates for each technology are multiplied by the corresponding monetary equivalents (or by the respective unit value in case of GHG emissions) and added to private costs. Table 4 shows the so calculated full costs in comparison with the respective social cost estimates presented in D.6.1.

Fig. 3 gives a graphical representation of the recorded deviation between the two valuation approaches.

As expected, the highest the contribution of environmental externalities to total social costs, the largest the deviation between the two valuation approaches. Thus, in most renewable energy technologies the difference in full costs is about 1 c€/kWh and reaches 3-5 c€/kWh only for the PV technologies. On the contrary, the difference becomes much higher in the technologies using fossil fuels. The deviation for the most polluting ones (conventional coal and lignite units, CHP coal) varies around 18 to 20 c€/kWh, with the MCDA costs being 4 times higher than the social cost estimates. A similarly high cost difference of 8 c€/kWh is observed in the nuclear power plant, with the MCDA estimate appearing 4 times higher than the social cost estimate, mainly because of the high monetary equivalent calculated for Radionuclides.

Table 4: Comparison of social costs (c€/kWh)

Technology type		**WP6**	**RATIO Method**	**LEVEL Method**
HYD L	hydropower, run of river >100MW	4.7	5.5	5.3
HYD M	hydropower, run of river <100MW	4.7	5.6	5.4
WIND ON	wind, on-shore	6.2	7.0	6.8
WIND OFF	wind, off-shore	6.3	7.2	7.0
HYD S	hydropower, run of river 10MW	7.5	8.8	8.5
HYD DAM	hydropower, dam (reservoir)	7.6	9.3	8.9
HYD PMP	hydropower, pump storage	7.7	9.3	8.9
CHP COAL CCS	hard coal CHP with extraction condensing turbine with CO2 capture	2.6	9.6	8.1
CHP WOOD	biomass (woodchips) CHP with an extraction condensing turbine	4.6	9.9	8.8
CHP GAS CCS	natural gas CHP with extraction condensing turbine with CO2 capture	6.3	11.9	10.7
NUC	nuclear power plant	3.0	12.0	11.1
SOL TH	solar thermal, parabolic trough	12.1	12.8	12.6
LIG IGCC CCS	lignite IGCC with CO2 capture	4.7	12.8	11.0
GAS STAG CCS	natural gas combined cycle with CO2 capture	6.8	12.8	11.5
SOFC	SOFC (natural gas)	8.1	14.0	12.7
CHP GAS	natural gas CHP with extraction condensing turbine without CO2 capture	5.6	14.3	12.4
COA IGCC CCS	hard coal IGCC with CO2 capture	5.6	14.7	12.7
GAS STAG	natural gas combined cycle without CO2 capture	6.0	15.4	13.3
CHP GAS STAG	natural gas combined cycle CHP with backpressure turbine	5.7	15.8	13.6
COA IGCC	hard coal IGCC without CO2 capture	6.0	21.5	18.0
LIG IGCC	lignite IGCC without CO2 capture	5.5	21.8	18.1
CHP COAL	hard coal CHP with extraction condensing turbine without CO2 capture	3.9	22.5	18.4
GAS GT	natural gas, gas turbine	8.9	23.5	20.3
LIG CL	lignite condensing power plant	5.1	23.6	19.4
CHP STRAW	biomass (straw) CHP with an extraction condensing turbine	7.0	23.9	20.5
MCFC NG	MCFC (natural gas)	9.8	23.9	20.6
CHP COAL BP	hard coal CHP with backpressure turbine	3.8	24.2	19.7
COA CL	hard coal condensing power plant	6.5	27.1	22.5
OIL CL	heavy oil condensing power plant	10.2	27.5	23.5
PV ROOF	solar PV, roof	25.8	29.2	28.4
PV OPEN	solar PV, open space	22.2	29.4	27.7
OIL GT	light oil gas turbine	12.6	29.9	25.9
MCFC BIO	MCFC (biogas)	12.0	35.8	30.3

