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Estimating Human Health Impacts and Costs Due to Iranian Fossil Fuel Power Plant Emissions through the Impact Pathway Approach

Mojtaba Jorli [1], Steven Van Passel [2,3,*], Hossein Sadeghi [1], Alireza Nasseri [1] and Lotfali Agheli [4]

1 Department of Economics, Faculty of Management & Economics, Tarbiat Modares University, 14115-111 Tehran, Iran; Mojtaba.Jorli@gmail.com or Mojtaba.Jorli@student.uantwerpen.be (M.J.); sadeghih@modares.ac.ir (H.S.); nasseri@modares.ac.ir (A.N.)
2 Department of Engineering Management, University of Antwerp, Prinsstraat 13, 2000 Antwerpen, Belgium
3 Centre for Environmental Sciences, Hasselt University, Martelarenlaan 42, 3500 Hasselt, Belgium
4 Economic Research Center, Tarbiat Modares University, 14115-111 Tehran, Iran; aghelik@modares.ac.ir
* Correspondence: Steven.VanPassel@uantwerpen.be; Tel.: +32-3-265-4895

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Abstract: Air pollutants from fossil fuel fired power plants harm the environment and human health. More than 91% of Iran's electricity production is from thermal power plants that use natural gas, diesel, and fuel oil. We apply the impact pathway approach to estimate the health impacts arising from Iranian fossil-based electricity generation emission, and in a next step, we calculate monetary costs of the estimated damages, for a one-year period starting from 20 March 2016 through 2017. We use the new version of SIMPACTS (International Atomic Energy Agency, Vienna, Austria) to investigate the health effects from 61 major Iran fossil-based power plants separately. The selected plants represent 95.6% of total Iran fossil-based power generation. Using the individual and different power plant estimates, we avoid extrapolation and our results can be considered more reliable, taking into account spatial differences. The total damage cost is 723.42 million USD (2000). The damage cost per generated electricity varies from 0.06 to 22.41 USD/MWh and average plant damage cost is 2.85 USD/MWh. Accounting for these external costs indicates the actual costs of fossil energy. The results are useful for policy makers to compare the health costs from these plants and to decide on cleaner energy sources and to take measures to increase benefits for society.

Keywords: Iran electricity generation; fossil fuels; external costs; air pollution; impact pathway approach; benefit transfer; SIMPACTS 2

1. Introduction

Countries around the world are facing increasing environmental problems resulting from the rapid growth of energy generation. According to the recent key world energy statistics, electricity generation has continuously increased, and reached 24,255 terawatt-hours (TWH) in 2015. Nevertheless, 66.3% of 2015 world's electricity was generated from fossil fuels (coal, oil, and natural gas). Fossil-fuel power generation has carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), particulates, liquid and solid wastes. The fossil-fuel fired power plants produce pollutants that are harmful to health and are a source of climate change.

The most important environmental impact associated with fossil fuel fired power plants is airborne pollution [1,2]. Air pollutants' dispersion is governed by chemical and physical atmospheric conditions. In addition, the majority of pollutants undergo some chemical transformations [3]. However, fossil fuel remains the main sources of primary energy, especially in the developing countries [4]. It is widely recognized that air pollution from power plants adversely affects public health. Pollutants cause significant damage to both mortality and morbidity due to long- or short-term exposure. A number of studies show a significant relationship between air pollution and health impacts [5–7].

In energy markets across the world, prices for fossil fuels are lower than the prices of energy generated from renewable sources, regardless of their negative effects to public health and the environment. These negative effects are called external costs because those are outside of the pricing system. The sum of the private costs and external costs gives social costs. External costs are an important category of market failure and are imposed on society; accounting for these externalities can make fossil fuels more expensive than renewables [8–10]. Choosing one energy option over another may influence many aspects of society and the environment, which should be accounted for if we want to obtain the highest benefits for society [11]. Internalizing the external cost into energy production cost is a useful measure to indicate the actual costs of energy. The results can be applied by policy makers to take measures to avoid additional costs and promote applications of newer and cleaner energy sources [12,13].

Iran is one of the most hydrocarbon-rich areas in the world and has large reserves of natural gas and crude oil. In Iran, most of the power plants are based on fossil fuels, such as natural gas, diesel, and fuel oil. Iran is the world's 6th- and 4th-largest producer of electricity from oil and natural gas, respectively [14]. Hence, the overall objective of this paper is to estimate the health effects and related costs of fossil electricity generation in Iran. In this analysis, we cover for the first time the whole country and investigate health effects from all major Iranian electricity plants (96% of fossil fuel electricity generation), one by one. In this way, we provide a complete and very detailed estimation of external costs of Iranian fossil power plants while previous estimations were based on extrapolation of a single plant or a small number of plants.

The remainder of the paper is organized as follows: Section 2 describes the method for calculation of external costs from fossil electricity generation, Section 3 presents a short overview of electricity sector in Iran and its emissions, Section 4 indicates the results, and Section 5 discusses of the achieved results and concludes the paper.

2. Modelling of Externalities in Electricity Generation

2.1. The Impact Pathway Approach (IPA)

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 [15,16]. Two main methods for the study of externalities of electricity generation are the top-down and bottom-up approaches [17]. The top-down approach is normally based on highly aggregated damages and emissions at the national or regional level. The results of this approach provide overall average figures that do not include site-specific information. The prominent bottom-up approach is the Impact Pathway Approach (IPA) implemented in the ExternE (Externalities of Energy) project [13,15].

The ExternE project is among the first attempts to take a comprehensive, bottom-up approach to evaluate the external costs associated with electricity production. Many efforts have been made to estimate the impacts, especially in developed countries. The European Commission, in conjunction with the United States, produced the ExternE project aimed at developing a methodology for monetizing the external damages in the European Union resulting from electricity. That project has been updated repeatedly [10]. There is consensus among the scientific community that the IPA should be followed, provided that sufficient data and information are available [18]. IPA is one of the most applied approaches for evaluating the environmental impacts of the energy sector and estimating its social costs. This approach starts by identifying a source of emissions, modelling their atmospheric dispersion, and estimating their impacts on society. The final stage consists of valuing the impacts [9,13,16]. Figure 1 shows the IPA calculation steps.

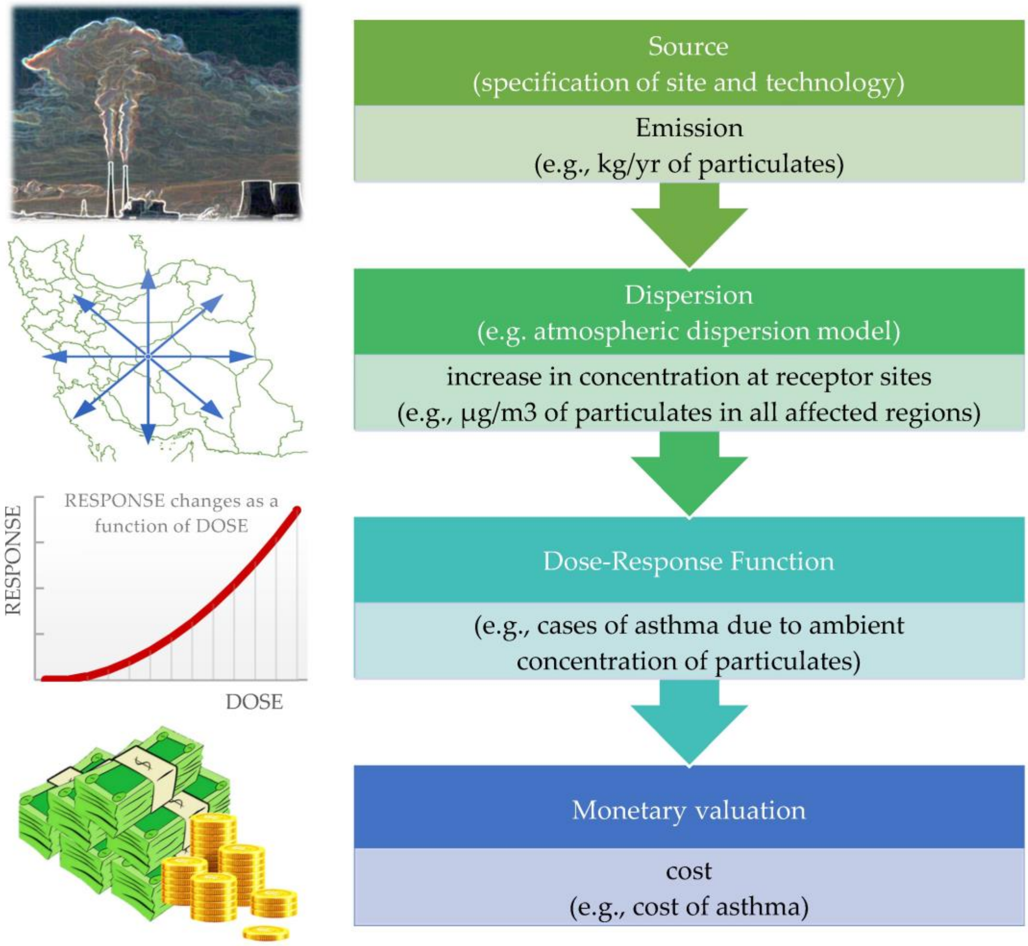

Figure 1. The principle impacts pathway approach steps for assessing air pollution. Source: Based on [15].

The quantities of emitted pollutants depend on fuel type, plant efficiency, and whether or not the plant is equipped with filters. To link air emissions to human illness requires an understanding of air dispersion patterns, human exposure to environmental quality risks, and the dose-response or exposure-response functions [19]. The estimated physical impacts are quantified and transferred to human health impacts using the Exposure Response Function (ERF). An ERF presents a relationship between an incremental change in ambient concentrations of a pollutant and the additional number of health disorder occurrences. The exposure-response functions have been collected and reviewed in several studies. To find an approximate solution to the ERF and physical impacts equation, several simplifications and assumptions are adopted [15,20,21].

In the last IPA step, to obtain the 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. However, for non-market goods (especially damages to human health), evaluation is mainly derived from 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 [9,22].

2.2. Benefit or Value Transfer

Although a full-scale, site-specific analysis of electricity externality is the most accurate measure, it may not be possible in some settings or countries. Researchers have therefore tried to estimate the external costs of electricity generation in developing countries mostly by using benefit transfer methods [10]. Benefit or value transfer studies involve taking economic values from one context and applying them to another [23]. Benefit transfer is defined as the use of research results from pre-existing primary studies at one or more sites or policy contexts (often called study sites) to predict welfare estimates, such as WTP or related information for other, typically unstudied sites or policy contexts (often called policy sites) [24]. It has also been described as the application of values and other information from a study site where data are collected to a policy site with little or no data [25]. Benefit transfer studies can never be as accurate as original or primary studies. However, by using the results of primary studies, a benefit transfer can take advantage of all the expertise in original research. Furthermore, a benefit transfer study provides faster and less costly analyses [10,26].

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, which uses the benefit function transfer method and meta-analysis. The unit transfer with income adjustment method has been the most-used practice for policy analysis [27], since the values reflect the amounts that individuals are willing and able to pay to avoid certain risks in their economies. Hence, it is adjusted by the ratio of purchasing power parity (PPP) to apply in policy sites. This type of method of transferring values from one economy to another assumes that the two risk groups are sufficiently alike with respect to their personal preferences and attitudes towards improving air quality standards [28]. If the damage cost for the study site is available (D_s), that 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 are available or the information is incomplete [29].

2.3. The Model

To calculate the damage costs, the corresponding models are used. For this calculation, ExternE uses the EcoSense software package (Institute of Energy Economics and Rational Energy Use, Stuttgart, Germany), 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. The 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 [15,30]. In addition, the EXMOD (Externalities Model) has been developed in the same way as the European EcoSense model. The EXMOD is a bottom-up American model that quantifies externalities associated with facilities generating electricity using the damage function approach [31,32].

Furthermore, the Simplified Approach for Estimating Environmental Impacts from Electricity Generation (SIMPACTS (International Atomic Energy Agency, Vienna, Austria)) model was developed by the International Atomic Energy Agency (IAEA) for the application in developing countries. The model is based on the EcoSense that is applied in the ExternE study. 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. SIMPACTS can assess the environmental impacts of different types of technologies. It covers radiological air and water pollution from nuclear power generation, non-radiological air pollution from fossil-based power plants, and project impacts from hydropower. Moreover, for airborne pollution, whether from fossil-fired or nuclear power plants, SIMPACTS utilizes a simplified version of IPA, also known as the damage function approach. With fossil-fired power plants, SIMPACTS estimates the impacts from exposure to pollutants [16,33]. In general, the SIMPACTS approach is a simplification of EcoSense methodology.

There are several studies that have estimated external costs of fossil electricity generation in developing countries by benefit transfer methods. Figure 2 shows eight studies that estimated external costs of fossil electricity generation. All of the selected studies are bottom-up studies. They applied the impact pathway approach to calculated external costs resulting from impact of air pollution of fossil electricity generation on human health. These studies transferred several values from primary studies, such as emission rates of pollutants, pollutant's depletion velocity, and exposure response functions. The main pollutants considered in the studies were SO_2, NO_X, and particulate matters. The studied power plants in these countries used different fossil fuels like coal, lignite, pulverized coal, diesel oil, heavy fuel oil, and natural gas. Additionally, Figure 2 outlines the estimation of external costs from fossil electricity generation in these studies that have been translated to USD (year 2000) per MWh to show the differences in the results of the studies. The estimated externalities in these studies vary from 0.60 USD/MWh in the natural gas-fired power plants of Syria to 188.25 USD/MWh in the coal-fired power plants of Bosnia & Herzegovina with high-sulfur coal without abatement equipment. The difference in the external costs in the selected studies reflects differences in impacts, monetary valuation of the damages, exposure-response functions, and locations and specifications of the power plants. These studies find that the calculated external costs are high [34,35] and that it is possible to find an estimation of external costs of fossil electricity generation, regarding incomplete or unavailable local data.

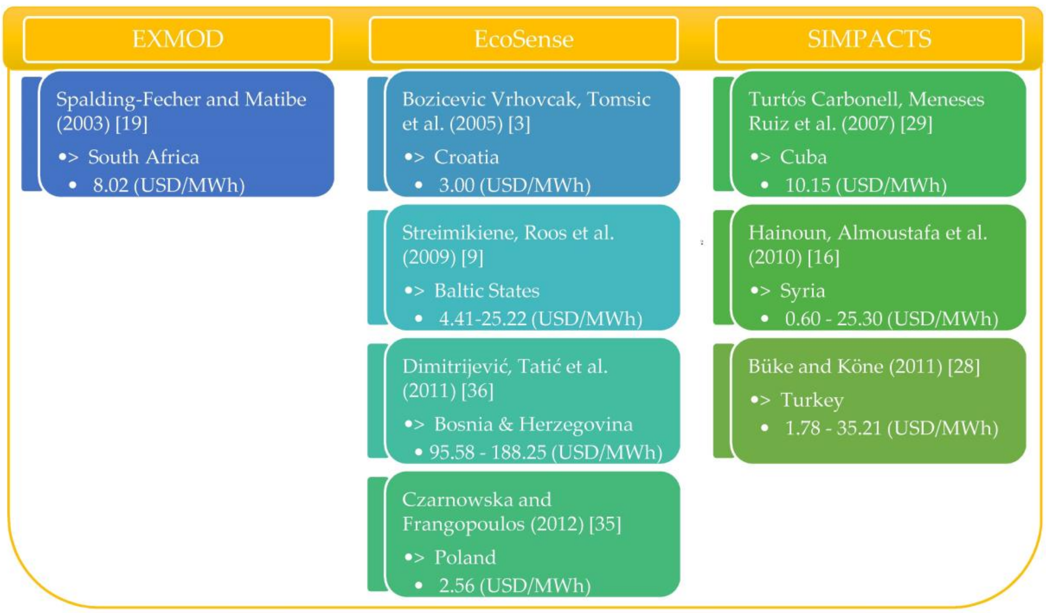

Figure 2. Summary of electricity externality studies by different models applied in different countries.

