# ASSESSMENT OF EXTERNAL COST AS AN AGGREGATED INDICATOR OF SUSTAINABLE INDUSTRIAL DEVELOPMENT - AIR POLLUTION CASE STUDY IN UKRAINE

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## INTRODUCTION

The size of the Gross Domestic Production (hereinafter, "GDP") is not the sole indicator for measuring the richness of a nation, because it doesn't reflect the costs to public welfare, human health and environment as well as the other various costs that the macro-economy pays elsewhere within a nation such as energy security cost. In microeconomics theory, these unaccounted costs are called "external costs". Traditional economic assessment of industrial development has tended to ignore these costs. However, when the government plans and promotes the industrial development, it is necessary to account all those different costs for decision making [1-4].

This study focuses on the impacts to the human health that are caused by air pollutions from the industrial activities. As possibilities, various indicators can be used for showing the degree of health impacts [2]. In general, there might well be several pathways and end points that result from any emissions. These end points are indicators of impacts. In this connection, the indicators selected may depend on the choice of methodologies. As many impact indicators are selected, the process of comparison becomes complex. Therefore, a preferred approach is to choose priority impacts on which to focus comparisons [2].

Primary indicators of the impacts are estimates of the specific effects themselves, such as increased mortality rate and increased rates of respiratory illness. Other indicators are often informative surrogates for these effects, particularly when they are difficult to estimate directly. The magnitude of pollutant emission (and of other types of burdens) is one type of indirect indicator (e.g., tons of sulfur dioxide emitted). However, it must be recognized that indirect indicators are shown to be a good surrogate only in particular situation and cannot be used generally [2].

When Y. Matsuki [1] organized the Coordinated Research Program on Health and Environmental Impacts of Nuclear and Other Energy Systems at the International Atomic Energy Agency between 1994 and 2000, involving 12 research institutes such as Oak Ridge National Laboratory, Kruchatov Institute, Ecole des Mine and Stuttgart University, there was a discussion regarding aggregated health indicators. While there was no consensus on which to use, "years of life lost" was becoming a commonly used indicator for mortality impacts, and "lost working person-days" for morbidity impacts [2].

Some analysts supported more aggregated indicators, such as an integrated health index. Other analysis opposed this approach because detailed information would be lost through the aggregation process. There was also discussion of the validity of an indicator derived by monetary valuation. One viewpoint was that only things that can be bought or sold have an economic value. Another was that monetary valuation was synonymous to the use of weighting factors (i.e. making trade-offs) [1, 2].

Regardless, monetary valuation is appropriate when the decision process for which the study is being done requires it (e.g., for cost internalization into the market price through public policy tools such as excise tax and insurance) and when valid monetary values can be identified as the impact indicators [2].

One problem with monetary valuation is that it is difficult to place a monetary value on everything. An example is the bio-diversity issue, such as disturbing the habitat of a rare bird. Another example is that of using currency values for the impacts in different countries with different economic situations and social values [2].

Among several different types of methodologies such as life-cycle analysis, life-cycle costing, and ecological risk analysis [2, 3], the methodology taken in this study is the Impact Pathway Approach (see Fig 1, [2]), which gives transparency of assessment process and which many studies in the US and in the EU followed [5-26]. This methodology is indicated in a guideline document that Y. Matsuki published at the International Atomic Energy Agency [3]. First, the path of events beginning with various activities in the industries is tracked. Second, the emissions and changes in the ambient concentrations of the pollutants are assessed. Finally the incremental impacts that result from these concentrations are evaluated. In addition, many studies also estimate the costs of these impacts. In case of electricity generation systems, the results are presented 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 industrial products such as electricity [4].

In defining an impact pathway, analysts have to distinguish between various terms – emissions, concentrations, impacts, damages, and the degree of "external cost" (see Table-1 [2]). Emissions are the discharges from industrial plants. Interpreted broadly, emissions include any residual effect such as noise (e.g., from wind turbines), the existence of a power plant where there was none before, or change in erosion (as a result of change in land use). With many pollutants, their emissions undergo chemical reactions or are dispersed from the source of emission to neighboring and far away places. This dispersion changes the concentrations of pollutants relative to their levels without the industrial activities. Populations, ecosystems, and infrastructure (such as buildings and roads) that become exposed to these changes in pollutants may be at great risk of certain damaging impacts [2].