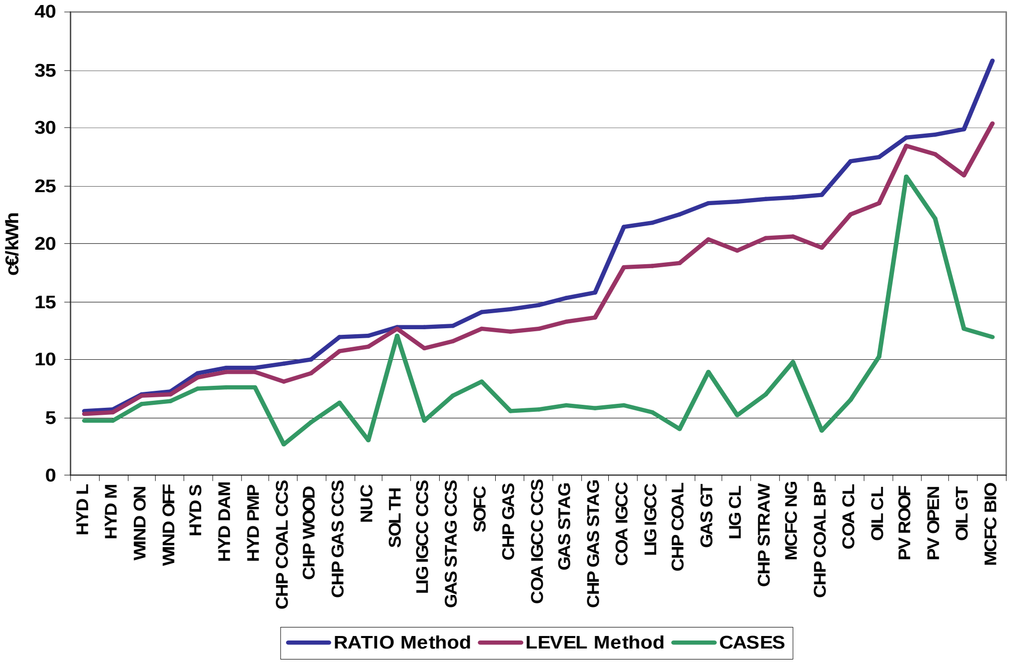

Figure 3: Range of social cost estimates of electricity generation technologies

Certainly, the degree to which the so calculated MCDA full costs reflect the values attached by society to the environmental goods affected by electricity generation is rather questionable. The defined weights are not expressing the Willingness To Pay of the respondents, mainly because they were not asked to articulate their concerns in such a scale and they have not been informed during the workshop of the translation of their preferences in a monetary scale.

It can therefore be deduced that MCDA has the capacity to act as a valuation approach, provided that it is implemented in an interactive, learning procedure giving the stakeholder the opportunity to go deeper into the decision problem and better understand the real trade-offs behind the available choices. If such a condition is satisfied, MCDA can be proved as a valuable tool for handling complex decision situations, especially at the local level, where monetary estimates for specific environmental impacts are not available or not convincing for the wider public. Moreover, in such a decision situation the active participation of stakeholders in the decision procedure is generally considered as very important for achieving a common understanding of the problem faced and a wide acceptance of the proposed solution. In these cases, MCDA and monetary valuation can be exploited in a complementary way. MCDA facilitates participation and articulation of preferences, whereas monetization can be exploited for translating preferences in a tangible and more familiar value scale that can guide the process of preference elicitation towards more realistic judgments.

2. Comparative assessment of scenarios

2.1 The scenarios

Cost-benefit analysis (CBA) aims at aggregating all costs and benefits associated with a specific policy option, the former defined as reductions and the latter as increases in human wellbeing. In the specific case study, the policy option to be assessed is the full internalisation scenario (**INTERN)** and the outcome of the assessment procedure is the degree this scenario is preferred over the base case (no-internalisation) scenario (**BASE**). In other words, one has to compare the additional investment costs C induced by the realisation of the INTERN Scenario with the resulting benefits B.

The two sets of scenarios (BASE and INTERN) have been produced in WP 1 by using the ECON model and by taking into account a number of working hypothesis about the growth of electricity demand, fuel prices, carbon cost etc. [3]. Each scenario consists of the model runs for the years 2007, 2010, 2020 and 2030. In the BASE scenario, it was assumed that the marginal production costs are equal to the private costs, while in the INTERN scenario the full social costs (private + external costs) were taken into account.