In this study, we use SIMPACTS 2, the new (March 2016) version of SIMPACTS, obtained from the Planning & Economic Studies Section of the IAEA's Department of Nuclear Energy. With fossil-fired plants, it needs several inputs, such as: (i) site characteristics by location of power plant; (ii) source characteristics by stack specification (included are base elevation, stack height, stack diameter, exit temperature, and exit velocity), and emission rates of pollutants; (iii) distribution of receptors around the plant; (iv) exposure-response functions; and (v) unit costs for the impacts. The main pollutants considered in SIMPACTS consist of SO_2, NO_X, and PM_{10} (particulates less than 10 microns in diameter) as primary pollutants and nitrate and sulfate aerosols as secondary pollutants. Primary pollutants are emitted at the source while secondary pollutants are those created downstream of the source location due to chemical activities. However, there are some other harmful pollutants from fossil power plants, such as heavy metals which, because of their very small contribution, are disregarded [22,36]. SIMPACTS 2 has a world database for topography, land use characteristics, and meteorological conditions. After providing the coordinates for the power plant, the model extracts the included data for that assessment area from the database distributed with the model. These data are used as starting point for the calculation of the dispersion and transport of pollutants. After subsequently supplying the other required data, the model can evaluate the environmental effects of one power plant, every time. That is each time only one power plant can be investigated by SIMPACTS. Then environmental damage costs of air pollution are estimated by assigning economic values to the physical impacts, caused by exposure to concentrations of pollutants, which in turn resulted from dispersion, transformation of contaminants being emitted to the air by a given source [37]. The CALPUFF (California Puff Model) air quality modeling system is used in SIMPACTS to calculate pollutants concentration. It is a multi-layer, multi-species, non-steady-state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal [38]. CO_2 emissions, which are a primary cause of global problems, are not included in SIMPACTS and the global effects are beyond the scope of this paper.

SIMPACTS calculates the human health impact (I_{ik}) of type k and pollutant species type i (cases per year) as follows:

$$I_{ik} = G^2 \times \sum_{x=1}^{41} \sum_{y=1}^{41} \rho_{xy} \times erf_{ik} \times C_{ixy} \quad (2)$$

where; G is the grid size for each exposure area within the impact domain (kilometers), ρ_{xy} is the population density within the exposure area (person per km^2), erf_{ik} is the unit health impact for health impact type k and species type i (cases per year per person per µg/m^3) and C_{ixy} is the increase in ground-level ambient air concentration within the exposure area (µg/m^3).

For monetary evaluation of health impacts, the annual external costs due to health impact k and species type i are calculated according to the following equation:

$$ECY_{ik} = I_{ik} \times U_k \quad (3)$$

where I_{ik} is the health impact for the impact type k and species type i (cases per year) and U_k is the unit cost for health impact k (dollar per cases).

In SIMPACTS, the impact analysis can be done locally or regionally. The user can choose a cell size of 5 × 5 km for local analysis and 50 × 50 km for regional analysis. SIMPACTS creates 1681 blocks (41 × 41) for the selected domain. Thus, the local domain will be a square area size of 205 × 205 km and the regional domain will be a square area size of 2050 × 2050 km. Then the power plant is located in the center of this square and SIMPACTS calculates pollutant concentrations, impacts, and costs for every grid of the square.

3. External Costs from Iran Fossil Electricity Generation

Currently, 100% of urban and 99.9% of rural populations in Iran have full access to electricity [39,40]. In the last three decades, on average, more than 91% of Iran electricity production has been from thermal power plants that consume fossil fuels (natural gas, diesel, and fuel oil). Energy balance sheets issued by Iran's Ministry of Energy state that power plants have a high contribution in air pollutants (especially SO_2 and NO_X) with respect to other sectors (transportation, industry, agriculture, and residential sectors) and more than one-third of SO_2 and NO_X emanate from electricity generation.

In this study, we investigate health damages from Iran fossil-based electricity generation for one year. Using the latest available statistical data for Iranian calendar year 1395, the study encompassed a one-year period starting from 20 March 2016 through 20 March 2017. In this year, Iran gross generation was 289,195.8 GWH. Fossil-fuel power plants generated 265,775.6 GWH; that is, 91.9% of total generation. The electricity production of different fossil plants varies from 0.5 to 13,913 GWH. We selected all large power plants with generation of more than 1000 GWH in the year of analysis. There are 61 power plants with this condition, so our study includes 95.6% of total Iran fossil power generation. Most of the 61 fossil plants are multi-fuel plants, which use a variety of fossil fuels. Seven plants consume three types of fossil fuels. Forty three plants consume both of natural gas and diesel, and also 4 plants consume both of natural gas and fuel oil. Six plants consume only natural gas, and one plant also consumes only diesel. The plants have different geographical and climate conditions, so estimation of health effects from these 61 plants, independently, increase the accuracy of the results. Furthermore, with respect to the model, this study is only about the electricity production phase, externalities and life cycle assessment has not been included.

In Iran, Tavanir organization is responsible for management of generation, transmission, and distribution of electric power. According to the statistical reports of Iran electric power industry issued by this organization, in the past 30 years, the total nominal capacity of Iran's power plants has increased from 13.3 GW to 76.4 GW. In this period, natural gas consumption has reached from 5.45 to 61.78 billion cubic meters, diesel from 1.48 to 5.87 billion liters, and fuel oil from 3.56 to 4.48 billion liters. These facts demonstrate that the share of natural gas in generation, as the cleanest fuel among commercial fossil fuels, has improved. Moreover, the share of fossil fuels with high sulfur content (especially fuel oil) has decreased. Figure 3 shows fuel shares of Iran electricity generation for the year of the analysis.

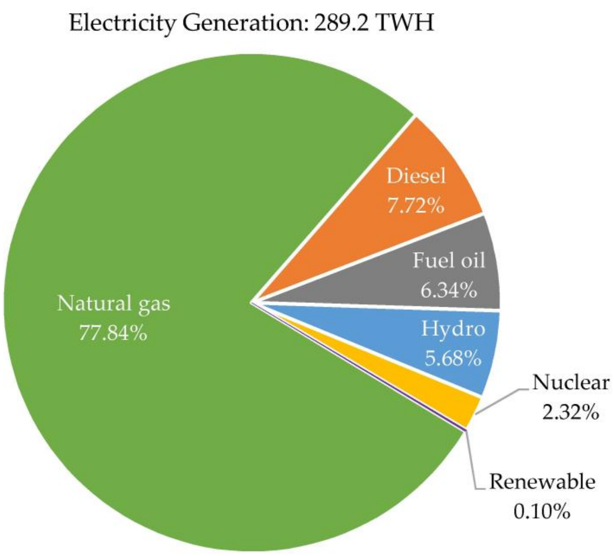

Figure 3. Fuel shares of Iran electricity generation, 2016–2017. Source: Based on [41].

In these three decades, Iran's population has increased from 50.7 to 79.9 million. The average age of Iran's thermal power plants is about 16 years and Iran has 10 GW fossil plants over 30 years old. At the time of the power plants' construction, they were far from populated areas. Because of population growth, the number of people near the plants has increased.

The determination of the population at risk from power plant pollutants is one of the major components of external cost calculation. Several studies, especially in the developing countries, assume constant population in the whole country or provinces and use the average population density for these areas. In this study, to find a better estimation of population density around every power plant, we collected the population of all sub-provinces from the 2016 National Population and Housing Census of Statistical Centre of Iran. According to Ministry of the Interior data, Iran currently has 31 provinces and 429 sub-provinces. Figure 4 displays the locations of the selected 61 power plants and population density for all sub-provinces. These plants have been given a number according to their generation in descending order from highest generation (#1) to lowest generation (#61).

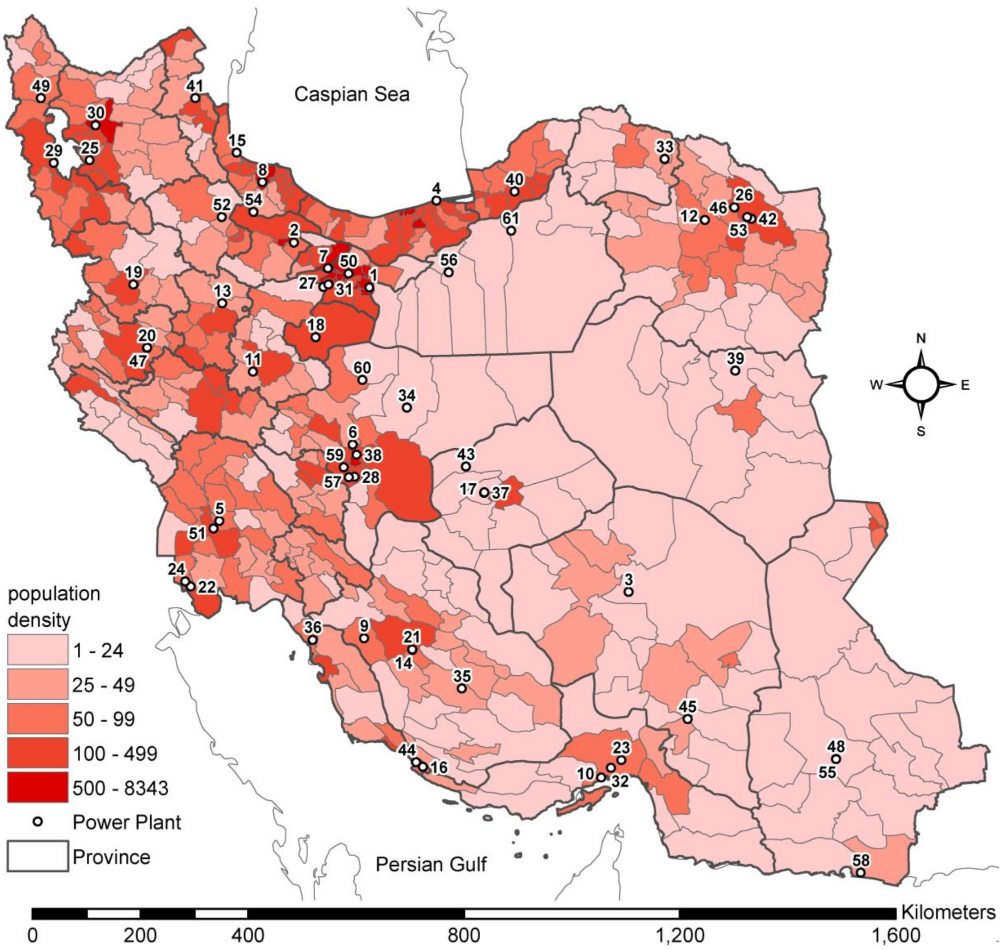

Figure 4. Iran provinces, population density of sub-provinces, and locations of the 61 fossil power plants.

As shown in Figure 4, the population north and west of Iran is comparatively high and most of the fossil plants are in the high-density areas. The average population density of Iran (total population ratio to the total country area) is 49 person/km^2. The population density in the sub-provinces varies from 1 to 8343 persons/km^2. The highest populated areas are near Tehran, where the plants numbered 1, 7, 27, 31, and 50 are located.

In this study, we chose the regional level in SIMPACTS to investigate the effects of power plant's air pollution 1025 km from the plant. We used the ArcGIS 10.5 (Esri (Environmental Systems Research Institute), California, CA, USA) to calculate the precise population density in 1681 cells 50 × 50 km at a square area size of 2050 × 2050 km around each of the 61 plants, individually. Figure 5 exhibits the population density for the sample power plant, Yazd (#17), that is located almost in the center of Iran. To find a better view of the population near the plant, the density at a square size of 250 × 250 km (i.e., in 25 cells) around of the plant has been shown as well. Impacts of pollutants from power plants act over 1000 km or even more [3,13]; however, in this study, only those impacts arising on Iran's borders and territory are assessed.

In addition, in Appendix A, Table A1 summarizes the population density around the selected plants. This table displays Iran's population coverage at square size of 2050 × 2050 km by each of the plants. The population at square size of 250 × 250 km (i.e., in 25 cells) around of the selected plants has been presented in Table A1 as well. According to this table, the plants Besat (#50), Parand (#31), MontazerQaem (#7), RoodShur (#27), Damavand (#1), Rajayi (#2), and Qom (#18) have the highest population in the 250 × 250 km range. For example, the plant Besat (#50) is in the capital and 19.84 million persons live in a square size of 250 × 250 km around it.

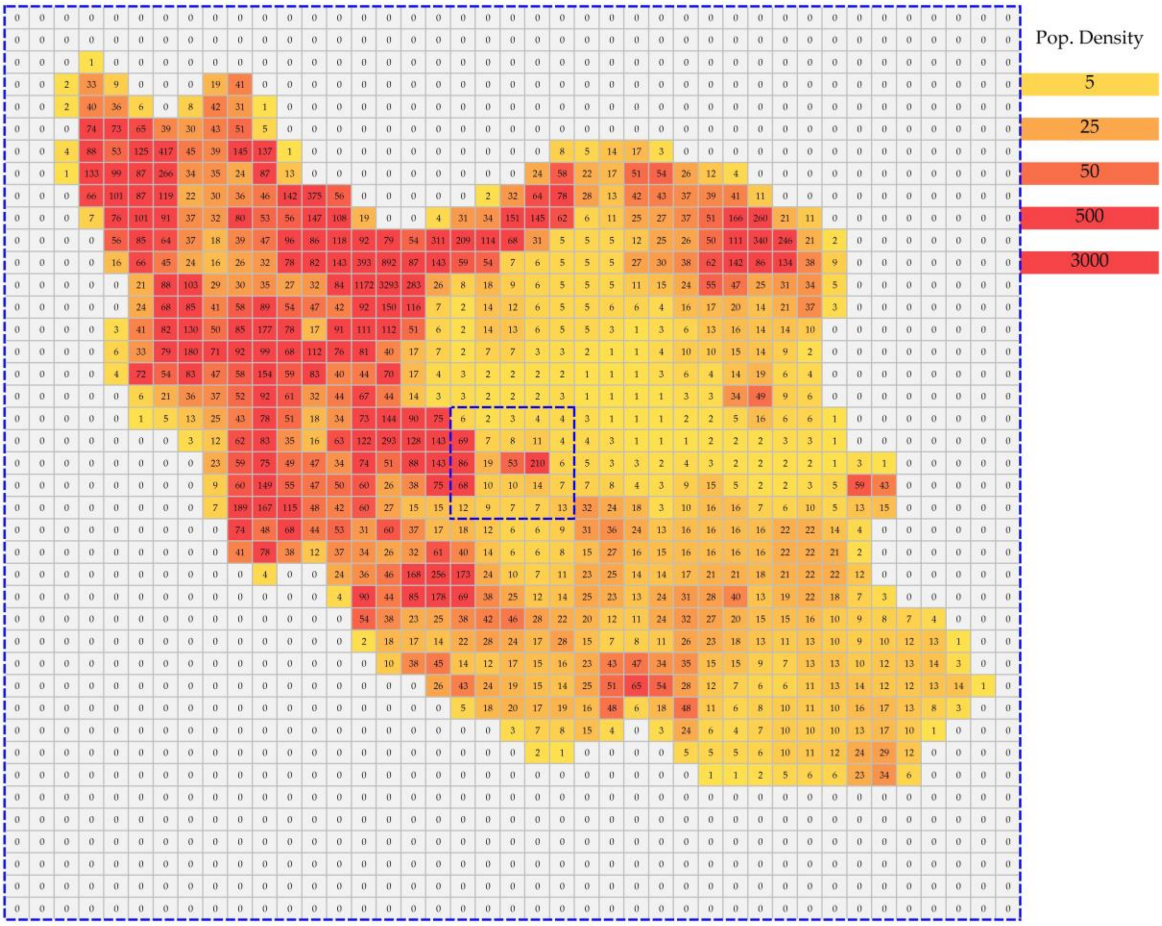

Figure 5. Population density at squares size of 2050 × 2050 and 250 × 250 km around Yazd (#17) power plant.

