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# Clean Alternatives For Household Coal - Case Study: Izmir, Turkey

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## Abstract

Household coal consumption during the heating season affects Izmir's air quality adversely to the point where air quality indicators show that pollution levels exceed limit concentration values that World Health Organization set for a habitable and healthy ambient air. The objective of this paper is to evaluate alternatives that utilize low-carbon emitting methods of domestic heating fueled by renewable energy sources and develop a model which would replace household coal. Research shows that 223,969 tonnes of coal were burned in households of Izmir in 2019 and analysis results show that 2.72 million MMBtu of heat energy was supplied to these households from burning coal. Considering the high potential for wind and solar energy in Izmir, the proposed model utilizes a combination of heating with natural gas, electric heaters, air-source heat pumps and ground source heat pumps that would be powered by solar PVs and wind turbines. Cost analysis reveals that an initial investment of 1,346,706,220 Turkish Liras is required where the elimination of household coal would prevent approximately 58 premature deaths and 189 disease cases related to ambient and household air pollution per year. The legislature and policy ideas for supporting this transformation are investigated and other possible ways of generating clean electricity and more efficient household heating methods are discussed.

## Chapter 1 – Introduction

### 1.1 City of Izmir

Turkey is the second-largest country in Eurasia with a land area of 780,580 km$^2$. Following the ratification of the Kyoto Protocol and signing the Paris Agreement (ratification pending), the Turkish Government has pledged to reduce 21% of greenhouse gas emissions by 2030 [1]. Izmir, formerly known as Smyrna for most of its history, is one of the oldest settlements throughout the Mediterranean basin with a history of up to 8500 years. Set in a geopolitically advantageous location at the head of a gulf in a deep indentation midway along Anatolia's western coast, the city has been one of the major port cities of the Mediterranean Sea since the late 16th century [2]. Today, the city is Turkey's third-largest metropolis, home to 4.32 million citizens and covers an area of 11,973 km$^2$ in the Aegean Region [3]. Izmir's location (latitude 38◦25′N, longitude 27◦08′E) is fortunate also in terms of energy resources. The region holds a substantial share of Turkey's wind energy potential as well as a decent and profitable level of solar radiation. Furthermore, city grounds possess great geothermal energy potential while the wave energy potential of the city's shores has been indicated as high by NATO's Science for Peace department [4].

According to the address-based population statistics report of Turkish Statistical Institution (TUIK), in 2019 there were a total of 1,436,392 households in Izmir of which 281,001 of them were single-person, 915,247 were single-family, 203,356 were extended-family (family of 4 or more) and 36,788 were multi-person non-family households. Average size of a household was 2.9 for the city in the same year [5].

### 1.2 Household Energy Use for Space Heating in Izmir

In the winter season of 2008-09, about 74% of households used coal for residential heating in Izmir. Coal was followed by electricity with 18% and natural gas with only 6%. The same year, according to Izmir Provincial Directorate of Environment and Forestry, nearly 1-ton coal was consumed in a house and a total of 1.1 million tonnes of coal was provided to the city [6]. Although the share of coal in residential fuel consumption has dwindled throughout the years, it is still possible to smell the soot and see the air pollution through central neighborhoods of Izmir on a cold winter night in 2020 [personal observation].

Insulation is one of the most crucial factors in energy efficiency of a house. In Turkey, the average insulation material content of buildings is one-sixth of the European Union. In the United States, the average amount of insulation material used in buildings is 1 m$^3$/capita, in Europe 0.6 m$^3$/capita, while in Turkey only 0.1 m$^3$/capita is used [4]. Around 30% of the total energy consumption by residential buildings in Turkey is for heating and the average energy consumption for space and water heating in residential buildings is 175 kWh/m$^2$ whereas in European countries this value is 100 kWh/m$^2$ [7].

Izmirgaz, the only natural gas provider (except for portable, small size tanks) to the residences of the city, has more than 1,114,116 member households and small businesses that are scattered across the 25 of 30 districts of the city as of February 2020 [8]. 54,000 of the Izmirgaz member households have not used natural gas in 2019. The total amount of natural gas supplied to households in 2019 was 660,870,941 Sm$^3$ and the average yearly natural gas usage of a household was 933 Sm$^3$. Izmirgaz currently does not have a gas pipeline infrastructure in Beydağ, Çeşme, Dikili, Karaburun and Kiraz districts where the total populations added up to 155,193 in 2019 [9].

Another popular method of domestic heating is geothermal house heating. Izmir holds about 33% of the theoretical capacity of geothermal energy district heating in Turkey. There are 4 regions that geothermal energy is present in Izmir, Balçova-Narlıdere, Bergama, Dikili and Çeşme. Since the amount of hot water generated in Çeşme is only 49 $m^3$ per hour and the temperature of the water is 57 $C^{\circ}$, geothermal heating is mainly used in geothermal pools. In the rest of these regions, geothermal house heating is used in 39,205 households as of April 2019. This accounts for about 73% of Izmir's theoretical geothermal heating capacity of 53,850 households [10].

Air-conditioners, electric resistance heaters and burning coal are the most commonly preferred methods of space heating for houses that does not have access to natural gas, geothermal heating or sufficient, on-property renewable energy systems due to economic or logistic reasons.

### 1.3 Air Quality and Impacts

Poor air quality can be lethal. The World Health Organization (WHO) estimates that 4.2 million premature deaths worldwide were related to bad outdoor air conditions in 2016. Air pollution has been linked to heart diseases, lung cancer, stroke and acute respiratory diseases such as asthma. Particulate matter of less than 10 and 2.5 microns in diameter ($PM_{10}$ and $PM_{2.5}$), ozone ($O_3$), sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), lead (Pb), benzene, arsenic, cadmium and nickel are classified as pollutants that pose a significant threat to public health and well-being. The evidence on particulate matter's long-term life-threatening effects are especially well documented. PM can cause respiratory, cardiovascular and cerebrovascular impacts by penetrating deep into lung passageways and entering into the bloodstream. PM was classified as a cause of lung cancer by WHO in 2013 [11].

According to the Air Quality Bulletin that was published in December 2019 by Turkey's Ministry of Environment and Urban Planning there is no limit value set for pollutant $PM_{2.5}$ whereas the standard for air quality in the European Union (EU) is not to exceed the highest $PM_{2.5}$ concentration of 25 µg/$m^3$ annual mean and 2005 WHO air quality guidelines suggest an even stricter concentration limit of 10 µg/$m^3$ [12-14]**.** Within the scope of national air quality monitoring and management regulations, Turkey applies EU standards on limit values for $SO_2$, $NO_x$, CO and Pb, $PM_{10}$ but not for $PM_{2.5}$ and $O_3$ [12].

Besides its large and growing population, Izmir is one of the most substantial and critical cities in Turkey, when cultural, historical, climatic, ecologic and geographical factors are considered. The city's air quality is negatively affected by industrial operations, high-density housing around the city center, heavy car traffic and burning of solid fuels during the heating season.

### 1.4 Scope of the paper

Although Turkey has a very high potential for energy from natural and clean resources, the share of renewable energy is far below its full potential in Turkey's energy profile. Furthermore, the utilization of renewable energy systems (RES) at an urban scale is very low and incentivization for household RES is not sufficient for residents to make investments in them. At a regional scale, case study of Izmir in 2020 is a good example of a city with sufficient economic and natural resources that can, with the support of certain policies, achieve technological advancements that would provide environmental and economic benefits and improve quality of life.

The goal of this paper is to analyze the feasibility of using low-carbon emitting and renewable energy technologies supported by government and municipal policies as an alternative to the coal used in residential areas of Izmir. The paper will begin with an analysis of the current energy infrastructure, potential and city's strategic plan. Next, research data will be used to estimate the total energy content of coal used in residential buildings of the city. Based on this value, the amount and cost of energy that needs to be replaced by each alternative technology will be calculated. An optimal combination of the energy generation and heating technologies that are included in the analysis will be modeled based on environmental benefit, feasibility and limitations. Finally, the policies and investments that are required to achieve the clean alternative will be discussed.

## Chapter 2 – Background

### 2.1 Energy and Air Quality Monitoring Infrastructure

As of January 31, 2020, the total electricity generation capacity of Turkey is 91,342 MW. Izmir was the second fastest growing metropolitan economy in 2014 according to the Global Metro report that was published by Brookings Institute. The city is home to 6% of the employment and 9.3% of the industrial production in Turkey and accounts for a significant share of the energy consumption of the nation and the demand for energy is increasing with the growing population, economy and industry. Izmir has one coal power plant with a capacity of 350 MWe with an annual generation of 2562 GWh which amounts to around 13.3% of the city's total electricity consumption in 2016 and 8.2% of total electricity generation [3, 15, 16, 17]. According to World Resources Institute's Global Power Plant Database, the major source of electricity generation of the city is natural gas where natural gas combined cycle power plants account for 54.3% of the total generation capacity and have an aggregate capacity of 2,324 MWe. Natural gas is followed by wind energy where total wind power plant generation capacity was 1294.62 MWe and held 30.2% share of Izmir's total electricity generation capacity in 2018 while solar PVs held only 0.4% share, with 16.1 MW. The rest of the energy generation comes from mostly fuel-oil thermal power plants with a combined capacity of 281.29 MW [18].

