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Assessment of external costs for electricity production in Slovenia based on the ExternE methodology

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Abstract

The ExternE methodology for the estimation of external costs due to energy production is briefly summarised. The methodology was implemented for the estimation of externalities due to thermal power plant Šoštanj (Slovenia) for the years 1994, 1998 and 2001. Results show that the estimated regional external costs are in the range of 174/118/46 mEURO/kWh for the years 1994/1998/2001, respectively (applying costs of CO_2 emissions at 18 EURO/t). The human health damages on adult population represent major part of the monetized damages due to secondary sulphate aerosols impacts and the consequently decreased expected lifetime of humans (1070/630/63 years on common European population, for the years 1994/1998/2001, respectively).

1 Introduction

The environmental pollution from energy production is a widely recognised problem. In order to quantitatively assess impacts to the environment in its wider sense, an appropriate methodology has to be used. Such is the ExternE methodology developed on the EU level in 1995 [1]. It is widely recognised that the (electrical) energy has its own price covering only production costs. Production consists of all the technological phases involved in the life cycle of the energy production such as, fuel extraction (e.g. coal mining), construction (e.g. coal mine, power plant), fuel transportation, work force expenses and costs of disposal of the waste produced (e.g., fly and bottom ash disposal, waste water treatment). All mentioned can be identified as internal costs of energy production which are generally accepted.

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On the other hand impacts on the environment, human health, buildings, materials, etc., seems not to be included in the electricity price. Therefore the so-called external costs, or externalities were introduced to evaluate economical damages to the environment in its wider sense.

It is obvious that the total costs of the energy production for society (in wider sense) consist of the internal and the external costs. The ExternE methodology can assist in the decision process of selecting energy production technology.

2 Brief description of the ExternE methodology

In order to better understand the results in this paper, a brief description of the methodology is given.

The ExternE methodology is suitable for the assessment of all possible technologies for energy production, e.g., power plants using various fossil fuels (coal, lignite, fuel oil, methane), nuclear power plants, wind driven power plants, geothermal power plants, photovoltaic power plants and waste incinerators.

The methodology uses the "bottom-up" approach (meaning phases from energy production and pathways of impacts from technologies to the environment).

Description of the life cycle, for example for the coal-fired power plant, usually consists of the phases of coal mining, limestone mining (for flue gas desulphurisation, where applicable), power plant construction, transportation of coal, ash and other wastes and power production (usually most important).

It is usually valid that emissions of flue gases have the prevailing impact to the environment (e.g., energy production phase when using coal).

The main pollutants in flue gases are SO_2, NO_x, particulate matter, heavy metals (e.g. Hg), micro-pollutants (PCDD/PCDF, PAH), CO, CO_2 (main green house gases).

In order to explain impacts of the pollutants to the environment, and the calculation procedure of the damages in monetary values, the impact pathways approach is applied. The calculation procedure is performed in four steps:

- Emissions: Inventory of all emissions must be carried out, including description of the technology for a given plant. For example, inventory of the SO_2 emissions can be reported in tons per year.
- Dispersion: For each pollutant, the air dispersion modelling is performed separately on regional (all Europe) and local scale (100 by 100 km around the plant). Result: the imission concentrations per pollutant around Europe (model cell grid 100 by 100 km) and on local scale.
- Impacts: For each regional grid cell increase in the impact is calculated from the increased concentration of the pollutant. Impacts from all the cells are added to the calculated regional impact per pollutant. The same applies for the local scale. Calculation is based on the pan-European inventory/distribution of the damage receptors. Result: quantified impacts per pollutant to the damage receptors such as humans (health effects), crops

(yield loss), materials (degradation of), forests (acid rain damage, timber loss), ecosystems (additional areas with eutrofication).

- Damages: Identified impacts have to be added to the common base. Monetization is a process of transformation of the impacts to their equivalent of estimated monetary value. The idea is to use widely accepted values of the caused harm, or to use the established "willingness to pay" principle by the society. Time shift between the pollution and the identified impact, GDP and inflation rate must also be considered (today damages will be payed later). This means that the damages get less expensive. Overall, discount rate is used (in the range from 0 to 10 %, usually 3 % is used).

