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EXTERNAL COST AS AN INDICATOR FOR SUSTAINABLE ELECTRICITY GENERATION SYSTEM

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This research applies the Impact Pathway Approach [1] for identifying the external cost for the fossil-fuel electricity production in Ukraine. Using the SimPact Computer Code and Willingness to Pay survey, it calculates the external costs of the morbidity and mortality of population due to the air pollutants emitted from an electricity generation plant using as an example Triypilska Electric Power Generation Plant in Ukrainka town. Based on the research results there were made recommendations to include the external costs into the price of electricity in Ukraine generated from the fossil fuel combustion.

INTRODUCTION

Ukraine is one of the countries where industries play the significant role in its economic developments. Among various industries, the energy sector takes an important role, to satisfy not only the demands for energy in Ukraine, but also the demands from the other European countries. However, when talking about energy production, nobody should ignore the fact that this activity is exactly the source of harmful emissions into the atmosphere.

Considerable fraction of all the emissions is being generated during the process of fossil fuel combustion, especially of coal, at fossil-fuel electricity generation stations. Today, the fossil-fuel electricity generation stations supply 45.2 percent of the total electricity in Ukraine [2], of which share is next to the nuclear power's 46.2 percent. However, the facilities and the equipments of power stations are in insufficient conditions. About 40 percent of the facilities/equipments need to be replaced because they were built in the 1950s, and their working periods have already expired [3].

The National Inventory of anthropogenic emissions in Ukraine reports that the sector of energy production emits the largest amount of greenhouse gases among the other industrial sectors [4]. Also, at the same time, the process of energy production leads to the emissions of total suspended particles (TSP), sulfur dioxide (SO_2) and nitrogen oxides (NO_x).

Total suspended particles are the air pollutants which can be divided into two types by their aerodynamic diameters: PM_{10} (aerodynamic diameter is less than 10 μm) and $PM_{2.5}$ (aerodynamic diameter is less than 2.5 μm). These particles are especially harmful to the human health because particles can penetrate the human organism, such as respiratory system, owing to their small sizes. At the same time, they cause illnesses of cardio-vascular system, which can end with mortality cases, among people who live in the industrial centers near the power stations [5].

However, the same impacts are also observed in the energy production sector of the United States and the EU countries [5–7]. These countries have already developed the methodology to assess the health impacts of air pollutions, and to evaluate the monetary values of those health impacts (damage costs), including the method to assess the values of the deaths after years from the exposures to the pollutants [8–9]. The results of those studies in the US and in the EU show that the monetary values (damage costs) of the health impacts caused by the pollutions are significantly large [1, 8]. Considering the evaluated health impacts and the damage costs in the US and in the EU, it is assumed that the processes of the energy production in Ukraine also cause the considerable size of the impacts and the damage costs, hence the external costs of human health.

IDENTIFICATION OF THE PROCEDURE

In order to identify the necessary procedure to assess the size of the health impacts and the external costs of human health in Ukraine, the following topics were investigated.

1. **External cost assessment**. The supply and utilization of energy impose risks and damages to a wide range of receptors, including human health, natural ecosystems, and the built environment. Such damages are not accounted for the costs in the decisions making on electricity generation; therefore, they are external costs [10]. The external costs of the electricity generation systems are the costs imposed on society and the environment that are not accounted for by the producers and consumers of energy, i.e. that is not included in the market price [8]. Traditional economic assessment of electricity generation systems has tended to ignore these costs.

2. **Development of the methods**. Since the early 1990s, the results of several major studies have been published on environmental impacts and resulting external costs; and, through these studies, the consistent framework for the quantification of the energy related external costs was formulated; among them there were the EC funded ExternE study [8, 11–17], the study on External Costs of Fuel Cycles of the US Department of Energy [18–25], and the New York Study [26–31].

There are two approaches used for the assessment of health impacts and the external costs of air pollutions emitted from the power plants: the top-down approach and the bottom-up approach. In the top-down approach, generic damage costs are estimated at the national level for various types of impact and are then ascribed to registered emissions of pollutants in order to determine an average external cost per unit of emission. Usually, this method requires highly aggregated data for emissions and damages they cause [32]. The bottom-up approach, known as the Impact Pathway Approach, is supposed to measure impacts of the energy generation systems through step-by-step analysis, starting from emissions and completing with economic valuation of the damages to health and environment. The procedure starts from the identification of the pollutants from the plants, the assessment of atmospheric dispersion of the pollutants, the estimation of the ground concentration of the pollutants, the estimation of various health impacts on the ground, and the estimation of the monetary values of those health impacts. Together with the US EPA guideline [33], many of the studies carried out in the US and in the EU [1, 8, 11–25] used the Impact Pathway Approach, and reported the results with the normalized monetary value of the damages, i.e. the damage cost in US dollars per unit electricity generation, US dollars/kWh, to further compare the results with the price of electricity.