According to Turkish Engineers and Architects Chambers Union's (TMMOB) 2019 Izmir Environmental Status Report, Municipality of Izmir measures and reports $PM_{10}$, CO, $NO_2$ and $SO_2$ concentrations in the air from eight stations throughout the city. Four of these stations do not report nor monitor $NO_2$ and CO levels. TMMOB points out that $SO_2$ levels in the city's air were within the limit regulations throughout 2018 and the first half of 2019 while $PM_{10}$ levels often exceeded the concentration limit. The analysis shows that $PM_{10}$ level in Bayraklı, Bornova, Gaziemir neighborhoods exceeded the limit value for about one-thirds of a year. Moreover, average annual $PM_{10}$ concentrations measured in Bayraklı, Bornova, Gaziemir and Şirinyer stations were above the limit value and concentrations pretty close to the limit value were reported in Alsancak, Çiğli and Güzelyalı stations. Furthermore, TMMOB states that due to lack of monitoring of several parameters and adequate number of air quality measurement stations throughout the city only a limited assessment of Izmir's air quality can be made [19].

An Air Quality Index (AQI) is calculated from each station, for each monitored pollutant. Historical data on daily $PM_{10}$ concentrations from Izmir's Bayraklı Station shows that for most of the time the index indicated "good" and "moderate" air quality and occasionally worse throughout the year for $PM_{10}$ [Appendix 1]. AQI for $PM_{2.5}$ usually tends to be worse than $PM_{10}$ due to safe levels of $PM_{2.5}$ being lower than of $PM_{10}$ [Appendix 2]. This might result in a false sense of safety in terms of air quality in cases where $PM_{10}$ levels are accounted for and $PM_{2.5}$ is not when assessing overall air quality. Considering the risk of adverse health effects, and societal and environmental damage that fine particles pose, it is neither possible to explore the effects of the air pollution to its full extent nor to declare a metropolitan city's air clean and safe without measuring its $PM_{2.5}$ concentration.

### 2.2 Renewable Energy Potential

Wind potential of Turkey is among the top ten in Europe. The wind speed and direction have been measured to determine the regions with the highest potential for energy generation since the 1990s. Coastal areas, mountainous regions and open lands have been declared as the most suitable locations for wind energy generation. The highest average wind speeds were measured across the western coast, the Sea of Marmara and a small region near Antakya in the East Mediterranean Region where open lands are present. According to the Wind Energy Potential Atlas (REPA), published in 2006 by the Ministry of Energy and Natural Resources, the total wind energy potential of Turkey is 114 GW and 30% of the areas suitable for wind energy generation in Turkey are located in the Aegean Region [20].

Alaçatı, Izmir is home to Turkey's first ever wind power plant (WPP) that was established in 1998. As one of the locations that received the initial investment in wind energy, Izmir is the city that has the highest wind energy generation capacity in the country. In the Izmir Wind Resources section of the REPA the potential for wind energy generation capacity (theoretical capacity) and the total area available are given as 11,854.32 MW and 2,370.86 km$^2$ respectively [21]. As of July 2019, wind generation capacity of Izmir is 1,462.20 MW, accounting for 19.6% of the total wind energy capacity of Turkey and is the second greatest electricity generation source of the city following natural gas. WPPs that are currently under construction in Izmir are expected to add another 125.9 MW of generation capacity bringing the utilization of the city's wind potential around to 13.4% upon activation [22]. The abundance of potential yet to be fulfilled is an indication that wind energy will constitute an important part of the energy grid of the city far into the future.

Turkey has a significantly high untapped solar energy potential. Solar Energy Map of Turkey that was created by the Ministry of Energy and Natural Resources, shows Turkey's average annual solar radiation as 1,527 kWh/m$^2$ with 7.5 hours average daily insolation time [23]. The share of solar energy in the total installed electricity generation mix is 6.6% in 2020 with 6032 MW [24]. In Germany, where the annual mean global radiation is 1054 kWh/m$^2$ (1261 kWh/m$^2$ maximum), the share of solar photovoltaics (PVs) in the electricity generation was 9.1% with 46.54 TWh in 2019. Total solar PV capacity of Germany was 49.78 GW by the end of 2019 [25,26]. Izmir, on the other hand, has an annual global radiation of 1639 kWh/m$^2$ and 8.19 hours average daily sunshine. A city with such potential for solar energy surely needs to take such an opportunity and utilize solar PVs heavily in its energy generation profile but for now the share of solar PVs is only around 0.6% [27].

### 2.3 City's Strategic Plan on Energy

The Izmir Metropolitan Municipality (IBB) publishes their strategic plan, that covers certain topics such as the infrastructure, quality of life and economy every five years. In the latest edition of this publication it is shown that the budget for setting up clean and renewable energy sources in the 2015-2019 period was 7,321,000 Turkish Liras (₺), roughly $2,712,000 US in 2015, and 75.8% of it was used [28]. IBB pledges to make affordable, reliable and sustainable energy accessible to everyone by taking advantage of the wide selection of clean energy resources available to the city. For the period of 2020-2024 the municipality has planned to provide workshops for raising awareness on concepts such as global warming, low carbon emissions and energy efficiency as well as training for the installation of renewable energy facilities (solar energy, biogas facilities, etc.) but most importantly there are 10 new renewable energy power plants planned to be built in the span of the next 5 years with an estimated cost of 93,147,541₺, roughly $15,350,000 [28]. According to the Izmir Development Agency, a target is set to reach 2540 MW of WPP capacity until the year 2023 for the city [29].

Since after the World War II, a speedy and uncontrolled urbanization has been taking place throughout Turkey where the capital accumulation was not enough to support the growth and Izmir is one of the cities that has been affected by this the most. As a result, slum areas have risen in different parts of town where the lack of infrastructure and city planning causes problems today. In the last 50 years, single detached houses along the coastline have been replaced by modern 8-story buildings and apartment buildings were built throughout the inner districts of the city to house the growing population [30]. An ongoing project that IBB is undertaking is Urban Transformation, Development and Renovation activities. IBB's goal with this project is to improve livability in healthier and safer housing and living areas, protect existing cultural and historical heritage, support social transformation and improve social and technical infrastructure of the city under transparent, sustainable and interdisciplinary principles with a holistic perspective where inclusive participatory decision making is a priority [31]. IBB sees this project as an opportunity to transform small shantytowns into modern living areas and utilize new air conditioning and heating systems in households including the distribution of natural gas to each central district in the city. The Industrial Development Bank of Turkey (TSKB) is leader in financing renewable energy projects in the country and other sources for financing these projects include development and national banks such as the French Development Agency, European Bank for Reconstruction and Development, European Investment Bank, The International Finance Corporation and more [32]. According to Fitch Ratings, IBB holds a debt sustainability assessment and a national long-term rating of AAA [33].

The law on utilization of renewable energy sources for the purpose of generating electrical energy that was set in motion in 2005 and published in the Official Gazette No. 25819 incentivizes the use of locally made energy equipment and investments towards renewable energy technologies including research and development [34]. According to the law, for every kWh of electricity generated and supplied to the grid from wind turbines and solar PVs, $0.073 and $0.133 US is paid to the producer respectively. In case locally made equipment is used, production premiums up to $0.037 and $0.067 are added to wind and solar feed-in-tariffs for the first five years of operation depending on the type of locally made equipment used. In her review and analysis of the 2005 law, A. Özdemir, pointed out that there weren't enough incentives for entities generating electricity from renewable energy sources and that this would be an important issue until after renewable energy systems become economically competitive with conventional electricity generation technologies [35]. However, the most recent update to the law regarding unlicensed electricity generation that was published in the Official Gazette No. 30772 on May 2019 grants residents and businesses the right to set up solar PV systems on their roofs from 3 kW up to 10 kW without the need of an official approval and an exemption from 5% income tax on earnings generated from the sale of excess power to the city grid. According to the law, a minimum self-consumption rate of 50% is required and every resident is able to export power to the grid for half the price they pay for electricity [36].

## Chapter 3 – Methods and Analysis

### 3.1 Calculating Household Energy Use from Coal in Izmir

In order to know the capacity of an alternative technology needed to replace the coal used in households, we need to know how much heat is actually supplied through the furnaces to households. According to the Turkish Coal Operations Authority (TKI) 223,969 metric tonnes of coal were used in households of Izmir in the year of 2019 [37]. Lignite, or brown coal, is the major type of coal used in households in Turkey [38]. There are various types of coal available to the end user. A type of domestic lignite coal, Soma Kısrakdere 10-18mm, is an average choice of coal in terms of price and lower heating value which are 503 $\frac{₺}{kg}$ and 5101 $\frac{kcal}{kg}$ respectively [39]. According to the standard, TS 4900, issued by Turkish Standards Institution (TSE) the thermal efficiency of the furnaces for burning solid fuels used in households should be at least 70% [40]. R. Koç, a physicist and researcher at the Turkish Energy Foundations (TENVA) presents the two most commonly used coal furnace types and their thermal efficiencies as %42.5±1.5 and %55.3±1.2 respectively and points out the fact that TS 4900 is not enforced and the real average thermal efficiency of a household coal furnace is still significantly below 70% levels in 2017 [41].