Calculation pathway is from the emissions to the monetary values (damages) see on Table 1 and Figure 1.

Table 1: Examples of the identified impacts and damages to the receptors.

Receptor:	**Human health**	**Crops**	**Materials**	**Forests**	**Ecosystems**
Impact example:	increased mortality or diseases	yield loss	increased corrosion	forest dying	ecosystems damage
Damage example:	adult with chronic bronchitis = 169330 EURO (2000)	1 ton less potato = 8,2 EURO (1993)	repainting 1m^2 area = 11 EURO (1990)	timber losses (-)	critical load of nutrient nitrogen exceeded, increased damaged areas (-)

3 Estimation of the uncertainty

Uncertainty of the assessed impacts and damages has many sources, among them are:

- The original uncertainty in any input data in all calculation phases.
- Extrapolation of the laboratory data to the model environment.
- Extrapolation of the dose/response functions among the geographical locations.
- The assumptions regarding the threshold in dose/response functions.
- Missing data about the human behaviour and values.
- Political and ethical issues, especially regarding the monetary discount rates.
- Simplified scenarios for the long-term assessments.
- Some impacts cannot yet be monetary evaluated (e.g., ecosystems damage, CO_2 emissions damage, damage to the monuments, etc.).
- The uncertainty regarding completeness of the identified impacts and damages.

The overall uncertainty is considerable and must be handled with alternative methods. The usual assessments of the uncertainty intervals does not make sense, thus the assessments with the sensitivity analysis, expert opinion and decision analysis are used.

The typical example is uncertainty in the monetary value of the greenhouse gases emissions resulting in the global warming. The IPCC reports that the monetary values are somewhere in the range from 5 to 125 US $ per ton of CO_2 equivalent. Values used in ExternE studies and implementations are in the range from 3.8 to 139 EURO(1995)/t CO_2 (95 % confidence interval), restricted illustrative value between 18 and 46, other data use average value of 35 EURO (1995) /t CO_2.

4 Implementation for the TPP Šoštanj

Emissions of the pollutants from the energy production phase at the thermal power plant (TPP) Šoštanj were identified. Due to the phased construction of the flue gas desulphurisation (FGD) plants at given operational units, inventories for the year 1994 (before FGD units construction), year 1998 (about half of the flue gases were treated) and projection for the year 2001 (complete FGD on the

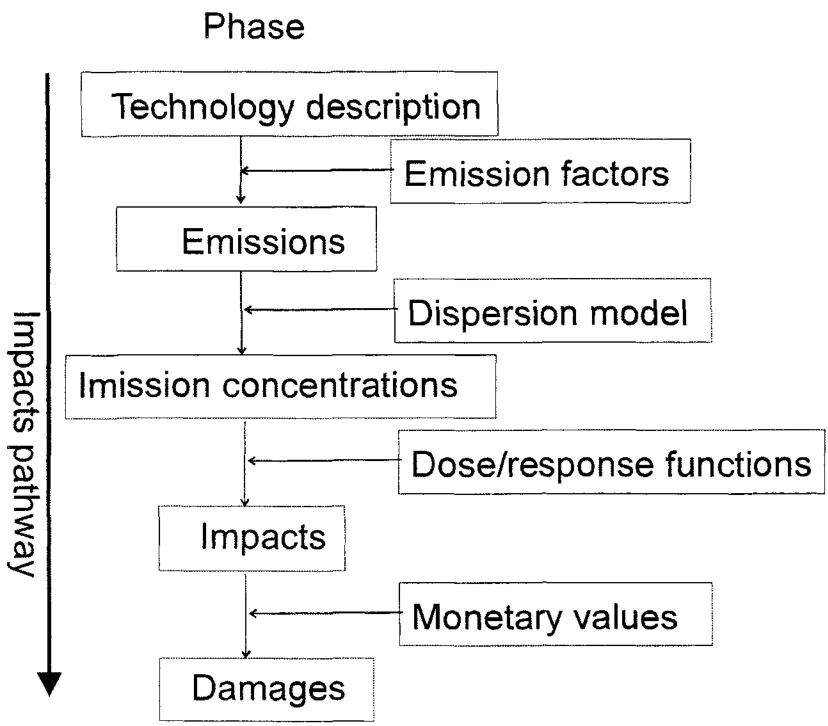

Figure 1: Scheme of the calculations pathway in the ExternE methodology.

plant). Main source of information and data about the technology and emissions was TPP Šoštanj's Annual report [2]. In this report all five units on the site were considered. Annual emissions from all five units were incorporated to one model unit considered in calculations.