Later, the methodology was published by the International Atomic Energy Agency as the guideline document [34], and also a computer code, EcoSense, was developed by Stuttgart University and used in the ExternE project of the European Commission. In the guideline document [34], it was forecasted that a simplified computer code would be developed because there had been enough number of reports published in the United States and in the European Union, to find what parameters are more influential than others. And then, the SimPact Computer Code [35] was developed. With this Computer Code, the possibility of calculating the health impacts and the damage costs of air pollution increased, also in Ukraine; however, there has not been any published report on the case study of this topic in Ukraine.

3. **Assessment of the health impacts**. The method of estimating the health impacts from the ground concentration have also been published in several major reports, including Rabl [9] and Wilson and Spengler [36]. These publications define the factors that are to be multiplied with the ground concentration levels, to get the number of the cases of different types of the health impacts. Among them, Pope et al. [5] and Dockery et al. [6] reported the positive correlations between the exposure to particles and the total mortality. And then, the methodology to estimate the mortalities several years after the exposure to the air pollutants, the long-term mortality, were developed [8].

Almost all of the currently available epidemiological studies of air pollution fall into two classifications of studies, which include:

- acute exposure studies that are typically time-series studies and use short term changes in air pollution over time (usually 1–5 days) as the source of exposure variability;
- chronic exposure studies which use longer-term pollution data (usually one year or even more) [36].

The primary pollutants from the fossil-fuel electricity generation stations are PM_{10}, SO_2 and NO_x [9], but there are also the secondary pollutants that are to be chemically transformed from the primary pollutants after the emission into the air. The SimPact Code [37] assumes that the nitrates and the sulfates are to be formulated only beyond 50 km radius from the emission source, causing different types of health impacts from those of the primary pollutants. Table 1 shows the types of the health impacts due to the air pollutants.

4. **Assessment of the damage costs**. The necessity to estimate the damage cost for the long-term mortality led to the method, including the technique to survey the people's Willingness to Pay (WTP) for the prolongation of human life [38] and the technique to calculate the unit cost of the long-term mortality, which takes into account the discount-rate for a long period from the present time [39].

The unit costs to calculate the other types of health impacts are also reported in ExternE [17]. Those unit costs such as in Rabl [9] are the values in the EU countries, but the method to estimate the country specific unit costs in non-EU countries was also reported by Markandya [40] that is included in the IAEA's SimPact Computer Code by Spadaro [35], which is called the Benefit Transfer Model that considers the ratio of the Purchasing Power Parity Gross National Product (PPP GNP) of the EU and the non-EU countries. About the unit cost of Ukraine, it is reported that the methodology developed by the US EPA and adjusted in Russia for Eastern European transition countries was used for the assessment of the air pollution costs from $PM_{2,5}$ in Ukraine [41].

5. **The Power Station**. Under the framework of this research, the assessment was performed for the Trypilska Power Station. This power station is located in Kyiv region, in Ukrainka town, which is 36 kilometers from Kyiv to the south. There are several reasons for choosing Trypilska Power Station to be a theme of this research. First of all, it is the power station with a big size of energy production capacity in Ukraine (1800 MWt), besides, it supplies energy to three regions of Ukraine: Kyiv, Zhytomyr, and Cherkasy. Secondly, according to the National report of Kyiv region in 2006, the Trypilska thermoelectric power station, which is the biggest industrial object in Kyiv region, located about in the center of Ukraine, is the main source of emissions in the whole region [42].

METHODOLOGY

As described in above section, there are two approaches used for the assessment: the top-down and the bottom-up approaches. For this study, the bottom up approach is appropriate to take, because this is the common approach used in the recent studies on the health impacts and the damage costs in the US and in the EU ([1, 8, 11–31]); and, because, by using this approach, each step of the procedure and the input data can be examined for the case study in Ukraine.

