External costs from fossil electricity generation: A review of the applied impact pathway approach

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Review

External costs from fossil electricity generation: a review of the applied impact pathway approach

Abstract

This paper reviews and compares eleven studies that have estimated external costs of fossil electricity generation by benefits transfer. These studies include thirteen countries and most of these countries are developing countries. The impact pathway approach is applied to estimate the environmental impact arising from fossil fuel fired power plant's air emission and the related damages on human health. The estimated damages are used to value the monetary external costs from fossil fuel electricity generation. The estimated external costs in the thirteen countries vary from 0.51 to 213.5 USD (2005) per MWh due to differences in fossil fuel quality, location, technology and efficiency of power plants and additionally differences in assumptions, monetization values and impact estimations. Accounting for these externalities can indicate the actual costs of fossil energy. The results can be applied by policy makers to take measures to avoid additional costs and to apply newer and cleaner energy sources. The described methods in the selected studies to estimate external costs with respect to incomplete local data, can be applied as a useful example for other developing countries.

Keywords

Electricity generation; Fossil fuels; External costs; Benefits transfer; Impact pathway approach.

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1. Introduction

Energy production and consumption are the main important anthropogenic sources of air pollutant emissions such as particulate matter, sulfur oxides, and nitrogen oxides. Millions of tons of these pollutants are released into the atmosphere each year, from mobile sources (meaning the road traffic) and stationary sources (mainly industry and power plants) [1-3]. The fossil fuel-fired power plants are one of the major stationary sources that produce environmental pollutions that are harmful to health and are a source of climate change [4].

Electricity is a key factor for economic and social development. The rapid economic growth in developed and developing countries has led to increases in energy consumption. Therefore, there has been a continuing growth in the total installed capacity and energy generation. Countries around the world are facing increasing environmental problems resulting from rapid growth of energy consumption. As shown in Fig. 1 according to key world energy statistics 2016, the electricity generation from year 1973 to 2014 has increased from 6131 to 23816 terawatt-hours (TWh). This figure also shows that the share of fossil fuels (coal, oil and natural gas) in electricity generation is high [5]. The generation of electricity has both health benefits and costs. In other words, power generation aside from its benefits to society, causes unwanted side effects. Human health will benefit from access to electricity and reduction of pollutions from its generation as well [6]. There are significant damages to human health, built environment, crops, forests and ecosystems, but the most thoroughly investigated among them are damages to human health. The most important environmental impact associated with fossil fuel-fired power plants is airborne pollution caused by fuel combustion [7, 8]. Air pollutants from fossil fuel combustion are emitted into the atmosphere from the stack of power plants and affect local and regional air quality. Their dispersion is governed by chemical and physical atmospheric conditions. In addition, the majority of pollutants undergo some chemical transformations [9].

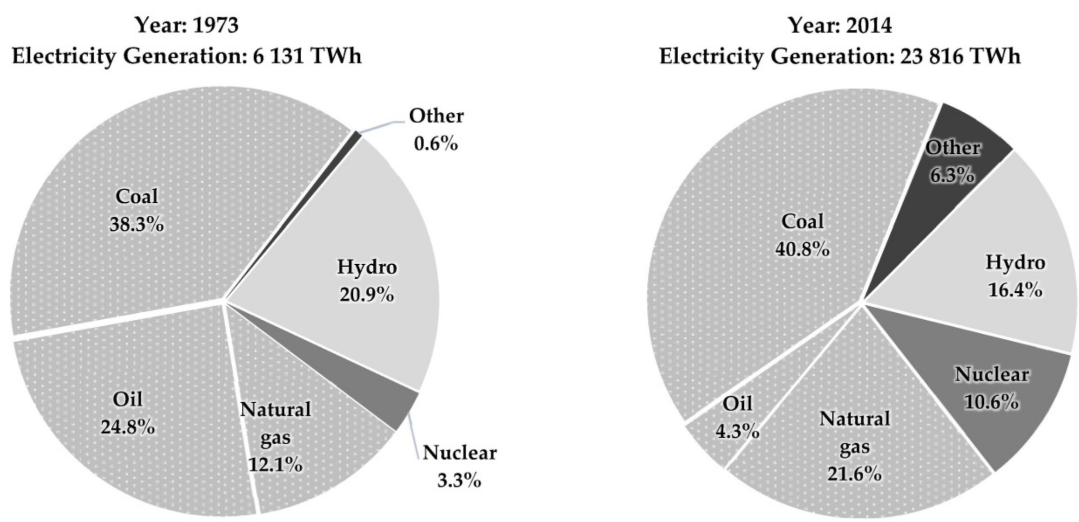

Fig. 1. 1973 and 2014 fuel shares of world electricity generation. Source: [5].