These impacts can, in many cases, be expressed in economic terms. One is "damage", and another is "externality". Damage is the full economic cost associated with a physical impact. In some cases, the damages are not reflected in the market of the industrial products. In such cases, they are considered as external costs or "externalities". Therefore, a portion of damage is the externality. The size of that portion depends on the extent to which market, insurance, and regulatory conditions explicitly account for the damages. For example, the damages from $SO_2$ emissions in the Impact Pathway Approach include the economic values of the expected increase in morbidity and mortality. In cases where $SO_2$ emission permits can be traded, some portion of the damages is internalized, so the portion which is not internalized is the externality. However, in region without ways of internalizing the damages, the externality equals the damage [2].

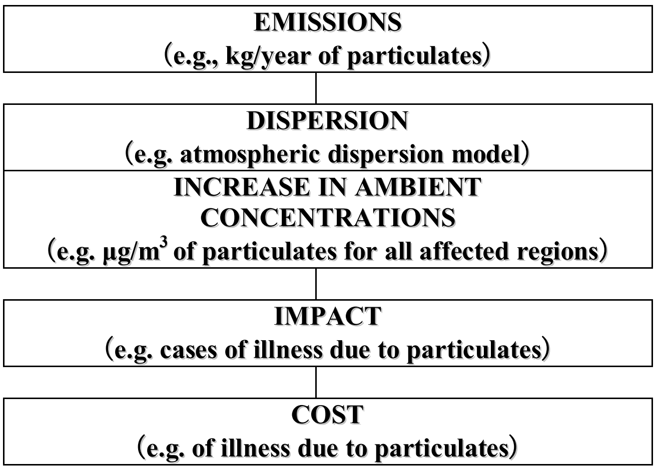


*Fig 1 Flow chart of Impact Pathway Approach [3]*

Table 1 Distinguishing the terms [2]

| Emission or discharge | Change in concentration | Impact | Damage Cost | External Cost |
|---|---|---|---|---|
| $CO_2$ | Increased concentration of $CO_2$ in the atmosphere. | Estimates of impacts are imprecise but thought to include changes in coastal ecosystems and in the built environment; changes in agriculture production, and possible starvation due to increased frequency of floods and droughts. | Economic value of the impacts. | In most countries, none of the damages are internalized; thus, all of the damages are externalities. In the countries who have ratified Kyoto Protocol, with trading of $CO_2$ emissions permits, an indeterminate portion of the damages is internalized. |
| $SO_2$ | Formation and dispersion of sulfates, for example. | Increased risk of morbidity and mortality from respiratory problems due to inhalation of sulfates. | Economic value of the expected increase in morbidity and/or mortality. This value includes decreased, or lost, quality of life –not just medical costs and lost wages or productivity. | In regions without internalization of these damages, the externality equals the damage. In the US, with trading of $SO_2$ emissions permits, an indeterminate portion of the damages is internalized. |
| Radio- nuclides in the event of a nuclear power plant accident. | Changes in concentrations of these radio-nuclides could extend for thousands of kilometers. | Increased risk of mortality and morbidity from certain cancers. | Economic value of the expected increase in cancers. | A portion of damages is internalized, for example, in the US through the Price-Anderson Act. |
| Noise from wind turbines. | Changes in noise levels at locations near the wind farm. | Undesirable effects on auditory senses. | Individuals express a willingness to pay to avoid noise, for example through real estate prices of land near the site. | All of these economic damages are externalities because there is not any market mechanism that internalizes them. |
| Reduced flow of a waterfall caused by hydro dam. | Reduced flow of a waterfall caused by hydro dam (same as the 'discharge'). | Reduced visual aesthetics of the waterfall. | Economic value of the reduced aesthetics, as estimated for example in a contingent valuation study of Individual's willingness to pay. | None of the damage is internalized; thus all of the damages are externalities. |

Source: Matsuki Y., Lee R.[2]

In line with the guideline document on the Impact Pathway Approach [3], many analysts in the EU use a computer code, EcoSense, developed by Stuttgart University and used in the ExternE project of the European Commission. However, this computer code requires extensive input data that are not available in the developing world. Under this situation, in the guideline document [3], 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 [27] was developed. With this Computer Code, the possibility of calculating the health impacts and the damage costs of air pollution increased for the case studies of the regions where enough meteorological data are not available such as in Ukraine.

