ECONOMIC, SOCIAL AND ENVIRONMENTAL IMPACTS OF URBAN ENERGY SYSTEMS: THE CASE OF İZMIR NATURAL GAS NETWORK

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ABSTRACT

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Urban infrastructure systems are high-cost urban components that provide physical and socio-economic functioning in daily life and affect livability and modernization processes. Infrastructure systems, which directly affect the urbanization and are shaped by existing urban settlements, are investments of which efficiency is achieved in the long run and directly related to the planning process. Energy networks, being constituted of natural gas and electricity, are among urban infrastructure systems. Urban energy services need to be provided in an uninterrupted, efficient and standardized way. While energy contributes to economic growth, social justice should be considered, and its impact on the environment should be minimized. The investigation of the relationship between energy infrastructure and sustainability becomes important at this point, considering the social, economic and environmental impacts of energy, which play vital roles in the continuity of the urban dynamics.

In this study, it is aimed to reveal the socio-spatial effects of the natural gas system, which is cleaner and more efficient compared to other fossil fuels, although not being a domestic and a renewable energy resource. Sustainability of natural gas has been discussed with regard to its economic, social and environmental impacts. (1) Its

economic advantages or disadvantages have been examined by calculating investment costs and the annual heating cost of natural gas. Then, these costs are compared to other fuel types. (2) In social terms, the tendency of the households being fuel poor is examined by using a 10% fuel poverty indicator that seek to the households who are spending more than 10% of their income to demonstrate whether energy is distributed equitably to residents in the city and whether household can afford this energy service. (3) Finally, how natural gas consumption affects the pollutant emissions is examined, particularly during the winter season. The variation of the temporal and spatial distributions of PM_{10} emission was compared by using the Kriging method.

Keywords: Urban Energy Infrastructure, Natural Gas Network, Energy Justice, Domestic Heating, Air Pollution

ÖZ

KENTSEL ENERJİ SİSTEMLERİNİN EKONOMİK SOSYAL VE ÇEVRESEL ETKİLERİ; İZMİR DOĞAL GAZ AĞI ÖRNEĞİ

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Kentsel altyapı sistemleri, günlük hayatta fiziksel ve sosyo-ekonomik işleyişi sağlayan, yaşanabilirlik ve modernleşme süreçlerini etkileyen yüksek maliyetli kent bileşenleridir. Kentleşme sürecini doğrudan etkileyen ve mevcut kentsel yerleşimlere göre şekillenen altyapı sistemleri, verimliliği uzun zamanda elde edilen yatırımlardır. Doğal gaz ve elektrik sistemlerinden meydana gelen enerji altyapısı kentsel altyapının bileşenlerindendir. Enerji akışının sağlanmasında bu altyapı hizmetinin kesintisiz, verimli ve belli standartlarda sağlanması gerekmektedir. Bu sayede ekonomik büyümeye katkı sağlarken sosyal adalet göz önünde bulundurulmalı ve çevresel etkileri minimuma indirilmelidir. Kentlerin dinamik yapılarının devamlılığında kilit rol oynayan enerjinin ekonomik, sosyal ve çevresel etkileri düşünüldüğünde enerji sistemlerinin sürdürülebilir olması çok önemlidir. Bu araştırmada, diğer fosil yakıtlara göre daha temiz, ekonomik ve enerji verimi daha yüksek olan doğal gaz sistemi için sürdürülebilirlik çerçevesinde bir sosyo-mekansal etki değerlendirmesi yapılması amaçlanmaktadır. Çalışma alanı olarak Türkiye'nin üçüncü büyük kenti İzmir ilinin alındığı araştırmada, doğal gazın sürdürülebilirliğe etkisi (1) ekonomik yönden diğer yakıtlara göre avantaj ya da dezavantajlarını ortaya koymak için yıllık ısınma maliyetleri ve yatırım maliyetleri hesaplanmıştır ve farklı

yakıt türleri ile karşılaştırılmıştır. (2) Sosyal açıdan enerjinin kentte herkese hakça dağıtılıp dağıtılmadığı ve hane halkının bu yakıt türünü satın alabilirliğini ortaya koymak için %10 yakıt fakirliği indikatörü kullanılıp yakıt fakiri olma eğilimi incelenmiştir. Son olarak (3) çevresel yönden özellikle kış sezonunda ısınmaya yönelik doğal gaz tüketiminin kirletici gazların salımını nasıl etkilediği incelenmiştir. Kriging yöntemi kullanılarak, PM10 emisyonunun zamansal ve mekansal dağılımlarının değişimi karşılaştırılmıştır.

Anahtar Kelimeler: Kentsel Enerji Altyapısı,, Doğal Gaz Dağıtım Şebekesi, Enerji Adaleti, Evsel Isınma, Hava Kirliliği

To my beloved family

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INTRODUCTION

1.1 Energy and Urban Infrastructure

Urban infrastructure systems, essential urban components that provide the basis for all physical processes in daily life, stimulate economic growth at local and national levels, and affect the socio-economic structure of the society. According to Tekeli (2009), infrastructure is the physical structure that enables the production of various services required to facilitate human life, make it healthy, and ensure the country's economic operability and competitively provided by public semi-public institutions.

Critical urban infrastructure, such as transportation, energy and water network, sanitation and waste water systems maintain sustainability of daily life. Cities have dynamic structures consisting of the organization of physical, environmental, social, and economic components (Alberti, 1996). In this regard, energy is one of the main requirements to maintain the dynamic structure of the cities. Heating, industrial production, and transportation are the main fields that needs energy. Population increase and accordingly intensified human-induced activities result in the excessive use of scarce resources to produce energy. So that sustainability of these activities become important. The sustainability notion came into question after the publication of Our Common Future by the World Commission on Environment and Development which brought sustainable development concept forward in 1987. Sustainability means the continuity of human life and the ecosystem not only today but also in the future (Finco & Nijkamp, 2001). The issue of sustainability of energy includes the following two issues; (i) obtaining energy from renewable sources; and (ii) using existing non-renewable energy resources most efficiently and economically to ensure their future use and reduce the economic, social and environmental burdens in the present. Within this scope, this study revolves around the latter concept.

1.1.1 Energy Usage Fields and Main Energy Resources

Energy is used for several purposes in both rural and urban areas. Different energy sources are being used for human activities and continuity of everyday life. While nutrition covers the primary energy needs of human body, energy sources provide maintenance of the human activities. Energy sources can be classified into three main categories – fossil fuels, renewables, and nuclear energy – with regard to their obtaining method. Fossil fuels are those of a class of hydrocarbon-containing materials of biological origin occurring within the Earth's crust (Kopp, 2020). Coal, oil and natural gas are the fossil fuels that are used for energy generation. These resources are vast, but limited, and are not renewable. Renewable energy resources, on the other hand, are forms of energy that are naturally replenished in the world. Wind, wave, tidal, solar, hydropower, biomass and geothermal are those of renewable energy sources. Last, nuclear energy is another type of energy that comes from splitting atoms in a reactor to generate electricity.