Generally, Iran's plants don't have conventional abatement technologies like flue-gas desulfurization equipment, so the annual quantities of emitted air pollutants from each power plant are estimated by multiplying the emission factors with the consumed fuel quantity. To determine the flue gas emission factor, a project entitled "developing pollutant map of Iran's thermal power plant" has been done in Tavanir, during 2007–2008. Thus, 50 thermal power plants, with the total installed capacity of 34,863 MW, have been investigated [42]. According to the results of this project, we use the average emission factors of SO_2 and NO_X for different fossil fuels. These values are grams per KWH (g/KWH) generated electricity. Since there is no local value for PM_{10} emissions, we used PM_{10} emission factors from the 2016 EMEP (European Monitoring and Evaluation Programme)/EEA (European Environment Agency) air pollutant emission inventory guidebook. These values are grams per gigajoules (g/GJ) of thermal input for electricity production. Consequently, Table 1 shows the emission factors for the three pollutants with respect to fuel types. Since the average sulfur content of Iran's fuel oil is 3%, we used 45 g/GJ for PM_{10} emissions from fuel oil as well. According to the updated permit of Iran Department of Environment, SO_2 emission limits for existing plants depending on the type of fuel are 200, 150, and 800 milligrams per normal cubic meter (mg/Nm^3) for natural gas, diesel, and fuel oil, respectively. Furthermore, NO_X emission limits are 300, 250, and 400 mg/Nm^3 for natural gas, diesel, and fuel oil, respectively. Particulates emission limits is 150 mg/Nm^3. On the other hand, old plants with low efficiency, high consumption of heavy oil in cold seasons, and lack of emission abatement equipment increase air pollutants.

Moreover, average calorific values of fuel used in Iran's thermal power plants for natural gas, diesel, and fuel oil are 35.98 (MJ/m^3), 38.63 (MJ/Lit), and 40.96 (MJ/Lit), respectively.

Table 1. Average emission factors of SO_2, NO_X, and PM_{10} depending on fuel type.

Fuel	Emission Factor of Pollutant		
	SO_2	NO_X	PM_{10}
	g/KWH		g/GJ
Natural Gas	0.00	2.30	0.9
Diesel	3.08	4.79	3.2
Fuel oil	15.28	2.52	45

Source: [42,43].

According to the manual of the SIMPACTS, for a power plant with multiple stacks, since the stacks are not far from each other, we model them as one. Accordingly, we use the average values for stack specification. Additionally, according to the available statistical reports of Tavanir Org., we use average values for exit temperature and exit velocity of stacks. Average exit temperatures for steam, combined cycle, and gas power plants are 440, 550, 780 Kelvin, respectively. Additionally, average exit velocities for steam, combined cycle, and gas power plants are 21, 30, and 46 m per second, respectively.

In Appendix A, Table A2 shows characteristics of the selected 61 power plants. It displays generation, fuel consumption, and pollutant emissions for the year of the study as well. These plants have been arranged according to their generation from largest to smallest. The total nominal capacity and gross generation of the 61 power plants are 53.6 GW, and 254 GWH, respectively. The generation of the selected plants varies from 1.1 GWH to 13.9 GWH. As shown in Figure 3, these plants use mostly natural gas. The plants Ramin (#5), Montazeri (#6), Rajayi (#2), Damavand (#1), Kerman (#3), MontazerQaem (#7), and Neka (#4) have the highest consumption of natural gas. Furthermore, Damavand (#1), Chabahar (#58), Gilan (#8), Pareh-sar (#15), Rajayi (#2), Sanandaj (#19), and Uromieh (#29) are largest in diesel consumption. As mentioned above, fuels with more pollutants (i.e., fuel oil and diesel) gradually are being replaced by natural gas. According to Table A2, in the year of this study, 10 plants did not consume diesel, 50 power plants did not consume fuel oil.

In addition, Neka (#4), Bandar-abbas (#10), Bistoon (#20), Mofateh (#13), Toos (#26), Rajayi (#2), and Iran-shahr (#55) use the most fuel oil, consuming 92.1% of the total. Consequently, Neka (#4), Bandar-abbas (#10), Bistoon (#20), Mofateh (#13), Rajayi (#2), Toos (#26), and Sahand (#25) are largest producer of SO_2 pollutants and these seven plants produce 75.4% of total SO_2.

The large natural gas consuming plants have the main contribution in NO_X emissions. Therefore, Damavand (#1), Rajayi (#2), Kerman (#3), Neka (#4), Ramin (#5), Montazeri (#6), and MontazerQaem (#7), with respect to their high generation, are the top seven in NO_X production.

Also, Neka (#4), Bandar-abbas (#10), Bistoon (#20), Mofateh (#13), Toos (#26), Rajayi (#2), and Iran-shahr (#55) have the highest PM_{10} emissions and 72.6% of PM_{10} emanate from these seven plants.

After the characteristics of the plants, their precise latitude and longitude in decimal degree format is put into the model. The time frame for the model is a full year. The final required data for the SIMPACTS are exposure-response functions and unit costs for the impacts. The ExternE has collected exposure–response functions from several epidemiological studies. Additionally, sulfates and nitrates are treated as particles, assuming for sulfates the toxicity of PM_{10} and for nitrates, half the toxicity of sulfates [15]. Table A3 summarizes health impacts of pollutants, including mortality (chronic, acute, and infant) and morbidity (chronic bronchitis, bronchodilator usage, lower respiratory symptom, restricted activity days, and hospital admissions) and related ERFs that have been considered in the current study.

In this study, the ERFs have also been assumed to be linear, without threshold behavior, which is vital for linear transfer of values and their adjustment. The simplification of linearized functions without thresholds to very low increments in air pollution may lead to an overestimation of effects, which must be remembered when using the results of such studies [3,13,28,29,44].

Since most of the developing countries have no WTP studies, SIMPACTS offers the possibility of transferring the values assessed for European Union. According to Equation (1), we use the unit transfer with income adjustment. Per capita GDP (at PPP) for Iran and EU are 5910 and 20,269 USD (2000), respectively. Also in this modification, the elasticity of willingness to pay with respect to income is supposed to be one ($\gamma = 1$). Table 2 presents the results of the applied adjustments and unit damage costs for different health impacts.

Table 2. Unit damage cost of the health impacts and their adjustments for Iran from EU values.

Health Impact	Economic Unit Value (Year 2000 USD)	
	Iran	European Union
Chronic Mortality	13,375.28	45,872.00
Infant Mortality	267,502.95	917,431.00
Acute Mortality	20,062.63	68,807.00
Bronchodilator Usage	0.29	1.00
Lower Respiratory Symptom	10.21	35.00
Restricted Activity Days (working adults)	34.70	119.00
Restricted Activity Days (non-working adults)	12.25	42.00
Hospital Admissions (Respiratory or Cardiac)	538.84	1848.00
Chronic Bronchitis	53,500.53	183,486.00

Source: [37].

4. Results

After collecting and calculating the required data, we ran the model for every plant separately and individually and calculated the health impacts and costs from air pollution of the fossil plants.

Table A4 demonstrates the results of the considered human health impacts from the 61 plants with respect to the type of pollutants. Additionally, according to this table, Figure 6 shows the share of each health impact in total cases from all the 61 power plants.

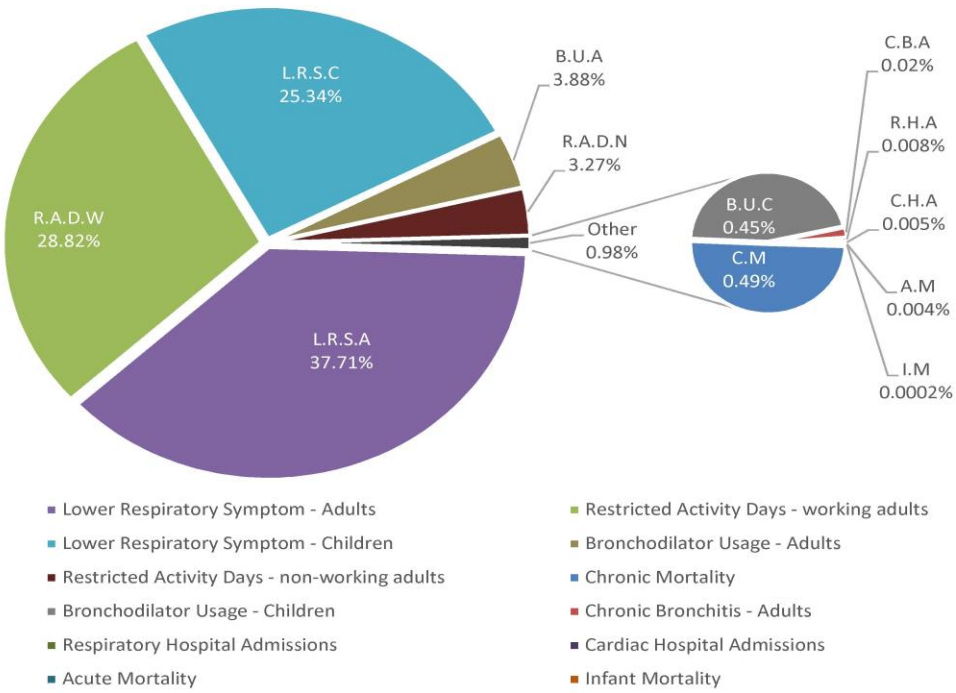

Figure 6. Share of each health impact in total cases from all the 61 power plants.

As shown in Figure 6, in the all impacts from the total power plants, Lower Respiratory Symptom in Adults, Restricted Activity Days in Working Adults, and Lower Respiratory Symptom in Children have the highest health impacts with shares of 37.71%, 28.82%, and 25.34%, respectively. Multiplying the number of cases of each impact to the unit cost of the impact gives the damage cost from the impacts.

Furthermore, in Appendix A, Table A5 presents the health damage costs from the 61 power plants by type of pollutants and damage cost per generated electricity, as well. This table shows that the total damage cost from all the 61 power plants is 723.42 million USD (2000) and health damage costs vary from 0.11 to 93.59 million USD. The plants Bistoon (#20), Neka (#4), Mofateh (#13), Bandar-abbas (#10), Rajayi (#2), Damavand (#1), Besat (#50), MontazerQaem (#7), and Toos (#26) are the highest in total health damage costs. These nine plants cause 72.9% of total damage costs. Figure 7 shows health damage costs from these nine plants with respect to the type of pollutants. The majority of these nine plants have the high contribution in fuel oil consumption and consequently in SO_2 pollution, except for Besat (#50) and MontazerQaem (#7). These two plants are near the capital with very high population density, and hence the large amount of the receptors increases the health costs from these plants. As mentioned earlier, SIMPACTS shows the results for all 1681 grids around the plant. Therefore, it shows that 98% and 82% of health costs occur on 25 grids around Besat (#50) and MontazerQaem (#7), respectively. Generally, on average, about 35% of health costs occur on 25 grids around the 61 power plants (i.e., at a square size of 250 × 250 km).

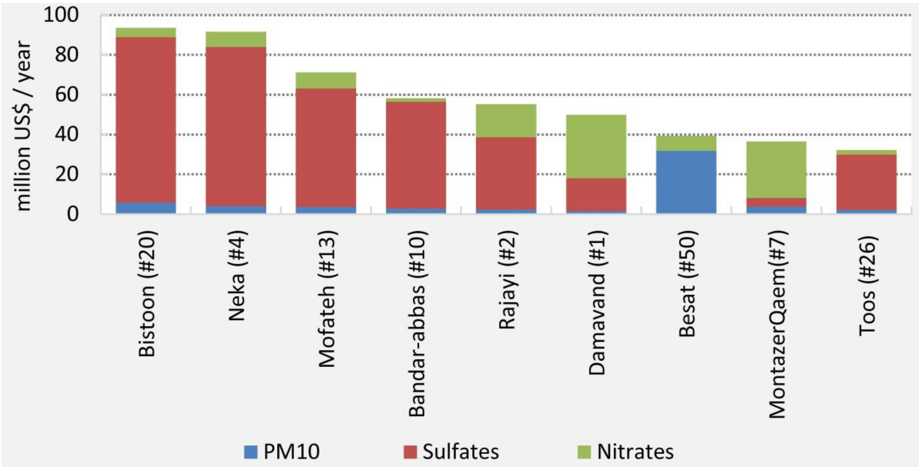

Figure 7. Top nine plants at the health damage costs with respect to the type of pollutants (million USD/year).

Furthermore, Iran-shahr (#55) consumes a large quantity of diesel and this plant is 8th-largest in SO_2 emissions. Nevertheless, according the Figure 4 and Table A1, this plant is in the low-density population area. Consequently, the location of the power plant has a significant effect on the external cost due to pollution. Generally, the low quality of fossil fuel and high population density around power plants account for large health effects.

In addition, Table A5 shows that damage cost per generated electricity varies from 0.06 to 22.41 USD/MWh. The average cost from the 61 plants (i.e., total health damage costs to total electricity generation from the 61 plants) is 2.85 USD/MWh. The damage cost per generated electricity of Besat (#50), Bistoon (#20), Mofateh (#13), Neka (#4), Toos (#26), and Bandar-abbas (#10) are highest and their values are more than 8 USD/MWh. Since Besat (#50) is a comparatively small plant, but with a high damage cost, its damage cost per generated electricity is 22.41 USD/MWh.

Table 3 displays the total health damage costs from the 61 power plants by type of the health impact and by type of the pollutants.

With respect to Table 3, Figure 8 shows that the impacts of Chronic Mortality, Chronic Bronchitis in Adults, and Restricted Activity Days in Working Adults have the highest health costs, with shares of 68.56%, 12.47%, and 10.40%, respectively.

Table 3. Human health damage costs from the 61 power plants of Iran by health impact and pollutant type (million USD 2000).