The thermal efficiency ($\eta$) of a furnace can be expressed as the heat capacity of the furnace ($Q_{furnace}$) divided by the product of the amount of coal burned ($M_y$) and lower heating value of coal ($H_u$) [42]. $Q_{furnace}$ (see Equation 1) represents the amount of heat that is supplied to the household after the losses. Considering that most of the houses that use coal instead of natural gas in winter prefer coal due to its relatively easier affordability, an average thermal efficiency ($\eta$) of 60% for coal furnaces in Izmir households is assumed for calculating the heat energy supplied to the residences from burning coal.

$$\eta = \frac{Q_{furnace}}{M_y \times H_u}$$

Equation 1: Thermal efficiency of a coal furnace (MMO, 1995)

Based on these values;

| | |
|---|---|
| $\eta = 60\%$ | (Coal furnace thermal efficiency) |
| $M_y = 223{,}969\ metric\ tons$ | (Total amount of coal used in households of Izmir) |
| $H_u = 5101\ \frac{kcal}{kg}$ | (LHV of domestic coal) |

we can estimate that the amount of heat energy supplied to the households from coal furnaces in 2019, $Q_{furnace}$, was $6.85 \times 10^{11}\ kcal$, roughly $2.72 \times 10^{6}\ MMBtu$ or $7.96 \times 10^{8}\ kWh$. For the remainder of this report $Q_{furnace}$ and $Q_{coal}$ will be used interchangeably.

### 3.2 Calculating Energy Replacement with Alternative Methods

To replace the heat energy that is currently acquired from coal in households, a cleaner source of heat or electricity is needed. Sources such as geothermal energy or natural gas can be utilized for domestic heating whereas electricity generated from wind, solar or other clean natural sources can be used to power up electric resistance heating applications, heat pumps or air conditioning systems.

Equation 2 is used to approximate the amount of fuel, or electricity, needed from various heating technologies ($F_t$) to replace the heat currently acquired from coal throughout the year ($Q_{coal}$) where $\eta$ represents either thermal efficiency or coefficient of performance and $H_v$ is the heating value of the technology.

$$F_t = \frac{Q_{coal}}{\eta \times H_v}$$

Equation 2: Fuel needed to replace coal using technology t

### 3.2.1 Natural Gas

In Hepbasli and Canakci's case study of heating in Izmir, the heating value and average efficiency of natural gas home heating systems are given as 9.59 kWh/m$^3$ and 90% and the number of degree days for Izmir at base temperature of 18 $C^\circ$ as 1223 days per year [43]. Based on this, 8.63 kWh or 29,446 BTU of heat is acquired per cubic meter of natural gas and if all the households that used coal had used natural gas heating systems instead, approximately $92.24 \times 10^6$ m$^3$ natural gas would have been consumed to replace the heat energy supplied to the households from coal ($7.96 \times 10^8\ kWh$ or $2.72 \times 10^6\ MMBtu$) (See Calculation 2).

$$F_{natural\ gas} = \frac{7.96 \times 10^8\ kWh}{90\% \times 9.59\ {kWh}/{m^3}} = 92.24 \times 10^6\ m^3$$

Calculation 1: The amount of natural gas needed to replace the heat supplied by coal

According to the values obtained from Izmirgaz, as previously presented, total amount of natural gas supplied to households in 2019 was 660,870,941 standard cubic meters (at 288.16 Kelvin temperature and 1 atmosphere pressure) and the average yearly natural gas usage of a household was 933 Sm$^3$ [9]. Based on this, about 708,329 households used only natural gas for domestic heating or in other words, considering the total number of residences is 1,436,392, about half of the residences (728,063 houses) acquired the heat needed for space heating from other technologies.

### 3.2.2 Electric Heating

The three methods for space heating in residences using electricity that are most accessible in Izmir and therefore selected for analysis in this report, are electric resistance, air source electric heat pumps and ground source electric heat pumps. Heating values and efficiencies, or coefficient of performances (CoP), that are used to quantify the energy needed year-round are taken from Hepbasli and Canakci's case study of Izmir and presented below along with the calculations using Equation 2.

Electric resistance (ER): *Heating value: 3600 kJ/kWh or 3412.14 Btu/kWh, Efficiency: 99%*

$$F_{E.Resistance} = \frac{2.72 \times 10^{12}\ Btu}{99\% \times 3412.14\ {Btu}/{kWh}} = 8.05 \times 10^8\ kWh$$

Calculation 2: The amount of electricity needed to replace the heat supplied by coal using Electric Resistance

Air sourced Electric Heat Pump (ASHP): *Heating value: 3600 kJ/kWh, CoP: 2.8*

$$F_{ASHP} = \frac{2.72 \times 10^{12}\ Btu}{2.8 \times 3412.14\ {Btu}/{kWh}} = 2.85 \times 10^8\ kWh$$

Calculation 3: The amount of electricity needed to replace the heat supplied by coal using Air Source Heat Pump

Ground Sourced Electric Heat Pump (GSHP): *Heating value: 3600 kJ/kWh, CoP: 4.65*

$$F_{GSHP} = \frac{2.72 \times 10^{12}\ Btu}{4.65 \times 3412.14\ {}^{Btu}/_{kWh}} = 1.72 \times 10^{8}\ kWh$$

Calculation 4: The amount of electricity needed to replace the heat supplied by coal using Ground Source Heat Pump

We can see that, without the use of any sort of heat pump, the amount of electricity needed is about 4-5 times more than of the systems that utilize heat pumps where the heat energy in the air, ground or water is used. Even though it seems as the obvious choice with a significantly higher heating coefficient of performance, a notable disadvantage for ground source heat pumps is that it is not feasible nor possible to dig the ground beneath or near apartment buildings in the central neighborhoods of the city and this system is accessible to only single detached houses and neighborhoods where housing density is low. For the remainder of this paper the values for $F_{E.Resistance}$, $F_{ASHP}$ and $F_{GSHP}$ will be converted from kWh to GWh. These values are as follows:

$$F_{E.Resistance} = 805\ GWh \qquad F_{ASHP} = 285\ GWh \qquad F_{GSHP} = 172\ GWh$$

## 3.3 Cost of Coal Energy Replacement

Price of the most commonly used domestic coal in Izmir (Soma Kısrakdere 10-18mm) for the period of 2019-2020, taxes included, is 0.96 ₺/kg [44]. Based on this price, citizens who used coal for space heating have paid a total of approximately 21,500,160 ₺, roughly \$3,071,450 (exchange rate of \$1 US = 7 ₺ is used for the entirety of this paper), for 223,969 metric tonnes of coal in 2019.

There are two steps to calculating the cost for replacing coal with an alternative method for heating households: Cost of fuel or electricity and cost of equipment. In order to determine the cost of equipment, a rough estimation of how many houses will switch from coal to an alternative is needed. According to Sari and Bayram's study for quantifying the emissions from domestic heating in residential areas of Izmir, the city's Provincial Directorate of Environment and Forestry reported that nearly 1 ton of coal were consumed in a house every year [6]. The number of houses that use coal for space heating is estimated by dividing the total amount of coal used in residences of Izmir by the average coal consumption of a household in Izmir over the heating season (See Calculation 5).

$$\frac{223{,}969\ tons\ of\ coal}{1\ {}^{ton\ of\ coal}/_{household}} = 223{,}969\ households$$

Calculation 5: Number of houses that use coal for space heating in Izmir (from coal data)

The estimated 223,969 households will be used for the remainder of this report for calculating the cost of heating equipment needed to replace coal.

### 3.3.1 Natural Gas

According to Izmirgaz's price list for residential members natural gas is priced at 1.573445 ₺/$m^3$ or 0.147880169 ₺/kWh (%18 KDV tax excluded) [45]. For a building with 10 units, the cost of a central heating boiler is around 10000 ₺ including installation, membership activation fee for houses up to 200 $m^2$ is 781.13 ₺ per unit [9].

$$C_{NG} = 1.573445 \ ₺/_{m^3} \times 92.24 \times 10^6 \, m^3 \times 1.18 = 171.26 \times 10^6 \ ₺$$

Calculation 6: Cost of fuel (natural gas) to replace household coal

$$C_{EqNG} = 223{,}969 \ households \times \left( \frac{10000 \ ₺}{10 \ households} + \frac{781.13 \ ₺}{household} \right) = 398.92 \times 10^6 \ ₺$$

Calculation 7: Cost of equipment to replace household coal with natural gas

Based on Calculation 6, the cost of fuel to replace household coal with natural gas is 171,260,000 ₺, roughly $24,530,000. This is about 8 times the annual cost of coal for the citizens. The total initial cost for natural gas equipment and installation is (see Calculation 8) 398,917,000 ₺, about $56,988,000.