Housing, commercial areas, industrial production, and transportation are the prior fields where these energy sources are used. While residential and commercial areas require energy for hot water, heating, and cooking purposes besides lightning, power is also needed in industrial production and transportation facilities. The highest share of final energy consumption belonged to transportation in the United States (37%) in 2018 (EIA, 2019) and in European Union Member States (31%) in 2017 (EEA, 2020). In Turkey, however, residential and service sectors accounted for 32.3% of total final energy consumption, the greatest share, followed by industry (31.7%) and transportation (25%) sectors in 2017 (Ministry of Environment and Urbanism, n.d.) When residential consumption is considered, house heating is one of the leading fields requiring energy. In EU-28 countries, 64.1% of final energy consumption in the residential sector is used for space heating (Eurostat, 2017). On the other hand, in Turkey, heating accounts for 85 % of the total energy consumption in residential sector (Öztürk, 2018). House heating is related to the quality of life while inadequately heated houses may cause serious health problems for the households. When the energy source of residential heating is considered, oil and natural gas had the highest shares (30.5% each) followed by solid fuels (27%) and renewables(12%) as primary fuels in Turkey in 2017 (Ministry of Environment and Urbanism, n.d.).

1.1.2 Energy Services and Features of Energy Investments

Primary energy is directly or indirectly obtained from nature but not yet converted for the customers to be readily used, while energy services ensure it becomes usable and serves the end user's benefit. Sovacool (2011) describes energy services as what energy users actually want. End-use energy is the content of energy delivered to the consumers to be readily used. Heating houses, cooking meals, lighting indoor and outdoor spaces, using electronic devices, moving with vehicles are examples of what energy services can supply for human well-being. Energy services differ among usage purposes. While energy services enable space heating, water heating, cooking and the use of other appliances in the residential sector, it maintains commercial and sectoral activities, helps agricultural production with water pumping, harvesting with machines, and helps the mobility of motorized transportation vehicles (Sovacool, 2011). All of these comprehensive energy services are supplied with energy systems. Urban energy services are supplied by gas and electricity grids, besides the portable energy sources such as solid fuels, propane tank stations. Energy services cover generation, transmission and distribution systems. The production and transmission phases depend on the geographic distribution of the energy sources and transmission lines, which may transcend national and international regions. However, the distribution service, taking place in urban areas and carrying energy to the end-users, is directly related to urban planning policies and practices (Şenyel & Guldman, 2016).

Electricity is generated at power plants and transported through a complex system called the grid and power lines to end-users. It is a secondary energy source produced from fossil fuels, nuclear energy, and renewable energy sources with steam turbines, gas turbines, hydro turbines, wind turbines, and solar photovoltaics and transferred to the consumer (EIA). After generation, transmission lines carry electricity long distances from the power plants to the distribution network, while distribution lines carry electricity to the end-users in the built up area.

Natural gas is a primary resource found underground, between rock formations, and extracted through drilling. It needs to be processed before use. After processing and gathering, natural gas moves into the transmission system, which is generally composed of high-strength steel piper to be able to carry natural gas in long-distances. These transmission lines carry natural gas from the producing regions where natural gas is extracted or processed to distribution lines. Distribution pipes that are dispersed in urban areas carry the gas to the end-users.

These urban energy systems are high cost, large scale, and risky investments. They have a direct impact on the spatial pattern and society. There is a link between the provision of energy services and the achievement of social objectives and economic growth (Modi et al., 2005). Energy service investments shape the urbanization process and affect the relationship of citizens with urban space.

Despite the fact that natural gas has been used since the beginning of the 20th century for heating purposes globally (American Public Gas Association, 2019), it started to be used in 1988 in the residential and commercial fields in Turkey (Armagaz,2019). Although being relatively cleaner and more efficient than other fossil fuels such as coal and oil, natural gas is among fossil fuels that renew itself for quite a long time. It is not locally supplied in sufficient volumes in Turkey, so that the country is dependent on imported gas. However, it has become widely used over the years owing to the infrastructure investments and its advantages over other fuel types. More than half of the population in Turkey is using natural gas (GAZBİR, 2019), while it is is distributed to all cities. Such an extensive and preferred system is expected to have economic, social, environmental and spatial impacts by all means.

1.2 Aim of the Research and Research Questions

Edward (2003) stresses that infrastructures are co-construct that simultaneously shape and are shaped by the condition of modernity and society. Urban infrastructures have become the dynamic structure that affects society's development, livability, and democratization processes while reassembling the social (Edwards, 2003: Latour, 2005). Thus, infrastructure should be evaluated not only physically and economically but also socio-technically (Graham & Marvin, 2001). In that sense, natural gas distribution systems are researched to understand the influence of urban energy investments on urban sustainability. Indeed, social, spatial and environmental effects of natural gas distribution network, are analyzed to demonstrate its comparative advantages and disadvantages to the other energy alternatives.

The study aims to investigate the economic, social and environmental effects of natural gas distribution system through discussing whether it is more profitable, equitable and environmental friendly in domestic heating.

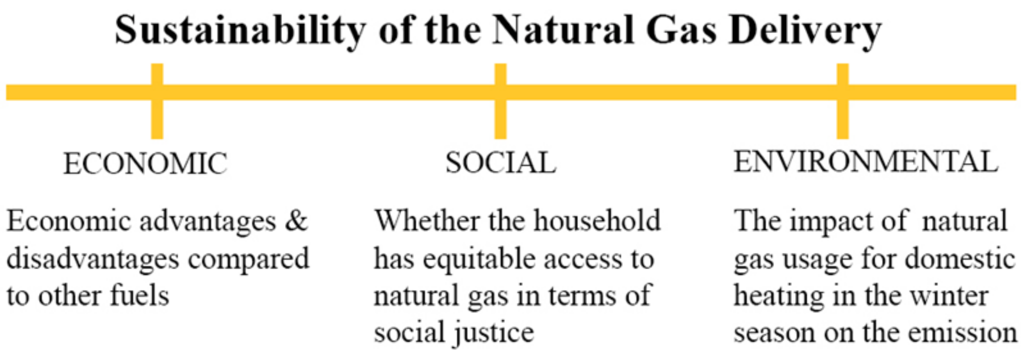

Figure 1.1 Sustainability Dimensions of Natural Gas Distribution Systems

The research questions regarding the aim of this study are;

• In what ways natural gas network affect urban sustainability in terms of economic, social and environmental aspects in residential sector?

- Has natural gas been economically more preferable over the other fuels in domestic heating?
- Does everyone in society benefit from the natural gas investments equitably?
- Has the natural gas network helped to reduce gas emissions that stem from domestic heating?

1.3 Structure of the Research

This research consists of five chapters. The first chapter, the introduction, discusses the importance of the energy services, problem definition, the main objectives, research questions, and sub-questions, and explains the study's outline. The second chapter includes a literature review of energy systems within three parts related to the economies of domestic heating, equity of energy systems, and the environmental impact of the energy systems. In the third chapter, the study area and the history of urban development have been explained. The historical backgrounds of the natural gas investments in Turkey and İzmir have been summarized. In the fourth chapter, firstly, the domestic heating costs have been calculated for different fuel types and are compared with the cost of natural gas. Secondly, to examine whether fuel consumptions cause injustice, the tendency of fuel poverty has been analyzed with the help of the income data taken from the İzmir Great Municipality survey study, which was conducted in 2015. Present values of household incomes are calculated for fuel poverty analysis and the tendency of being fuel poor was investigated. Lastly, the change in air quality in terms of the domestic heating induced emissions before and after the widespread use of natural gas is been analyzed.. In the conclusion, all research findings have been evaluated from a critical perspective, and limitations of the study and recommendations for future studies are given.