Health Impacts		Pollutants			
		PM_{10}	Sulfates	Nitrates	All
Mortality	Chronic (C.M)	47.674	299.003	149.326	496.003
	Infant (I.M)	0.429	2.691	1.344	4.464
	Acute (A.M)	0.515	3.229	1.613	5.357
Bronchodilator Usage	Asthmatic Adults (B.U.A)	0.008	0.051	0.025	0.085
	Asthmatic Children (B.U.C)	0.001	0.006	0.003	0.010
Lower Respiratory Symptom	Adults (L.R.S.A)	2.798	17.550	8.618	28.966
	Children (L.R.S.C)	1.871	11.737	5.862	19.471
Restricted Activity Days	Working Adults (R.A.D.W)	7.309	45.841	22.104	75.254
	Non-working Adults (R.A.D.N)	0.292	1.833	0.884	3.010
Hospital Admissions	Cardiac (C.H.A)	0.020	0.126	0.063	0.210
	Respiratory (R.H.A)	0.033	0.205	0.106	0.344
Chronic Bronchitis	Adults (C.B.A)	8.674	54.401	27.169	90.244
Total		**69.624**	**436.675**	**217.117**	**723.416**

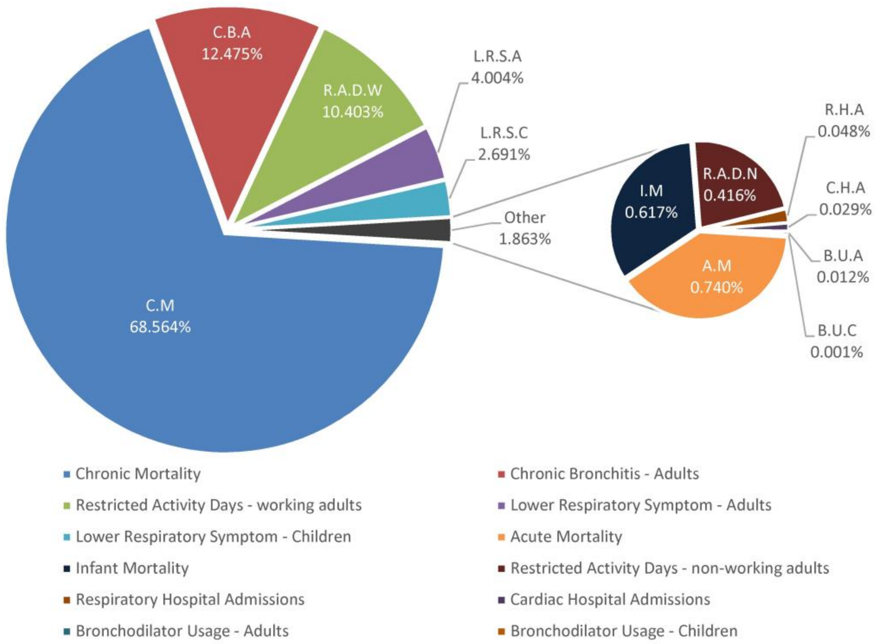

Figure 8. Share of each health impact in total damage costs from all the 61 power plants.

The results show that the pollutants caused significant damage to both mortality and morbidity. These results describe that chronic mortality costs stand for majority of the total damage costs obtained. Additionally, the low damage costs are mainly due to the negligible sulfur content in the fuel and the low PM_{10} and NO_X emissions and lower population density near the power plants. In addition, sulfur species represent main part of the total costs. The last row of Table 3 states that the major impacts for all considered pollutants have been made by sulfates, which accounted up to 60.4% of the total damage costs, and the costs from nitrates and PM_{10} contributed 30.0% and 9.6%, respectively. Since Iranian plants consume large amounts of natural gas, the sulfate share in the total cost is smaller than similar studies; further, the nitrate share is larger than in similar studies. For example, Thai and Syrian studies have estimated that sulfates accounted up to 83% and 88% of the total damage costs, respectively, with the costs from nitrates being 9% and 10%, and the costs from PM_{10} being 8% and 2%, respectively.

In these studies, Thai power plants consume natural gas, lignite, and oil, while Syrian plants use heavy fuel oil and natural gas [13,16].

As a final point, Figure 9 depicts distribution of total health costs from all 61 power plants in Iran. According to Table A5, the health costs of 41 plants are less than 5 million USD. Moreover, Figure 9 shows that the health costs are high mainly around the capital and west provinces of the capital, where pollutants from electricity generation cause significant damage on human health.

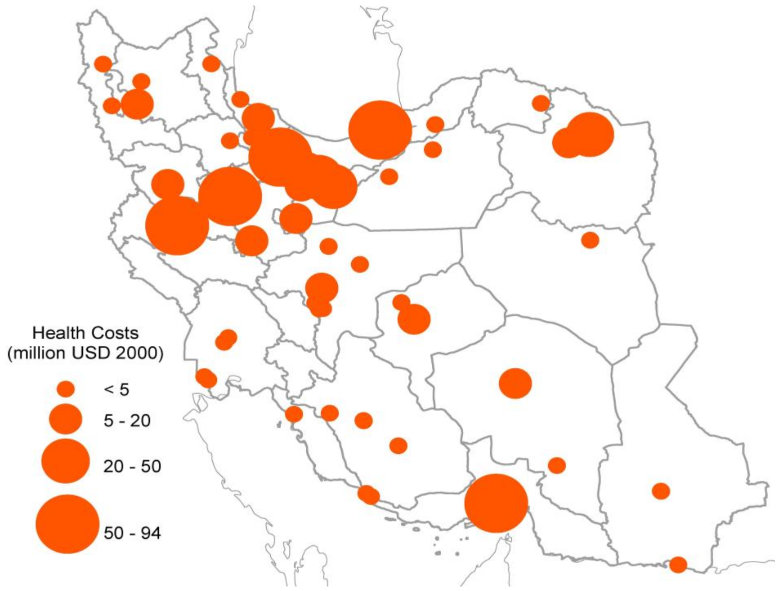

Figure 9. Distribution of total health costs from all 61 power plants in Iran.

5. Discussion and Conclusions

The most important impact of fossil-based power plants is airborne pollution. The external costs of electricity generation represent the uncompensated monetary value of the associated environmental and health damages. Thus, society will accept the excess costs from electricity production that are not reflected in market prices.

In this study, we apply the impact pathway approach to estimate the health impacts arising from air emissions stemming from Iranian fossil-based electricity generation for one year. In a next step, we evaluate the monetary costs of the estimated damages. We use the new version of SIMPACTS (March 2016) to investigate the health effects from the 61 fossil power plants separately and individually. In this analysis, we cover the whole country and investigate health effects from all large fossil power plants, one by one. Our detailed approach strongly increases the reliability of the results because the different locations, the distribution of population around the plants, the meteorological conditions, the fuel consumption, and the pollutant emissions are jointly taken into account. In this way, our approach provides more reliable estimations in comparison with previous studies using extrapolations based on one or a limited number of plants. Moreover, to find a better value for population density around every power plant, we use the population of all sub-provinces of Iran. Subsequently with the help of the ArcGIS 10.5, we calculate the precise population density for each of the 61 power plants. Since fossil plants have a high contribution in SO_2 and NO_X emission, we use the appropriate national values for emission factors of these air pollutants from electricity generation. We use the benefit transfer method to fill in gaps in the availability of information. The calculated total health damage cost is 723.42 million USD 2000. The damage cost per generated electricity unit varies from 0.06 to 22.41 USD/MWh, and its average is 2.85 USD/MWh.

There is another Iran study conducted in 2007 selecting only five fossil plants to calculate external costs by generalizing the results to all regions of Iran. The damage cost per generated electricity of their study vary from 15.94 to 74.66 USD (2000) per MWh [44]. Their study consists of SO_2, NO_X, and SO_X pollutants. Additionally, their results include the environmental damage cost of CO_2. They mention that for the estimation of total external damages generated by power plants (besides health costs), a medium value of 85% is selected for external health effects of air pollution. Thus, these matters cause the different results between the 2007 study for Iran and the current study. In addition, the fuel oil consumption in Iran has decreased by about 50% from 2007 to 2017.

Although economic issues are still the main factor in choosing the generation method, Iran has taken several measures to consider environmental issues and to decrease the adverse effects of electricity generation, such as the implementation of environmental assessment in construction of new power plants, developing and using renewable energy, and increasing efficiency of thermal power plants by construction of steam section of combined cycle power plants, and dispatching units with respect to higher efficiency. One of the most significant actions in reduction of pollutants from Iran power plants in the last years is replacing liquid fuels (fuel oil and diesel) with natural gas as a clean fuel, especially in plants close to large cities. This action started in 2014 and has continued by cooperation between Iran's Ministry of Petroleum and Ministry of Energy. Nevertheless, in the cold seasons, due to consumption of natural gas in residential sectors, several plants, despite the proximity to high density population areas, use liquid fuels.

This study exhibits the health impacts and costs for every 61 plants. These independent results are useful to classify the power plants based on their health damages and taking measures according to their priority. We found that there are power plants near the densely populated regions that create high health impacts and costs. The plants Bistoon, Neka, Mofateh, Bandar-abbas, Rajayi, Damavand, Besat, MontazerQaem, and Toos cause high health damage costs. These nine plants cause 73% of total damage costs from Iran electricity generation. The majority of these nine plants have a high contribution in fuel oil consumption. In addition, Damavand, Rajayi, and MontazerQaem use large amounts of diesel. Consequently, at first, the liquid fuels in these plants should be replaced quickly. For instance, the statistical reports show that MontazerQaem has consumed large amounts of fuel oil in the past years but then the fuel oil consumption in this plant has reached to zero. Such actions decrease the emissions of health-harmful air pollutants. In addition, improving efficiency and fuel consumption, using the appropriate emission reduction technologies, and locating polluting plants farther from densely populated areas decrease the external costs.

There are uncertainties involved in calculating external costs for power generation, for example, estimating of the data, the applied assumptions in models, and deriving the monetary valuation of damage costs. Nevertheless, it is better to have even an estimation of the externalities instead of disregarding them entirely. Also despite the uncertainties in the results, it is possible to reach meaningful conclusions. However, more research in the field of fossil electricity externality is necessary.

A general conclusion from this study is that air emissions from fossil plants have a large impact on human health and the related external costs are high. Considering the external costs can affect the electricity generation expansion planning. Internalization of the external costs in the price of electricity would increase the production cost from fossil fuels and hence fossil electricity alternatives become competitive. Therefore, cleaner and low emissions energy technologies with lower external costs (even with higher private costs) can be used to increase benefits for society.

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Author Contributions: Mojtaba Jorli analyzed the data and did the modelling using SIMPACTS 2. Steven Van Passel formulated the main research idea. Steven Van Passel and Mojtaba Jorli designed the work and interpreted the results. Mojtaba Jorli, Hossein Sadeghi, Alireza Nasseri and Lotfali Agheli gathered and calculated the population and pollution data. All authors contributed to the manuscript and the writing of the paper. Mojtaba Jorli and Steven Van Passel edited and revised the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of status of population around of the selected power plants.

Nr.	Power Plant Name	Coverage of Iran Population in 2050 × 2050 km	Population in 250 × 250 km	Nr.	Power Plant Name	Coverage of Iran Population in 2050 × 2050 km	Population in 250 × 250 km
		%	Million Person			%	Million Person
1	Damavand	99.2%	19.04	**2**	Rajayi	97.4%	18.37
3	Kerman	96.1%	1.20	**4**	Neka	96.7%	3.62
5	Ramin	94.8%	3.93	**6**	Montazeri	99.5%	4.90
7	MontazerQaem	98.6%	19.22	**8**	Gilan	94.1%	4.75
9	Kazeroon	98.4%	4.01	**10**	Bandar-abbas	76.5%	1.42
11	Shazand	96.9%	4.76	**12**	Neishabur	84.6%	4.66
13	Mofateh	95.0%	3.96	**14**	Fars	98.2%	3.80
15	Pareh-sar	92.1%	4.37	**16**	Asaluyeh	79.6%	0.90
17	Yazd	100.0%	1.62	**18**	Qom	98.5%	11.30
19	Sanandaj	87.0%	3.54	**20**	Bistoon	87.9%	4.64
21	Hafez	98.2%	3.80	**22**	Abadan	91.7%	2.51
23	Khalij-fars	81.1%	1.67	**24**	Khoramshahr	90.9%	2.55
25	Sahand	81.9%	5.85	**26**	Toos	81.2%	5.05
27	RoodShur	98.6%	19.22	**28**	Chehel-sotun	99.6%	5.07
29	Uromieh	80.6%	5.41	**30**	Tabriz	81.1%	5.49
31	Parand	98.7%	19.28	**32**	Isin	79.2%	1.55
33	Shirvan	85.5%	1.69	**34**	Zavareh	99.9%	2.70
35	Jahrom	93.4%	2.71	**36**	Ganaveh	97.2%	1.88
37	Shirkooh	100.0%	1.62	**38**	Dorcheh	99.6%	5.10
39	Kaveh	84.1%	0.84	**40**	Golestan	96.1%	2.46
41	Sabalan	85.4%	2.31	**42**	Shariati	79.0%	5.05
43	Chadormalou	100.0%	2.23	**44**	Pars-jonubi	80.8%	0.92
45	Shobad	84.1%	1.49	**46**	Ferdoosi	81.3%	5.05
47	Zagros	87.9%	4.64	**48**	Bampoor	62.5%	0.72
49	Khoy	77.8%	3.72	**50**	Besat	98.9%	19.84
51	Zargan	94.3%	3.84	**52**	Soltaniye	93.7%	4.53
53	Mashhad	79.7%	5.09	**54**	Loshan	95.3%	5.50
55	Iran-shahr	62.4%	0.72	**56**	Semnan	99.3%	3.30
57	Mobarakeh	99.5%	4.93	**58**	Chabahar	28.6%	0.55
59	Zob-ahan	99.4%	4.80	**60**	Kashan	99.6%	2.87
61	Bastami	98.2%	2.26				

Table A2. The selected power plants characteristics used in the SIMPACTS analysis.