### 3.3.2 Electric Heating

In this section, the cost of equipment for electric heating and generating electricity to replace household coal and the cost of energy for each heating application are analyzed. There are two pricing options for residential electricity in Turkey: Single rate energy tariff and time of use (ToU) tariff. The tax included prices for each time period and tariff are listed below [46].

| Single Rate | ToU Day (06:00 – 17:00) | ToU Peak (17:00 – 22:00) | ToU Night (22:00 – 06:00) |
|---|---|---|---|
| 0.5375 ₺/kWh | 0.5445 ₺/kWh | 0.7997 ₺/kWh | 0.3404 ₺/kWh |

Table 1: Pricing options for residential electricity

It is assumed that energy consumption for space heating is inversely proportional to outside temperature. According to weather data taken from Weather Spark, the table for average hourly temperature in January 2020 indicates that the outside temperature between 6pm to 8am was very cold ($32^0$F – $45^0$F), 8am to 1pm was cold ($45^0$F – $55^0$F) and 1pm to 6pm was cool ($55^0$F – $65^0$F) [47]. When calculating the energy consumption in different time periods it is assumed that when the outside temperature is very cold the system works at full capacity, when cold at 50% and when cool at 25%. Based on these data and assumptions, the share of energy consumption for each time period of ToU tariff is given below.

| ToU Day (06:00 – 17:00) | ToU Peak (17:00 – 22:00) | ToU Night (22:00 – 06:00) |
|---|---|---|
| 31% | 24% | 45% |

Table 2: Share of energy consumption for residential heating in ToU time periods

Using the information from Table 1 and 2, the cost of residential electricity is calculated and presented below for each tariff and electric heating application. The weighted average of ToU rates based on hourly energy consumption for heating is 0.513903 ₺/kWh.

| | Electric Resistance (805 GWh) | Air Source Heat Pump (285 GWh) | Ground Source Heat Pump (172 GWh) |
|---|---|---|---|
| **Single Rate Tariff** | 432,687,500 ₺ | 153,187,500 ₺ | 92,450,000 ₺ |
| **Time of Use Tariff** | 413,691,915 ₺ | 146,462,355 ₺ | 88,391,316 ₺ |

Table 3: Total cost of electricity for residential heating for each tariff and heating application

Time of Use tariff is cheaper for space heating purposes throughout the year. For calculating the cost of heating equipment, the models with high energy efficiency ratings and affordable prices are picked. The price of each heating appliance can be observed in Table 4. It is assumed that an average household needs either 3 electric resistance heaters or 2 air source heat pumps or a single ground source heat pump. The total cost of equipment for each type of heating appliance for estimated 223,969 households are given in Table 5 below.

| Electric Resistance | Air Source Heat Pump | Ground Source Heat Pump |
|---|---|---|
| Nobo NFK4T 20 Front Heater | Vestel Flora Doğa A++ | Nibe 1345 |
| 1,151.35 ₺ | 2,399.00 ₺ | 93,353.56 ₺ |

Table 4: Prices for heating appliances

| Electric Resistance | Air Source Heat Pump | Ground Source Heat Pump |
|---|---|---|
| 773,600,124 ₺ | 1,074,603,262 ₺ | 20,908,303,480 ₺ |

Table 5: Total cost of equipment for all the residences that use household coal

#### 3.3.2.1 Solar Energy

In Ozcan and Ersoz's project and cost-based evaluation of photovoltaic energy production in Izmir, a project where 391 20-kW AC inverters and 35,460 Poly 250W 60-cell type modules, with installed power of 8865 kWp, are utilized is simulated [48]. Simulation inputs, system losses, normalized production per unit installed power and investment costs can be found in Appendix 3. The rate of electricity production after losses is given as 4.205 kWh per kW of installed power per day where the total produced energy is 13,606 MWh/year, panel efficiency is 15.39% and the production performance ratio is 83%. This project requires an area of 180,330 m$^2$ where in Izmir a land of this size costs about 5,410,000 ₺ and the cost of equipment is 26,528,388 ₺ excluding the 18% tax on equipment which amounts to 4,775,109 ₺. Return on investment based on 25 years life cycle, including the cost of land, is calculated as 1.53 with a payback period of 7.03 years in Ozcan and Ersoz's simulation. Based on this information and these values, the cost of generating the energy needed for each heating application is calculated with a top-down approach where every parameter is assumed to be directly proportional to the annual energy production and the results are presented in Table 6 below.

| PV Projects (Annual Production) | Reference Project (13.6 GWh) | Electric Resistance (805 GWh) | Air Source Heat Pump (285 GWh) | Ground Source Heat Pump (172 GWh) |
|---|---|---|---|---|
| **Installed Power** | 8,865 kWp | 524,730 kWp | 185,774 kWp | 112,116 kWp |
| **Cost of Land** | 5,410,000 ₺ | 320,224,264 ₺ | 113,371,323 ₺ | 68,420,588 ₺ |
| **Cost of Equipment** | 26,528,388 ₺ | 1,570,246,495 ₺ | 555,925,777 ₺ | 335,506,608 ₺ |
| **Tax on Equipment** | 4,775,109 ₺ | 282,644,369 ₺ | 100,066,639 ₺ | 60,391,189 ₺ |
| **Energy Sales Revenue (Annual)** | 9,524,200 ₺ | 563,748,602 ₺ | 199,588,014 ₺ | 120,453,117 ₺ |
| **Area Required** | 180,330 m$^2$ | 10,673,944 m$^2$ | 3,778,974 m$^2$ | 2,280,644 m$^2$ |

Table 6: Resources and costs associated with energy generation from PVs to supply each electric heating application

#### 3.3.2.2 Wind Energy

In a case study of technical and economic feasibility of a potential wind farm located in Izmir, Ozerdem, Ozer and Tosun investigate three different scenarios and compares them with respect to net present value, payback period and internal rate of return [49]. The study concludes that the higher the installed capacity is, the lower the cost of generating electricity with wind turbines. The scenario of independent power producer yielded the lowest generating cost in the study which was 2.68 UScent per kWh of electricity generated. In this case, 13 NEG-Micon NM52 wind turbines were utilized with a plant capacity of 11.7 MW and an estimated annual energy production of 41,596 MWh where the cost of turbines was $14,030,155. Using this case study as a reference for achieving the lowest costs associated with electricity generation from wind, the cost of equipment to supply each electric heating option is calculated and presented in Table 7 below.

| WPP Projects | Reference Project | Electric Resistance | Air Source Heat Pump | Ground Source Heat Pump |
|---|---|---|---|---|
| **Installed Power** | 11.7 MW | 226.43 MW | 80.16 MW | 48.38 MW |
| **Number of Wind Turbines** | 13 | 252 | 89 | 54 |
| **Cost of Equipment** | 98,211,085 ₺ | 1,900,661,684 ₺ | 672,905,068 ₺ | 406,104,111 ₺ |
| **Annual Energy Delivered** | 41.596 GWh | 805 GWh | 285 GWh | 172 GWh |

Table 7: Cost of equipment for wind energy generation to supply each electric heating application

The analysis shows that for cost of electric heating appliances is directly proportional to their energy efficiency. Cost of wind turbines is slightly higher than of the solar PVs of same annual electricity generation capacity. Natural gas heating equipment costs less than all electric heating alternatives but annual cost of natural gas (fuel) is the second most expensive following electric resistance heating.

### 3.4 Environmental Benefit

Emissions for each pollutant per ton of coal and cubic meter of natural gas is determined by the emission factors of U.S. Environmental Protection Agency (USEPA) and given in the table below [50].

| | Unit | $SO_2$ | $NO_2$ | $PM_{10}$ | CO |
|---|---|---|---|---|---|
| **Coal** | **g/kg** | 10.89 | 1.33 | 4.89 | 55.69 |
| **Natural Gas** | **g/m$^3$** | 0.02 | 1.85 | 0.02 | 1.01 |

Table 8: Emission factors used to calculate emissions from coal and natural gas (USEPA, 1998)

Considering 223,969 tonnes of annual coal consumption and the amount of natural gas needed to replace the coal is 92.23 x $10^6$ $m^3$, the total emissions of contaminants from each fuel and the difference when natural gas is used instead of coal is calculated and presented in the table below.

| | Unit | $SO_2$ | $NO_2$ | $PM_{10}$ | CO |
|---|---|---|---|---|---|
| **Coal** | **Metric ton** | 2439 | 298 | 1095 | 12473 |
| **Natural Gas** | **Metric ton** | 1.84 | 171 | 1.84 | 93 |
| **Difference** | **Metric ton** | -2,437.16 | -127 | -1093.16 | -12380 |

Table 9: Emissions from coal and natural gas and the pollutants eliminated

In a scenario where natural gas is used instead of coal in every household 2437 tonnes of $SO_2$, 127 tonnes of $NO_2$, 1093 tonnes of $PM_{10}$ and 12380 tonnes of CO are eliminated each year. Electric heating appliances do not directly emit contaminants where the electricity they consume is generated from clean resources. Therefore, in a scenario where every household that uses coal switches to electric heating then 2439 tonnes of $SO_2$, 298 tonnes of $NO_2$, 1095 tonnes of $PM_{10}$ and 12473 tonnes of CO emissions will be eliminated each year.