Overview of the annual pollutant emissions (SO_2, particulates, NO_x, CO, CO_2), the calculated average emission concentrations, and the emission factors regarding energy produced are given in the Table 2.

Table 2: Overview of the input data regarding the pollutants emitted at the TPP Šoštanj for three model years. Projection is used for the year 2001.

		Scenario (year)		
Parameters	Unit	1994	1998	2001
El.energy produced-gen.	GWh	3237.2	3680.3	3680.3
El.energy produced-out	GWh	2913.5	3282.5	3282.5
Full load operation	hours	4324.1	4930.9	4930.9
Generator power	MW	726	742.7	742.7
Delivered power	MW	653.4	661.9	661.9
SO_2 emission	t	80516	55053	6000
SO_2 emission conc.	mg/m3	4564	2737	298.2
NO_x emission	t	9483	11963	11000
NO_x emission conc.	mg/m3	538	594.6	546.8
Particulates emission	t	4917	2316	1000
Particulates emission conc.	mg/m3	279	115	49.7
CO emisssion	t	700	734	700
CO emisssion conc.	mg/m3	40	36.5	34.8
CO_2 emission	Mt	3.234	3.822	3.8
CO_2 emission (out)	g/kWh	1110	1164	1158

5 Results

The impacts and external costs on local and regional level (Europe) for years 1994, 1998 and 2001 were calculated according to the methodology and the emission inventory. All the calculations were carried out using Ecosense 2.0 software (part of the ExternE methodology).

Some calculated results for external costs for the TPP Šoštanj are presented on Tables 3 and 4. It should be noted that only summary of the results is given. Results are presented for the base year 2000, 3 % discount rate and monetization of morbidity based on the YOLL principle (years of life lost).

From the details on the human health consequences one can analyse impacts on the sub-receptor groups (endangered groups of the humans), type of the health consequences, pollutant, dose-response function used, unit of the

Table 3: Overview of the assessed damages by receptors, for three scenarios considered.

receptor/year	Damage in mEURO/kWh					
1994	Local			Regional		
Value	low	medium	high	low	medium	high
crops	-	-6.06E-04	-	-	0.5	-
ecosystems	-	-	-	-	-	-
forests	-	-	-	-	-	-
human	1.31E-01	1.44E-01	1.56E-01	129.9	150.1	170.3
materials	-	-	-	-	-	9.0
Sum:	1.31E-01	1.43E-01	1.56E-01	133.1	**155.9**	179.3
1998	Local			Regional		
Value	low	medium	high	low	medium	high
crops		-5.25E-04		-	0.2	-
ecosystems				-	-	-
forests				-	-	-
human	1.14E-01	1.24E-01	1.36E-01	82.8	95.3	107.8
materials	-	-	-	2.0	3.3	5.6
Sum:	1.14E-01	1.24E-01	1.35E-01	84.8	**98.8**	113.4
2001	Local			Regional		
Value	low	medium	high	low	medium	high
crops	-	-5.25E-04	-	-	-0.1	-
ecosystems	-	-	-	-	-	-
forests	-	-	-	-	-	-
human	1.14E-01	1.25E-01	1.35E-01	24.0	26.6	29.2
materials	-	-	-	0.4	0.6	1.1
Sum:	1.14E-01	1.24E-01	1.35E-01	24.3	**27.1**	30.3

Note: - : monetary value unknown.

health and environmental impact and three calculated values for low, mid and high values of expected impacts and damages.

We see, that the total regional damages to the environment for year 1994 are in the range of 133/156/180 mEURO/kWh (low/medium/high value, respectively), for the year 1998 damages are in the range of 85/99/113 mEURO/kWh (low/medium/high value, respectively) and for the year 2001 damages are in the range of 24/27/30 mEURO/kWh (low/medium/high value, respectively).