Nr.	Power Plant Name	Type	Nominal Capacity	Gross Generation		Fuel Consumption			Emissions			Stack Specification		
						Natural Gas	Diesel	Fuel Oil	SO_2	NO_X	PM_{10}	Height	Diameter	Elevation
			MW	MWH	Share	Million m^3	Million Liters		Ton/Year			Meter		
1	Damavand	C [a]	2868	13,912,678	5.5%	2458.9	580.53	0.0	8674.7	38,980.9	151.4	35	6	1053
2	Rajayi	C,S [b]	2043	11,936,083	4.7%	2515.0	240.01	332.3	24,900.3	30,181.6	723.6	130	5	1308
3	Kerman	C	1912	11,000,245	4.3%	2342.4	98.69	0.0	1467.8	26,470.4	88.1	35	6	1750
4	Neka	S,C	2215	10,943,624	4.3%	1891.6	0.00	965.7	61,445.9	26,042.0	1841.3	110	5	0
5	Ramin	S	1903	10,318,644	4.1%	2875.1	0.01	9.6	595.6	23,727.8	110.8	200	6	35
6	Montazeri	S	1616	9,585,574	3.8%	2609.6	0.00	0.0	0.0	22,034.0	84.5	150	4	1677
7	MontazerQaem	C,S	1623	8,739,549	3.4%	2088.3	164.81	0.0	2104.8	21,787.9	88.0	35	5	1246
8	Gilan	C	1306	7,324,948	2.9%	1296.8	405.22	0.0	5673.6	21,416.1	92.1	25	6	62
9	Kazeroon	C	1372	7,322,559	2.9%	1645.5	22.66	0.0	328.9	17,097.6	56.1	35	6	838
10	Bandar-abbas	S,G [c]	1330	7,252,100	2.9%	1160.6	0.90	842.9	50,127.3	17,401.3	1591.4	80	6	19
11	Shazand	S	1300	6,622,608	2.6%	1695.5	0.48	31.9	2125.7	15,258.6	113.7	200	9	1939
12	Neishabur	C	1040	5,835,730	2.3%	1137.4	185.56	0.0	2681.9	15,578.6	59.8	35	5	1266
13	Mofateh	S	1000	5,310,506	2.1%	932.0	0.00	454.8	28,970.2	12,624.9	868.5	150	5	1642
14	Fars	C	1035	5,300,617	2.1%	1175.5	16.29	0.0	239.7	12,377.7	40.1	40	5	1522
15	Pareh-sar	C	968	5,138,049	2.0%	871.4	268.20	0.0	3934.8	14,986.0	61.4	35	6	0
16	Asaluyeh	G	954	4,777,938	1.9%	1607.5	0.14	0.0	1.4	10,984.0	52.1	30	7	39
17	Yazd	C,G	1005	4,710,870	1.9%	950.3	78.26	0.0	1179.9	11,780.9	40.4	35	6	1209
18	Qom	C	714	4,442,176	1.7%	877.2	175.08	0.0	2417.0	12,161.5	50.1	35	6	1026
19	Sanandaj	C	956	4,369,461	1.7%	724.8	239.16	0.0	3524.4	12,888.1	53.0	35	6	1539
20	Bistoon	S	640	4,289,350	1.7%	353.0	0.00	702.8	45,464.0	10,515.5	1306.9	160	5	1320
21	Hafez	G	972	4,236,129	1.7%	1371.1	31.97	0.0	319.0	9994.9	48.4	25	6	1532
22	Abadan	C	814	4,182,643	1.6%	867.5	10.13	0.0	159.7	9743.4	29.3	25	6	2
23	Khalij-fars	G	990	4,106,068	1.6%	1260.7	41.61	0.0	433.2	9788.1	46.0	25	6	68
24	Khoramshahr	G	972	4,027,770	1.6%	1162.4	102.67	0.0	1075.7	10,126.6	50.3	30	6	3
25	Sahand	S	650	3,992,910	1.6%	766.1	0.00	272.1	17,560.8	9431.7	526.3	204	4	1293
26	Toos	S	600	3,952,910	1.6%	695.6	1.74	397.1	23,764.5	9444.8	754.7	100	3	1128
27	RoodShur	G	789	3,929,872	1.5%	915.8	202.75	0.0	2327.1	10,911.4	54.7	25	6	1114
28	Chehel-sotun	G	954	3,612,743	1.4%	1128.6	42.05	0.0	428.4	8650.2	41.7	25	6	1730
29	Uromieh	G	960	3,456,578	1.4%	919.6	218.95	0.0	2169.7	9696.4	56.8	25	6	1339
30	Tabriz	S,G	800	3,213,003	1.3%	941.5	0.29	30.7	1758.6	7413.4	87.1	140	5	1330
31	Parand	G	954	3,210,622	1.3%	895.8	152.80	0.0	1532.4	8616.8	47.9	35	6	1075
32	Isin	G	648	3,046,666	1.2%	957.0	33.72	0.0	342.4	7279.6	35.2	25	6	67
33	Shirvan	G	954	3,042,788	1.2%	755.0	105.88	0.0	1227.7	7985.1	37.5	25	6	1110
34	Zavareh	C	484	3,022,881	1.2%	560.1	66.70	0.0	1056.6	7801.3	26.4	45	5	988
35	Jahrom	G	954	2,995,806	1.2%	936.2	29.05	0.0	297.8	7126.7	33.9	25	6	1065

Table A2. *Cont.*

Nr.	Power Plant Name	Type	Nominal Capacity	Gross Generation		Fuel Consumption			Emissions			Stack Specification		
						Natural Gas	Diesel	Fuel Oil	SO_2	NO_X	PM_{10}	Height	Diameter	Elevation
			MW	MWH	Share	Million m^3	Million Liters		Ton/Year			Meter		
36	Ganaveh	C	484	2,925,544	1.2%	589.9	17.69	0.0	281.3	6951.8	21.3	35	6	2
37	Shirkooh	C	484	2,839,356	1.1%	570.5	32.39	0.0	502.9	6932.6	22.5	35	6	1190
38	Dorcheh	S	835	2,712,428	1.1%	764.1	0.00	0.0	0.0	6235.0	24.7	70	4	1610
39	Kaveh	G	636	2,673,012	1.1%	749.3	106.94	0.0	1095.1	7028.1	37.5	25	6	1465
40	Golestan	G	972	2,597,197	1.0%	705.3	175.53	0.0	1688.6	7332.8	44.5	25	6	114
41	Sabalan	G	960	2,577,551	1.0%	753.2	130.83	0.0	1249.2	6933.0	40.6	25	6	1338
42	Shariati	C,G	497	2,446,626	1.0%	577.9	57.13	0.0	723.8	6208.1	25.8	35	5	958
43	Chadormalou	C	492	2,389,805	0.9%	597.5	0.00	0.0	0.0	5493.4	19.3	35	6	1159
44	Pars-jonubi	G	954	2,389,442	0.9%	796.5	0.00	0.0	0.0	5492.5	25.8	25	6	38
45	Shobad	C	484	2,342,615	0.9%	642.0	6.75	0.0	80.6	5449.9	21.6	35	6	533
46	Ferdoosi	G	954	2,204,088	0.9%	636.0	119.87	0.0	1143.8	5989.5	35.4	25	7	1122
47	Zagros	G	648	2,143,001	0.8%	687.7	113.00	0.0	990.8	5725.6	36.2	25	6	1326
48	Bampoor	G	324	1,919,485	0.8%	586.9	7.60	0.0	81.2	4477.8	19.9	25	6	542
49	Khoy	C	349	1,889,962	0.7%	295.1	149.82	0.0	2056.0	6003.6	28.1	35	5	1183
50	Besat	S	248	1,751,915	0.7%	563.2	0.42	0.0	4.3	4030.6	18.3	26	3	1114
51	Zargan	S,G	418	1,699,941	0.7%	461.0	0.00	0.0	0.0	3907.6	14.9	60	5	23
52	Soltaniye	G	648	1,688,208	0.7%	467.1	80.04	0.0	808.9	4533.4	25.0	25	6	1838
53	Mashhad	S,G	328	1,546,817	0.6%	533.7	23.63	0.0	216.4	3730.2	20.2	45	5	965
54	Loshan	S,G	360	1,424,962	0.6%	380.1	62.83	0.0	662.3	3809.9	20.1	45	5	313
55	Iran-shahr	S	256	1,423,528	0.6%	120.8	0.16	326.3	16,404.5	3510.0	605.3	110	5	551
56	Semnan	G	324	1,337,634	0.5%	312.5	91.92	0.0	989.8	3873.5	21.5	25	6	1231
57	Mobarakeh	S,G	318	1,336,549	0.5%	441.7	9.60	0.0	94.0	3148.1	15.5	35	6	1784
58	Chabahar	G	414	1,261,563	0.5%	0.0	435.45	0.0	3890.0	6039.1	53.8	25	6	7
59	Zob-ahan	S,G	275	1,167,857	0.5%	272.7	0.00	0.0	0.0	2684.5	8.8	110	4	1757
60	Kashan	G	324	1,108,778	0.4%	303.5	65.75	0.0	645.1	3069.3	18.0	25	6	991
61	Bastami	G	324	1,063,864	0.4%	285.1	57.00	0.0	579.7	2913.2	16.3	25	6	1231
	Total Power Plants		53,603	254,024,426	100.0%	58,434.7	5260.59	4366.1	334,499.7	639,809.0	10,590.5			

[a] Combined cycle; [b] Steam; [c] Gas

Table A3. Health impacts of pollutants and exposure-response relations.

Health Impact	Affected Population	Unit	Pollutant	ERF Slope Cases Per Year Per Person Per μg/m^3
Chronic Mortality	entire population	years of life lost	PM_{10} Sulfates	4×10^{-4}
			Nitrates	2×10^{-4}
Acute Mortality			PM_{10} Sulfates	2.88×10^{-6}
			Nitrates	1.44×10^{-6}
Infant Mortality	children less than 12 month old		PM_{10} Sulfates	1.8×10^{-7}
			Nitrates	9×10^{-8}
Bronchodilator Usage	asthmatic adults, 20+	cases of usage	PM_{10} Sulfates	3.15×10^{-3}
			Nitrates	1.575×10^{-3}
	asthmatic children 5–14		PM_{10} Sulfates	3.663×10^{-4}
			Nitrates	1.7908×10^{-4}
Lower Respiratory Symptom	adults with chronic respiratory symptoms	days	PM_{10} Sulfates	3.0756×10^{-2}
			Nitrates	1.51217×10^{-2}
	Children, 5–14		PM_{10} Sulfates	2.057×10^{-2}
			Nitrates	1.0285×10^{-2}
Restricted Activity Days	working adults, 15–64		PM_{10} Sulfates	2.36379×10^{-2}
			Nitrates	1.14114×10^{-2}
	non-working adults, 15–64		PM_{10} Sulfates	2.67786×10^{-3}
			Nitrates	1.29276×10^{-3}
Cardiac Hospital Admissions	entire population	admissions	PM_{10} Sulfates	4.2×10^{-6}
			Nitrates	2.1×10^{-6}
Respiratory Hospital Admissions			PM_{10} Sulfates	6.82×10^{-6}
			Nitrates	3.534×10^{-6}
Chronic Bronchitis	adults, 27+	cases	PM_{10} Sulfates	1.81944×10^{-5}
			Nitrates	9.0972×10^{-6}

Table A4. Human health impacts from the 61 plants of Iran by type of pollutants.

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	I.M.	A.M.	B.U.A.	B.U.C.	L.R.S.A.	L.R.S.C.	R.A.D.W.	R.A.D.N.	C.H.A.	R.H.A.	C.B.A.
1	**Damavand**	PM_{10}	81.0	0.0	0.6	638.1	74.2	6230.2	4166.8	4788.3	542.4	0.9	1.4	3.7
		Sulfates	845.7	0.4	6.1	6660.3	774.5	65,029.5	43,492.6	49,979.2	5662.0	8.9	14.4	38.5
		Nitrates	1630.6	0.7	11.7	12,841.1	1460.1	123,288.6	83,854.6	93,038.2	10,540.0	17.1	28.8	74.2
		All	2557.4	1.2	18.4	20,139.5	2308.7	194,548.3	131,513.9	147,805.7	16,744.4	26.9	44.6	116.3
2	**Rajayi**	PM_{10}	117.2	0.1	0.8	922.6	107.3	9008.5	6025.0	6923.6	784.4	1.2	2.0	5.3
		Sulfates	1861.3	0.8	13.4	14,657.4	1704.4	143,111.8	95,715.0	109,990.3	12,460.4	19.5	31.7	84.7
		Nitrates	851.5	0.4	6.1	6705.5	762.4	64,379.6	43,787.7	48,583.2	5503.8	8.9	15.0	38.7
		All	2829.9	1.3	20.4	22,285.5	2574.2	216,499.9	145,527.7	165,497.2	18,748.6	29.7	48.8	128.7
3	**Kerman**	PM_{10}	10.4	0.0	0.1	81.8	9.5	798.3	533.9	613.5	69.5	0.1	0.2	0.5
		Sulfates	120.1	0.1	0.9	946.1	110.0	9237.9	6178.4	7099.9	804.3	1.3	2.0	5.5
		Nitrates	154.3	0.1	1.1	1215.2	138.2	11,667.7	7935.8	8804.9	997.5	1.6	2.7	7.0
		All	284.8	0.1	2.1	2243.1	257.7	21,703.9	14,648.1	16,518.3	1871.3	3.0	5.0	13.0
4	**Neka**	PM_{10}	204.2	0.1	1.5	1608.4	187.0	15,704.2	10,503.1	12,069.6	1367.3	2.1	3.5	9.3
		Sulfates	4092.6	1.8	29.5	32,229.2	3747.8	314,679.6	210,461.7	241,850.9	27,398.5	43.0	69.8	186.2
		Nitrates	393.5	0.2	2.8	3098.6	352.3	29,750.3	20,234.6	22,450.7	2543.4	4.1	7.0	17.9
		All	4690.3	2.1	33.8	36,936.2	4287.1	360,134.1	241,199.5	276,371.2	31,309.2	49.2	80.2	213.3
5	**Ramin**	PM_{10}	14.4	0.0	0.1	113.6	13.2	1109.0	741.7	852.3	96.6	0.2	0.2	0.7
		Sulfates	39.3	0.0	0.3	309.5	36.0	3022.3	2021.4	2322.9	263.1	0.4	0.7	1.8
		Nitrates	179.6	0.1	1.3	1414.2	160.8	13,577.8	9235.0	10,246.4	1160.8	1.9	3.2	8.2
		All	233.3	0.1	1.7	1837.3	210.0	17,709.1	11,998.0	13,421.5	1520.5	2.4	4.1	10.6
6	**Montazeri**	PM_{10}	17.9	0.0	0.1	140.6	16.4	1372.9	918.2	1055.1	119.5	0.2	0.3	0.8
		Nitrates	498.2	0.2	3.6	3923.0	446.0	37,664.7	25,617.6	28,423.2	3220.0	5.2	8.8	22.7
		All	516.0	0.2	3.7	4063.6	462.4	39,037.6	26,535.8	29,478.3	3339.5	5.4	9.1	23.5
7	**MontazerQaem**	PM_{10}	192.4	0.1	1.4	1514.8	176.1	14,790.1	9891.8	11,367.1	1287.7	2.0	3.3	8.7
		Sulfates	220.4	0.1	1.6	1736.0	201.9	16,950.1	11,336.4	13,027.2	1475.8	2.3	3.8	10.0
		Nitrates	1456.9	0.7	10.5	11,473.4	1304.5	110,157.3	74,923.3	83,128.8	9417.4	15.3	25.7	66.3
		All	1869.7	0.8	13.5	14,724.2	1682.6	141,897.5	96,151.6	107,523.1	12,180.9	19.6	32.8	85.0
8	**Gilan**	PM_{10}	20.5	0.0	0.1	161.1	18.7	1572.7	1051.8	1208.7	136.9	0.2	0.3	0.9
		Sulfates	202.2	0.1	1.5	1592.2	185.2	15,546.4	10,397.6	11,948.4	1353.6	2.1	3.4	9.2
		Nitrates	250.2	0.1	1.8	1970.6	224.1	18,919.4	12,868.0	14,277.3	1617.4	2.6	4.4	11.4
		All	472.9	0.2	3.4	3723.9	427.9	36,038.5	24,317.5	27,434.4	3108.0	5.0	8.2	21.5
9	**Kazeroon**	PM_{10}	18.8	0.0	0.1	148.2	17.2	1447.1	967.8	1112.2	126.0	0.2	0.3	0.9
		Sulfates	29.1	0.0	0.2	229.1	26.6	2236.7	1496.0	1719.1	194.7	0.3	0.5	1.3
		Nitrates	173.3	0.1	1.2	1364.9	155.2	13,104.5	8913.0	9889.1	1120.3	1.8	3.1	7.9
		All	221.2	0.1	1.6	1742.2	199.1	16,788.3	11,376.8	12,720.4	1441.0	2.3	3.9	10.1