The bottom-up approach, known as the Impact Pathway Approach, is supposed to measure impacts of the electricity generation systems through step-by-step analysis, starting from emissions and completing with economic valuation of the damage costs. The main idea of the Impact Pathway Approach is a logical way of quantifying the damage costs, which results in the observation of the whole process of the electricity generation activities, emitted pollutants, their ambient concentrations and their incremental impacts on the environment and people's health, and, at last, monetary valuation of such impacts. In the case of pollutants, the approach begins with determining the quantity of emissions from a defined source, and then makes use of dispersion models and dose–response functions to determine the marginal damages resulting from the emissions. The final step consists of multiplying the marginal damages by their estimated unit monetary value. The approach is site specific and the marginal external costs obtained are in principle not transferable [32]. In order to measure impacts of fuel use on the health, the Impact Pathway Approach is being widely used in Europe and North America as the main approach of the external cost assessment.

The first step of the analysis is to identify the amount and the types of air pollutants, which are specific to the concerned power station. In this study, the primary pollutants are PM_{10}, SO_2 and NO_x, which lead to different types of morbidities and mortalities.

The second step is to measure atmospheric dispersion. The local and the regional dispersion models are used to account for all significant damages. Local domain is a territory up to 50 km around from the source of emissions, whereas regional domain covers larger territory which expands up to 1000 km from the emission source [35]. In this study, the atmospheric dispersion was calculated by two different models for these two different dispersion ranges, as shown by formulas 1 and 2. In this study, Gaussian plume model was used for estimating the ground concentrations within the local domain (up to 50 km radius), and the Uniform World Model was used within the regional domain (from 50 km to 1000 km radius) in the SimPact Computer Code [35]. The outlines of these two models are shown by formulas 1 and 2.

Simplified Gaussian plume model for the local domain of less than 50 km [35]:

$$\left.\frac{C}{Q}\right|_{\text{LOCAL}} = \left[\frac{1}{\pi u \sigma_Y \sigma_Z}\right] e^{-\left(\frac{y}{\sqrt{2}\sigma_Y}\right)^2} e^{-\left(\frac{h_E}{\sqrt{2}\sigma_Z}\right)^2}, \quad (1)$$

where, C — the concentration of pollutant in quantity per unit volume (μg/m^3); Q — the quantity emitted per unit time by a chimney stack considered to be at the origin or coordinates; σ_Z — the standard deviation of the normal distribution densities in the vertical dispersion, depends upon the atmospheric stability (m); σ_Y — standard deviation in the horizontal dispersion, depends upon the atmospheric stability (m); u — wind speed (m/s); x — distance from the source of emission (m); y — height from the ground (m); h_E — the height of the plume, not simply the stack height because hot gases usually make the plume rise even after leaving the stack, although adverse meteorological conditions can cause downwash (m).

Uniform World Model for regional domain from 50 km to about 1000 km [35]:

$$\left.\frac{C}{Q}\right|_{\text{REGIONAL}} = \left(\frac{1}{2\pi u h_{\text{MIX}}}\right)\frac{1}{r} e^{-\left(\frac{k_{\text{UNI}}}{u h_{\text{MIX}}}\right) r}, \quad (2)$$

where, h_{MIX} — a mixing layer height, in which the atmospheric dispersion occurs (m); r — radius from the emission source (m); k_{UNI} — depletion velocity (m/s); u — an average wind speed (m/s).

During this study, in order to estimate the health impacts from the air pollutants emitted from the Trypilska Power Station, the list of Exposure-Response Factors (ERF) was used, as shown in Table 1. These factors are to be multiplied by the ground concentration to calculate the health impacts. PM10 Restricted Activity Days is from ExternE 1998 [17], and the others are from Rabl 2001 [44]. The Exposure-Response Factors of these two references are based on the studies of health impacts from the air pollutions that were started after Dockery et al. 1993 [6] found the correlation between the air pollutions and the health impacts. The correlations are assumed as the linear functions.

The next step is to calculate the health impact caused by increased ambient concentrations of the pollutants [34]. Impacts are estimated by the dose-response function, also known as the concentration-response or the Exposure-Response Factor (ERF) [43]. The ERF is concerned about the quantity of the pollutant that affects a receptor (for example, population) to the physical impact on the receptor (for example, the number of the hospital admissions). It was assumed that the human body of average Ukrainian is as same as average European, and then the ERF used for the European case studies [17, 44] was used for the case study in Ukraine.