The human health damages are the most important (medium value of 150 mEURO/kWh for year 1994). For the human health damages, the medium damage (adult population) is estimated at 103 mEURO/kWh (impact: reduction of the human lifetime expectancy of the total European population is 1070 years for each TWh of the energy produced). This type of health damage has the prevailing impact. We can observe that the local impacts and damages are lower

than regional, for about a factor of 1000, which is expected regarding the number of receptors.
The suggested negative damages (assumed benefits) in Table 3 on the local and regional scale from the nitrates due to the emitted NO_x need clarification: this is due to the secondary chemical reactions in the atmosphere between SO_2, NO_x in NH_3 [1]. Results in the Table 3 can be rearranged to calculate the specific damages for given pollutant emitted. For the greenhouse gases emitted, the medium monetary value of 18 EURO/t CO_2 has been applied. Results for the scenarios/year considered are presented in Table 4.

Table 4: Medium specific damages and total damages, arranged by all emitted pollutants for the three years considered. Medium damage used for the emitted CO_2 is 18 EURO/t.

year 1994

			Emission		
Pollutant	**mEURO/kWh**	**EURO**	**annual (t)**	g/kWh	**EURO/t**
SO_2	147.55	4.78E+08	80516	16.77	5932.2
NO_x	-2.28	-7.39E+06	9483	3.644	-779.7
particulates	10.58	3.43E+07	4917	0.706	6967.1
CO	0.06	1.78E+05	700	0.224	254.4
CO_2	17.98	5.82E+07	3234000	1164.2	18.0
Sum:	**173.88**	**5.63E+08**			

year 1998

			Emission		
Pollutant	**mEURO/kWh**	**EURO**	**annual (t)**	g/kWh	**EURO/t**
SO_2	87.34	2.83E+08	55053	16.77	5135.9
NO_x	7.14	2.31E+07	11963	3.644	1932.9
particulates	4.31	1.39E+07	2316	0.706	6018.0
CO	0.05	1.62E+05	734	0.224	220.2
CO_2	18.69	6.88E+07	3822000	1164.2	18.0
Sum:	**117.53**	**3.89E+08**			

year 2001

			Emission		
Pollutant	**mEURO/kWh**	**EURO**	**annual (t)**	g/kWh	**EURO/t**
SO_2	9.10	2.95E+07	6000	16.77	4910.0
NO_x	16.11	5.21E+07	11000	3.644	4740.3
particulates	1.87	6.06E+06	1000	0.706	6058.8
CO	0.05	1.55E+05	700	0.224	221.4
CO_2	18.59	6.84E+07	3800000	1164.2	18.0
Sum:	**45.71**	**1.56E+08**			

6 Comparison to the other national ExternE implementations

Majority of the EU member states has already implemented ExternE methodology for calculation of the external costs of the energy production. The presented results for the TPP Šoštanj can be compared to estimated values of the external costs from some European countries for a given pollutant [1]. Comparison is given in Table 5.
The estimated external costs for the TPP Šoštanj are comparable with the range of values obtained in the European countries. Large variations in the environmental damages between the countries are caused by the variations of the concentration of the receptors (demographic data) in the Europe. The damages are lower in the countries with less inhabitants. The areas outside the Europe were not considered.

Table 5: The comparison of the estimated specific damages between various European countries and presented case for the TPP Šoštanj.

Estimated damages due to the emitted pollutants to the air (in EURO per ton emitted)			
Country	SO_2	NO_x	Particulates
Austria	9000	9000-16800	16800
Belgium	11388-12141	11536-12296	24536-24537
Denmark	2990-4216	3280-4728	3390-6666
Finland	1027-1486	852-1388	1340-2611
France	7500-15300	10800-18000	6100-57000
Germany	1800-13688	10945-15100	19500-23415
Greece	1978-7832	1240-7798	2014-8278
Ireland	2800-5300	2750-3000	2800-5415
Italy	5700-12000	4600-13567	5700-20700
Netherlands	6205-7581	5480-6085	15006-16830
Norway	no data	no data	no data
Portugal	4960-5424	5975-6562	5565-6955
Spain	4219-9583	4651-12056	4418-20250
Sveden	2357-2810	1957-2340	2732-3840
United Kingdom	6027-10025	5736-9612	8000-22917
TPP Šoštanj (SLO)	*4900-5900*	*1900-4700*	*6000-7000*