CHAPTER 2

LITERATURE REVIEW

Urban networks for electricity, water, gas, and transportation connect and interconnect everything and create its region beyond the administrative borders (Dupuy,2008, p.23). This networks create a new understanding of the region. As networks expand and become more complex the defined regions grow and reach to global dimension. These networks cover transportation, communications, and energy systems. In the 21st century, high-density urban areas and industrial production facilities are strongly dependent on energy networks. They also influence decisions and arrangements related to urban infrastructure and its size. In this regard, the purpose of this literature review is to analyze the economic, social and environmental dimensions of natural gas network investments as a one of the energy infrastructure. The development of the technology and infrastructure creates a bundle of complex socio-technical structures closely bound up with broader socio-technical, political and cultural components. Thus it has different "contingent effects" anywhere and at any time (Graham, 2000a). Energy investments are also a kind of network needed in both urban and rural life. As the high-modern city approach expanded with the integration of network construction and legal regulation in states, these complex and technically developed infrastructure networks bring about not only new "modern" urban planning systems but also the emergency of uneven welfare states (Graham,2000b;185).

According to Graham (2000a):

> *"Street systems and power, water, transport and telecommunications networks are carefully configured for selected powerful spaces and* users *whilst "bypassing" less profitable locations and users.*

Technological developments, modern planning approaches aim to create new, well-designed and developed spaces. Although new urban planning approaches such as smart cities, assume ubiquitous standardized development everywhere is possible and calls it a "networked metropolis," this ideal deserving ubiquitous dispersed network is not likely happen everywhere. In contrast, privatization and liberalization prioritize the more profitable spaces or powerful people for investment. Although urban investments are required in every field of urban activities to maintain life, the aim of standardized, well-developed networks of power, transport, communication, and water become "unbundled" or even splintered (Graham & Marvin, 2001). These new fragmented prioritized network systems are called "premium networked spaces" by Graham (2000b; 185).

The premium networked infrastructure systems may lead to particular issues for both society and the environment. Graham (2000b) states that these investments accelerate nations' liberalization processes with the support of economic growth. However, as these investments are made in financial priority areas to guarantee the profits of investors, fragmented infrastructure networks emerge as opposed to the planned to provide ubiquitously and simultaneously everywhere. Because of the global economic activities, a comprehensive urban planning approach has shifted to an understanding to capture the desired city form based on mega projects. However, area-based development, which results from a liberalized economic approach to meet the high demand, is another situation that people could not reach the infrastructure services equally. Environmental and spatial impacts are overlooked in such large-scale investments in general. As the area-based development continues, the investors or decision-makers may neglect the sustainability of the environment, and people may force to abandon their needs due to being a burden to their budget. As a result, either access to the networks or the distribution of the network itself becomes unequal. Among the infrastructure investments, the energy network constituted of natural gas and electricity are required to provide continuous services to people and institutions. Energy services should reach to everyone in the society to meet their basic needs and sustain their lives, whileit should be sustainable as well.

> "*The radical economic liberalization of infrastructure and markets in the energy sector since the 1980s has allowed for the 'unbundling' of infrastructures relating to energy transmission and for the 'bypassing' of less valued or powerful consumers and places".* (Robinson et al., 2018, p.80*).*

The changing economic trends in the world also affected energy services. While some parts of the cities have access to the energy network due to its importance in the market system, some cities have no access to the energy network. The nonexistence of the fuel sources in the region, high fuel prices due to carrying or importing costs, or geographical barriers like topography cause a fault in sustainability of the energy services.

In this context, market decisions cause an increase in the cost of energy investments and fuel prices and accordingly poverty and inequality all around the world. Apart from the investment decisions, the availability of the energy, fuel costs, and the flexibility to be able to switch fuels are other challenges regarding energy supply. In this sense, the sustainability of the resources and sustainable usage becomes important. Sustainable development has not occurred only to solve the market problems or ecological degradation issues but also the other problems, socio-economic issues: poverty, deprivation, inequality (Hopwood et al., 2005), and urban dereliction occurred all over the world (Dempsey et al., 2019). Walker and Day (2012) accentuate that to resolve injustice, social and environmental concerns should also be taken into consideration in addition to the location and distribution network of the energy.

Since energy is indispensable in human life and its impact to sustainability are also important. Sustainability concept is concerned with three aspects -environmental, social, and economic- which are thought associated with each other's related to future of humanity (Dempsey et al., 2011; Cuthill et al., 2019; Hopwood et al., 2005 and Finco & Nijkamp, 2001).

According to Sahely et al. (2005,p.73), sustainability implies the provision of more efficient services that maintain public health and welfare, are cost-effective, and reduce negative environmental impacts, today and into the future. Sahely et al. (2005) define a framework that demonstrates the interaction of environmental, engineering, social, and economic systems. These systems are mutually dependent on each other. While environmental sustainability includes the natural resources and residual production, the sustainability of engineering systems can perform and provide the end-user services with help of energy infrastructure. The last part of the system, which is the socio-economic environment, comprises the consumer's demand, revenue, expenditures, and investment in innovation as well as accessibility, health, and safety. Thus, these three systems work in harmony, and sustainability is possible in this way.

In this part of the study, under the head of sustainability, the literature review of the impacts of the energy infrastructure investments is analyzed in three domains; economy, energy equity and environment.

2.1 Domestic Heating Economy

Domestic heating is an essential physical human need that takes a big part in the household budget. House heating costs vary with the climatic conditions, the houses' physical structure, and householders' socio-economic characteristics. While the variables such as the heating degree days, thermal quality of the building, the facade, the size of the house, heating system, and whether it has a common facade with other houses affect the heating costs; socio-economic factors such as income, household size, presence of young children, vulnerable groups such as ill and elderly affect household energy consumption behaviors (Scott, 1980; Douthitt, 1989: Hass et al., 1998:Nesbakken, 1999: Sardianou, 2008: Rosas et al.2010).

First, domestic heating needs stem from climate conditions. There is a correlation between the external temperature and the internal temperature, so each 1 °C external temperature decrease causes a 0.5 °C drop in the internal temperature (Scott, 1980, p.130). According to the World Health Organization standards, the safe temperature is given as 21 °C in the primary living room and 18°C in the other occupied rooms (WHO Housing, Energy and Thermal Comfort, 2007). Hence, people need energy to heat or cool their living areas. While cold climate region residents require energy for heating, those living in mild and warm climate regions need energy for cooling their houses.