Table 1. Exposure-Response Factors to calculate the health impacts [17, 44]

Range	Health Impact	Cases/μg/m^3
Local Range (<50 km radius) and Regional Range (from 50 to about 1000 km)	PM10 long-term mortality	2.600×10^{-4}
	PM10 Chronic Bronchitis	$5,855 \times 10^{-5}$
	PM10 Restricted Activity Days	2.500×10^{-2}
	NOx Chronic Bronchitis	5.055×10^{-5}
	SO_2 Short-term Mortality	2.300×10^{-6}
	PM10 Bronchodilator Use	1.404×10^{-3}
	PM10 Lower Reparatory Symptoms	3.750×10^{-3}
Regional Range (from 50 to about 1000 km)	Nitrates Cardiovascular Hospital Admission	8.400×10^{-4}
	Sulfates Long-term Mortality	4.342×10^{-4}
	Nitrates Long-term Mortality	2.600×10^{-4}
	Sulfates Chronic Bronchitis	9.778×10^{-5}
	Nitrates Chronic Bronchitis	5.055×10^{-5}
	Nitrates Respiratory Hospital Admission	2.840×10^{-6}
	Sulfates Respiratory Hospital Admission	4.743×10^{-6}

METHOD FOR MONETERY VALUATION

The damage costs are to be calculated from the health impacts that should have been calculated in the previous step, by multiplying the unit cost of each mortality or morbidity with the number of cases of the mortality or morbidity. In this case study, the results are shown with the unit costs used in the other case studies carried out in the EU [17, 44], and with the unit costs with Ukrainian value, which were evaluated by the contingent valuation for the monetary values of the long-term mortalities, and by the Benefit Transfer Model [40] for the other health impacts. Contingent Valuation is the general expression of evaluating people's willingness to pay for their life, by setting a hypothetical market condition that doesn't exist. The estimated monetary values are to be obtained through the interview process.

For monetary valuation of the long-term mortalities caused by the air pollutions, such as PM10, nitrates and sulfates, the contingent valuation was used to assess the Willingness to Pay (WTP) and to evaluate the unit cost. This method provides the values of the environment goods, such as clean air, clean water, and quiet environment, based on the individual preferences in terms of the willingness to pay (WTP) for the improvement of the quality of the environment, or by the willingness to accept the current cost of the environment [38].

In this research, the WTP Questionnaire developed during 2005–2006 by the team of European experts headed by Rabl [38] was used. This questionnaire presents an innovative approach of the valuation because it is based directly on the change of life expectancy (LE), in contrast to the previous valuations of air pollution mortality that were based either on accidental deaths or on small changes in the probability of dying. The inquirer consists of four sections, which are developed in the form of questionnaire and also in the form of article about the correlation of life expectancy and air pollution. Thus, there is the information about negative influence of air pollution on human health and possible approaches that can decrease the level of the air pollution. Interviewees are supposed to mention the amount of money they are ready to pay for prolongation of their life on 3 and 6 months, in other words, they need to measure a value of increase in their life expectancy if air pollution is reduced. So, as a result, a value of one year of life, VOLY, can be measured.

VOLY obtained by the WTP Survey can be applicable for further calculations of the values of the unit costs, which are defined as the unit damage costs for the long-term mortality.

The Benefit Transfer Model is widely used for measurement of unit damage cost of health impacts in one country through already estimated unit damage cost of health impacts in the other country. In this research, this model was used for evaluating the damage costs of various health impacts, except the long-term mortalities. In order to estimate a damage cost, an adjustment should be made to reflect differences in real income, and hence the WTP to reduce damages, between two countries [40]. Markandya recommends the following equation (3) [40] to be used for such an adjustment:

$$\text{Unit Cost in COUNTRY} = \text{Unit Cost in EU} \times \left(\frac{\text{PPP GNP}_{\text{COUNTRY}}}{\text{PPP GNP}_{\text{EU}}} \right)^{\gamma}, \quad (3)$$

where, PPP $\text{GNP}_{\text{COUNTRY}}$ is the Purchasing Power Parity Gross National Product of the country normalized per capita, PPP GNP_{EU} is the average European Union Purchasing Power Parity Gross National Product normalized per capita, and γ is the income elasticity coefficient, which shows how the WTP value will change with the income change. As revealed by Rabl et al., if the income elasticity equals 1, the benefit transfer error is just about 36–41 % [39]. But, if income elasticity is less then 1 (e.g. 0.35, 0.40–0.60), then the transfer error is about 67–72 % [39]. In this research, it was assumed that the income elasticity is 1.