Air pollution is a typical example of negative externalities in economics. Pollution emissions impose serious social negative externalities, especially in terms of public health [10]. Pollutants cause significant damage to both mortality and morbidity (such as bronchitis, respiratory hospital admissions, emergency room visits, asthma, and restricted activity days) due to long or short-term exposure [11-13].

In energy markets across the world, market prices for fossil fuels are lower than the prices of energy generated from renewable sources. These market prices, don't take into consideration the social or true cost of the energy and ignores its negative externalities to public health and the environment. An external cost occurs when producing or consuming a good or service imposes a cost upon a third party. Taking into account the negative impacts of fossil electricity generation, which increases the vulnerability of public health facing environmental deterioration and climate change, can make it more expensive than other sources [14]. For example, the social costs of a renewable technology may be competitive or even smaller than the social costs of a fossil fueled technology, even if private costs of renewable technology are higher [15, 16]. Consideration of external costs may make renewable electricity more attractive than fossil electricity generation. External cost, i.e., the monetary value of damages caused by electricity production is a common term to compare various electricity production technologies and their environmental and health damages [17]. In general, evaluating the environmental impacts of the energy sector could be expressed in terms of external or additional cost per energy unit. This is a useful measure to show the actual costs of energy. The results can be applied by policy makers to take measures to avoid additional costs and promote the application of newer and cleaner energy sources [18, 19].

The overall objective of this paper is to review the external costs studies of fossil electricity generation associated with the health impacts. The remainder of the paper is organized as follows; section 2 presents the modelling of externalities in electricity generation, section 3 reviews and compares the studies in different countries that have estimated external costs of fossil electricity generation. Finally, section 4 presents the discussion and concludes the paper.

2. Modelling of externalities in electricity generation

The impacts from fossil fuel on the environment and human health are a matter of interest and concern throughout the world. There are many studies that estimate the air pollution-related health damages. They apply various methods to estimate the economic burden of air pollution, such as the computable general equilibrium model (CGE) to capture the key features of related sectors and markets, as well as the effects of economic activities [20], the flexible functional forms in demand system analyses to study energy demand or fuel demand (e.g. the Rotterdam model, the Almost Ideal Demand System (AIDS), and the quadratic AIDS (QUAIDS) model) [3, 14, 21], the Long range Energy Alternatives Planning System (LEAP) model to track energy consumption, production and resource extraction in all sectors of an economy and consideration of both demand and supply side technologies [22], and the input-output (I-O) method to distinguish the sectoral emissions and identify the shares of individual industries [10].

This paper focuses on the studies that applied the Impact-Pathway-Approach (IPA) to estimate health impacts and costs caused by air pollution emissions of fossil electricity generation in developing countries. Monetary valuation of damages caused by electricity production is a convenient method for aggregating environmental and health effects with different physical units into a single damage estimate [23]. One of the main methods to study externalities of electricity generation is the bottom-up approach [24]. The prominent bottom-up approach in the impact pathway approach has been developed during the ExternE project-series. ExternE is the acronym for "External Costs of Energy" and it's among the first attempts to take a comprehensive, bottom-up approach to evaluate the external costs associated with electricity production [17]. The European Commission, in conjunction with the United States financed the ExternE project to develop a methodology for monetizing the external damages in the European Union resulting from electricity. That project has been updated repeatedly [25]. One of the most applied approaches to evaluate the environmental impacts of the energy sector and estimating its damage costs on the society is the impact pathway approach. There is consensus among the scientific community that the impact pathway approach should be followed, provided that sufficient data and information are available [26].