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	**I.M.**	**A.M.**	**B.U.A.**	**B.U.C.**	**L.R.S.A.**	**L.R.S.C.**	**R.A.D.W.**	**R.A.D.N.**	**C.H.A.**	**R.H.A.**	**C.B.A.**
10	**Bandar-abbas**	PM_{10}	148.3	0.1	1.1	1168.1	135.8	11,405.1	7627.9	8765.5	993.0	1.6	2.5	6.7
		Sulfates	2745.0	1.2	19.8	21,617.1	2513.8	211,065.4	141,163.2	162,216.9	18,377.0	28.8	46.8	124.9
		Nitrates	82.0	0.0	0.6	645.8	73.4	6200.7	4217.4	4679.3	530.1	0.9	1.4	3.7
		All	2975.4	1.3	21.4	23,431.1	2723.0	228,671.3	153,008.5	175,661.7	19,900.1	31.2	50.8	135.3
11	**Shazand**	PM_{10}	17.5	0.0	0.1	137.6	16.0	1343.8	898.8	1032.8	117.0	0.2	0.3	0.8
		Sulfates	193.8	0.1	1.4	1525.9	177.4	14,898.3	9964.2	11,450.3	1297.2	2.0	3.3	8.8
		Nitrates	276.3	0.1	2.0	2175.9	247.4	20,891.2	14,209.1	15,765.3	1786.0	2.9	4.9	12.6
		All	487.5	0.2	3.5	3839.4	440.8	37,133.3	25,072.1	28,248.4	3200.2	5.1	8.5	22.2
12	**Neishabur**	PM_{10}	17.0	0.0	0.1	133.8	15.6	1306.1	873.5	1003.8	113.7	0.2	0.3	0.8
		Sulfates	173.3	0.1	1.2	1365.0	158.7	13,327.2	8913.4	10,242.8	1160.4	1.8	3.0	7.9
		Nitrates	177.0	0.1	1.3	1394.2	158.5	13,385.7	9104.3	10,101.4	1144.4	1.9	3.1	8.1
		All	367.4	0.2	2.6	2892.9	332.8	28,019.1	18,891.2	21,348.0	2418.4	3.9	6.4	16.7
13	**Mofateh**	PM_{10}	183.9	0.1	1.3	1448.3	168.4	14,140.8	9457.6	10,868.1	1231.2	1.9	3.1	8.4
		Sulfates	3046.6	1.4	21.9	23,992.2	2789.9	234,255.1	156,672.8	180,039.6	20,396.1	32.0	51.9	138.6
		Nitrates	412.2	0.2	3.0	3246.0	369.1	31,165.1	21,196.9	23,518.4	2664.3	4.3	7.3	18.7
		All	3642.7	1.6	26.2	28,686.5	3327.4	279,561.1	187,327.2	214,426.1	24,291.6	38.2	62.4	165.7
14	**Fars**	PM_{10}	24.5	0.0	0.2	193.0	22.4	1884.2	1260.2	1448.1	164.1	0.3	0.4	1.1
		Sulfates	22.2	0.0	0.2	174.6	20.3	1705.1	1140.4	1310.5	148.5	0.2	0.4	1.0
		Nitrates	115.5	0.1	0.8	909.9	103.5	8735.6	5941.5	6592.2	746.8	1.2	2.0	5.3
		All	162.2	0.1	1.2	1277.5	146.2	12,324.9	8342.0	9350.8	1059.3	1.7	2.8	7.4
15	**Pareh-sar**	PM_{10}	8.2	0.0	0.1	64.3	7.5	628.1	420.1	482.8	54.7	0.1	0.1	0.4
		Sulfates	112.4	0.1	0.8	884.9	102.9	8639.9	5778.5	6640.3	752.3	1.2	1.9	5.1
		Nitrates	125.2	0.1	0.9	986.1	112.1	9467.7	6439.4	7144.7	809.4	1.3	2.2	5.7
		All	245.8	0.1	1.8	1935.3	222.5	18,735.8	12,638.0	14,267.8	1616.3	2.6	4.3	11.2
16	**Asaluyeh**	PM_{10}	5.9	0.0	0.0	46.7	5.4	456.1	305.1	350.6	39.7	0.1	0.1	0.3
		Sulfates	0.1	0.0	0.0	0.6	0.1	6.0	4.0	4.6	0.5	0.0	0.0	0.0
		Nitrates	37.3	0.0	0.3	293.9	33.4	2822.2	1919.5	2129.8	241.3	0.4	0.7	1.7
		All	43.3	0.0	0.3	341.3	38.9	3284.3	2228.6	2484.9	281.5	0.5	0.8	2.0
17	**Yazd**	PM_{10}	11.3	0.0	0.1	89.1	10.4	869.6	581.6	668.3	75.7	0.1	0.2	0.5
		Sulfates	120.5	0.1	0.9	949.1	110.4	9266.6	6197.6	7121.9	806.8	1.3	2.1	5.5
		Nitrates	146.1	0.1	1.1	1150.4	130.8	11,045.2	7512.4	8335.1	944.3	1.5	2.6	6.6
		All	277.9	0.1	2.0	2188.5	251.5	21,181.4	14,291.6	16,125.4	1826.8	2.9	4.8	12.6
18	**Qom**	PM_{10}	11.2	0.0	0.1	88.0	10.2	858.8	574.4	660.0	74.8	0.1	0.2	0.5
		Sulfates	246.1	0.1	1.8	1937.7	225.3	18,919.4	12,653.5	14,540.8	1647.3	2.6	4.2	11.2
		Nitrates	341.9	0.2	2.5	2692.2	306.1	25,848.2	17,580.6	19,506.1	2209.8	3.6	6.0	15.6
		All	599.1	0.3	4.3	4717.9	541.7	45,626.4	30,808.5	34,706.8	3931.8	6.3	10.4	27.3

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	**I.M.**	**A.M.**	**B.U.A.**	**B.U.C.**	**L.R.S.A.**	**L.R.S.C.**	**R.A.D.W.**	**R.A.D.N.**	**C.H.A.**	**R.H.A.**	**C.B.A.**
19	**Sanandaj**	PM_{10}	81.6	0.0	0.6	642.9	74.8	6277.2	4198.3	4824.4	546.5	0.9	1.4	3.7
		Sulfates	276.9	0.1	2.0	2180.8	253.6	21,292.5	14,240.7	16,364.6	1853.9	2.9	4.7	12.6
		Nitrates	275.2	0.1	2.0	2167.3	246.4	20,808.1	14,152.6	15,702.6	1778.9	2.9	4.9	12.5
		All	633.8	0.3	4.6	4990.9	574.8	48,377.8	32,591.6	36,891.6	4179.3	6.7	11.0	28.8
20	**Bistoon**	PM_{10}	289.7	0.1	2.1	2281.6	265.3	22,277.3	14,899.3	17,121.5	1939.6	3.0	4.9	13.2
		Sulfates	4259.1	1.9	30.7	33,540.5	3900.3	327,482.9	219,024.7	251,691.0	28,513.2	44.7	72.6	193.7
		Nitrates	243.4	0.1	1.8	1916.6	217.9	18,401.4	12,515.7	13,886.4	1573.1	2.6	4.3	11.1
		All	4792.2	2.2	34.5	37,738.7	4383.5	368,161.6	246,439.7	282,698.9	32,026.0	50.3	81.9	218.0
21	**Hafez**	PM_{10}	13.4	0.0	0.1	105.4	12.3	1029.1	688.3	791.0	89.6	0.1	0.2	0.6
		Sulfates	26.4	0.0	0.2	207.7	24.2	2027.9	1356.3	1558.6	176.6	0.3	0.4	1.2
		Nitrates	75.1	0.0	0.5	591.7	67.3	5681.4	3864.2	4287.4	485.7	0.8	1.3	3.4
		All	114.9	0.1	0.8	904.8	103.7	8738.4	5908.8	6636.9	751.9	1.2	2.0	5.2
22	**Abadan**	PM_{10}	1.4	0.0	0.0	10.9	1.3	106.5	71.2	81.9	9.3	0.0	0.0	0.1
		Sulfates	4.2	0.0	0.0	33.4	3.9	326.6	218.4	251.0	28.4	0.0	0.1	0.2
		Nitrates	20.4	0.0	0.1	160.8	18.3	1544.1	1050.2	1165.2	132.0	0.2	0.4	0.9
		All	26.1	0.0	0.2	205.2	23.4	1977.2	1339.9	1498.1	169.7	0.3	0.5	1.2
23	**Khalij-fars**	PM_{10}	5.8	0.0	0.0	46.0	5.4	449.3	300.5	345.3	39.1	0.1	0.1	0.3
		Sulfates	21.7	0.0	0.2	170.6	19.8	1665.3	1113.8	1279.9	145.0	0.2	0.4	1.0
		Nitrates	38.0	0.0	0.3	299.6	34.1	2876.6	1956.5	2170.8	245.9	0.4	0.7	1.7
		All	65.5	0.0	0.5	516.2	59.3	4991.1	3370.7	3795.9	430.0	0.7	1.1	3.0
24	**Khoramshahr**	PM_{10}	1.9	0.0	0.0	15.2	1.8	148.1	99.0	113.8	12.9	0.0	0.0	0.1
		Sulfates	24.5	0.0	0.2	192.8	22.4	1882.4	1259.0	1446.8	163.9	0.3	0.4	1.1
		Nitrates	18.2	0.0	0.1	143.3	16.3	1375.5	935.6	1038.0	117.6	0.2	0.3	0.8
		All	44.6	0.0	0.3	351.2	40.5	3406.0	2293.6	2598.6	294.4	0.5	0.8	2.0
25	**Sahand**	PM_{10}	44.7	0.0	0.3	352.3	41.0	3440.1	2300.8	2643.9	299.5	0.5	0.8	2.0
		Sulfates	571.4	0.3	4.1	4499.7	523.2	43,933.9	29,383.5	33,765.9	3825.2	6.0	9.7	26.0
		Nitrates	112.1	0.1	0.8	882.9	100.4	8476.4	5765.2	6396.6	724.6	1.2	2.0	5.1
		All	728.2	0.3	5.2	5734.8	664.6	55,850.3	37,449.5	42,806.4	4849.4	7.6	12.5	33.1
26	**Toos**	PM_{10}	113.4	0.1	0.8	892.9	103.8	8717.7	5830.5	6700.1	759.0	1.2	1.9	5.2
		Sulfates	1419.6	0.6	10.2	11,179.2	1300.0	109,151.6	73,002.0	83,889.8	9503.6	14.9	24.2	64.6
		Nitrates	115.2	0.1	0.8	907.3	103.2	8710.7	5924.5	6573.4	744.7	1.2	2.0	5.2
		All	1648.2	0.7	11.9	12,979.3	1507.0	126,580.0	84,757.0	97,163.3	11,007.3	17.3	28.2	75.0

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	**I.M.**	**A.M.**	**B.U.A.**	**B.U.C.**	**L.R.S.A.**	**L.R.S.C.**	**R.A.D.W.**	**R.A.D.N.**	**C.H.A.**	**R.H.A.**	**C.B.A.**
27	**RoodShur**	PM_{10}	15.7	0.0	0.1	123.5	14.4	1205.5	806.2	926.5	105.0	0.2	0.3	0.7
		Sulfates	217.8	0.1	1.6	1715.3	199.5	16,747.6	11,201.0	12,871.6	1458.2	2.3	3.7	9.9
		Nitrates	440.3	0.2	3.2	3467.7	394.3	33,293.6	22,644.6	25,124.6	2846.3	4.6	7.8	20.0
		All	673.8	0.3	4.9	5306.4	608.1	51,246.7	34,651.9	38,922.7	4409.4	7.1	11.8	30.6
28	**Chehel-sotun**	PM_{10}	8.9	0.0	0.1	70.4	8.2	686.9	459.4	527.9	59.8	0.1	0.2	0.4
		Sulfates	39.9	0.0	0.3	314.1	36.5	3066.5	2050.9	2356.8	267.0	0.4	0.7	1.8
		Nitrates	134.7	0.1	1.0	1060.8	120.6	10,184.6	6927.0	7685.7	870.7	1.4	2.4	6.1
		All	183.5	0.1	1.3	1445.2	165.3	13,938.0	9437.3	10,570.4	1197.5	1.9	3.2	8.3
29	**Uromieh**	PM_{10}	6.9	0.0	0.0	54.5	6.3	532.0	355.8	408.9	46.3	0.1	0.1	0.3
		Sulfates	58.1	0.0	0.4	457.2	53.2	4464.3	2985.7	3431.1	388.7	0.6	1.0	2.6
		Nitrates	99.4	0.0	0.7	782.5	89.0	7513.2	5110.1	5669.7	642.3	1.0	1.8	4.5
		All	164.3	0.1	1.2	1294.2	148.5	12,509.4	8451.6	9509.6	1077.3	1.7	2.9	7.5
30	**Tabriz**	PM_{10}	7.5	0.0	0.1	58.7	6.8	573.4	383.5	440.7	49.9	0.1	0.1	0.3
		Sulfates	39.1	0.0	0.3	307.5	35.8	3002.8	2008.3	2307.9	261.4	0.4	0.7	1.8
		Nitrates	76.2	0.0	0.5	600.4	68.3	5765.0	3921.0	4350.5	492.8	0.8	1.3	3.5
		All	122.8	0.1	0.9	966.7	110.9	9341.2	6312.9	7099.0	804.2	1.3	2.1	5.6
31	**Parand**	PM_{10}	13.4	0.0	0.1	105.5	12.3	1030.0	688.9	791.6	89.7	0.1	0.2	0.6
		Sulfates	139.3	0.1	1.0	1097.3	127.6	10,713.9	7165.6	8234.3	932.8	1.5	2.4	6.3
		Nitrates	328.7	0.1	2.4	2588.5	294.3	24,852.1	16,903.1	18,754.4	2124.6	3.5	5.8	15.0
		All	481.4	0.2	3.5	3791.3	434.2	36,596.0	24,757.6	27,780.3	3147.1	5.1	8.4	21.9
32	**Isin**	PM_{10}	3.6	0.0	0.0	28.0	3.3	273.1	182.6	209.9	23.8	0.0	0.1	0.2
		Sulfates	17.5	0.0	0.1	137.7	16.0	1344.0	898.9	1033.0	117.0	0.2	0.3	0.8
		Nitrates	28.1	0.0	0.2	221.4	25.2	2125.4	1445.6	1603.9	181.7	0.3	0.5	1.3
		All	49.1	0.0	0.4	387.0	44.4	3742.5	2527.1	2846.7	322.5	0.5	0.9	2.2
33	**Shirvan**	PM_{10}	5.6	0.0	0.0	44.1	5.1	430.4	287.9	330.8	37.5	0.1	0.1	0.3
		Sulfates	56.3	0.0	0.4	443.0	51.5	4325.6	2893.0	3324.5	376.6	0.6	1.0	2.6
		Nitrates	49.4	0.0	0.4	388.8	44.2	3732.6	2538.7	2816.7	319.1	0.5	0.9	2.2
		All	111.2	0.1	0.8	875.9	100.8	8488.6	5719.6	6472.1	733.2	1.2	1.9	5.1
34	**Zavareh**	PM_{10}	5.0	0.0	0.0	39.2	4.6	383.2	256.3	294.5	33.4	0.1	0.1	0.2
		Sulfates	115.8	0.1	0.8	911.8	106.0	8902.3	5954.0	6842.0	775.1	1.2	2.0	5.3
		Nitrates	132.5	0.1	1.0	1043.7	118.7	10,020.4	6815.4	7561.8	856.7	1.4	2.3	6.0
		All	253.3	0.1	1.8	1994.7	229.3	19,306.0	13,025.7	14,698.3	1665.1	2.7	4.4	11.5
35	**Jahrom**	PM_{10}	5.8	0.0	0.0	45.9	5.3	447.8	299.5	344.1	39.0	0.1	0.1	0.3
		Sulfates	23.6	0.0	0.2	185.6	21.6	1812.3	1212.1	1392.9	157.8	0.2	0.4	1.1
		Nitrates	42.7	0.0	0.3	336.5	38.3	3231.1	2197.7	2438.3	276.2	0.4	0.8	1.9
		All	72.1	0.0	0.5	568.0	65.2	5491.2	3709.2	4175.4	473.0	0.8	1.3	3.3