In the study, the above equation was applied for adjusting the EU unit costs to the Ukrainian unit costs. The calculated values of Ukrainian unit costs are presented in Table 2. The unit costs for the long-term mortalities by PM_{10}, nitrates and sulfates are to be estimated by the contingent valuation (WTP survey).

Table 2. Unit damage costs for European Union countries and estimated unit costs in Ukraine in $US\$_{1998}$, by the Benefit Transfer Model

Rangle	**Health Impact**	**EU**	**UKRAINE**
		Unit cost (US$/case)	Unit cost (US$/case)
Local Range (<50 km radius) and Regional Range (from 50 to about 1000 km)	PM10 long-term mortality	101 000	15 600
	PM10 Chronic Bronchitis	177 800	27 462
	PM10 Restricted Activity Days	116	18
	SO2 Short-term Mortality	174 000	26 875
	PM10 Bronchodilator Use	42	6
	PM10 Lower Reparatory Symptoms	8	1
Regional Range (from 50 to about 1000 km)	Nitrates Cardiovascular Hospital Admission	3 420	528
	Sulfates Long-term Mortality	101 000	15 600
	Nitrates Long-term Mortality	101 000	15 600
	Sulfates Chronic Bronchitis	177 800	27 462
	Nitrates Chronic Bronchitis	177 800	27 462
	Nitrates Respiratory Hospital Admission	4 540	701
	Sulfates Respiratory Hospital Admission	4 540	701
PPP GNP (1998) in US$[45]		20 269	3 130

RESULTS

1. Input data

In order to carry out an impact assessment from electricity generation at the Trypilska Power Station, the level of emissions per year in tons, meteorological data of the region, the emission data of the power station, and number of affected population were identified. This power station is located in Kyiv region, in Ukrainka town, which is 36 kilometers from the capital city, Kyiv, to the south.

Table 3 shows the level of emissions in 2006 from the Trypilska Power Station, provided by the national report about the environment in Kyiv region in 2006 [3]. The amount of the emissions of SO_2 and NO_x were identified; however, because the air-pollution monitoring in Ukraine provides only the data of Total Suspended Particles (TSP), but not the data about the level of PM_{10} . Therefore, the conversion factor was used to estimate the emission level of PM_{10}. According to the US Environmental Protection Agency [33], the ratio between TSP and PM_{10} is $PM_{10} = 0.5TSP$

Table 3. Level of emissions in 2006, Trypilska Power Station [3]

Name of the pollutant	**Emissions, tons/year**
Total	74 605 000
Metals and their compounds	22 087
Total suspended particles (TSP): PM_{10}	21 951 116 10 975 560
Nitrogen compounds	11 108 921
Sulfur oxide and other sulfur compound	40 909 568
Carbon oxide	564 363

Table 3 shows the technical characteristics of the emission source of the Trypilska Power Station.

After ground concentration is calculated, the health impact can be calculated by multiplying the ground concentration of pollutants by the value of the Exposure-Response Factor for each type of the pollutant (See Table 2).

Table 4. Technical characteristics of the emission source [4]

Parameters	**Value of parameters**
Stack height, m	180
Diameter of the stack, m	9.6
Flow rate from the stack, m/s	14
Released gas temperature, K	413

Table 5 shows the input data for calculating the ground concentrations of the pollutants by atmospheric dispersion models for the local and the regional domains. The atmospheric stability D type was assumed, as this type represents the neutral dispersion condition.

Table 5. Input data for the assessment in the atmospheric dispersion

Parameter	**Value**
Local Population Density	62.0 persons/ km^2
Radius of Local Domain	56.0 km
Regional Population Density	76.9 persons/km^2
Anemometer height	10.0 m
Air Temperature	285.5 degree K
Wind speed	2.62 m/sec
Atmospheric stability	D type

2. Willingness to Pay (WTP) survey

In order to evaluate the Willingness to Pay (WTP) for the prolongation of life for one year, the contingent valuation was carried out among Ukrainians. This research was the first time of such exploitation in Ukraine. The contingent valuation was carried out with the questionnaire developed in European Union in 2005–2006 by a team of experts headed by Ari Rabl [38]. The WTP Survey was conducted in between April and May 2008 upon 70 people in Kyiv City which is the capital of Ukraine. The aim of the research was to question Ukrainian people in order to reveal an amount of money which they are willing to pay to prolong their life. Interviews, which were carried out on one-to-one basis, in general, lasted on average about for 20 minutes. During an interview people were supposed to answer questions developed by Rabl [38] for the purpose of defining a Value of Life Year Lost (VOLY). This characteristic is especially important for the impact assessment in areas with air pollution, because it shows the amount of money in which people value one year of their life lost.