IPA is a useful method to evaluate the external costs of electricity generation. The principal factors affecting the results are mainly associated with geophysical locations, distribution of population density, meteorological conditions, quality of fuel used, and emission abatement technologies. IPA has been widely used for decision aid in the fields of energy conversion, transport and environmental protection. The approach starts by identifying a source of emissions, modelling the dispersion of these emissions into the atmosphere and estimating their impacts on society. The final stage consists of valuing the impacts [27]. Fig. 2 shows the calculation steps of IPA.

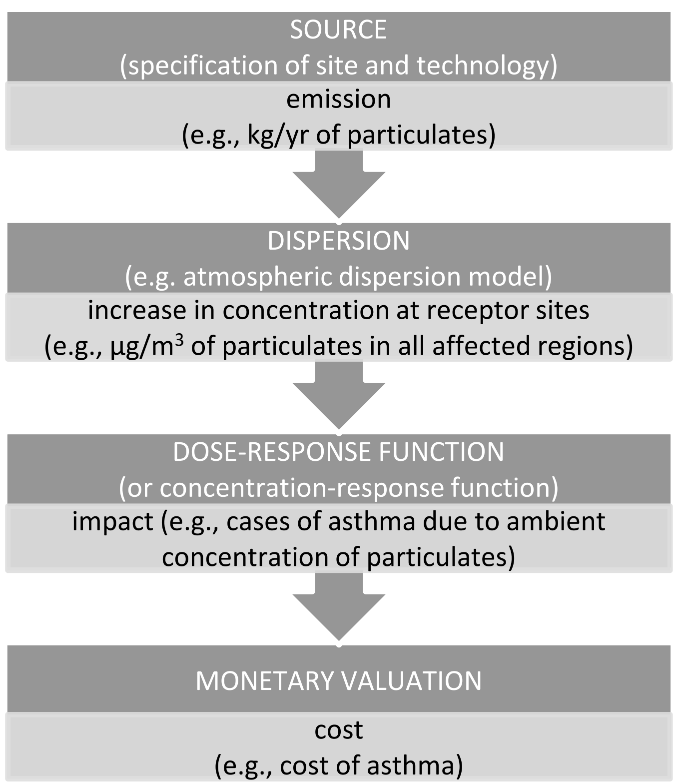

Fig. 2. The principal steps of impacts pathway approach for air pollution. Source [17].

The quantities of emitted pollutants depend on fuel type, plant efficiency and abatement equipment. Once the change in air pollutant concentration level is determined, the consequent risks in health outcomes can be assessed using exposure–response functions (ERF) from epidemiological studies [17, 28, 29] which typically include mortality (acute and chronic), respiratory hospital admission, cardiovascular hospital admission, restricted activity day, work loss day, asthma attack [21, 30]. An ERF presents a relationship between an incremental change in ambient concentrations of a pollutant and the additional number of health disorder occurrences. It is essential in estimating additional years of life lost or new cases of illnesses or hospital admissions attributable to a given increase in pollutant concentration [23].

In the last step of IPA, in order to obtain the external costs, the physical impacts are evaluated in monetary terms. According to welfare theory, damages represent welfare losses for individuals. For some of the impacts (crops and materials), market prices can be used to evaluate the damages. However, for non-market goods (especially damages to human health), evaluation is mainly possible on the basis of the Willingness-To-Pay (WTP) or willingness-to-accept approach that is based on individual preferences. Economists have developed several techniques for valuing non-market goods. Contingent valuation, which obtains WTP estimates by asking individuals how much money they are willing to pay to achieve a benefit, is widely used. For mortality impacts, one needs to determine the value of a life year lost, which in turn is based on the so-called value of statistical life, the amount of money that society is willing to pay to avoid an anonymous premature death. Finally, the health impacts are multiplied with the unit cost of health impact to calculate the related damage costs [27, 31, 32].

To perform the calculation of damage costs, ExternE uses the EcoSense software package, an integrated impact assessment model that combines atmospheric models with databases for receptors (population, land use, agricultural production, buildings and materials, etc.), exposure-response functions and monetary values. EcoSense provides air quality and impact assessment models together with a database containing the relevant input data for the whole of Europe. The meteorological data, which are needed for dispersion modelling, are included in the EcoSense program package database [17, 33].