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	I.M.	A.M.	B.U.A.	B.U.C.	L.R.S.A.	L.R.S.C.	R.A.D.W.	R.A.D.N.	C.H.A.	R.H.A.	C.B.A.
36	**Ganaveh**	PM_{10}	2.5	0.0	0.0	19.9	2.3	194.2	129.9	149.2	16.9	0.0	0.0	0.1
		Sulfates	20.2	0.0	0.1	158.7	18.5	1549.8	1036.5	1191.1	134.9	0.2	0.3	0.9
		Nitrates	38.6	0.0	0.3	304.0	34.6	2918.8	1985.2	2202.7	249.5	0.4	0.7	1.8
		All	61.3	0.0	0.4	482.6	55.3	4662.8	3151.6	3543.0	401.4	0.6	1.1	2.8
37	**Shirkooh**	PM_{10}	6.7	0.0	0.0	52.4	6.1	512.0	342.4	393.5	44.6	0.1	0.1	0.3
		Sulfates	51.2	0.0	0.4	403.5	46.9	3939.8	2635.0	3028.0	343.0	0.5	0.9	2.3
		Nitrates	83.4	0.0	0.6	656.7	74.7	6305.4	4288.6	4758.3	539.0	0.9	1.5	3.8
		All	141.3	0.1	1.0	1112.7	127.7	10,757.1	7266.0	8179.7	926.7	1.5	2.5	6.4
38	**Dorcheh**	PM_{10}	6.5	0.0	0.0	51.2	6.0	499.7	334.2	384.0	43.5	0.1	0.1	0.3
		Nitrates	141.8	0.1	1.0	1116.7	127.0	10,721.3	7292.1	8090.7	916.6	1.5	2.5	6.4
		All	148.3	0.1	1.1	1167.9	132.9	11,221.0	7626.3	8474.8	960.1	1.6	2.6	6.7
39	**Kaveh**	PM_{10}	3.6	0.0	0.0	28.7	3.3	280.2	187.4	215.4	24.4	0.0	0.1	0.2
		Sulfates	81.6	0.0	0.6	642.8	74.7	6276.2	4197.6	4823.6	546.5	0.9	1.4	3.7
		Nitrates	32.5	0.0	0.2	255.7	29.1	2455.2	1669.9	1852.8	209.9	0.3	0.6	1.5
		All	117.7	0.1	0.8	927.2	107.2	9011.6	6054.9	6891.8	780.7	1.2	2.0	5.4
40	**Golestan**	PM_{10}	57.3	0.0	0.4	451.4	52.5	4407.9	2948.0	3387.7	383.8	0.6	1.0	2.6
		Sulfates	106.3	0.0	0.8	837.3	97.4	8175.3	5467.7	6283.2	711.8	1.1	1.8	4.8
		Nitrates	79.9	0.0	0.6	629.2	71.5	6041.1	4108.8	4558.8	516.5	0.8	1.4	3.6
		All	243.6	0.1	1.8	1918.0	221.4	18,624.2	12,524.6	14,229.8	1612.0	2.6	4.2	11.1
41	**Sabalan**	PM_{10}	3.1	0.0	0.0	24.4	2.8	237.9	159.1	182.8	20.7	0.0	0.1	0.1
		Sulfates	17.2	0.0	0.1	135.1	15.7	1318.7	882.0	1013.5	114.8	0.2	0.3	0.8
		Nitrates	28.5	0.0	0.2	224.7	25.5	2156.9	1467.0	1627.7	184.4	0.3	0.5	1.3
		All	48.8	0.0	0.4	384.1	44.1	3713.5	2508.1	2824.0	319.9	0.5	0.8	2.2
42	**Shariati**	PM_{10}	6.0	0.0	0.0	47.4	5.5	463.2	309.8	356.0	40.3	0.1	0.1	0.3
		Sulfates	40.7	0.0	0.3	320.2	37.2	3126.0	2090.7	2402.5	272.2	0.4	0.7	1.8
		Nitrates	69.7	0.0	0.5	548.8	62.4	5269.2	3583.8	3976.3	450.5	0.7	1.2	3.2
		All	116.4	0.1	0.8	916.4	105.1	8858.4	5984.3	6734.9	763.0	1.2	2.0	5.3
43	**Chadormalou**	PM_{10}	3.6	0.0	0.0	28.4	3.3	277.0	185.3	212.9	24.1	0.0	0.1	0.2
		Nitrates	76.3	0.0	0.5	601.1	68.3	5771.0	3925.1	4355.0	493.4	0.8	1.3	3.5
		All	79.9	0.0	0.6	629.5	71.6	6048.0	4110.4	4567.9	517.5	0.8	1.4	3.6
44	**Pars-jonubi**	PM_{10}	3.8	0.0	0.0	30.1	3.5	294.1	196.7	226.1	25.6	0.0	0.1	0.2
		Nitrates	20.0	0.0	0.1	157.3	17.9	1510.0	1027.0	1139.5	129.1	0.2	0.4	0.9
		All	23.8	0.0	0.2	187.4	21.4	1804.2	1223.8	1365.6	154.7	0.2	0.4	1.1

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	**I.M.**	**A.M.**	**B.U.A.**	**B.U.C.**	**L.R.S.A.**	**L.R.S.C.**	**R.A.D.W.**	**R.A.D.N.**	**C.H.A.**	**R.H.A.**	**C.B.A.**
45	**Shobad**	PM_{10}	1.6	0.0	0.0	12.2	1.4	119.6	80.0	91.9	10.4	0.0	0.0	0.1
		Sulfates	3.3	0.0	0.0	26.1	3.0	254.6	170.3	195.7	22.2	0.0	0.1	0.2
		Nitrates	20.7	0.0	0.1	163.2	18.6	1567.2	1065.9	1182.7	134.0	0.2	0.4	0.9
		All	25.6	0.0	0.2	201.6	23.0	1941.4	1316.2	1470.3	166.6	0.3	0.4	1.2
46	**Ferdoosi**	PM_{10}	4.7	0.0	0.0	37.0	4.3	361.6	241.9	277.9	31.5	0.0	0.1	0.2
		Sulfates	56.1	0.0	0.4	441.9	51.4	4314.7	2885.7	3316.1	375.7	0.6	1.0	2.6
		Nitrates	43.4	0.0	0.3	342.0	38.9	3283.7	2233.4	2478.0	280.7	0.5	0.8	2.0
		All	104.2	0.0	0.8	821.0	94.6	7960.1	5361.0	6072.1	687.9	1.1	1.8	4.7
47	**Zagros**	PM_{10}	19.7	0.0	0.1	155.4	18.1	1517.5	1014.9	1166.3	132.1	0.2	0.3	0.9
		Sulfates	77.5	0.0	0.6	610.0	70.9	5955.5	3983.1	4577.1	518.5	0.8	1.3	3.5
		Nitrates	104.8	0.0	0.8	825.1	93.8	7921.7	5387.9	5978.0	677.2	1.1	1.9	4.8
		All	202.0	0.1	1.5	1590.5	182.8	15,394.6	10,385.9	11,721.4	1327.9	2.1	3.5	9.2
48	**Bampoor**	PM_{10}	0.5	0.0	0.0	3.7	0.4	36.5	24.4	28.0	3.2	0.0	0.0	0.0
		Sulfates	0.8	0.0	0.0	6.1	0.7	59.8	40.0	46.0	5.2	0.0	0.0	0.0
		Nitrates	4.5	0.0	0.0	35.2	4.0	338.4	230.1	255.3	28.9	0.0	0.1	0.2
		All	5.7	0.0	0.0	45.1	5.2	434.7	294.5	329.4	37.3	0.1	0.1	0.3
49	**Khoy**	PM_{10}	14.8	0.0	0.1	116.5	13.5	1137.6	760.8	874.3	99.0	0.2	0.3	0.7
		Sulfates	25.2	0.0	0.2	198.4	23.1	1936.8	1295.4	1488.5	168.6	0.3	0.4	1.1
		Nitrates	48.8	0.0	0.4	384.5	43.7	3691.9	2511.1	2786.1	315.6	0.5	0.9	2.2
		All	88.8	0.0	0.6	699.4	80.3	6766.3	4567.2	5148.9	583.3	0.9	1.5	4.0
50	**Besat**	PM_{10}	1630.7	0.7	11.7	12,841.7	1493.3	125,384.4	83,858.6	96,365.7	10,917.0	17.1	27.8	74.2
		Sulfates	0.6	0.0	0.0	4.8	0.6	46.8	31.3	36.0	4.1	0.0	0.0	0.0
		Nitrates	380.0	0.2	2.7	2992.3	340.2	28,728.8	19,539.9	21,679.8	2456.0	4.0	6.7	17.3
		All	2011.3	0.9	14.5	15,838.8	1834.1	154,160.0	103,429.8	118,081.5	13,377.1	21.1	34.5	91.5
51	**Zargan**	PM_{10}	2.3	0.0	0.0	18.1	2.1	176.7	118.1	135.8	15.4	0.0	0.0	0.1
		Nitrates	28.0	0.0	0.2	220.5	25.1	2117.2	1440.0	1597.7	181.0	0.3	0.5	1.3
		All	30.3	0.0	0.2	238.6	27.2	2293.8	1558.1	1733.5	196.4	0.3	0.5	1.4
52	**Soltaniye**	PM_{10}	2.2	0.0	0.0	17.2	2.0	168.4	112.6	129.4	14.7	0.0	0.0	0.1
		Sulfates	39.7	0.0	0.3	312.3	36.3	3048.8	2039.1	2343.2	265.4	0.4	0.7	1.8
		Nitrates	61.5	0.0	0.4	484.3	55.1	4650.0	3162.7	3509.1	397.5	0.6	1.1	2.8
		All	103.3	0.0	0.7	813.8	93.4	7867.1	5314.4	5981.6	677.6	1.1	1.8	4.7
53	**Mashhad**	PM_{10}	4.7	0.0	0.0	37.0	4.3	361.4	241.7	277.7	31.5	0.0	0.1	0.2
		Sulfates	12.2	0.0	0.1	95.9	11.2	936.8	626.6	720.0	81.6	0.1	0.2	0.6
		Nitrates	40.2	0.0	0.3	316.7	36.0	3041.0	2068.3	2294.9	260.0	0.4	0.7	1.8
		All	57.1	0.0	0.4	449.7	51.5	4339.2	2936.6	3292.6	373.0	0.6	1.0	2.6

Table A4. *Cont.*

Nr.	Power Plant Name	Pollutant	Human Health Impacts [a] (Cases/Year)											
			C.M.	**I.M.**	**A.M.**	**B.U.A.**	**B.U.C.**	**L.R.S.A.**	**L.R.S.C.**	**R.A.D.W.**	**R.A.D.N.**	**C.H.A.**	**R.H.A.**	**C.B.A.**
54	**Loshan**	PM_{10}	26.7	0.0	0.2	210.3	24.5	2053.6	1373.5	1578.3	178.8	0.3	0.5	1.2
		Sulfates	38.3	0.0	0.3	301.7	35.1	2945.5	1970.0	2263.8	256.5	0.4	0.7	1.7
		Nitrates	73.6	0.0	0.5	579.4	65.9	5563.0	3783.7	4198.1	475.6	0.8	1.3	3.3
		All	138.6	0.1	1.0	1091.4	125.4	10,562.1	7127.2	8040.2	910.8	1.5	2.4	6.3
55	**Iran-shahr**	PM_{10}	15.5	0.0	0.1	122.5	14.2	1195.6	799.6	918.9	104.1	0.2	0.3	0.7
		Sulfates	185.4	0.1	1.3	1460.4	169.8	14,259.2	9536.8	10,959.1	1241.5	1.9	3.2	8.4
		Nitrates	4.1	0.0	0.0	32.3	3.7	310.2	211.0	234.1	26.5	0.0	0.1	0.2
		All	205.1	0.1	1.5	1615.2	187.7	15,765.0	10,547.4	12,112.1	1372.1	2.2	3.5	9.3
56	**Semnan**	PM_{10}	5.2	0.0	0.0	40.6	4.7	396.8	265.4	305.0	34.6	0.1	0.1	0.2
		Sulfates	77.6	0.0	0.6	611.0	71.1	5966.1	3990.2	4585.3	519.5	0.8	1.3	3.5
		Nitrates	58.1	0.0	0.4	457.4	52.0	4391.6	2986.9	3314.1	375.4	0.6	1.0	2.6
		All	140.8	0.1	1.0	1109.1	127.8	10,754.5	7242.5	8204.3	929.4	1.5	2.4	6.4
57	**Mobarakeh**	PM_{10}	4.9	0.0	0.0	38.7	4.5	378.3	253.0	290.7	32.9	0.1	0.1	0.2
		Sulfates	9.9	0.0	0.1	77.6	9.0	757.8	506.8	582.4	66.0	0.1	0.2	0.4
		Nitrates	54.1	0.0	0.4	425.9	48.4	4089.6	2781.5	3086.1	349.6	0.6	1.0	2.5
		All	68.9	0.0	0.5	542.3	62.0	5225.6	3541.3	3959.3	448.5	0.7	1.2	3.1
58	**Chabahar**	PM_{10}	0.7	0.0	0.0	5.7	0.7	55.7	37.3	42.8	4.9	0.0	0.0	0.0
		Sulfates	22.6	0.0	0.2	177.9	20.7	1736.6	1161.5	1334.7	151.2	0.2	0.4	1.0
		Nitrates	2.9	0.0	0.0	23.2	2.6	222.6	151.4	168.0	19.0	0.0	0.1	0.1
		All	26.3	0.0	0.2	206.8	24.0	2015.0	1350.2	1545.6	175.1	0.3	0.4	1.2
59	**Zob-ahan**	PM_{10}	2.0	0.0	0.0	16.1	1.9	156.8	104.8	120.5	13.6	0.0	0.0	0.1
		Nitrates	55.8	0.0	0.4	439.2	49.9	4216.4	2867.8	3181.9	360.5	0.6	1.0	2.5
		All	57.8	0.0	0.4	455.2	51.8	4373.2	2972.7	3302.4	374.1	0.6	1.0	2.6
60	**Kashan**	PM_{10}	3.9	0.0	0.0	30.4	3.5	296.5	198.3	227.9	25.8	0.0	0.1	0.2
		Sulfates	63.0	0.0	0.5	495.9	57.7	4841.6	3238.1	3721.0	421.5	0.7	1.1	2.9
		Nitrates	52.4	0.0	0.4	412.7	46.9	3962.2	2694.9	2990.0	338.7	0.6	0.9	2.4
		All	119.2	0.1	0.9	938.9	108.1	9100.3	6131.3	6939.0	786.1	1.3	2.1	5.4
61	**Bastami**	PM_{10}	2.1	0.0	0.0	16.8	1.9	163.6	109.4	125.8	14.2	0.0	0.0	0.1
		Sulfates	44.0	0.0	0.3	346.6	40.3	3384.3	2263.5	2601.1	294.7	0.5	0.8	2.0
		Nitrates	29.2	0.0	0.2	229.9	26.1	2207.6	1501.5	1665.9	188.7	0.3	0.5	1.3
		All	75.3	0.0	0.5	593.3	68.4	5755.5	3874.4	4392.7	497.6	0.8	1.3	3.4
Total Power Plants		PM_{10}	3564.3	1.6	25.7	28,068.9	3264.0	274,059.7	183,294.6	210,631.9	23,861.8	37.4	60.8	162.1
		Sulfates	22,354.9	10.1	161.0	176,045.1	20,471.5	1,718,870.5	1,149,602.2	1,321,059.0	149,658.4	234.7	381.2	1016.8
		Nitrates	11,164.3	5.0	80.4	87,918.9	9996.5	844,116.0	574,124.2	637,001.5	72,163.8	117.2	197.3	507.8
		All	37,083.5	16.7	267.0	292,032.9	33,732.1	2,837,046.2	1,907,021.0	2,168,692.4	245,684.0	389.4	639.2	1686.8

C.M.: Chronic Mortality; I.M.: Infant Mortality; A.M.: Acute Mortality; B.U.A.: Bronchodilator Usage (asthmatic adults); B.U.C.: Bronchodilator Usage (asthmatic children); L.R.S.A.: Lower Respiratory Symptom (adults); L.R.S.C.: Lower Respiratory Symptom (children); R.A.D.W.: Restricted Activity Days (working adults); R.A.D.N.: Restricted Activity Days (non-working adults); C.H.A.: Cardiac Hospital Admissions; R.H.A.: Respiratory Hospital Admissions; C.B.A.: Chronic Bronchitis (adults).