Second, physical properties of the housing stock affect heating costs significantly. Thermal efficiency in the design and construction of the house, types of dwelling, and size of houses have an essential share in energy efficiency so thus domestic heating cost (Nesbakken, 1999: IDAE, 2011). According to the final report of analyses of the energy consumption of the household sector in Spain, the consumption in single-family houses exceeds that of the housing blocks, especially in heating. The total single-family house consumption doubles the housing block one, where the heating consumption is four times higher due to their size (IDEA, 2011: p.63). The physical condition and construction time also affect the cost of heating. Energy-saving and energy consumption patterns are affected by the dwelling's construction year. Healy & Clinch (2002) show that older dwellings have less insulation level and require much more energy consumption for domestic heating in Ireland.

Even though energy saving measures such as retrofitting the house and new technology constructions reduce heating cost, it is affected by the socio-demographic structure of the society. While energy usage is consistent for low-income groups, the retrofitted houses of middle and higher-income groups have reduced their energy consumption (Webber et al., 2015). Socio-economic characteristics of individuals are also influential on the choice of energy sources. The availability of new energy sources, purchasing power, and cultural choices are the three crucial determinants of transition from the usage of traditional energy sources to modern energy sources (Emeç et al., 2015).

According to energy ladder theory, which describes the differences in energy use pattern, residents' fuel choice and the use of energy sources depend on their living standards. As income rises, households prefer more environmentally friendly and modern energy sources (Kroon et al., 2013: Heltberg, 2004). The energy ladder theory conceptualizes households’ energy preferences in three phases. According to the theory, people firstly rely on biomass, especially who are living in rural or suburban areas. The second phase is that there is a transition to new fuel types. Kerosene, coal, and charcoal are the transitional fuel types that are using more urbanized areas where biomass is not available, or households can afford these fuels (Heltberg, 2004). Nevertheless, the consequence of the urbanization on residential energy consumption is varied over income stages (Yang et al., 2019). When urbanization rate increase is constant (1%), the amount of energy consumption of lower-income people is rising more than high-incomes and middle incomes (Yang et al., 2019, p. 176).

Economic development and welfare increase result in the growth of the energy demand and shifting fuel usage from primitive and transitional to modern fuel types, so the third phase of fuel switching is characterized by the use of LPG, natural gas, and electricity. (Wang et al., 2019; Heltberg, 2004, p.870). This theory explains the fuel-switching mostly with respect to the external factors. Geography, fuel availability, climate conditions, economic structure have an impact on the households' fuel choices, but these factors mainly explain the national and global scale conditions. House heating economies also depend on internal factors. Kroon et al. (2013) conceptualize these factors in three categories which determine household decision environment as unique for each individual. The first category is the country's external environment that frames where society functions, such as climate, geographic location, and history. The second is countries internal and households' external context that reflects the political and economic circumstances of defined locations such as capital market, consumer market, and government policies. The last factor influencing the household decision environment is the opportunity set that exemplifies the characteristics and factor endowment of the household (Kroon et al., 2013, p.507).

While Scott (1980) is trying to make an economic model for house heating, he takes house characteristics such as its size, physical conditions like its insulation level, the construction type, income and size of the household, fuel price, and even standard charge for energy consumption into consideration. Thus, external and internal factors have an impact on house heating. The availability of the fuel, climatic conditions, house characteristics, and socioeconomic conditions of the households influence house heating habits. Verhallen and Raaij (1981) also explain that human behavior is related to energy consumption, which is directly related to house-heating, the household's socio-demographic structure, house characteristics, attitudes, and unique circumstances of the home living. For instance, as the fuel payment increases, households give up heating some part of the home apart from their main living areas or prefer small houses to economize. However, the general tendency is that the energy demand rises due to the increases in population. Increasing energy demand affect not only household budget and the GDP of the country but also the environment. To illustrate, while electricity consumption raised from 16.1% to 22.51%, CO_2 emissions increased from 10.24 to 10.83 M tons per year in Macedonia, from 1990 to 1998,. Furthermore, the increase in energy consumption can also be seen in the energy intensity of GDP (Buzar, 2007, p.82)

Energy-related attitudes, social demographic variables, home characteristics, and special circumstances, and household behavior factors are related to the use of natural gas for house heating (Varhallen & Raaij, 1981, p.253). The behavior of consumers towards energy consumption changes according to households' income levels and their social status. The high-income group does not need to energy savings. The low-income people, on the other hand, could not do that since they are already using energy as minimum as possible to be able to pay. However, middle-income groups are more flexible than the others to the price increases. It is emphasized that the availability of energy usage or the existence of the natural energy sources in a specific place can make these locations more preferable in terms of development than those lacking such sources. However, people who are not able to afford these fuels could not benefit from this advantage. Thereby, the availability and affordability of energy sources have an impact on human decisions. If they could not afford these higher-cost new energy sources, they abandon their comfort or prefer the cheaper fossil fuels. The study of Yang et al. (2019) demonstrates that the energy consumption amount changes with income.

There are different fuel types and heating systems for domestic heating. Residential heating with natural gas is one of the most economical ways of residential heating. The advantages of natural gas-fired boilers against other heating systems compared in the study are that natural gas is not only economical in terms of the amount of the initial costs but also it is used for heating, hot water, and cooking without the need for other fuel types (Ateş, 2015, p.631). In the gas-based systems, there are two kinds of criteria – direct and indirect systems – to supply gas. In the direct systems, dwellings are being heated by natural gas brought through a gas distribution system and then combusted in domestic gas boilers in each dwelling individually, while indirect systems are the district heating (Brkić and Tanaskovic, 2008, p.1738). Heating comfort, operating the cost of house heating individually and making energy-saving are the advantages of the auxiliary heating systems. The production and distribution of the heat in a single unit prevent heat losses. When these two systems are compared in terms of their initial investment costs, operating costs, annual depreciation costs, and annual maintenance costs, the results show that the central heating system is more economical than the other (Türkeri, 2007).

If energy efficiency policies were not made without using technological developments or driving force to move the fuel poor to the most suitable energy-efficient housing according to their budget, the future fuel price increases would require additional income for the households (Roberts, 2008, p.4472). To provide energy efficiency and make energy more affordable in UK, there is an intervention called Warm Front that seeks ways to provide insulation and upgrade the heating system for those who cannot afford such costs (Walker and Day, 2012). Because making insulation and upgrading the heating system by itself could not solve fuel poverty and energy scarcity problem. As long as people could not set off these investment costs, the increase of their income to pay more could not solve the fuel poverty problem. Hence, insulation, upgrading the existing heating system, and using more affordable energy types according to households' income are ways to deal with the heating issue. Among these attitudes, choosing fuel types is the most common and the easiest way. In this study, the aim is to investigate the fuel types and determine if natural gas has been economically more preferable over the other fuel sources.

2.2 Equity of Urban Energy Services

There is a relationship between access to clean, adequate, economical and modern energy sources, and poverty. *Energy justice, energy poverty, and energy vulnerability* are the most discussed interrelated concepts in the literature.