## METHODOLOGY

The first step of the analysis is to identify the amount and the types of air pollutants, which are specific to the concerned industrial plant. 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. 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 [27]. 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]:

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

where, C – the concentration of pollutant in quantity per unit volume ($\mu g/m^3$);

Q – the quantity emitted per unit time by a chimney stack considered to be at the origin or coordinates;

$\sigma_z$ – the standard deviation of the normal distribution densities in the vertical dispersion, depends upon the atmospheric stability and the down wind distance (m);

$\sigma_y$ – standard deviation in the horizontal dispersion, depends upon the atmospheric stability and the down wind distance (m),

u – wind speed (m/s);

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]^

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

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).

The third step is to estimate the health impacts from the ground concentrations of the air pollutants emitted from the emission source, which are to be obtained at the second step shown above. On this step, the list of Exposure-Response Factors (ERF) is used, as shown in Table 2. These factors are to be multiplied by the ground concentration to calculate the health impacts.

**Table 2** Exposure-Response Factors to calculate the health impacts [12, 28]

| | **Health Impact** | **Cases/µg/m³** |
|---|---|---|
| Local Range (<50 km radius) and Regional Range (from 50 to about 1000 km) | $PM_{10}$ long-term mortality | $2.600 \times 10^{-4}$ |
| | $PM_{10}$ Chronic Bronchitis | $5,855 \times 10^{-5}$ |
| | $PM_{10}$ Restricted Activity Days | $2.500 \times 10^{-2}$ |
| | $SO_2$ Short-term Mortality | $2.300 \times 10^{-6}$ |
| | $PM_{10}$ Bronchodilator Use | $1.404 \times 10^{-3}$ |
| | $PM_{10}$ Lower Reparatory Symptoms | $3.750 \times 10^{-3}$ |
| Regional Range (from 50 to about 1000 km) | Nitrates Cardiovascular Hospital Admission | $8.400 \times 10^{-4}$ |
| | Sulfates Long-term Mortality | $4.342 \times 10^{-4}$ |
| | Nitrates Long-term Mortality | $2.600 \times 10^{-4}$ |
| | Sulfates Chronic Bronchitis | $9.778 \times 10^{-5}$ |
| | Nitrates Chronic Bronchitis | $5.055 \times 10^{-5}$ |
| | Nitrates Respiratory Hospital Admission | $2.840 \times 10^{-6}$ |
| | Sulfates Respiratory Hospital Admission | $4.743 \times 10^{-6}$ |

Note: Table 2 is based on ExternE 1998 [12] and Rabl 2001 [28]. $PM_{10}$ Restricted Activity Days is from ExternE 1998 [12], and the others are from Rabl 2001 [28]. 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 [29] found the correlation between the air pollutions and the health impacts. The correlations are assumed as the linear functions.

**METHOD FOR MONETERY VALUATION**

On the fourth step, the damage costs are to be calculated by multiplying the unit cost of each mortality or morbidity with the number of cases of the mortality or morbidity, which are to be calculated at the previous step. The unit costs are available in the other case studies carried out in the EU [12, 28], and with the unit costs with Ukrainian values, which were evaluated by the contingent valuation[1] for the monetary values of the long-term mortalities, and by the Benefit Transfer Model [30] for the other health impacts.

In general, there are two basic categories of the methods for monetary valuation: the damage based valuation and the control cost valuation. The damage based valuation approach uses the concept of the Willingness to Pay (hereinafter, "WTP"), which is central to modern economic theory. An important characteristic of the approach is that it is based on the estimated damages to human health and the environment, and not on the costs of controlling the responsible emissions. This approach was used by most of the seven states in the USA that required regulated electric utility companies to consider quantitative external costs in their integrated resource planning. These regulations were established before the Impact Pathway Approach was established [3]. In this category of the method, there are both direct (i.e. market price method and the contingent valuation) and indirect method (i.e. hedonic pricing method and travel cost method).