Table A5. Human health damage costs from the 61 power plants of Iran by type of pollutants and damage costs per generated electricity.

Human Health Damage Costs (Million USD 2000/Year)							Human Health Damage Costs (Million USD 2000/year)						
Nr.	**Power Plant Name**	**Pollutant**					**Nr.**	**Power Plant Name**	**Pollutant**				
		PM_{10}	**Sulfates**	**Nitrates**	**All**	**US$/MWh**			**PM_{10}**	**Sulfates**	**Nitrates**	**All**	**US$/MWh**
1	Damavand	1.58	16.52	31.71	49.81	3.58	**2**	Rajayi	2.29	36.36	16.56	55.21	4.63
3	Kerman	0.20	2.35	3.00	5.55	0.50	**4**	Neka	3.99	79.94	7.65	91.59	8.37
5	Ramin	0.28	0.77	3.49	4.54	0.44	**6**	Montazeri	0.35	0.00	9.69	10.04	1.05
7	MontazerQaem	3.76	4.31	28.33	36.40	4.16	**8**	Gilan	0.40	3.95	4.87	9.22	1.26
9	Kazeroon	0.37	0.57	3.37	4.31	0.59	**10**	Bandar-abbas	2.90	53.62	1.59	58.11	8.01
11	Shazand	0.34	3.78	5.37	9.50	1.43	**12**	Neishabur	0.33	3.39	3.44	7.16	1.23
13	Mofateh	3.59	59.51	8.02	71.12	13.39	**14**	Fars	0.48	0.43	2.25	3.16	0.60
15	Pareh-sar	0.16	2.19	2.44	4.79	0.93	**16**	Asaluyeh	0.12	0.00	0.73	0.84	0.18
17	Yazd	0.22	2.35	2.84	5.42	1.15	**18**	Qom	0.22	4.81	6.65	11.67	2.63
19	Sanandaj	1.59	5.41	5.35	12.36	2.83	**20**	Bistoon	5.66	83.20	4.73	93.59	21.82
21	Hafez	0.26	0.52	1.46	2.24	0.53	**22**	Abadan	0.03	0.08	0.40	0.51	0.12
23	Khalij-fars	0.11	0.42	0.74	1.28	0.31	**24**	Khoramshahr	0.04	0.48	0.35	0.87	0.22
25	Sahand	0.87	11.16	2.18	14.22	3.56	**26**	Toos	2.21	27.73	2.24	32.18	8.14
27	RoodShur	0.31	4.25	8.56	13.12	3.34	**28**	Chehel-sotun	0.17	0.78	2.62	3.57	0.99
29	Uromieh	0.14	1.13	1.93	3.20	0.93	**30**	Tabriz	0.15	0.76	1.48	2.39	0.74
31	Parand	0.26	2.72	6.39	9.38	2.92	**32**	Isin	0.07	0.34	0.55	0.96	0.31
33	Shirvan	0.11	1.10	0.96	2.17	0.71	**34**	Zavareh	0.10	2.26	2.58	4.94	1.63
35	Jahrom	0.11	0.46	0.83	1.41	0.47	**36**	Ganaveh	0.05	0.39	0.75	1.19	0.41
37	Shirkooh	0.13	1.00	1.62	2.75	0.97	**38**	Dorcheh	0.13	0.00	2.76	2.88	1.06
39	Kaveh	0.07	1.59	0.63	2.30	0.86	**40**	Golestan	1.12	2.08	1.55	4.75	1.83
41	Sabalan	0.06	0.34	0.55	0.95	0.37	**42**	Shariati	0.12	0.79	1.36	2.27	0.93
43	Chadormalou	0.07	0.00	1.48	1.55	0.65	**44**	Pars-jonubi	0.07	0.00	0.39	0.46	0.19
45	Shobad	0.03	0.06	0.40	0.50	0.21	**46**	Ferdoosi	0.09	1.10	0.84	2.03	0.92
47	Zagros	0.39	1.51	2.04	3.94	1.84	**48**	Bampoor	0.01	0.02	0.09	0.11	0.06
49	Khoy	0.29	0.49	0.95	1.73	0.92	**50**	Besat	31.85	0.01	7.39	39.25	22.41
51	Zargan	0.04	0.00	0.54	0.59	0.35	**52**	Soltaniye	0.04	0.77	1.20	2.01	1.19
53	Mashhad	0.09	0.24	0.78	1.11	0.72	**54**	Loshan	0.52	0.75	1.43	2.70	1.90
55	Iran-shahr	0.30	3.62	0.08	4.01	2.81	**56**	Semnan	0.10	1.52	1.13	2.75	2.05
57	Mobarakeh	0.10	0.19	1.05	1.34	1.00	**58**	Chabahar	0.01	0.44	0.06	0.51	0.41
59	Zob-ahan	0.04	0.00	1.08	1.12	0.96	**60**	Kashan	0.08	1.23	1.02	2.32	2.10
61	Bastami	0.04	0.86	0.57	1.47	1.38	**Total Power Plants**		69.62	436.67	217.12	723.42	2.85

References

1. Abu-Khader, M.M.; Speight, J.G. The concepts of energy, environment, and cost for process design. *Int. J. Green Energy* **2004**, *1*, 137–151. [CrossRef]
2. Samadi, S. The social costs of electricity generation—Categorising different types of costs and evaluating their respective relevance. *Energies* **2017**, *10*, 356. [CrossRef]
3. Bozicevic Vrhovcak, M.; Tomsic, Z.; Debrecin, N. External costs of electricity production: Case study Croatia. *Energy Policy* **2005**, *33*, 1385–1395. [CrossRef]
4. Hao, J.; Wang, L.; Shen, M.; Li, L.; Hu, J. Air quality impacts of power plant emissions in Beijing. *Environ. Pollut.* **2007**, *147*, 401–408. [CrossRef] [PubMed]
5. Rabl, A. Mortality due to air pollution: How to interpret the results. *Environ. Health Risk* **2001**, *5*, 53–62.
6. Ostro, B.D. Air pollution and morbidity revisited: A specification test. *J. Environ. Econ. Manag.* **1987**, *14*, 87–98. [CrossRef]
7. Dockery, D.W.; Pope, C.A.; Xu, X.; Spengler, J.D.; Ware, J.H.; Fay, M.E.; Ferris, B.G., Jr.; Speizer, F.E. An association between air pollution and mortality in six U.S. cities. *N. Engl. J. Med.* **1993**, *329*, 1753–1759. [CrossRef] [PubMed]
8. Breitschopf, B.; Held, A.; Resch, G. A concept to assess the costs and benefits of renewable energy use and distributional effects among actors: The example of Germany. *Energy Environ.* **2016**, *27*, 55–581. [CrossRef]
9. Streimikiene, D.; Roos, I.; Rekis, J. External cost of electricity generation in Baltic States. *Renew. Sustain. Energy Rev.* **2009**, *13*, 863–870. [CrossRef]
10. Burtraw, D.; Krupnick, A.J.; Sampson, G. *The True Cost of Electric Power: An Inventory of Methodologies to Support Future Decision-Making in Comparing the Cost and Competitiveness of Electricity Generation Technologies*; Technical Report; International Nuclear Information System (INIS): Paris, France, 2012.
11. Schleisner, L. Comparison of methodologies for externality assessment. *Energy Policy* **2000**, *28*, 1127–1136. [CrossRef]
12. Becker, N.; Soloveitchik, D.; Olshansky, M. A weighted average incorporation of pollution costs into the electrical expansion planning. *Energy Environ.* **2012**, *23*, 1–15. [CrossRef]
13. Sakulniyomporn, S.; Kubaha, K.; Chullabodhi, C. External costs of fossil electricity generation: Health-based assessment in Thailand. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3470–3479. [CrossRef]
14. International Energy Agency. *Key World Energy Statistics*; International Energy Agency (IEA): Paris, France, 2017.
15. Bickel, P.; Friedrich, R.; Extern, E. *Externalities of Energy Methodology, Update*; European Commission: Brussels, Belgium, 2005.
16. Hainoun, A.; Almoustafa, A.; Seif Aldin, M. Estimating the health damage costs of syrian electricity generation system using impact pathway approach. *Energy* **2010**, *35*, 628–638. [CrossRef]
17. Kim, S.-H. Evaluation of negative environmental impacts of electricity generation: Neoclassical and institutional approaches. *Energy Policy* **2007**, *35*, 413–423. [CrossRef]
18. Schwermer, S. *Economic Valuation of Environmental Damage—Methodolocical Convention 2.0 for Estimates of Environmental Costs*; German Federal Environment Agency (UBA): Berlin, Germany, 2012.
19. Spalding-Fecher, R.; Matibe, D.K. Electricity and externalities in South Africa. *Energy Policy* **2003**, *31*, 721–734. [CrossRef]
20. Preiss, P.; Klotz, V. *Description of Updated and Extended Draft Tools for the Detailed Site-Dependent Assessment of External Costs*; Technical Paper; Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), University of Stuttgart: Stuttgart, Germany, 2007.
21. Rabl, A. *Reference Database of Concentration-Response Functions for Health Impacts of Air Pollution*; Technical Report; International Atomic Energy Agency: Vienna, Austria, 2001.
22. Georgakellos, D.A. Impact of a possible environmental externalities internalisation on energy prices: The case of the greenhouse gases from the Greek electricity sector. *Energy Econ.* **2010**, *32*, 202–209. [CrossRef]
23. Pearce, D.; Atkinson, G.; Mourato, S. *Cost-Benefit Analysis and the Environment: Recent Developments*; OECD: Paris, France, 2006.
24. Johnston, R.J.; Rolfe, J.; Rosenberger, R.S.; Brouwer, R. Introduction to benefit transfer methods. In *Benefit Transfer of Environmental and Resource Values*; Springer: Berlin, Germany, 2015; pp. 19–59.
25. Rosenberger, R.S.; Loomis, J.B. Using meta-analysis for benefit transfer: In-sample convergent validity tests of an outdoor recreation database. *Water Resour. Res.* **2000**, *36*, 1097–1107. [CrossRef]

26. Rosenberger, R.S.; Loomis, J.B.; Rocky Mountain Research Station. *Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan (2000 Revision)*; U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: Fort Collins, CO, USA, 2001; p. 59.
27. Navrud, S. Value Transfer and Environmental Policy. In *The International Yearbook of Environmental and Resource Economics 2004/2005: A Survey of Current Issues*; Edgar Elgar Publishers: London, UK, 2004.
28. Büke, T.; Köne, A.Ç. Estimation of the health benefits of controlling air pollution from the Yatağan coal-fired power plant. *Environ. Sci. Policy* **2011**, *14*, 1113–1120. [CrossRef]
29. Turtós Carbonell, L.; Meneses Ruiz, E.; Sánchez Gácita, M.; Rivero Oliva, J.; Díaz Rivero, N. Assessment of the impacts on health due to the emissions of Cuban power plants that use fossil fuel oils with high content of sulfur. Estimation of external costs. *Atmos. Environ.* **2007**, *41*, 2202–2213. [CrossRef]
30. Braun, M. Environmental External Costs from Power Generation by Renewable Energies. Master's Thesis, University of Stuttgart, Stuttgart, Germany, 2004.
31. Bernow, S.; Biewald, B.; Dougherty, W.; White, D. Counting the Costs: Scientific Uncertainty and Valuation Perspective in EXMOD. In *Social Costs and Sustainability: Valuation and Implementation in the Energy and Transport Sector*; Hohmeyer, O., Rennings, K., Ottinger, R.L., Eds.; Springer: Berlin/Heidelberg, Germany, 1997; pp. 200–231.
32. Rowe, R.D.; Lang, C.M.; Chestnut, L.G.; Latimer, D.A.; Rae, D.A.; Bernow, S.M.; White, D.E. *New York State Environmental Externalities Cost Study*; Empire State Electric Energy Research Corporation: Oceana, NY, USA, 1995.
33. Spadaro, J.V. *Airpacts Manual (Version 1.0): A Tool for Assessing the Environmental Impacts and Damage Costs to Human Health, Agricultural Crops and Man-Made Structures from Exposure to Routine Atmospheric Emissions*; International Atomic Energy Agency (IAEA): Vienna, Austria, 2002.
34. Wang, L.; Watanabe, T.; Xu, Z. Monetization of external costs using lifecycle analysis—A comparative case study of coal-fired and biomass power plants in Northeast China. *Energies* **2015**, *8*, 1440–1467. [CrossRef]
35. Czarnowska, L.; Frangopoulos, C.A. Dispersion of pollutants, environmental externalities due to a pulverized coal power plant and their effect on the cost of electricity. *Energy* **2012**, *41*, 212–219. [CrossRef]
36. Dimitrijević, Z.; Tatić, K.; Knežević, A.; Salihbegović, I. External costs from coal-fired thermal plants and sulphur dioxide emission limit values for new plants in Bosnia and Herzegovina. *Energy Policy* **2011**, *39*, 3036–3041. [CrossRef]
37. Planning & Economic Studies Section. *SimPacts2 E-Learning*; Obtained from IAEA with the Model; International Atomic Energy Agency (IAEA): Vienna, Austria, 2002.
38. Scire, J.S.; Strimaitis, D.G.; Yamartino, R.J. *A User's Guide for the CALPUFF Dispersion Model*; Earth Tech, Inc.: Concord, MA, USA, 2000.
39. Tavanir Organization. *Statistical Report on 49 Years of Activities of Iran Electric Power Industry (1967–2015)*; Tavanir Organization: Tehran, Iran, 2016.
40. Tavanir Organization. *Electric Power Industry in Iran (2015–2016)*; Tavanir Organization: Tehran, Iran, 2016.
41. Tavanir Organization. *Detailed Statistics of Iranian Power Industry Specially for Power Generation—1395 (in Farsi)*; Tavanir Organization: Tehran, Iran, 2017.
42. Nazari, S.; Shahhoseini, O.; Sohrabi-Kashani, A.; Davari, S.; Paydar, R.; Delavar-Moghadam, Z. Experimental determination and analysis of CO_2, SO_2 and NOx emission factors in Iran's thermal power plants. *Energy* **2010**, *35*, 2992–2998. [CrossRef]
43. European Environment Agency (EEA). *EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016*; European Environment Agency (EEA): Copenhagen, Denmark, 2016.
44. Karimzadegan, H.; Rahmatian, M.; Farsiabi, M.M.; Meiboudi, H. Social cost of fossil-based electricity generation plants in Iran. *Environ. Eng. Manag.* **2015**, *14*, 2373–2381.

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