In their analysis of phasing out coal in households in Beijing, Jin, Andersson and Zhang quantify premature deaths and disease cases each year attributable to 600,000-ton coal used in households [51]. The values for premature deaths and disease cases for each disease type are calculated for 223,969-ton coal consumption based on the median values in 600,000-ton case and presented below in Table 10.

| Disease Type | Premature Deaths | Disease Cases |
|---|---|---|
| **Acute Lower Respiratory Infection** | 1 | 29 |
| **Chronic Obstructive Pulmonary Disease** | 26 | 129 |
| **Lung Cancer** | 31 | 31 |
| **Total that can be avoided** | 58 | 189 |

Table 10: Health effects attributable to 223,969-ton coal used in households each year

By eliminating the coal used in households in Izmir, about 58 premature deaths and 189 cases of diseases related to ambient and household air pollution can be avoided each year.

## Chapter 4 – Alternative Model

### 4.1 China's Approach Towards Coal Control

According to the Global Carbon Atlas, China is the country that had the highest $CO_2$ emissions in the world with almost one-third of the total emissions (36573 $MtCO_2$) by 10065 $MtCO_2$ in 2018 [52]. The Worldbank indicates that, following India, China has the highest population (1.126 billion) that is exposed to very low-quality air [53]. In September 2013, China State Council issued a National Action Plan on Air Pollution and Control which set goals for air quality improvement, adjusting the energy structure and increasing the clean energy supply [51].This action proposes mid and long-term targets for national coal consumption as well as a target responsibility system for tracking progress and success of this plan's implementation where the key progress indicators are the amount and the ratio of nationwide coal consumption reduced each year. As a target, China State Council set a cap of 3 billion tons of coal consumption to be met by 2020. Some of the interventions that Chinese Government include coal-to-gas projects, mandatory coal reduction targets for local governments and making coal combustion process cleaner. Investments in construction sector towards improving the thermal efficiency of the existing houses and new buildings have been identified to have significant impacts on coal demand reduction [54].

There are three main combinations of methods to intervene the use of coal in households used in China that could apply to the case in Izmir. First, reconstructing houses for improved thermal insulation combined with the use of solar heat collectors where the goal is to reduce the amount of energy needed for space heating and utilizing solar heat energy. Second, switching to electric-heating stoves and promoting this by the resources of the local municipal government. Third, reconstructing houses for both thermal insulation improvement and the switch to an electric-heating stove or another cleaner method of space heating.

### 4.2 Finding an Alternative

We can see that supplying the electric heating appliances with the energy needed each year is slightly more expensive with wind power plants than it is with solar PV systems. The city of Izmir has a growing renewable energy portfolio in both wind and solar as well as a high potential for each. A long-term investment and transformation plan for these renewable energy power plants can be implemented into IBB's Urban Transformation, Development and Renovation project and backed up by tax incentives on both energy generation and heating equipment as well as discounts on natural gas to low-income citizens, caps on coal consumption in households, and legislature that would discourage the use of coal such as carbon taxes which would increase the price of coal further and close the price gap between coal and alternative technologies. Currently, none of the supplementary legislature and incentives mentioned, except for the 5% income tax on earnings generated from the sale of excess power, exist in Turkey.

The research yields ground source heat pumps as the most efficient yet also the most expensive technology with the shortest payback period. Electric resistance is the least efficient technology with the lowest initial investment. Air source heat pump is the median for both efficiency and cost of equipment among the electric space heating technologies. The initial investment for natural gas systems is cheaper than all electric heating applications whereas the annual cost of fuel is slightly more expensive than of air source heat pumps and significantly cheaper than of electric resistance heaters.

Considering the vast distribution network that has been built in the majority of the city, natural gas will play an important role for reducing the coal consumption in the households in Izmir. The houses where ground source heat pumps are applicable are very few and a very small portion of residents who use coal can afford this technology. Taking into account the low cost-efficiency of electric heaters, they should be utilized minimally. Air source heat pumps are convenient for low income residents as the initial investment is affordable and the annual cost of electricity is lower than of natural gas and electric heaters thus, they will have a high share of the alternative technologies that will replace coal.

Since both wind and solar PV systems has a high potential on the city grounds and both wind turbines and PV equipment are manufactured in Turkey, they are likely to have equal share in future investments for renewable energy technologies in the city. Based on this train of thought and assumptions a model that would replace household coal with technologies assessed in this paper is presented in Table 11 where the share of each technology in the transformation from coal and the costs associated with them are given.

| | **Space Heating Technologies** | | | | **Electricity Generation** | |
|---|---|---|---|---|---|---|
| | **Natural Gas** | **ER** | **ASHP** | **GSHP** | **WPP** | **Solar PV** |
| **Proposed Share of Utilization** | 50% | 9% | 40% | 1% | 50% | 50% |
| **Cost of Equipment** | 199,458,500₺ | 69,624,011₺ | 429,841,305₺ | 209,083,034₺ | 222,141,309₺ | 216,558,061₺ |
| **Annual Cost of Fuel** | 85,630,000 ₺ | 37,232,272₺ | 58,584,942₺ | 883,913₺ | - | - |
| **Generation Capacity** | - | - | - | - | 52.93 MW | 122.66 MW |

Table 11: Alternative model to household coal: share of technologies and cost of equipment and fuel

With this model the total initial cost for the citizens for the cost of heating equipment is 908,006,850₺ where 163,441,233₺ of this expense is tax, and 744,565,617₺ is the tax excluded cost of heating equipment. The annual cost of fuel for space heating is 182,331,127₺. To supply the electric heating systems with clean energy, an investment of 438,699,370₺ is needed to install the wind turbines and solar PV systems. To further support this transformation, tax exemption or discount for electric heating equipment to low-income residents could be granted and to discourage citizens from using more coal a carbon tax could be applied.

## 4.3 Challenges and Limitations

### 4.3.1 Technical Limitations

Current installed solar PV capacity of Izmir is 16.1 MW and about 8 times of this capacity is needed to be installed to supply the energy needed from solar PVs in this model. Due to the majority of the buildings in the city being apartment buildings the rooftop area per household is not sufficient to meet the energy needs for space heating. Moreover, 3 kW minimum rooftop solar requirement creates a barrier for low income residents to utilize solar PVs on their roofs and benefit from net metering mechanism. Although ground source heat pumps recover the cost of the investments made in them in a short period, the houses eligible to utilize them are very few.

### 4.3.2 Economic Barriers

The major economic challenge for replacing coal with alternative technologies is the immense increase in annual cost of fuel. While the annual cost of coal for the residents is 21,500,160₺, when replaced by natural gas and electric heating technologies this annual cost will be 182,331,127₺, about 8 times more than of coal. Turkish Lira has been following a downward trend in value for the last decade. In May 11, 2010, the exchange rate for $1 US was 1.53 ₺ whereas today this exchange rate is above 7.00 ₺. This means that purchasing power of Turkish citizens has decreased significantly for imported goods and materials such as natural gas, ground source heat pumps and PV cells. Furthermore, the majority of citizens who use coal for space heating do so due to lack of natural gas infrastructure or low income which makes it impossible for them to switch to another technology, where there are higher expenses, without a sustainable model, help from both central and local governments and specific incentives.

### 4.3.3 Compatibility to the Strategic Plan and Legislature

IBB's Urban Transformation, Development and Renovation project presents great opportunities to apply high efficiency heating systems, such as district heating supported by solar collectors or ground source heat pumps, in the process of rebuilding slum areas with newly constructed buildings, and to build renewable energy power plants such as utility scale solar or wind power plants by utilizing the appropriate lands in the city's borders. Direct support of investment costs, price support for electricity from renewable resources, favorable interest rates, and tax incentives are needed for this model to be brought to life.

According to the 2020-2024 strategic plan of IBB, the funds IBB reserved for building 10 renewable energy power plants is 93,147,541₺ which would account for a significant portion for the 438,699,370₺ investment that is needed in the proposed alternative. Considering that bringing this model to life will require 5 to 10 years, finding the rest of the funding to invest in this model, from The Industrial Development Bank of Turkey and other aforementioned international development banks and with the help of the government, is possible especially with the high credit score that IBB has. Moreover, the requirement of 53 MW wind power plant that is proposed in the model is certain to be met with the government's goal of reaching an installed WPP capacity of 2540MW in Izmir by 2023, which is currently around 1295 MW and with the WPPs currently under construction in Izmir that will add 125.9 MW of wind energy generation capacity.