Additionally, SimPacts (simplified approach for estimating environmental impacts of electricity generation) model is developed by the International Atomic Energy Agency (IAEA) for the application of IPA in developing countries. The model is based on EcoSense. SimPacts assesses the impacts on human health, agricultural crops and buildings from exposure to atmospheric emissions of routine or steady state processes like power plants. It covers fossil-fired power plants, nuclear energy as well as hydropower installations. Moreover, for airborne pollution, whether from fossil fired or nuclear power plants, the SimPacts model utilizes a simplified version of IPA, also known as the damage function approach. In case of fossil fired power plants, the SimPacts provides estimates of the impacts from exposure to pollutants [23, 34]. Besides, the EXMOD model has been developed in the same way as the European EcoSense model.

The EXMOD model is an American model and it is a bottom-up study, also based upon the damage function approach [35].

Although a full-scale, site-specific analysis of electricity externality is the most accurate, nevertheless, in some settings or countries, it may not be possible. Researchers have tried to estimate the external costs of electricity generation in developing countries by using benefits transfer methods [25]. Benefit or value transfer studies take economic values from one context and apply them to another [36]. There are two main approaches for benefit transfer methods. The unit value transfer approach, which involves the methods known as simple unit transfer and unit transfer with income adjustment, and the function transfer approach that uses the benefits function transfer method and meta-analysis. The unit transfer with income adjustment method has been the most used practice for policy analysis [37]. Since the values reflect the amounts that individuals are willing and able to pay in order to avoid certain risks in their economies. Hence, it is adjusted by the ratio of purchasing power parity in order to apply in policy-sites. This assumes that someone's willingness to pay for better air quality is likely to be lower in a low-income economy. This type of method of transferring values from one economy to another economy assumes that the two risk groups are sufficiently alike with respect to their personal preferences and attitudes towards improving air quality standards [38]. If the damage cost for the study-site is available (D_s), the damage cost for the policy-sites (D_p) can be estimated as follows:

$$D_p = D_s \left(\frac{Y_p}{Y_s}\right)^{\gamma}, \tag{1}$$

Where Y_p and Y_s are the income levels and γ is the income elasticity of demand for the environmental good. Other data can be calculated or estimated by indirect ways, when no local data is available or the information is incomplete [32, 39].

3. External costs from fossil electricity generation

External costs related to power production technologies have been calculated by different methods [40]. Several studies have been conducted to compare the results of electricity externality mostly in developed countries [25, 41, 42]. The estimates of external cost from fossil fuel electricity generation outside the United States and European Union are less reported. In this section, we review eleven studies that have estimated external costs of fossil electricity generation. These studies are benefits transfer studies and rely on earlier primary studies, mainly from the ExternE project. These studies include thirteen countries and most of these countries are developing countries. The QGIS Geographic Information System (version 2.18.4) was used to show a better view of these countries. As shown in Fig. 3 these countries are in different regions of the world with different geographical and climate conditions. The majority of growing electricity consumption and generation in these countries is based on fossil fuels.