Energy Justice

Social and environmental justice theories conceptualize the energy justice combining three inequality notions that are *distribution (of goods and services among groups), procedure (for determining and contesting distribution), and recognition (of different groups' needs and rights)* (Gillard et al., 2017, p.54). According to Walker and Day (2012), unequal distribution of access to energy services is the root of fuel poverty and energy justice issues. As Rawls and Sen emphasize, the egalitarian approach and justice policies should be compensatory for the disadvantaged groups of the society to make them take part in life and to overcome their deficiencies. (Rawls, 1999; Sen, 1999). Egalitarian theorists defend that all people in the society should be treated equally. Rawls highlights the provision of the primary goods, which encompasses rights and liberties, powers and opportunities, and income & wealth (1971, p.62). According to Rawls, poverty or inequality problem can be solved with distributional justice. However, to provide justice, this distribution may be unequal to take care of the least advantageous people's interest, which are much more need than others. Rawls, Dworkin, and Ackerman, who are the pioneers of egalitarian theory, also declare that equality cannot be granted when additional resources are not provided to disadvantaged and disabled people in addition to the existing resources (Stein, 2006, p.102). An alternative concept to distributional justice is "recognition". Whereas income is merely one of the means of good living, looking directly at the quality of life that people are able to lead and the freedom they enjoy to live the way they would like (Sen, 2006, p.34).

Spaces of misrecognition mean that the needs or situations of certain groups are not identified or ignored (Bouzarovski & Simcock, 2017:641). Since some social groups are more vulnerable than others, in the case of the misrecognition, the vulnerable group of society exposure to energy poverty and increase inequality (Buzar, 2007, p.124). Sen (2006) stresses that to measure inequality or poverty accurately, the income and space itself is not enough, while social relations between the people should also be taken into attention. In this regard, energy expenditure is also one of the main issues since it has a large share in the household budget. And, the energy consumption behavior of households can give the information about their social and economic status. People do not produce places and actions without any references by themselves, the existing social and spatial structure that has been shaped by the availability of the resources or the conditions affect and direct their behavior (Cuthill et al., 2019). The study of Cutthil et al. (2019) explains that social equity associate with the accessibility to such services, education, employment, and social activities that demonstrate the improvement of life quality. Besides, the result shows that transportation investments are creating the ability to create actions even it does not make guarantee social justice by itself. They have searched the impact of the investment of public transportation on accessibility and justice in London, and find out that as accessibility to the urban facilities increases, inequalities and uneven development decreases. Another study made by Almeida et al. (2008) also explain the relationship between the transport and regional equity. Their case is Minas Gerais, the third richest and the second densely populated state of Brazil.

Nevertheless, there is a critical inequality issue despite being economically prosperous region according to the Human Development Index. This study demonstrates that the regional inequity becomes insignificant if the transportation investments are made only in roads in poor regions despite increasing real income, while regional inequalities increase when the investments concentrate only among the regions where high incomes accommodate. However, if the road links especially connecting poor regions to the rich ones are improved, the regional equities promote. These studies demonstrate that unless the sources are distributed to people fairly, the inequality and poverty problem could not be solved. Urban facilities such as energy and transportation are high-cost spending in households' total expenditure. Energy expenditure is higher for low-income groups than high-income groups; because they spend a larger share of their budget on energy costs and the fuels they use are inefficient than modern fuels" (Emeç et al. 2015). People could not afford their energy expenditures or even could not access the energy network. The oil crisis in 1973 caused the dramatic increases in oil prices and the studies show that fuel poverty increased, as well. The problems regarding lack of energy sources, high energy expenditures and lack of energy policies has started to be studied in the early 1980s.

Fuel Poverty

In the literature, the first study related to the difficulties of the energy payments of households due to their income, age and other socio demographic characteristics has been made by Isherwood and Hancock in 1979. The study examined the proportion of income that spent to energy. They defined the fuel poor as those whose spending is more than twice the median on fuel, light and power. Later studies also tried to define fuel poverty. It was first defined by Boardman (1991, p 219) as the inability to afford adequate warmth because of the inefficiency of the home. Richardson (1980) defines fuel poverty as the situation where following recent fuel price increases, people are unable to afford the fuel they need for heating, lighting and cooking. Lewis (1992) defines as the inability to afford adequate heat in the home.

Another definition belongs to Brandshaw & Hutton (1983) explains fuel poverty as;

> *"Individuals, families and groups in the population can be said to be in fuel poverty when they lack the resources to obtain the reasonably warm and well it homes which are customary, or at least widely encouraged or approved in the societies to which they belong"*

It is also defined as *"inability to attain the socially and materially necessitated domestic energy services that ensure the wellbeing of a household, allowing them to participate meaningfully in society "* by Robinson et al (2018).

Unlike Boardman, Richardson, and Lewis's definition, the other definitions do not specify the energy need only to heat the home. The study of Mastrucci et al. (2019) demonstrate that energy is needed for cooling, as well. Lack of access to electricity, and energy sources, more than 1 billion people are exposed to heat stress (Mastrucci et al., 2019 : SEforALL, 2019). Since all these have the same meaning, and they are describing the circumstances of *the inability of a household to access socially and materially necessitated levels of energy services in the home,* Bouzarovski (2014, p.277) uses the notions of 'fuel poverty,' 'domestic energy deprivation,' 'energy precariousness,' and 'energy poverty' alternatively.

Table 2.1 Fuel poverty definitions in the literature

Boardman (1991)	*"fuel poverty is the inability to afford adequate warmth because of the inefficiency of the home"*
Richardon (1980)	*"the situation where following recent fuel price increases, people are unable to afford the fuel they need for heating, lighting and cooking*
Lewis (1992)	*" the inability to afford adequate heat in the home"*
Brandshaw& Hutton (1983)	*"Individuals, families and groups in the population can be said to be in fuel poverty when they lack the resources to obtain the reasonably warm and well lit homes which are customary, or at least widely encouraged or approved in the societies to which they belong"*
Bauzarovski &Lninley (2018)	*"inability to attain the socially and materially necessitated domestic energy services that ensure the wellbeing of a household, allowing them to participate meaningfully in society*
DECC (2019) &Hills (2012)	*'A household is considered fuel poor is they have required fuel costs above the average (national median level) and if they were to spend that amount, they would be left with a residual income below the poverty line'*

The types of the energy used for heating and the methods to cover energy payments are two issues for people to transform their income for heating their houses (Hills, 2011). The first issue is related to how energy obtained, the second is the availability of the fuel types and accessibility to the sources makes available using income to turn heat. On the other hand, according to Li et al. (2014), Parajuli (2011) and Pereira et al. (2011) if households are not able to choose their energy services with regard to their income and could not use the energy they need they can be described as fuel poor.

> "*The absence of sufficient choice in accessing adequate, affordable, reliable, quality, safe and environmentally benign energy services to support economic and human development"* or "*the situation that households who cannot meet their basic energy needs by estimating a minimum limit of energy consumption"* (Li et al., 2014; Parajuli, 2011; Pereira et al., 2011).