## Chapter 5 – Conclusions and Recommendations

The purpose of this paper was to explore a model that utilizes low-carbon emitting methods of domestic heating and renewable energy technologies supported by government and municipal policies as an alternative to the coal used in residential areas of Izmir. The heat energy supplied by coal to the residences were quantified. Natural gas and three different methods of electric space heating (electric resistance, air source heat pump and ground source heat pump) were analyzed individually to replace household coal. This research found that the proposed model based on the analysis requires 1,346,706,220₺ of initial investment for the heating and electricity generation equipment. The annual cost of natural gas and electricity needed to replace household coal for space heating is 182,331,127₺.

Preliminary research and analysis also yielded the following:

- Lack of monitoring $NO_2$ and CO in half of the air quality measurement stations and $PM_{2.5}$ altogether, limits the accuracy of the air quality assessment throughout the city and even with the insufficient air monitoring infrastructure it has been seen that $PM_{10}$ levels exceed the limit concentration value.

- Upon activation of WPPs under construction 13.4% of Izmir's 11.85 GW wind energy potential will be utilized.

- Izmir's high solar energy potential is significantly underutilized as only 0.6% of the city's energy profile consists of solar PVs.

- Incentivization of generating electricity with renewable energy systems exists yet not sufficiently for low-income residents to utilize them on their rooftops. 3 kW minimum rooftop solar PV capacity creates a barrier.

- 223,969 tonnes of household coal is burned each year in Izmir, mostly by low-income residents, where the heat energy supplied to the residences through coal furnaces was approximately $2.72 \times 10^6$ MMBtu.

- Eliminating household coal with clean alternatives would prevent an estimated 58 premature deaths and 189 disease cases related to ambient and household air contamination each year.

- Financial aid, public funds and tax incentives from both local and central government is needed in direct support of investment costs for achieving the proposed model.

Research Recommendations:

- Monetization of the benefits associated with the elimination of household coal is needed for a detailed cost-benefit analysis.

- The neighborhoods where coal consumption is high should be targeted and the type of buildings in majority should be investigated for finding solutions specific to the topography and settling of the region

- The technical potential for wave energy in Gulf of Izmir, where all the city's central neighborhoods are built around, is 18000 GWh/year. Further research is recommended as this presents a great opportunity as a way to utilize energy from a renewable source.

- The opportunities for utilizing district heating, central solar heating and heat pumps that use the sea water should be researched in accordance with IBB's Urban Transformation, Development and Renovation project.

Policy Recommendations:

- Architectural regulations for higher thermal insulation, utilization of daylight and better enforcement of these regulations are recommended for higher efficiency in space heating.

- Carbon tax and cap on coal consumption should be considered for discouraging the use of coal.

- Tax incentives on procurement of low-carbon emitting heating technologies and renewable energy systems aimed at low-income households should be considered for promoting cleaner heating and energy technologies.

- The minimum 3 kW capacity requirement for roof solar PV systems should be lifted for giving low-income residents and households with small rooftops the ability to utilize as much renewable energy systems as can be.

The noble goal of this study is to lay the groundwork for the elimination of household coal to reach better air quality and provide low-income citizens of Izmir with cleaner and more efficient domestic heating technologies and prevent air pollution related diseases and premature deaths. Evaluation and simple methods of estimations show that this is possible as well as necessary. If the preliminary research and analysis and the model proposed in this study serve as a guide and a stepping stone towards further research and utilization of clean energy, then this study will serve its purpose.

## Chapter 6 - References Cited

[1] United Nations Framework Convention on Climate Change. (2015). Intended Nationally Determined Contributions for COP21 by Turkey, Paris, France. Retreived from: http://www4.unfccc.int/Submissions/INDC/Submission%20Pages/submissions.aspx

[2] Zarinebaf-Shahr, F. (2000). The Ottoman City between East and West: Aleppo, Izmir, and Istanbul, by Edhem Eldem, Daniel Goffman, and Bruce Masters.

[3] İzmir Valiliği. (2018). İstatistiklerle İzmir (in Turkish). Retrieved from: http://www.izmir.gov.tr/istatistiklerle-izmir (Accessed February 7, 2020)

[4] Turkey Chamber of Mechanical Engineers. (2008). Energy Efficiency in the World and Turkey (in Turkish). Retrieved from: http://www1.mmo.org.tr/resimler/dosya_ekler/a551829d50f1400_ek.pdf (Accessed February 7, 2020)

[5] Turkish Statistical Institution. (2019). Adress Based Population Statistics (in Turkish). Retrieved from: http://www.tuik.gov.tr/PreTablo.do?alt_id=1059 (Accessed March 4, 2020)

[6] Sari, D., Bayram, A. (2013). Quantification of emissions from domestic heating in residential areas of Izmir, Turkey and assessment of the impact on local/regional air-quality

[7] Kazanasmaz, T., Uygun, İ. E., Akkurt, G. G., Turhan, C., & Ekmen, K. E. (2014). On the relation between architectural considerations and heating energy performance of Turkish residential buildings in Izmir. Energy and Buildings, 72, 38–50.

[8] Izmirgaz. (2020). Official website members counter (in Turkish). Retrieved from: http://www.izmirgaz.com.tr

[9] C. Özdemir (Assistant General Manager of İzmirgaz). personal communication. February 20, 2020

[10] Energy Efficiency Forum and Expo. (2019). Jeotermal Kaynaklı Bölgesel Isıtma Sistemi Balçova-Narlıdere Örneği (in Turkish). Retrieved from: http://www.evf.gov.tr/content/files/Konusmaci_Sunumlari/turk-konusmacilar/hasan-cıg-sezer.pdf

[11] World Health Organization. (2018) Ambient air pollution fact sheet. Retreived from: https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (Accessed February 7, 2020)

[12] Çevre ve Şehircilik Bakanlığı. (2019). Hava kalitesi Bülteni (in Turkish). Retrieved from: https://webdosya.csb.gov.tr/db/ced/icerikler/bulten-aralik-2019-20200212083008.pdf (Accessed February 12, 2020)

[13] Gemmer, M., and B. Xiao. (2013). Air quality legislation and standards in the European Union: Background, status and public participation.

[14] World Health Organization. (2005). Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.

[15] Brookings Institute. (2014). Global Metro Monitor. https://www.brookings.edu/wp-content/uploads/2015/01/bmpp_GMM_final.pdf

[16] Izdemir Enerji. (2012) Technical specifications of Izdemir Energy Aliağa Coal Power Plant. Retrieved from: https://www.izdemirenerji.com/teknik-ozellikler/ (Accessed February 18, 2020)

[17] Izmir Kalkınma Ajanı. (2019). Why Izmir. Retrieved from: https://www.investinizmir.com/en/why-izmir

[18] World Resources Institute. (2019). Global Power Plant Database. Retrieved from: http://datasets.wri.org/dataset/globalpowerplantdatabase

[19] Turkish Engineers and Architects Chambers Union (TMMOB). (2019). Izmir Çevre Durum Raporu (in Turkish).

[20] T.C. Enerji ve Tabii Kaynaklar Bakanlığı. (2006). Rüzgar Enerjisi Potansiyel Atlası (in Turkish). Retrieved from https://eigm.gov.tr/tr-TR/Sayfalar/REPA

[21] T.C. Enerji ve Tabii Kaynaklar Bakanlığı. (2006). İzmir İli Rüzgar Kaynakları (in Turkish). Retreived from: https://www.eigm.gov.tr/File/?path=ROOT%2f4%2fDocuments%2frepa%2fIZMIR-REPA.pdf

[22] Turkish Wind Energy Association. (2019). Turkish Wind Energy Statistic Report July 2019. Retreived from: http://www.tureb.com.tr/files/bilgi_bankasi/turkiye_res_durumu/istatistik_raporu_temmuz_2019.pdf

[23] Republic of Turkey Ministry of Energy and Natural Resources. (2017). Solar Energy in Turkey. https://www.enerji.gov.tr/en-US/Pages/Solar

[24] T.C. Enerji İşleri Genel Müdürlüğü. (2020). Türkiye Elektrik Yatırımları 2020 Yılı Ocak Ayı Özet Raporu. (in Turkish). Retrieved from: https://eigm.gov.tr/File/?path=ROOT%2f4%2fDocuments%2fRapor%2fElektrik%20Yatırımları%202020%20Ocak%20Aylık%20Özet%20Raporu.pdf (Accessed February 20, 2020)

[25] Deutscher Wetterdienst. (2020). Maps on global radiation, annual average and monthly average. https://www.dwd.de/EN/ourservices/solarenergy/maps_globalradiation_average.html

[26] Fraunhofer Institute for Solar Energy Systems ISE. (2020). *Public Net Electricity Generation in Germany 2019*.