The samples were the people selected and interviewed on the streets in Kyiv, as well as the students of the National University of Kyiv-Mohyla Academy and the National Technical University «KPI». Table 6 shows the aspects of demography and socio-economics among interviewees, together with the national demography of Ukraine. This table shows that the selected samples represent the national demographic distribution of the public of Ukraine.

Table 6. Input data for the assessment in the atmospheric dispersion

<table>
<tr><th colspan="2">Aspects</th><th>Interviewees</th><th colspan="2">Ukraine Population[42]</th></tr>
<tr><td colspan="2">Number of observations</td><td>70</td><td colspan="2">48 457 000</td></tr>
<tr><td rowspan="2">Gender</td><td>Female, %</td><td>61.4</td><td colspan="2">53.7</td></tr>
<tr><td>Male, %</td><td>38.6</td><td colspan="2">46.3</td></tr>
<tr><td colspan="2">Individual’s net annual income ($ PPP)</td><td>4 510</td><td colspan="2"></td></tr>
<tr><td colspan="2" rowspan="2">Average age</td><td rowspan="2">34.04</td><td>Workable age, %
(Female:16-54/ Male:16-59)</td><td>58.0</td></tr>
<tr><td>Older than workable age, %
(Femail:55/Male:60)</td><td>23.9</td></tr>
<tr><td colspan="2">University education (%)</td><td>84.3</td><td colspan="2">31.3</td></tr>
</table>

Fig. 1 shows how the interviewed people in Kyiv are aware of air pollution and its influence on their health and the life expectancy.

Among 70 observations, 50 % of respondents replied that they are very concerned with how air pollution influences their health, 42.9 % — replied that they are somewhat concerned, 5.7 % — are not so much concerned, 0 % — is that this problem is out of their concern (not at all), 1.4 % of samples had missing answers. Therefore, it is obvious to conclude that about 90 % of people are concerned with the impact of air pollution in their living area.

The next step was to identify how many people are ready to accept a higher cost of living, therefore an increase in their daily expenses, to gain an increase in their life expectancy. It was revealed that 9 people were negative about such increase of expenses, two of them were not interested in living longer, two were negative because they believed that someone else should pay for better environment, and other five refused such a scenario of link between air pollution and life expectancy.

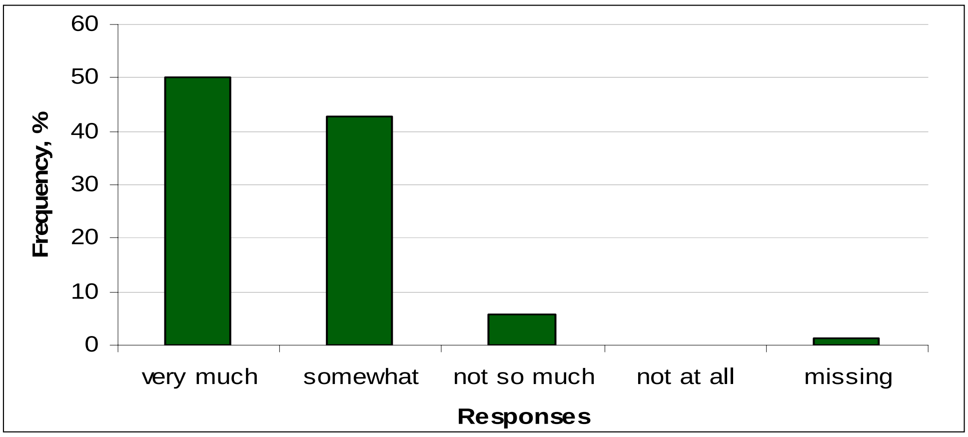

Fig. 1. Responses to Question: Are you concerned with the effects of air pollution on your health?

Out of 61 left observations, 17 samples were identified as defectives, because the willingness to pay for one year of life prolongation derived from 6 month gain and 3 month gain were not in the expected rational order. Therefore, the final VOLY for one year of life prolongation was calculated with 44 samples, from the willingness to pay for 6 month gain in life expectancy multiplied by two.