Notwithstanding, energy poverty and fuel poverty are considered as different terms in economically developed and undeveloped countries, but there are some similarities between the fuel poor and energy poor. Energy poverty focuses on the availability of the sources, but fuel poverty focuses on affordability, even though both emphasize the low-income groups and threats of poverty, health, equity in social development. (Li et al., 2014). These differences stem from the economic and geographic features of the countries. For instance, the fuel poverty notion is mostly used in European countries where the energy sources are available, but the prices are high, and the climate is cold. Energy poverty is used in developing countries where energy sources are limited, and both extreme cold and warm climate conditions can be observed. In this regard, in terms of the existence of the energy source, climate conditions, and economic structure, Turkey does not entirely match these definitions, but both can be used.

Being unable to get benefit from the energy services leads to an obstacle to reach the qualified living standards and to participate in the society of fuel poor as the wellbeing of household.

'A household is considered fuel poor if they have required fuel costs above the average (national median level) and if they were to spend that amount, they would be left with a residual income below the poverty line' (DECC, 2019,p.1).

Lindell et al. (2012) make a statement that the actual expenditure in the definitions of fuel poverty has turned into "needs to spend." Because, energy is a fundamental need and households should spend for it. The fundamental drivers of fuel poverty are household incomes, household energy efficiency and fuel prices (Department for

Business, Energy & Industrial Strategy, Annual Fuel Poverty Statistic S Report, 2018, p. 16).

> *"Although the energy poverty problem varies drastically across different spaces and contexts, it clearly does not conform to the conventional definition of poverty. Instead, domestic energy deprivation arises via the interaction of inadequate incomes, poor housing, and specific household circumstance (*Buzar, 2007, p.139*).*

According to Hall et al. (2013), the security of supply, increasing energy prices and climate change carry energy issues to the political agenda. These factors leads to increase in poverty in the world due to inaccessibility to energy.

Similar to Graham and Marvin as mentioned above (2000), Balta-Ozkan et al. (2015) emphasize the requirement of finding ways that cut down the disproportionate energy infrastructure investments. Aging of infrastructure, the impacts of climate change, energy price uncertainty, and the security of supply concerns are primary considerations related to sustainability (Balta-Ozkan et al., 2015, p.502). In their study, the clustering of low carbon technologies, the differences in energy demand between the urban and rural areas, the job creation potentials, the trade-offs between agglomeration economies, and the public-good problem in the liberalized economic market are discussed as matters causing uneven spatial distribution and inequality. Even so, as Balta-Ozkan et al. (2015) asserted, in the liberalized market, unlike state ownership model, energy structure is developed and integrated with the new technologies, while the conglomeration of the new energy structure brings dilemma with accelerated and radical changes in that structure. Some parts of the society who are not able to take part in the clusters could not benefit from the new energy arrangements. In addition to the availability of the energy, the accessibility to the energy sources may give rise to spatial inequalities. Bouzarovski and Simcock (2017) emphasize that space is not just a component where human activities realized and inequalities happen. Multidimensional places constructed with social relations and practices, produce and maintain the existing circumstance. All these demonstrate the requirement of spatial arrangements and new places to meet the demands in advance.

While developing and undeveloped countries barely have access to sustainable, affordable, and modern energy in most cases, economically well-developed countries do not face such circumstances. Nevertheless, even in developed countries, the urban population is not distributed economically equal, so different income groups might face with energy affordability issues. Goldthau and Sovacool (2012) emphasize the inadequacy of access to energy services in industrialized OECD countries like the UK (Robinson et al., 2018; Gillard et al., 2017), France and Northern Ireland (Mohan et al., 2018) in addition to the developing or underdeveloped countries. The study of Jaconsona et al. (2005), which analyzes the relationship between income and electricity usage, demonstrates that even in Norway, one of the most economically developed countries, half of the electricity usage belongs to 38% of the highest income households. The proportion of low-income group's electricity usage is fewer in Asian and African countries such as Thailand and Kenya. Hence, all these explain that energy justice affecting economic development and social welfare is a critical issue at the global scale.

> *"Whereas income is merely one of the means of good living, looking directly at the quality of life that people are able to lead and the freedom they enjoy to live the way they would like" (*Sen, 2006, p.34).

Energy poverty is related to economic power, fairness, and social justice. There are some indicators to measure energy poverty. According to European Union Selecting Indicators to Measure Energy Poverty report (Rademaekers et al. 2016, p.22), Of the 178 indicators assessed, 58 were related to income or expenditure while 51 were linked to physical infrastructure.

> *Indicators related to energy demand and demographics only amounted to 10 and 15, sequentially. One hundred thirty-nine are single metric indicators, while 39 are combinatory or constructed indicators, representing 22% of the total and mostly falling under the category of income/expenditure indicators.*

Among these indicators, expenditure-based and consensual-based approaches are defined as the main approaches. They require more accessible data which is available to perform a qualitative assessment while measuring fuel poverty. 10% fuel cost ratio, Low Income High Costs (LIHC), Twice the National Median share (2M), and Minimum Income Standard (MIS) are the prevalent indicators used to measure fuel poverty. A 10 % indicator is the most used measurement in Europe. Boardman defined it the first in 1991. The indicator has been used in England, France, Ireland, Northern Ireland, and Wales to measure fuel poverty (Selecting Indicators to Measure Energy Poverty Final Report, 2016). In this indicator, households are assumed as fuel poor if their energy expenditure is more than 10% of their total income. Nevertheless, Hills (2011) argues that the 10 % indicator of measuring fuel poverty is deficient due to its variability in terms of fuel prices and climate, and asserts that the introduction a new measurement criterion is necessary. While the 10% indicator is being used since 1991, the LIHC indicator, being proposed by Hills in 2012, is being used since 2015 (Robinson et al., 2018, p.1113). This metric defines energy-poor households as those having high energy costs (share of income spent on energy is above national median), and low income after energy costs (income after energy costs), falling below the national poverty line (Rademaekers et al. 2016).

Energy Vulnerability

Energy systems are concerned with revealing and exploring these complex and diverse intersections between energy and equity, justice and vulnerability "(Hall et al., 2013, p.413).

Energy Vulnerability notion is used

> "*to emphasize the technically and temporally precarious nature of access to energy services per se. Insights from the 'capabilities' approach and relative poverty have also been added to the equation"* (Bouzarovski and Petrova, 2015).

Gillard et al. (2017) state that this notion is used to clarify the systemic drivers and household level experiences of deprivation. Hence, the vulnerability can be expressed by deciding the target groups in the society who are disadvantaged in terms of income, health, or other factors. Energy is defined as "instrumental good" by Gillard et al. (2017, p.54), and the link between vulnerability and energy need is emphasized. The propensity of being unable to secure materially- and socially necessitated levels of domestic energy services makes households vulnerable (Bouzarovski and Petrova, 2015).

Bouzarovski and Petrova (2015) identify the vulnerability with six dimensions, which may prevent the efficiency of supplying energy services in the home. These are defined as affordability, energy efficiency, accessibility, flexibility, needs, and the practices. While affordability and energy efficiency are directly related to fuel poverty, access express the existence of appropriate fuel types, and flexibility refers to the availability of choices for the households to switch their energy services. Needs define inequality of what households require socially, economically, and culturally and what existing energy service system supply. Lastly, practices identify households' inefficient energy usage behaviors (Robinson et al., 2018; p., 1112).