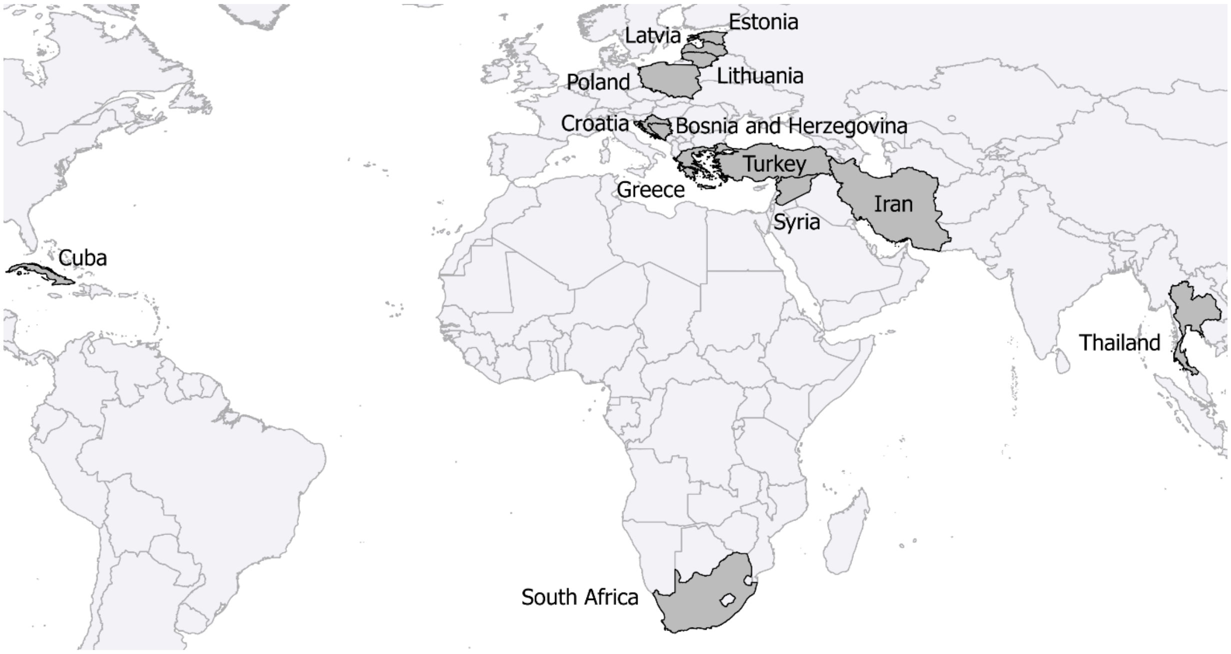

Fig. 3. Selected countries with benefits transfer studies of external costs from fossil electricity generation.

All of the selected studies are bottom-up studies. They apply the impact pathway approach to estimate the environmental impact arising from fossil fuel fired power plant's air emission and the related damages on human health. Next, the monetary costs are valued based on the estimated damages. Table 1 outlines the estimation of external costs from fossil electricity generation in these studies. These studies have been arranged according to year of analysis of their power plants. In Table 1, the results from the different studies have been translated to USD (year 2005) per MWh to show the differences in results between the studies.

There are similarities in methods, results and findings. The studies find that the calculated external cost is high and the pollutants cause significant damage on human health. Since the electricity markets are not flexible, internalization of these external costs would increase the production costs, which would affect electricity prices [30, 31, 43]. For instance, in the South Africa's study, the authors mention that relative to current electricity prices, the external costs are approximately 40 and 20 percent of industrial and residential tariffs, respectively. (ADD reference to South Africa study)

Table 1 - Summary and results of external costs of benefits transfer studies on fossil electricity generation in 13 countries

Study	Spalding-Fecher & Matibe (2003)	Bozicevic et al. (2005)	Turto´s Carbonell et al. (2007)	Georgakellos (2010)	Streimikiene et al. (2009)			Hainoun et al. (2010)	Sakulniyomporn et al. (2011)	Karimzadegan et al. (2015)	Buke & Cigdem (2011)	Dimitrijevic et al (2011)	Czarnowska & Frangopoulos (2012)
Country [a]	ZA	HR	CU	GR	LT	LV	EE	SY	TH	IR	TR	BA	PL
Year of Analysis	1999	2000	2003	2003 - 2004	2005			2005	2006 - 2008	2007	2007	2008	2010
Range of Study [b]	10 CFPs	9 FFP	3 FFP	FFP over 50 MW	main FFP			4 FFP	most of FFP	5 FFP	1 CFP	2 CFPs	1 CFP
Fuels [c]	coal	coal oil gas	Oil	LIG NG oil	HF NG	HF NG oil	NG oil	HF NG	NG LIG oil	NG oil	LIG	LIG coal	coal
Air Pollutant [d]	PP SP	PP SP	PP SP	PP SP	PP SP NH_3 NMVOC			PP SP	PP SP	SO_2 NO_x SO_x	SO_2 Sulfate	PP SP	PP SP
Particulates kg/MWh	0.84	0.16	-	-	0.02	0.0001	0.97	0.14	0.06	-	-	1.37	-
NOx kg/MWh	6.49	1.82	-	-	0.24	0.78	0.99	1.28	1.59	-	-	3.07	-
SO_2 kg/MWh	7.88	2.79	-	-	0.60	4.12	5.73	9.63	1.10	-	-	21.38	-
CO_2	Yes	No	No	Yes	No			No	No	Yes	No	No	No
Health Impacts [e]	MOT MOB	MOT RHA CBR RAD CER HFA	MOT RHA CBR RAD ERV AST	-	-			MOT CBR RAD	MOT RHA CBR RAD ERV CAR AST	MOT RHA CBR RAD ERV	MOT RHA	-	MOT RHA RAD CBR AST etc.
Modeling [f]	EXM	ECS	SIM	ECS	ECS			SIM	CAL	AIR	SIM	ECS	ECS
Benefits Transfer [g]	BFT	UT	UT	-	-			UT	UT	FT	UT	-	-
External Costs [h]	9.1	3.40	11.51	25.4	5	24.9	28.6	0.68-28.69	0.51- 41.7	18.08- 84.68	2.02-39.93	108.4-213.5	2.9