The market price method is a direct approach in which existing market data are used to place an economic value on an environmental impact. An example of an application of this method is the use of market price information to value crop losses associated with pollution damages resulting from electricity generation. The contingent valuation method is a direct method for monetary valuation based on survey techniques whereby individuals are asked in a controlled experiment what they would be willing to pay for improvements in (or willing to accept to tolerate a loss in) environmental quality. The hedonic pricing method is a technique that can be used to measure indirectly the effects of local environmental amenities through examination of real estate values or wage rates. As an example, in the case of real estate values, it would involve the use of statistical modeling to identify property value differentials which can be attributed to specific environmental and other differences between properties. The travel cost method is an indirect method for monetary valuation which uses the economic value of time as the central indicator of WTP. This method has been most frequently used to assess the feasibility of making improvements to recreational sites. These methods, together with some advantages and disadvantages, are discussed in Table 3 [3].

For monetary valuation of the long-term mortalities caused by the air pollutions, such as $PM_{10}$, nitrates and sulfates, the contingent valuation was used to assess the 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 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 [31] 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. 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 in Ukraine, 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 [30]. Markandya recommends the following equation (3) [30] to be used for such an adjustment:

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[1] 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.

$$Unit\ Cost\ in\ COUNTRY = Unit\ Cost\ in\ EU \times \left( \frac{PPP\ GNP_{COUNTRY}}{PPP\ GNP_{EU}} \right)^{\gamma} . \quad (3)$$

Where, PPP $GNP_{COUNTRY}$ 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 $\gamma$ 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% [32]. But, if income elasticity is less then 1 (e.g. 0.35, 0.40-0.60), then the transfer error is about 67-72% [32]. 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 Table4.

**Table 3 Advantages and disadvantages of selected damage costing methods ([3] TABLE XIX)**

| Method | Advantages | Disadvantages |
|---|---|---|
| Contingent valuation | Directed against specific pollution situation without inference of other issues. Open value can be revealed. | Deals with hypothetical situation. Five major sources of biased results:<br>- Difference between WTP and Willingness to Accept<br>- Incentive to misrepresent values (non-obligational nature of questioning).<br>- Implied value cues: these biases occur when elements of the contingent market are treated by respondents as providing information about the "correct" value of the good.<br>- Embedding effects: these may arise if the expressed WTP for the given good.<br>- Mis-specification of scenario: biases may occur when a respondent does not respond to the correct contingent scenario. |
| Hedonic pricing | Wide experience in economic literature. It concerns values observed in markets. | Its theoretical assumptions are not very realistic. Only the use value can be measured. It is difficult to separate the different factors affecting the price of a given commodity. It is not easy to measure the specific influence from noise or from air pollution on housing prices. The option value is not measured. Only externalities that are well perceived (e.g. noise) can be valuated. |
| Travel cost | Appropriate method to value environmental goods | Number of visits made is a discrete variable. Use of continuous estimation techniques is inappropriate. Truncation bias. Surveys cannot take account of those who do not visit the resource. If non-visitors were included in the survey, this would significantly affect the estimate of consumer surplus because of its effect on the specification of the demand relationship. |

**Table 4** Unit damage costs for European Union countries and estimated unit costs in Ukraine in US$$_{1998}$, by the Benefit Transfer Model

| | | EU | UKRAINE |
|---|---|---|---|
| PPP GNP (1998) in US$[45] | | 20 269 | 3 130 |
| | | Unit cost EU (US$/case) [17] | Unit cost UKRAINE (US$/case) |
| Local Range (<50 km radius) and Regional Range (from 50 to about 1000 km) | $PM_{10}$ long-term mortality | 101 000 | *15 600 |
| | $PM_{10}$ Chronic Bronchitis | 177 800 | 27 462 |
| | $PM_{10}$ Restricted Activity Days | 116 | 18 |
| | $SO_2$ Short-term Mortality | 174 000 | 26 875 |
| | $PM_{10}$ Bronchodilator Use | 42 | 6 |
| | $PM_{10}$ 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 |

Note: * In this research, the unit costs for the long-term mortalities by $PM_{10}$, nitrates and sulfates are to be estimated by the contingent valuation (WTP survey). Therefore, the number in this table, 15 600, is to be replaced by 18 000.

## ONE EXAMPLE – A CASE STUDY ON A UKRAINIAN FOSSIL POWER PLANT

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 [33], 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 [34].

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 [35]. 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 [36].

As one case study in Ukraine, 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 [37].

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, 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 5 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 [34]. 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 [38], the ratio between TSP and $PM_{10}$ is $PM_{10} = 0.5TSP$.

**Table 5** Level of emissions in 2006, Trypilska Power Station [34]

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

Table 6 shows the technical characteristics of the emission source of the Trypilska Power Station.