The results of this WTP survey showed that the average number of VOLY is 790 US dollars. According to the equation (4) below [39], the Value of Statistical Life (VSL), can be calculated, on the basis of which a unit cost for long-term mortality cases is measured,

$$VSL = V + \frac{V}{1+r} + \frac{V}{(1+r)^2} + \ldots + \frac{V}{(1+r)^N}, \qquad (4)$$

where, V is a value of one year of life lost, VOLY. r is a discount rate, because it is assumed that the VOLY will become smaller every year when seeing one's willingness to pay in one's own future at the present time. 3 percent was chosen for this calculation, as practiced in the precedent studies. N is the number of the years of a statistical human life. 37.5 years were chosen as N in this calculation, while 37 years were assumed as the total length of human life, and it was assumed that the a half of the total life length was the average life length left for the purpose of calculating the value of life after the exposure to the pollutions.

The calculated unit cost for the long-term mortality was 18.264 US dollars, and then 18.000 US dollars was chosen to calculate the damage costs of the chronic mortalities to be caused by the air pollutions from the Trypilska Power Station.

3. Damage cost

Table 8 shows the calculated numbers of the health impacts from energy production at the Trypilska Power Station in the local domain, which has a radius of less than 50 kilometers, and in the regional domain, which covers a territory with a radius up to about 1000 kilometers, and which covers most of the territory of Ukraine.

In the calculation for the local domain, the uniform wind direction, the uniform population density of 61.8 persons/km^2 for 50 km radius, and weighted average wind speed of 2.62 m/sec uniformly over all directions were assumed. For the regional domain, the population density assumed was 76.9 persons/km^2. The impact assessment in regional domain also includes the impact of secondary chemical transformations of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), as shown as sulfates and nitrates respectively in Table 7.

Table 7. The distribution of health impacts in local and regional domains by SimPact Code

Pollutant	**Health impact**	**cases/one year exposure**	
		Local domain	**Regional domain**
PM_{10}	Long-term mortality	14.300	954
	Chronic bronchitis	3.220	215
	Restricted Activity Days	1 374.000	91 690
	Bronchodilator use	77.200	5 149
	Lower Respiratory Symptoms	205.000	13 700
SO_2	Short-term mortality	0.471	29
Sulfates	Long-term mortality	–	2 504
	Chronic bronchitis	–	564
	Respiratory hospital admission	–	27
Nitrates	Cardiovascular hospital admission	–	32
	Long-term mortality	–	992
	Chronic bronchitis	–	193
	Respiratory hospital admission	–	11

As a result, the health impact in regional domain is higher than in local domain, because regional population density is higher than local one, and the area of the regional domain is larger.

In order to assess the external cost of air pollution due to the electricity generation, the total damage costs were calculated. Assessment was made with the European Union's unit damage costs for health impacts and Ukrainian unit damage costs shown in Table 2.

The calculated total damage costs of the air pollution at the Trypilska Power Station are presented in Table 8.

Table 8. Total damage cost, caused by air pollution from the Trypilska Power Station, Ukrainka, Ukraine

Pollutant	**Damage cost, 1000 US $**					
	With EU unit costs			**With Ukrainian unit costs**		
	Local domain	Regional domain	Total	Local domain	Regional domain	Total
PM_{10}	2 179	145 456	147 635	371	24 760	25 130
SO_2	82	4 983	5 065	13	770	782
Nitrates	–	134 649	134 649	–	23 180	23 180
Sulfates	–	353 324	353 324	–	60 570	60 570
TOTAL			640 673			109 662

If European unit costs are used for the calculations, the total damage cost from Trypilska Power Station is about 641 million US dollars. If the Ukrainian unit costs are used, the total damage cost is six times smaller than with European ones, and equals to about 110 million US dollars. While comparing the results of damage cost assessment separately for each pollutant, it is noticeable that damage costs of PM10 in local domain and sulfates in regional domain are bigger than the others in each domain; in the other words, PM10 and sulfates have more negative influence on human health, and, as a result, their damage costs are higher.

The average annual electricity generation at the Trypilska Power Station is 1.80 TWh [82]. Hence, a total damage cost per kilowatt-hour of electricity generation at Trypilska Power Station was calculated. Table 9 shows the damage costs per kilowatt-hour with the unit costs of the European Union and of Ukraine.

Table 9. Total damage cost per kilowatt-hour of electricity generation at the Trypilska Power Station

		Lokal	Regional	Total
Damage cost per kilowatt-hour, mUSD/kWh	EU	1.26	355	356
	Ukraine	0.213	60.7	60.9

To compare with the electricity price in Ukraine, damage cost per kilowatt-hour of electricity generation in US dollars was converted to Ukrainian national currency, Ukrainian Hryvnya (UAH), in Table 10.