New investments are assumed to take place in 2020 and 2030, as the lead time between 2008 and 2010 is perceived to be too short to get new, not yet decided capacity. If only private costs are taken into account, as in the BASE scenario, investments on renewable energies or other less polluting generation technologies are more difficult to be realised because they can not easily compete with the less costly conventional technologies. On the contrary, investments on renewable energy sources, especially on wind energy, are expected to be higher in the INTERN scenario, because including external costs makes conventional technologies more costly. The distribution of total additional capacity in 2030 for the two scenarios in each country is presented in Table 1.

It can be seen that the INTERN scenario leads to significant shifts towards natural gas and wind energy, while new investments on hard coal/lignite are completely eliminated from the electricity mix.

As shown in Table 5, the total new capacity in the INTERN scenario in EU-27 and other member states (UK, Germany, Poland) is significantly higher. Besides the lower load factor of wind power plants, this difference is due to the extended replacement of old units in the INTERN, instead of the refurbishment assumed in BASE scenario. In such cases CBA is difficult to be implemented since the cost of refurbishment is not available, and consequently the investment cost of the INTERN scenario appears to be much higher than the cost of the BASE scenario. Moreover, it can be seen that in some other countries (France, Austria, Sweden, Denmark, Finland, Bulgaria, Slovenia) the two scenarios are identical or present very small differences in the type and capacity of included technologies, making CBA of no use. This is mainly because the difference between private and social cost of the dominant technologies is very low (nuclear or renewables).

Table 5: New capacity in the Base case and the Internalisation scenarios, 2030 (MW)

Countries	Hard Coal		Natural Gas		Nuclear		Wind	
	BASE	INTERN	BASE	INTERN	BASE	INTERN	BASE	INTERN
EU27	121,224	0	5,811	131,786	28,576	28,854	193	56,928
AUSTRIA	0	0	0	0	0	0	0	814
BELGIUM	880	0	0	25	0	0	0	1,327
BULGARIA	0	0	0	0	931	1,000	0	0
CYPRUS	729	0	16	602	0	0	0	394
CZECH REPUBLIC	2,642	0		5,489	0	0	0	0
DENMARK	0	0	0	0	0	0	0	0
ESTONIA	292	0	582	633	0	0	0	198
SPAIN	18,574	0	0	8,919	0	0	0	4,205
FRANCE	0	0	0	0	15,000	15,000	0	0
FINLAND	0	0	0	0	645	854	0	0
UNITED KINGDOM	0	0	0	3,999	7,000	7,000	193	7,193
ROMANIA	7,717	0	522	8,195	0	0	0	1,770
GERMANY	35,473	0	0	38,002	0	0	0	20,617
GREECE	2,645	0	2,041	6,139	0	0	0	1,677
HUNGARY	1,028	0	889	2,426	0	0	0	161
IRELAND	2,673	0	410	2,828	0	0	0	299
ITALY	27,920	0	0	23,849	0	0	0	6,795
LITHUANIA	1,231	0	573	1,480	0	0	0	96
LUXEMBOURG	91	0	681	1,058	0	0	0	0
LATVIA	970	0	0	776	0	0	0	191
MALTA	293	0	97	297	0	0	0	151
NETHERLANDS	8,613	0	0	4,302	0	0	0	7,380
POLAND	1,279	0	0	15,803	0	0	0	1,562
PORTUGAL	5,643	0	0	4,637	0	0	0	2,207
SLOVAKIA	2,527	0	0	2,327	0	0	0	0
SLOVENIA	0	0	0	0	0	0	0	191
SWEDEN	0	0	0	0	5,000	5,000	0	0

2.2. Costs and Benefits of scenarios

Costs and benefits are defined as follows:

C= $IC_{INTERN} - IC_{BASE}$, where IC is the investment cost for the new capacity added up to 2030 in each scenario. C> 0 means that $IC_{INTERN} > IC_{BASE}$