[a] ZA: South Africa; HR: Croatia; CU: Cuba; GR: Greece; LT: Lithuania; LV: Latvia; EE: Estonia; SY: Syria; TH: Thailand; IR: Iran; TR: Turkey; BA: Bosnia & Herzegovina; PL: Poland.
[b] FFP: Fossil Fuel-Fired Power Plants; CFP: Coal-Fired Power Plant.
[c] HF: Heavy Fuel oil; NG: Natural Gas; LIG: Lignite.
[d] PP: Primary Pollutants (sulfur dioxide, nitrogen oxides, & particulate matters); SP: Secondary Pollutants (sulfate & nitrate aerosols); NMVOC: Non-Methane Volatile Organic Compounds.
[e] MOT: Mortality; MOB: Morbidity; RHA: Respiratory Hospital Admissions; CBR: Chronic Bronchitis; RAD: Restricted Activity Days; CER: Cerebrovascular; HFA: Heart failure; ERV: Emergency Room Visits; AST: Asthma; CAR: Cardiovascular.
[f] EXM: EXMOD; ECS: EcoSense; SIM: SimPacts; CAL: CALPUFF; AIR: AIRPACT.
[g] UT: Unit Value Transfer; FT: Function Transfer.
[h] 2005 USD per MWh.

The pollutants considered in the studies comprised of primary pollutants and secondary pollutants. The primary pollutants are emitted into the atmosphere directly from the sources and the secondary pollutants are formed when the primary pollutants interact with the atmosphere. The main primary pollutants from power generation are sulfur dioxide (SO_2), nitrogen oxides (NO_X), and particulate matters; also, secondary pollutants are sulfate and nitrate aerosols. Therefore, the majority of the analyzed studies are limited to nitrates, sulfates and particulates emissions. However, there are some other harmful pollutants from fossil power plants, such as heavy metals (Cd, As, Cr, Ni, Hg, and Pb), which, because due to their very small concentrations, are disregarded in the studies [31, 43].

The studied power plants in these countries use different fossil fuels like coal, lignite, pulverized coal, diesel oil, heavy fuel oil and natural gas. Table 1 shows also the average emission rates of pollutants. The emissions factors relate the quantity of a pollutant released to the atmosphere from different activities [44]. These countries have different fuel type, fuel quality and generation technology so the emissions per energy produced from the power plants are different. Moreover, the emissions used in health impact assessment are annual average concentrations, but the effects caused by hourly pollutant concentrations, which often exceed the yearly average concentration, have not been considered [39].

Although impacts of pollutants from power plants act over one thousand kilometers or even more, only impacts arising on the borders and territory have been assessed [9, 19]. Moreover about 41% of carbon dioxide (CO_2) emissions emanate from electric utility plants [45]. The carbon dioxide emission, which is the primary cause of global-level problems, has been included in few studies.

Table 1 displays the health impacts considered in these studies, as well. Health impacts include mortality and those morbidity effects that have showed in relation with the increment of pollutant concentration. The results show that the pollutants caused significant damage to both mortality and morbidity. These studies have found that mortality costs stand for the majority of the total damage costs obtained with respect to morbidity costs.