Although efficiency and equity are considered independent concepts, they are complementary notions for sustainability according to Alberti (1996). If some parts of the society or the next generations are regarded as responsible for meeting the cost of consumption, this approach displays a short-run solution. To supply long-term solutions and provide sustainability, the balance of the input and the output in the ecological system, defined by Alberti(1996) as urban ecological space (UES) including nature, humans and settlements, should not be disturbed, so energy saving is obligatory. According to the metaphor of the UES, social structure, environment, economy, infrastructure, and communities constitute the urban system and supply the flows of this system. At the same time, energy and other sources are the inputs, the waste and emissions are the USE's outputs. In this regard, overconsumption of the limited resources or over the waste generation and emissions threat sustainability. Thus, resource allocations should be efficient and equitable. Distributing the existing resource to people may not just mean equity and energy efficiency.As Alexandre and Michelis (1996) state, for instance, the OECD countries' residents may choose their living space considering both economic welfare and a high-quality environment, others might be exposed to live in a poor-quality environment. This situation conflicts with equity. Energy consumption is also related to the local potentials. Using alternative energy sources, consuming renewable energy depend on the availability of geography.

In the literature, energy justice is clarifying with the notion of the vulnerability to examine energy efficiency and fuel poverty (Gillard et al., 2017). To understand how people are being affected in case of uneven access to energy, Gillard et al. (2017) have made a study to recognize the links between energy needs and vulnerability. They selected three target groups: disabled people, low income, and older people in the United Kingdom and describe energy as an instrumental good, a fundamental requirement in daily life for heating, lighting, washing, and cooking. However, it is seen as a private good which is traded competitively, and the distribution and services of the energy becomes restricted. It can be said that this approach to energy causes injustice in energy distribution and energy usage. Although energy is a right, it is treated as a private good and traded in the market competitively, which may result in the energy deprivation of some areas. As a result, it leads to inequality in the society, fragmentation in the physical infrastructure, and uneven energy usage and emissions. Vulnerable groups are affected the most from these outcomes. It can be concluded that energy investments locate at the center of urban sustainability discussions.

According to UK fuel poverty strategies and Gillard et al. (2017, p.53), disabled people, low-income people, and older people are the most vulnerable in society. The age of households is also influential on fuel poverty and energy vulnerability. While the youngest members aged between 16 and 24 constitute the highest proportion of those experiencing fuel poverty, the oldest members aged 75 years or more are the second-ranking in fuel poverty (Annual Fuel Poverty Statistic Report, 2018). Since the youngest groups are mostly unemployed or the students, and the oldest group is likely retired or unable to work, these two groups tend to be fuel poor.

While energy poverty is defined, affordability is emphasized, and low income, local energy inefficiency and high energy prices are highlighted (Buzar, 2007).

Emeç et al. (2015) has a study related to energy poverty and energy choice profile to demonstrate the factors in Turkey's. Household size, income, education level of the head of household, and the number of rooms in the house are the independent variables. The results show that households with less income and work in less income generating professions in direct proportion to their education are fuel poor. Households have low education level could not prefer modern energy sources such as natural gas and electricity. As income and the age increase, the energy choice shifts to natural gas (Emeç et al. 2015, Özcan et al. 2013). In this study, as household size increases, the consumption of wood, coal and other fuel types increase, while natural gas consumption and electricity consumption decrease (Emeç et al., 2015, p.15).

Robinson et al. (2018) have a study that measures fuel poverty and its socio-spatial distribution using a 10% income and Low-income high-cost indicator in England. These two indicators give different results. While the 10% indicator demonstrates higher odds for fuel poverty especially in rural areas, the LIHC indicator indicates the inner-city areas appear as fuel poor clusters. Although the LIHC indicator decreases the ratio of fuel poverty in general, when rural and urban distinction is made at the local level, the fuel poverty increases in urban areas on the opposite of the result of the 10% indicator. 10 % indicator focuses on the energy prices and income. Since households living in rural areas have less opportunity to access to energy services and they are not able to afford alternative energies like the households in urban areas, the fuel poverty becomes more expanded in the rural area. Moreover, vulnerability increases in rural areas when there is an increase in energy prices. Buzar's (2007) research demonstrates this in Macedonia. While searching sociodemographic profiles of energy poverty, every city or even countries show differences. According to income level criteria, there are two disadvantaged groups. Low-incomes that mostly constituted of welfare beneficiaries, households headed by unemployed adults, multiple children households, and families who depend on agriculture for all of their income are the first energy poor group. The families whose house circumstances create a threat to be energy poor, which are pensioners and families with young children, are the second group (Buzar, 2007, p.114). In contradiction to 10% indicator, LIHC indicator takes various factors into consideration, such as the size of the dwelling unit, the heating cost per person, number of households, and even the mode of tenure. The prevalence of fuel poverty is not influenced a lot by the rise in energy prices but the other factors.

When the rural and urban distinctions have been made, the places fuel poverty decrease in rural areas and increase in urban areas. All around the world, studies regarding fuel poverty have a common point, indicating that it has gradually increased owing to different factors. In Macedonia and Czech Republic (Buzar, 2007), in England (Robinson et al., 2018), and Northern Ireland (Mohan et al., 2018), people encounter fuel poverty. The country's economic structure, housing characteristics, living standards, households' real income, and geography are remarkable determinants related to poverty. Despite rising fuel prices, energy efficiency is observed in Northern Ireland owing to significant energy investments, such as heating conversions, insulation, and glazing (Mohan et al., 2018, 610). As expressed in the Annual Poverty Statistics Report (2018), energy efficiency does not mean decrease in the amount of consumed energy but decrease in the energy requirements of the dwelling.

Infrastructure networks have played a vital role in the emergence of spatial differentiation among and within cities by "sustaining sociotechnical geometries of power and social or geographical biases in very real but often very complex ways" (cited Graham, 2000; Buzar, 2007 p.115).

Spatial distribution of fuel poverty can vary according to the material and infrastructural characterization of the area/geography in addition to household characteristics. While climate conditions, energy provision, and energy supply depend on geographic factors, demographic factors like income, age, and employment that affect different levels of energy dependency of households

(Robinson et al., 2018). According to Annual Fuel Poverty Statistics Report (2018), the fuel poverty gap of households in dwellings that do not have the gas grid connection is two times larger than those households who have a connection in England.

The economic well-being of the countries is another factor affecting fuel poverty. The likelihood of disadvantaged groups' to be fuel poor increases by restriction of government expenditure, austerity policies, and investment decisions due to a financial crisis. As Robinson et al. (2018) state, England and the USA have experienced these circumstances in 2008, through cuts of welfare, erosion of incomes, local services, and infrastructure.

In summary, under the title of the equity, the benefits of the energy investments to the region and exploring whether everyone in the society benefit from the natural gas investment the same way should be considered.

According to the report of the World Health Organization's meeting related to housing, energy, and thermal comfort, "*fuel poverty is a symptom,"* not a reason itself. (2007, p., 10). Actually, this approach can help to accept that this symptom occurs due to economies of the country, sociodemographic structure of the society and physical structure of the households' living area such as inadequate or poor-quality housing stock. Thus, focusing on the existing housing stock problems and households itself would be the best next step.