B= $SC_{BASE} - SC_{INTERN}$, where SC is the social cost associated with the operation of the new capacity added up to 2030 in each year (sum of fuel cost, operation & maintenance cost and external cost). B> 0 means that $SC_{BASE} > SC_{INTERN}$

Both C and B are expressed in present values, by reducing the costs and benefits realised in any year *t* up to 2030 to the year 2008 by using an appropriate discount rate *r* [2, 5]. It is clear that in order for the scenario INTERN to be preferred benefits should be higher than the respective costs, leading to a positive Net Benefit (NB):

$$NB = \left[\sum_t B_{I,t} \cdot (1+r)^{-t} - \sum_t C_{I,t} \cdot (1+r)^{-t} \right] > 0$$

Another expression of this decision rule is that the benefit to cost (B/C) ratio should exceed unity. The B/C ratio has the advantage of providing a dimensionless measure of attractiveness, irrespective of the absolute level of costs and benefits in each EU country [6, 7, 8].

$$\frac{\sum_t B_{I,t} \cdot (1+r)^{-t}}{\sum_t C_{I,t} \cdot (1+r)^{-t}} > 1$$

By considering the additional costs (C) and benefits (B) associated with the realisation of the INTERN scenario, EU countries can be classified into the following groups:

1. C > 0, B > 0: The INTERN scenario presents a higher investment cost but lower social costs.
2. C > 0, B < 0: The INTERN scenario presents a higher investment cost but social costs are also higher.
3. C < 0, B > 0: The INTERN scenario presents a lower investment cost and lower social costs.
4. C < 0, B < 0: The INTERN scenario presents a lower investment cost but higher social costs.

The classification of countries in each of the above groups depends on the specific mix of technologies included in the considered scenarios, their total capacity and the associated investment costs and social costs. Table 6 presents the classification of countries in each of the above groups.

Table 6: Classification of EU countries in Cost/benefit groups

Group 1: C>0, B>0	Group 2: C>0, B<0	Group 3: C<0, B>0	Group 4: C<0, B<0
NETHERLANDS	POLAND	ITALY	SLOVAKIA
BELGIUM	UN.KINGDOM	SPAIN	HUNGARY
ESTONIA	GERMANY	ROMANIA	
	GREECE	IRELAND	
	CZECH REPUBLIC	PORTUGAL	
	LUXEMBOURG	LATVIA	
		CYPRUS	
		MALTA	

In countries of Group 1, full internalisation of environmental externalities is expected to increase the cost of investment by at the same time creating social benefits. This is because in all three countries of this group internalisation causes a considerable shift from solid fuels to wind energy. In these three countries a meaningful B/C ratio can be calculated.

In the countries of Group 2, the INTERN scenario appears at first sight as a non cost effective option for the evolution of the electricity system, since the increased investment cost is accompanied by an increased social cost which is mainly due to the extended replacement of old coal units with a much higher capacity of natural gas which presents a significantly higher fuel cost. However, as already noticed, the cost of investment for refurbishment of old units in the BASE scenario is not taken into account, so that a reliable comparative assessment of the two scenarios is not possible.

Group 3 includes countries in which the internalisation of external costs appears as a Win-Win option. Namely, both investment costs and social costs are lower in the INTERN scenario which assumes a significant shift towards natural gas and wind energy, without considerable increases in total capacity. This means that no considerable replacement of old units takes place.

Finally, Group 4 includes two countries (Hungary and Slovakia) in which coal units are replaced by an almost equivalent capacity of gas units without any notable penetration of wind energy. This shift reduces total investment costs, by at the same time increasing social cost because of the higher cost of natural gas.

Fig. 4 shows the present value of the additional costs C ($C = IC_{INTERN} - IC_{BASE}$) induced by the realisation of the INTERN scenario, for the four groups of countries described above and displayed consecutively with a different colour for each group. It can be seen that in most countries the cost difference between the two scenarios is less than 1 billion €, with higher costs and benefits of around ± 6 billion € being found in the biggest EU countries, namely in Poland, UK and Germany and in Italy and Spain, respectively.