For modeling, EcoSense has been used in several studies, especially in European countries. As mentioned earlier, it is the most extensive and developed program supported by a rich database for the Europe area [46]. Other studies have been performed on health impacts of air pollution from electricity production and have estimated externalities with related software like SimPacts and EXMOD and air quality models such as CALPUFF and AIRPACT.

The IPA method has been created by and for developed countries and its application is limited to other developing countries due to the complementary studies and large data requirements [39]. Nevertheless, unavailable or incomplete data have been transferred from the studies of developed countries. Benefits transfer studies are usually performed when the necessary time, money, expertise or data to do a detailed study are lacking. These eleven studies are interesting because they estimate external costs with respect to inadequate data. They transfer several values from developed countries such as emission rates of pollutants, pollutant's depletion velocity and exposure response functions. The majority of the developing countries have no own WTP studies, and the selected studies transfer these values as well. The economic values of health impacts based on international studies are adjusted for each country. As has been shown in Table 1, these studies use benefit transfer methods to fill in gaps in the availability of information. Benefit transfer studies can never be as accurate as primary studies. However, by using the results of primary studies a benefits transfer can take advantage of the expertise in the original research. Furthermore, a benefit transfer provides faster and less costly analyses [25, 47]. Although function transfer approach of benefits transfer is more complex, it leads to more valid results and accurately adjusted coefficients compared with the unit value transfer approach. However, most of the selected studies use unit transfer with income adjustment method for transferring health damage costs and monetization of health impacts.

In these studies, the ERFs have been assumed to be linear, without threshold effects; which are vital for linear transfer of values and their adjustment. It is noteworthy that this simplification may overestimate the economic burden in the case where thresholds, below which damages do not occur, exist at a pollution level beyond the background level [9, 19, 20, 38, 39, 48].

The comparison of the estimated externalities shows differences in the external costs from country to country. The difference in the external costs in the studies reflects differences in negative impacts, monetary values of impacts, exposure-response functions and location and specifications of the power plants [42]. Most of the studies present a central estimate of the total external costs according to the type of fossil fuels, power plant's technology and units. Otherwise , a range of external cost is presented. As shown in the final row of Table 1, the estimated externalities in these thirteen countries vary from 0.51 to 213.5 USD (2005) per MWh in natural gas fired power plants of Thailand and coal-fired power plants of Bosnia & Herzegovina, respectively. The low damage costs in Thailand are mainly due to the negligible sulfur content in the fuel and the low PM_{10} and NO_X emissions and lower population density in the vicinity of the power plants. Correspondingly, the high damage costs of Bosnia & Herzegovinian coal-fired power plants are the result of low quality fossil fuels, i.e., coal with low calorific value and high sulfur content and lack of sulfur abatement equipment. As a result, the Bosnia & Herzegovinian external costs are larger than the internal costs of generation. In other words, in Bosnia & Herzegovinian the full social costs are far above the market price of electricity generated. According to Table 1, the Bosnia & Herzegovina has the highest emission rates of pollutants as well, especially SO_2 emissions [19, 43].

Besides, in the selected studies, costs derived from sulfur species (SO_2 and sulfate aerosol) represent the main part of the total costs. For example, in the case of Syria, the major impacts for all considered pollutants have been induced by sulfate which accounted up to 88% of the total damage costs while the costs from nitrates and PM_{10} contributed only 10% and 2%, respectively. In the selected studies, the lignite, coal and heavy fuel oil are the main sources of sulfur emissions. Due to the negligible sulfur content, natural gas has been considered as the cleanest fuel among commercial fossil fuels [49, 50]. The location of the power plant has also a significant effect on the external cost due to pollution. The damage costs of small power plants located in remote area with low population can be neglected. Also the fuel and technology improvements decrease emission of pollutants [23]. Moreover, the highest emissions per unit of electricity generation have been found in the power plants without appropriate abatement technology like Flue-Gas Desulfurization (FGD) equipment. In Turkey the health benefits are assessed by comparing the estimated health impacts with and without the FGD equipment. The FGD units of the power plant have been found to result in, on average, 77 fewer cases of short-term mortality, 2280 fewer cases of long-term mortality, and 88 fewer cases of respiratory hospital admissions annually. Therefore, as shown in Table 1, the estimated external costs vary from 2.02 to 39.93 USD (2005) per MWh. Finally, the benefits in monetary from FGD units exceed the investment costs in Turkey. These findings emphasize the necessity of appropriate emission abatement technologies, especially for the power plants that are located in the vicinity of the most densely populated regions [38].