Table 10. Total damage cost per kilowatt-hour of electricity generation in UAH

	With EU unit cost	With Ukrainian unit cost
Damage cost per kilowatt-hour, mUSD/kWh	1.78	0.30

There is no doubt about this amount of money to be the external cost of electricity generation in Ukraine; because, the sum of money is not included in the price of electricity, and at the same time, the people affected by the air pollution from the electricity generation do not receive any compensation for the health impacts. Nowadays, Joint Stock Company «Kyivenergo» has fixed the average weighted tariff of electricity for consumers in the total amount of 0.2872 UAH/kWh [46]. However, it does not necessarily mean that the amount of the external costs obtained during this research should be added to the current price of electricity. On a contrary, policy makers in Ukraine should take into consideration the estimated external costs. And, it is necessary to find possible ways to reduce and/or internalize the external cost into the price mechanism of the electricity.

As shown above, the assessment of damage cost of the impact of the fossil-fuel electricity generation station was able to be made, using the recently developed method of monetary valuation of health impacts. There is an internationally practiced method, the Benefit Transfer Model, to transfer the values of the EU to non-EU countries including Ukraine, using the ratio of PPP GNP between the EU and non-EU countries. Also, the method to evaluate the people's willingness to pay for prolonging their life was examined in Ukraine, and compared to the calculated unit cost by the Benefit Transfer Model. While the unit cost evaluated from the interview surveys on the people's willingness to pay for prolonging one year of life is 18,000 US dollars, the unit cost calculated by the PPP GNP ratio of the EU and Ukraine is 15,600 US dollars, which are comparable to each other.

CONCLUSIONS

Upon the results of the case study in Ukraine, the followings are concluded, and the direction of the future research is identified:

1. The externality study appeared in Europe and the United States in the 1990s as a result of existing problem of negative influence onto the human health,

natural environment, and built environment of air pollution from energy production. Since 1996, the ExternE project of the European Commission started the external cost assessment widely in the countries of the European Union. Unfortunately, in Ukraine this type of project had not been implemented.

2. The Impact Pathway Approach is the bottom-up method, which is to assess the impacts of electricity generation systems through step-by-step analysis, starting from emissions and completing with monetary valuation of the damages. It is a logical way of external cost assessment, which accounts the emitted pollutants and their ambient concentration, the impacts on human health, and their monetary values.

3. The Willingness to Pay Survey carried out among Kyiv citizens defined that Ukrainians estimate the value of life loss (VOLY) in the amount of 790 US dollars.

4. Calculation of health impacts and damage costs of air pollution from electricity generation at Trypilska Power Station in Ukrainka town were obtained, with the SimPacts Compute Code. These impacts and the damage costs were calculated in the local domain (up to 50 km radius) and in the regional domain (up to about 1000 km).

5. The damage cost of health impacts estimated by the EU unit costs is ten times larger than with the Ukrainian.

6. The estimated damage costs per kilowatt-hour of electricity generation is 360 mUSD/kWh and 61 mUSD/kWh by the EU unit cost and by the Ukrainian unit cost respectively. In comparison with the current electricity price in Ukraine, 57.6 mUSD/kWh or 0.2879 UAH/kWh (assuming 1 USD (dollars) = 5 UAH), it is concluded that the estimated external cost of the health impacts is sizable, in comparison with the price of electricity.

7. As shown above, the assessment of damage cost of the fossil-fuel electricity generation station was able to be made, using the recently developed method of monetary valuation of health impacts. There is an internationally practiced method, the Benefit Transfer Model, to transfer the value of the EU to non-EU countries including Ukraine, using the PPP GNP ratio between the EU and non-EU countries. Also, the method to evaluate the people's willingness to pay for prolonging their life was examined in Ukraine, and compared to the unit cost calculated by the Benefit Transfer Model. While the unit cost evaluated from the interview surveys on the people's willingness to pay for prolonging one year of life is 18 000 US dollars, the unit cost calculated by the PPP GNPs of the EU and Ukraine is 15 600 US dollars.

8. The estimated damage costs of Ukraine are the external cost that are not included in the price of electricity, and the people affected by the air pollution do not receive any compensation for the health impacts. The policy makers in Ukraine should take into consideration the estimated external costs and should find possible ways to reduce and/or internalize the external costs in the price mechanism.

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