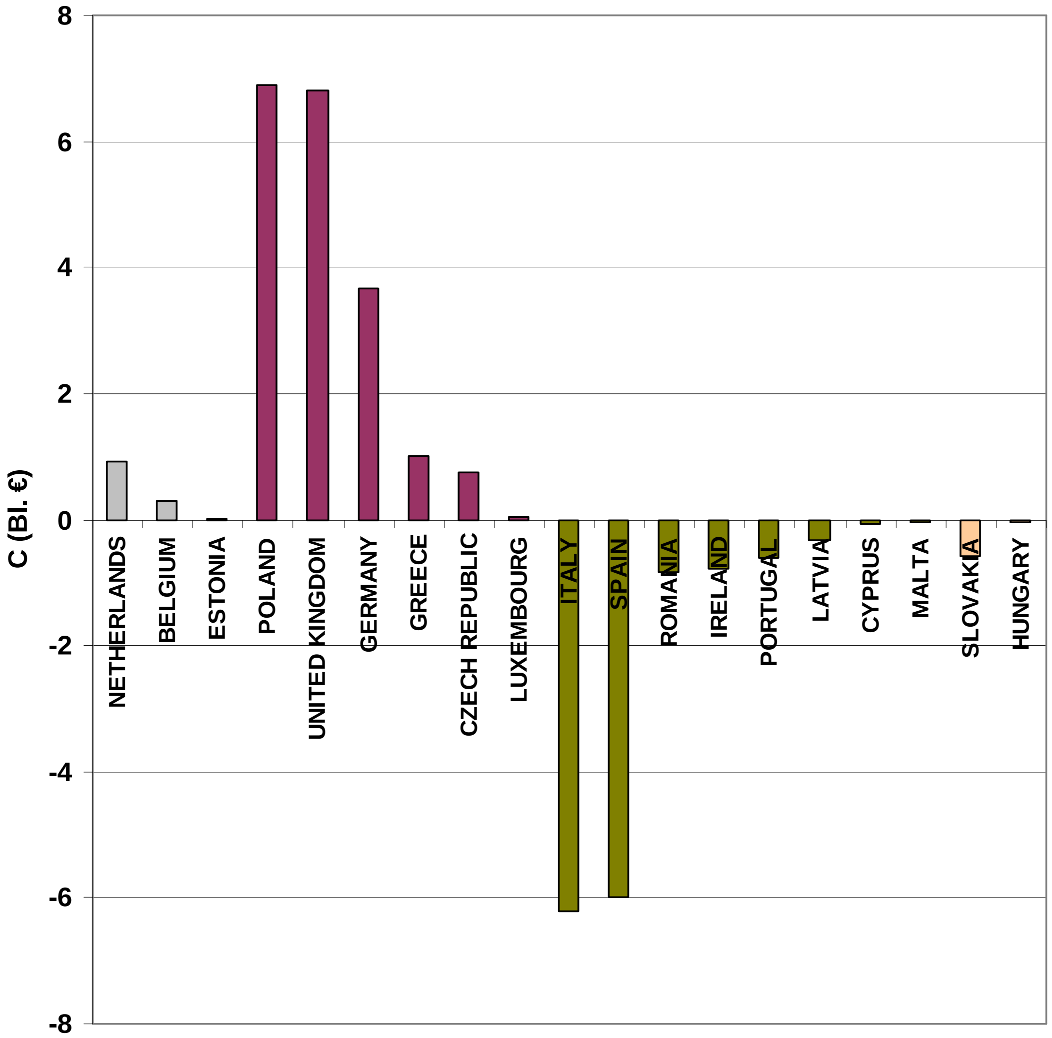

Figure 4: Range of the present value of the difference in total investment costs of the two scenarios (INTERN-BASE)

Fig. 5 shows the present value of the additional benefits B (B= SC_{BASE} – SC_{INTERN}) induced by the realisation of the INTERN scenario, for the same four groups of countries. It can be seen that the range of benefits is generally much larger, with Groups 1 and 3 presenting positive values and groups 2 and 4 negative values.