In general, according to the selected studies, the larger negative impacts from electricity generation result from the lower quality of fossil fuel, lower efficiency of power plant, lack of abatement technologies, higher population density and the lower depletion velocity (local and regional) around the power plants.

To find an approximate estimation of external costs, several simplifications and assumptions are adopted in the selected studies. For instance, the population densities are assumed to be constant at provincial level [19]. In several studies, the quantities of emitted air pollutants have been estimated by means of emission rates i.e. the power plants have been assumed to operate without emission reduction technologies [23]. Also, the elasticity of willingness to pay with respect to income is supposed to be one. Furthermore, the selected studies focus only on the externalities of the electricity production phase and life cycle assessment has not been included. Thus, there are many uncertainties associated with the external costs obtained from these studies due to assumptions, ERF, monetization values and impacts [42, 51].

Since almost all damage costs estimates incorporate the uncertainties, associated with the quality of data and the estimation procedure, simple sensitivity analysis are executed in only a limited number of cases. The aim of the sensitivity analysis is to identify if the calculated results differ in changes of different parameters and assumptions. As the resulting change for the damage cost is in the same range of the varied parameters, one can conclude that the damage cost is sensitive to the change in the considered parameters [23, 31, 38, 46].

In spite of the uncertainties, the results obtained in these countries represent a significant step forward to assess the externalities in developing countries. The studies show that it is possible to have an assessment of external costs of fossil electricity generation, with a sensible accuracy, regarding incomplete information and unavailable local data.

4. Discussion and Conclusions

Nowadays, as a result of high electricity consumption, the environmental and health impacts of electricity generation are important. Most of electricity is generated by burning fossil fuels. Fossil electricity-generating is a significant source of emissions of the air pollutants that harm human health. The external costs of electricity generation represent the uncompensated monetary value of the associated environmental and health damages. The external costs can be used by policy makers to assess the importance of different kinds of energy technologies. However, it is important to notice that the results of external costs of electricity generation can be influenced by difference in methods, impacts, exposure-response relations and monetary values.

This paper reviews and compares the studies of external costs from fossil electricity generation in thirteen countries. These studies use the impact pathway approach to evaluate the environmental impacts of the energy sector and to estimate the damage costs on the society. These analyses are not as comprehensive as the full-scale externality studies in United States and Europe and they estimate the external costs of electricity generation by benefit transfer methods. They transfer unavailable or incomplete local data such as emission rates, exposure response functions and economic values of health impacts from the studies of developed countries. The obtained results indicate that the negative impacts can add considerable external costs to the power generation costs. The estimated external costs in these thirteen countries vary from 0.51 to 213.5 USD (2005) per MWh. Comparing external cost of electricity generation in these countries shows that the external costs of fossil electricity generation could be reduced by suitable actions such as (i) improving efficiency of power plants, (ii) locating plants farther from populated areas, (iii) using the appropriate emission reduction technologies and (iv) fuel improvements.

There are uncertainties involved in calculating external costs for power generation. Nevertheless, it is better to have even an estimation of the externalities instead of disregarding them entirely. Also in spite of the uncertainties in the results, it is possible to reach meaningful conclusions. However, more research in the field of fossil electricity externalities is necessary. Hence the uncertainties will be reduced due to new research and collection of local data, especially for monetary valuation of health damage costs.

Internalization the costs derived from environmental and human health damage into the prices of electricity, would increase the production cost from fossil fuels with higher environmental impact. It is a useful measure to indicate the true costs of energy and it makes fossil energy less competitive with respect to renewable energy technologies. Therefore, external costs results can be used to assess the importance of different kinds of energy technologies and to choose cleaner technologies.

Generally, the described methods in the selected studies for estimation the external costs with respect to incomplete local data can be applied as a useful example for other developing countries.

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