**Table 6** Technical characteristics of the emission source [35]

| **Parameters** | **Value of the 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 |

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 4).

Table 7 shows the input data for calculating the ground concentrations of the pollutants by atmospheric dispersion models for the local and the regional domains.

**Table 7** 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 |

Note: * Annual average wind speed weighted by frequency of16 wind directions of 2006 at National Observatory in Kyiv

** The atmospheric stability D type was assumed, as this type represents the neutral dispersion condition.

2 Willingness to Pay (WTP) survey

In order to evaluate the 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 [31]. 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 [31] 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 Technical University “KPI” and the National University of Kyiv-Mohyla Academy. Table 8 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 8** Survey sample statistics on demography and socioeconomics

| **Aspects** | | **Interviewees** | **Ukraine Population[42]** | |
|---|---|---|---|---|
| Number of observations | | 70 | 48 457 000 | |
| Gender | Female, % | 61.4 | 53.7 | |
| | Male, % | 38.6 | 46.3 | |
| Individual’s net annual income ($ PPP *) | | 4 510 | | |
| Average age | | 34.04 | Workable age, % (F16-54/M16-59)** | 58.0 |
| | | | Older than workable age, % (F55/M60) | 23.9 |
| University education (%) | | 84.3 | 31.3 *** | |

Note: * $ PPP is the income per capita in US dollars.
** F: Female, M: Male
***Enrolment ratio in university (% of relevant age group)

*Fig. 2* shows how the interviewed people in Kyiv are aware of air pollution and its influence on their health and the life expectancy.

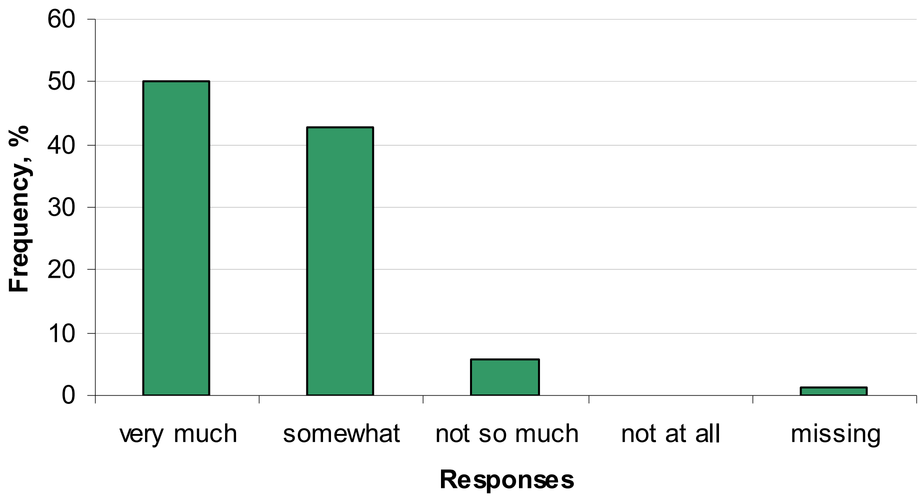


*Fig. 2* Responses to Question: Are you concerned with the effects of air pollution on your health?

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.

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 [32], 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 75 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 9 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 8.

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 4.

**Table 9** 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 |

The calculated total damage costs of the air pollution at the Trypilska Power Station are presented in Table10.

**Table 10** 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 | Regiona l 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 $PM_{10}$ in local domain and sulfates in regional domain are bigger than the others in each domain; in the other words, $PM_{10}$ 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 [39]. Hence, a total damage cost per kilowatt-hour of electricity generation at Trypilska Power Station was calculated. Table 11 shows the damage costs per kilowatt-hour with the unit costs of the European Union and of Ukraine.

**Table 11** Total damage cost per kilowatt-hour of electricity generation at the Trypilska Power Station

| | | **Local** | **Regional** | **Total** |
|---|---|---|---|---|
| Damage cost per kilowatt-hour, mUSD/kWh | EU Value | 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)[5], in Table 11.

**Table 11** Total damage cost per kilowatt-hour of electricity generation in UAH

| Damage cost per kilowatt-hour, UAH/kWh | With EU unit cost | With Ukrainian unit cost |
|---|---|---|
| | 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 [40]. 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.

## 5. 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[2], 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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