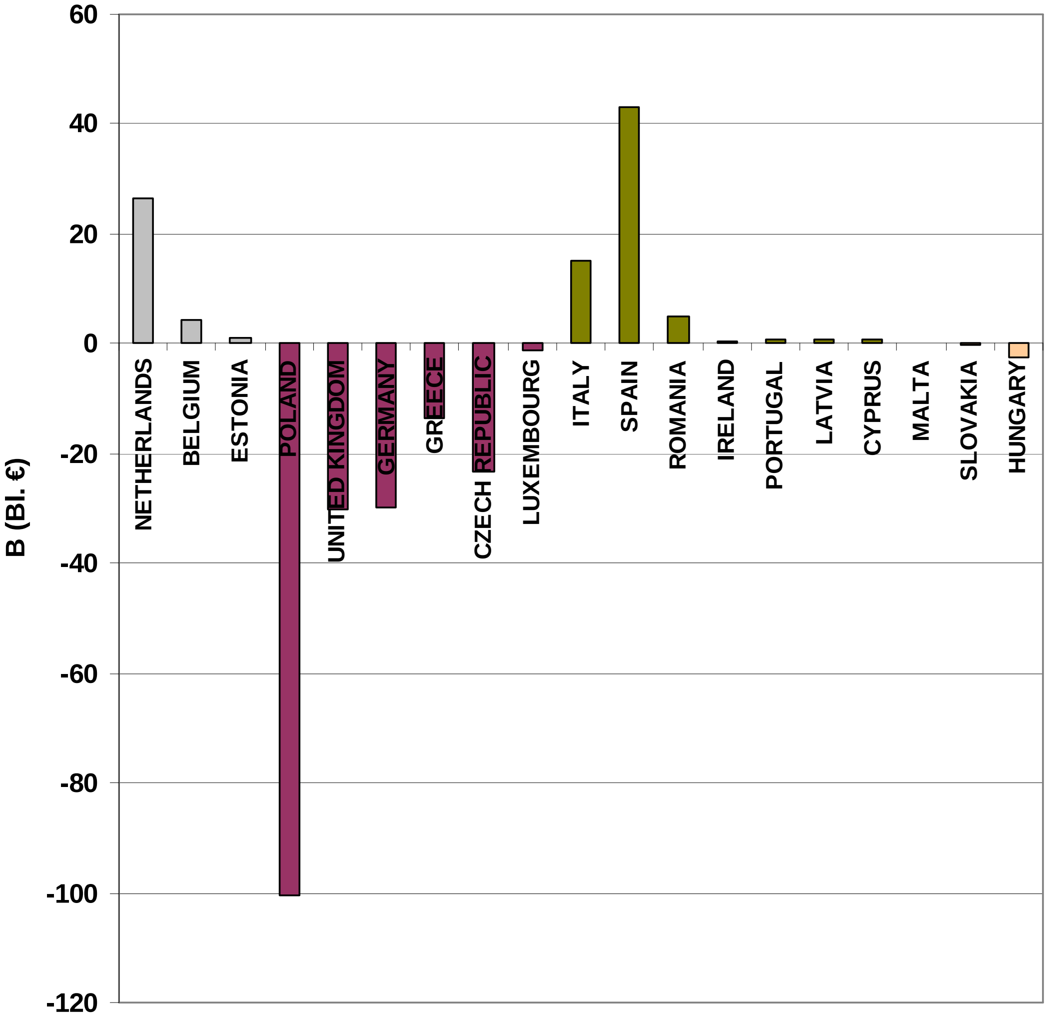

Figure 5: Range of the present value of the difference in total social costs of the two scenarios (BASE-INTERN)

Fig. 6 shows the NB index, namely the difference between benefits and costs. It can be seen that in the countries of Group 1 and 3, the realisation of the INTERN scenario results in considerable Net Benefits. On the contrary, in Group 2 and to a lesser extent in Group 4, the INTERN scenario appears as a non attractive option. It should be reminded that the results of this CBA have to be treated with great concern, since other positive or negative cost components have been ignored due to the lack of relevant data.