[27] Yenilenebilir Enerji Genel Müdürlüğü. (2006). Solar Energy Potential Atlas (in Turkish). Retrieved from: http://www.yegm.gov.tr/MyCalculator/Default.aspx

[28] Metropolitan Municipality of İzmir. (2019). Strategic Plan 2020-2024 (in Turkish). Retrieved from https://www.izmir.bel.tr/CKYuklenen/Dokumanlar_2020/Stratejik%20Plan2024.pdf (Accessed February 16, 2020)

[29] Izmir Kalkınma Ajansı. (2019). Wind Energy (in Turkish). Retrieved from: https://www.investinizmir.com/sektor-ruzgar-enerjisi

[30] Izmir Buyuksehir Belediyesi. (2017). Izmir – History Project: Design Strategy Report (in Turkish). Retrieved from: http://www.izmirtarih.com.tr/pdf/TasarimStratejisiRaporu.pdf

[31] Izmir Buyuksehir Belediyesi. (2018). Urban Transformation Development and Renovation Projects (in Turkish). Retrieved from: https://www.izmir.bel.tr/tr/Projeler/kentsel-donusum-gelisim-ve-yenileme-projeleri/1271/4

[32] PWC. (2012). Turkey’s Renewable Energy Sector from a Global Perspective. Retrieved from: https://www.pwc.com.tr/tr/publications/industrial/energy/assets/renewable-report-11-april-2012.pdf

[33] Fitch Ratings. (2020). Izmir Rating Action Commentary. Retrieved from: https://www.fitchratings.com/research/international-public-finance/fitch-affirms-izmir-at-bb-outlook-stable-03-04-2020

[34] Official Gazette of the Republic of Turkey. (2005) Law on the Utilization of Renewable Energy Sources for the Purpose of Generating Energy. Retrieved from: https://www.resmigazete.gov.tr/eskiler/2005/05/20050518-1.htm (Accessed on February 20,2020)

[35] Özdemir, A. (2008). Turkey`s Law on the Utilization of Renewable Energy Sources for the Purpose of Generating Energy.

[36] EPDK. (2019). Law on unlicenced generation of electricity in Turkey. Retrieved from: https://www.epdk.org.tr/Detay/Icerik/3-0-92/elektriklisanssiz-uretim

[37] Türkiye Kömür İşletmeleri (Turkish Coal Authorities). Personal Communication. Feb 27, 2020

[38] T. Ataman. (1973). Classification of Turkish Lignite Coal. Retreived from: http://www.maden.org.tr/resimler/ekler/3451e7ef8755c2a_ek.pdf

[39] Türkiye Kömür İşletmeleri. (2020). March 2020 Price List. Retrieved from: http://www.tki.gov.tr/depo/2020%20YILI%20MART%20AYI%20ANALİZLİ%20FİYAT%20LİSTESİ.pdf

[40] Turkish Standards Institution. (2003). Requirement for solid fuel burning room heaters and test methods. Retrieved from: https://intweb.tse.org.tr/Standard/Standard/Standard.aspx?081118051115108051104119110104055047105102120088111043113104073085066097097048084055056108118051

[41] Türkiye Enerji Vakfı (TENVA). (2017). Türkiye Enerji Görünümünde “Soba” Gerçeği (in Turkish). Retrieved from: http://www.tenva.org/turkiye-enerji-gorunumunde-soba-gercegi/

[42] Chamber of Mechanical Engineers. (1995). Higher thermal efficiency in residences and low emission heaters. Retrieved from: http://www1.mmo.org.tr/resimler/dosya_ekler/6a15d2eebd9a2b9_ek.pdf

[43] Hepbasli, A., & Canakci, C. (2003). Geothermal district heating applications in Turkey: a case study of Izmir–Balcova.

[44] Ulusoy Madencilik. (2020). Coal Price List for 2019-2020. Retrieved from: https://ulusoymadencilik.com/izmir-komur-fiyatlari/

[45] Izmirgaz. (2020). Natural Gas Prices, Service and Membership Fees. Retrieved from: http://www.izmirgaz.com.tr/tr/Abonelik-Hizmetleri/Tarifeler/Dogalgaz-Bedeli-konut-serbest-.html

[46] Enerji Piyasası Düzenleme Kurumu (EPDK). (2019). Electricity tariffs in effect in 2020. Retrieved from: https://www.epdk.org.tr/Detay/Icerik/3-23448/01012020-tarihinden-itibaren-gecerli-elektrik-t

[47] Weather Spark. Weather temperature data for Izmir in January, 2020. (2020). Retrieved from: https://weatherspark.com/m/94320/1/Average-Weather-in-January-in-İzmir-Turkey#Sections-Temperature

[48] Ozcan, O., & Ersoz, F. (2019). Project and cost-based evaluation of solar energy performance in three different geographical regions of Turkey: Investment analysis application.

[49] Ozerdem, B., Ozer, S., & Tosun, M. (2006). Feasibility study of wind farms: A case study for Izmir Turkey.

[50] USEPA. (1998). Compilation of air pollutant emission factors: AP-42. Volume I: stationary point and area sources, chapter 1: external combustion.

[51] Jin, Y., Andersson, H., Zhang, S. (2017). China’s Cap on Coal and the Efficiency of Local Interventions: A Benefit-Cost Analysis of Phasing out Coal in Power Plants and in Households in Beijijng

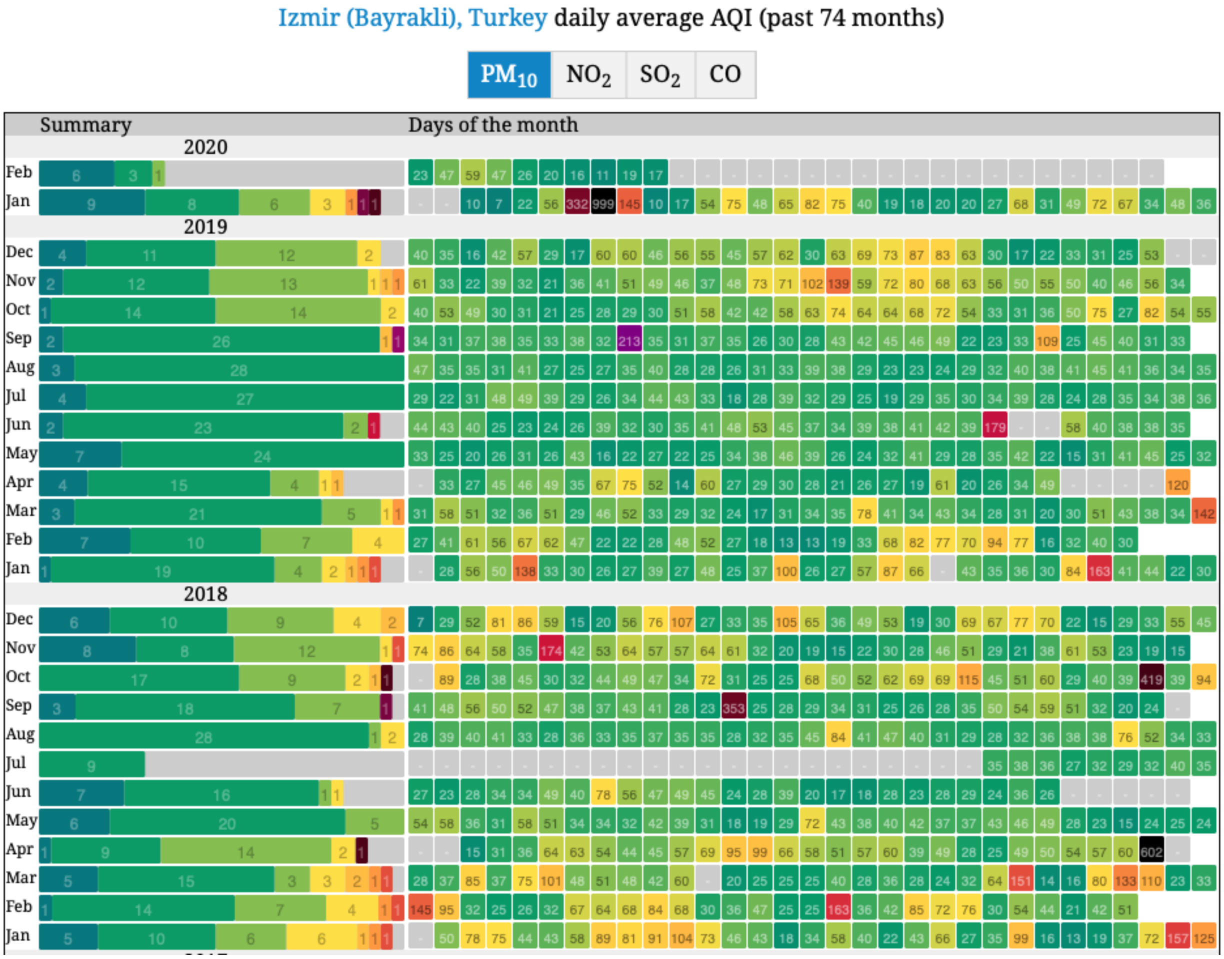
[52] Global Carbon Atlas. (2018). Carbon emissions by country in 2018. Retrieved from: http://www.globalcarbonatlas.org/en/CO2-emissions

[53] Worldbank. (2019). Global distribution of air pollution. Retrieved from: http://datatopics.worldbank.org/world-development-indicators/stories/the-global-distribution-of-air-pollution.html

[54] Chen, X., Liang, Q., Liu, L., Wang, C., Xue, M. (2019). Critical structural adjustment for controlling China's coal demand.