7 Conclusions

In this paper results of applying the ExternE methodology for the estimation of the local and regional scale external costs of the energy production are presented. The ExternE methodology is used in the EU as a tool for the

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estimation of the external costs of various technologies for the energy production (fossil fuels, nuclear energy, hydropower plants, photovoltaic plants, geothermal plants, incineration facilities, etc.). The estimated external costs to the environment should be considered together with the accepted internal (direct) costs of the energy production, when considering suitability of a given technology to the society in a wider sense. The society should thus consider actual costs of production, human health damages and other damages to the environment.

The results of the assessment of the regional scale impacts on the environment and their monetary values (damages to the environment expressed as monetary equivalent recognised by the society) for the TPP Šoštanj show the following:

- The overall external damages to all the receptors are in the range (low/medium/high value, respectively) 133/156/180 (year 1994), 85/99/113 (year 1998), 24/27/30 (year 2001) mEURO for each kWh of electrical energy produced at the power plant.
- The human health damage is the most important (medium value 150/95/27 mEURO/kWh (for years 1994/1998/2001, respectively)). The change in life expectancy of adult population is estimated at 103/60.8/6.1 mEURO/kWh (impact: reduction of the expected life time of the humans on the overall European population for 1070/630/63 years for each TWh of the produced energy). This health impact is prevailing for the years 1994 and 1998. In the year 2001 the nitrates (from NO_x emission) are causing the equivalent damage, estimated at 12.5 mEURO/kWh.
- The estimated environmental damages in their wider sense are between 24 and 180 mEURO/kWh (considering all three years). Comparable values for the lignite fired power plants in the EU are in the range from 20 to 35 mEURO/kWh, meaning that specific damages (were) considerably higher. That difference can be explained by the fact that comparable units in Europe are equipped with the SO_2 and NO_x pollution abatement technologies. The comparable units have a typical emission values about 100 mg SO_2/Nm^3, 180 mg NO_x/Nm^3 and 20 mg particulates/Nm^3. Average emission concentrations at the TPP Šoštanj are reported in Table 2, and are higher than typical in the EU.
- The damages due to the emissions of the greenhouse gases were also estimated, according to the conservative low value of damages (18 EURO/t CO_2). In this case the damages due to the CO_2 emissions are estimated at about 18 to 19 mEURO/kWh.
- The overall medium damages to the environment, including damages from the greenhouse gases were estimated at about 174/118/46 mEURO/kWh (for the years 1994/1998/2001, respectively), the medium annual overall damages are estimated at the 563/389/156 Mio EURO (for years 1994/1998/2001, respectively).
- The medium specific damages per ton of the emitted pollutant are: 49000-5900 EURO/t SO_2, 1900-4700 EURO/t NO_x and 6000-7000 EURO/t particulates. These values are comparable with the range of values

estimated in the national implementations of the ExternE methodology in the EU member states.

For comparable technologies using lignite in the EU, external costs are estimated at about 20-25 mEURO/kWh [1]. We can conclude that external costs for TPP Šoštanj were considerably higher for the years 1994 and 1998, but are already at the same level for the year 2001.

In the year 2001 prevailing part of the external costs are damages from the NO_x impacts on the human health (and no more SO_2), thus possible future further reductions of the external costs should be performed by reducing these emissions.

The internal price of the electrical energy produced at the TPP Šoštanj (unofficial data) is in the range of 45 to 55 mEURO/kWh (delivered at the TPP). We can conclude that the overall costs of the energy produced, from the view of the wider society, are underestimated by a factor of 2 to 3 (for the year 2001).

We plan to extend the assessment to the entire life cycle of energy production in the TPP Šoštanj (especially waste disposal phase), and to make comparative assessment with the nuclear power plant Krško.

8 References

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