In addition, Table 7 shows in more detail the calculated C and B values and the so derived B/C ratios for the three countries of Group 1. It can be seen that in all three cases the B/C ratios show that the internalisation scenario is a much more attractive option for the evolution of the electricity system compared to a business as usual scenario.

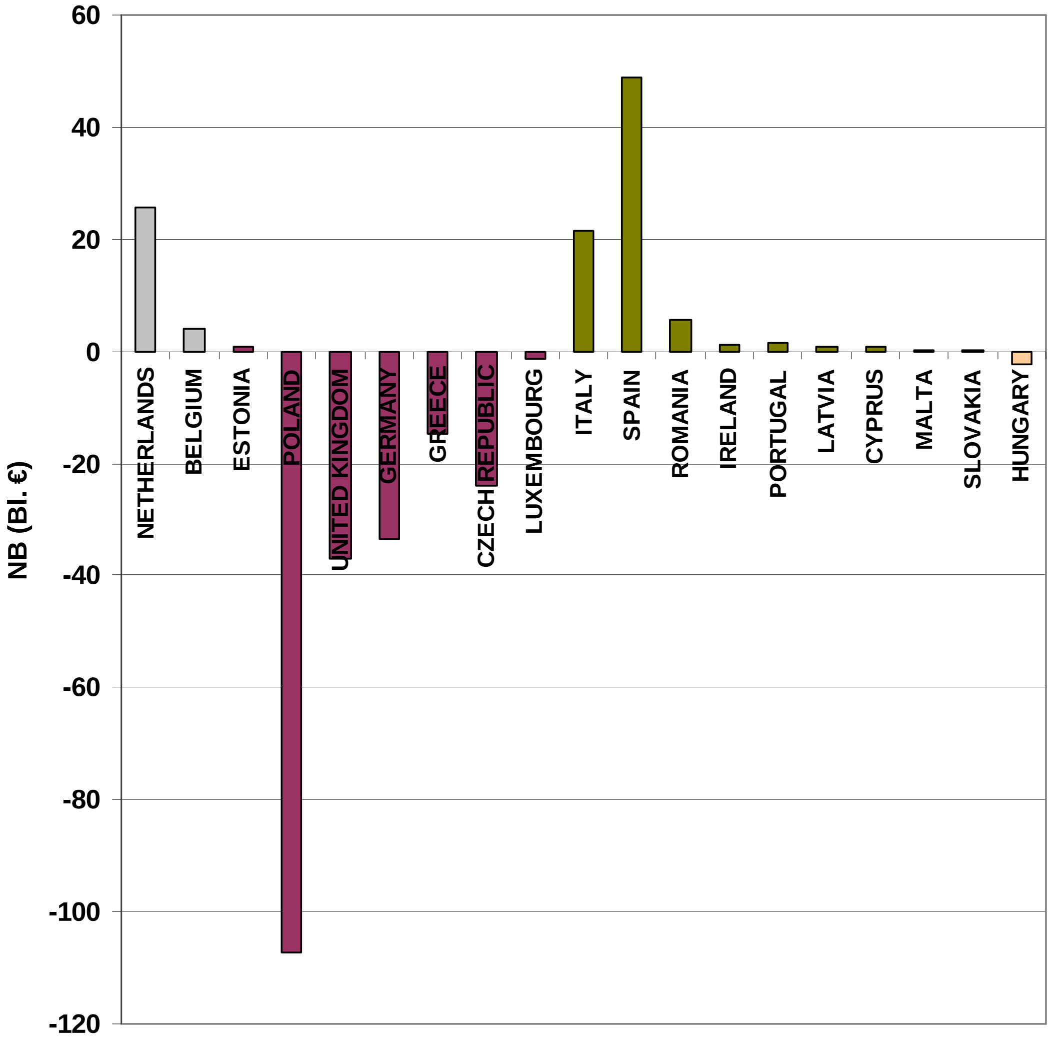

Figure 6: Range of the present value of the Net Benefits induced from the Internalisation scenario

Table 7: Data and results of CBA for three EU countries (in million €)

	NETHERLANDS	BELGIUM	ESTONIA
C	922	289	3.8
B	26,417	4,416	933
B/C	**28. 7**	**15.3**	**245.6**

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