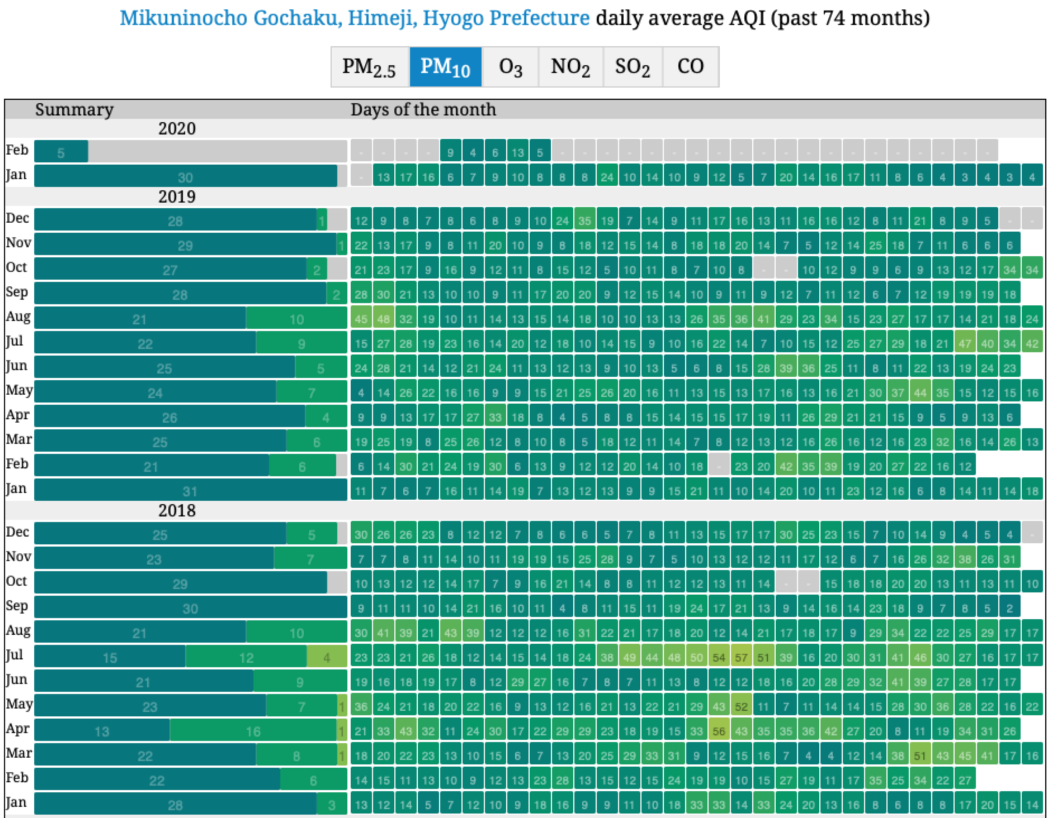
**Appendix 1:** Historical Data on $PM_{10}$ Air Quality Index Values in Izmir (Bayraklı Station)

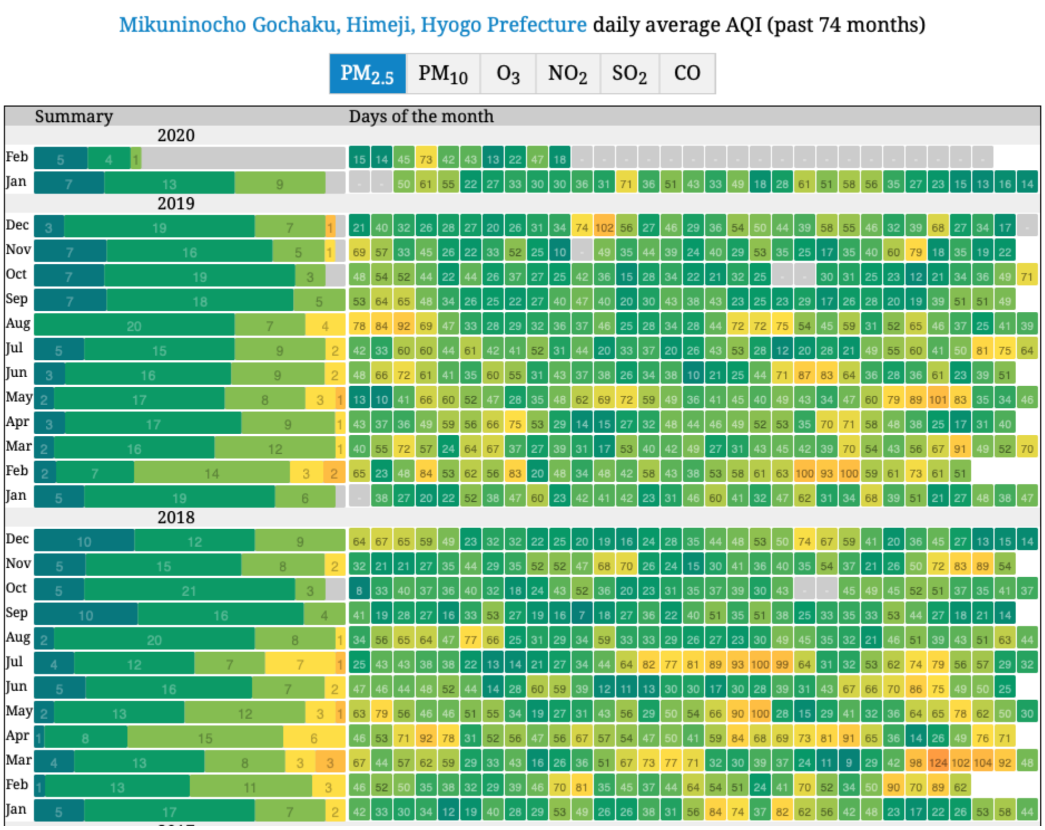
Data taken from: aqicn.org (The World Air Quality Index Project) accessed on February 17, 2020



**Appendix 2:** Benchmark of $PM_{10}$ and $PM_{2.5}$ Air Quality Index Values in Himeji, Japan

Data taken from: aqicn.org (The World Air Quality Index Project) accessed on February 17, 2020



## **Appendix 3:** Simulation input data and results for project and cost-based evaluation of solar energy performance in Izmir

Data taken from Ozcan, O., & Ersoz, F. (2019)

| Project | Izmir invesment |
|---|---|
| *Location information* | |
| Height (m) | 79 |
| Average sunshine time (daily) | 8.19 |
| Annual global radiation (KWh/m$^2$) | 1639 |
| Environmental shading | – |
| *Module İnformation* | |
| Type | Poly 250 w 60 cell |
| Nominal power (w) | 250 |
| Number of module used | 35,460 |
| Installed power (kWp) | 8865 |
| *Inverter information* | |
| Type | GW20K-DT |
| Inverter power (kW/ac) | 20 |
| Number of inverter used | 391 |
| *System losses* | |
| Annual global radiation (kWh/m$^2$) | 1639 |
| Global incident in coll. Plane (%) | 13.2 |
| Module shading: irradiance loss (%) | −2.9 |
| IAM factor on global (%) | −2.7 |
| PV loss due to irradiance level (%) | −0.5 |
| Panel efficiency at test condition (%) | 15.39 |
| PV loss due to temperature (%) | −9.6 |
| Module quality loss (%) | 1.3 |
| Mismatch loss, modules and strings (%) | −1.1 |
| Ohmic wiring loss (%) | −1.1 |
| Inverter loss during operation - efficiency (%) | −1.7 |
| *Production* | |
| Produced energy (MWh/year) | 13,606 |
| Production performance ratio (%) | 83 |

Investment costs and annual costs.

| | Izmir investment |
|---|---|
| Investment costs, A | 26 528 388 ₺ |
| Cost of land, B | 7 800 000 ₺ |
| Gross investment | 34 328 388 ₺ |
| Net investment (A + VAT) + B) | 39 103 372 ₺ |
| Annual costs | 820 743 ₺ |
| Credit payment | 3 137 756 ₺ |
| Energy sales revenue (annual) | 9 524 200 ₺ |
| Energy production cost | 0.29 ₺ |
| Net profit/loss (25 years) | 74 281 210 ₺ |
| Net present value (profit/loss) | 59 747 496 ₺ |