2.3 Environmental Impact of the Energy Services

Energy consumption has direct and indirect effects on the environment. Whether the economic activities lead to damaging effects while producing financial revenue is the matter of both environmentalists and economists. Hence, to enhance effectiveness and provide energy efficiency, environmental strategies should be considered while energy need is met (Finco and Nijkamp, 2001). Humans are dependent on the environment, but this dependency does not mean the exploiting the resources and moving on. Economic and environmental activities have interlaced for the sake of the continuity of both all creatures and the environment. As affirmed in the report of Our Common Future, to meet needs, to grow economically and to satisfy sustainability, people need to environment and life should be supported locally, regionally, nationally, and globally (WCED, 1987; Hopwood, 2005). Finco and Nijkamp state (2001, p.293) that "…Cities are not only the source of environmental decay but also the stepping stone for the solution of environmental problems…"

To guarantee the continuity of the ecosystem and human life, social, economic, and ecological systems should perform in a collective approach (Finco& Nijkamp, 2001). Rising urban populations, expanding urban settlements, and developing the production chain cause more energy consumption. Energy is used in every field of life. Industrial production, agriculture, transportation, heating, and cooling requires energy. In the world, as of 2017, 55.2 % of the total population lives in the cities (World Bank, 2019) and needs energy. Thus, with the population growth and increase in the urbanization rates, as well as changes in the lifestyles, result in the requirement of more energy (Weber & Perrels, 2000).

As a consequence, the tendency of more energy demand and more energy consumption in cities become inevitable. This tremendous amount of energy consumption results in various environmental problems such as acidification, solid, water and air pollution. According to the World Health Organization, 4.2 million people die because of exposure to ambient air pollution every year (WHO, 2020). Being exposed to over-polluted gas emissions causes destruction of the ecosystems as well as the local livability, and result in climate change globally. Greenhouse gas emissions cause rising sea levels, heavier droughts, and loss of habitats as a result of rising temperature due to the sera effect (Goldthau & Sovacool, 2012). Overuse of fossil-fuels causes emissions which increase the greenhouse gas concentrations in the atmosphere.

Energy itself and the way of getting energy from the resources may not directly damage nature. However, human behavior, while using and getting energy, can bring many environmental problems, which have direct and indirect impacts.

Industry, transportation, and housing sectors have significant shares in total energy use. While, transportation has the highest share (37 % and 31 % respectively) in 2017, in the US and European Union countries in Turkey residential and service sectors which have increased continuously since the 1990s are the first ranked in final energy consumption by sector. Moreover, these energy needs are covered mostly by oil (30.5%), natural gas (30.5), and solid fuels (27.5) that contain high amount of organic components causes pollutant gas emissions (Ministry of Environment and Urbanism, n.d.). Fossil fuels- oil, coal, and natural gas – include organic materials, and when they are combusted, they cause pollutant emission. China, the USA, and India have the highest level of carbon dioxide emissions in the world due to combusting coal, and they sought ways to reduce emissions. Air pollution results from not only high-level emission of CO_2, but also other pollutants such as $PM_{2.5}$, PM_{10}, NO_X, NO_2, SO_2, and O_3. Fossil-fuel combustion heating, transportation, and industrial production give rise to the emission of these pollutants. European Commission has an Air Quality Directive which aims to reduce these emissions through setting limits.

The concentration of these pollutants on the air, their chemical transformation and their capacities of moving to long distance causes air pollution are challenges at the global scale (Kinney, 2018). The pollutant gas emissions lead to air pollution and climate change, while threatening the sustainability of both. Air pollution also influences human health, such as cardiac deaths and hospital admissions, in addition to respiratory effects and even causes shortening human life expectancy (Brunekreef & Holgate, 2002). Being exposed to fossil fuel emissions and being poorly ventilated spaces causes high blood pressure, lung cancer in adults, pneumonia in children, cataract in eyes, and sometimes low birth weight (Wang et al., 2019: Mortimer et al., 2017: Matawle et al., 2017). The World Health Organization (WHO) underlines the loss of millions of people due to breathing pollutant air. According to the WHO (2018), “Exposure to smoke from cooking fires causes 3.8 million premature deaths each year, mostly in low- and middle-income countries”.

Finco & Nijkamp (2001) stress that there are scarcities of a healthy environment to work and live in, at the end of the 20th century. To eliminate the life-threatening conditions, avoid long-term risks of global climate change, and improve the quality of life at the local level, energy efficiency and alternative clean energy resources are essential (Alexandre & Michelis, 1996). Although it is less polluting than the others, natural gas is also a fossil fuel. Some studies are investigating whether natural gas investments reduce emissions or not. Nan et al (2019) have a study investigating the impacts of natural gas infrastructures and consumption on the annual average $PM_{2.5}$ concentrations in 204 prefecture-level cities in China during 2008 to 2016 period.(Nan et al.,2019). They utilized spatial autocorrelation and spatial econometric model specification. . Annual average $PM_{2.5}$ concentrations, the length of the gas supply to measure the natural gas infrastructure and constructed the number of households with access to and the total gas supplied to signify the natural gas consumption are selected as variable and GDP per capita, foreign direct investment per capita, population density, green area per capita and electricity consumption per capita have been chosen as a control variable to check the possible impact of natural gas investments to the air quality. The results indicate that $PM_{2.5}$ concentrations in different regions influence each other through the socioeconomic exchange, while especially $PM_{2.5}$ hot-spots that can disperse to the surrounding areas. Moreover, the increasing expansion of natural gas pipelines and gas consumption remarkably mitigate the average $PM_{2.5}$ concentrations. Its effect becomes significant and more considerable with the extension of the natural gas network.

Bellander et al. (2001) have conducted a study to demonstrate the effect of exposure to air pollution from traffic and house heating in Stockholm. Comparing NO_X, NO_2, and SO_2 emissions in historical periods, they found that while NO_2 and NO_X emissions substantially increased, the SO_2 emissions sharply decreased from 1955 to 1980. The reason for increasing NO_2 emission is explained by the increase in traffic volume and the construction of new major roads in urban areas. Nevertheless, decreases in the dispersion of SO_2 emissions in years result from restrictions in the sulfur contents of heating oil and the huge investments on the district heating system. Changing fuel types and transition to the district heating system in central Stockholm reduced the SO_2 emissions level from above 130 µg/m³ to less than 50 µg/m³ (Bellander et al. 2001, p.636). This reduction of the concentration of the air pollutants in the urban area result in increases the quality of life and prevent the threats to human health and the environment. Transition district heating system while reducing the supply cost, it also supplies the fuel-saving .Expanding the district heating system is also one of the main goals in the Danish region from 46% to %50-70 (Möller & Lund, 2010).

Cassaso et al. (2019) have conducted a study in the Aosta Valley Region, Italy aiming to demonstrate economic and environmental benefits by eliminating the oil heating. Since the underground storage tanks have the risk of leakage even though the LPG is the cheapest and less polluted than the other fossil fuels, its harmful environmental effects exceed the economic benefits. In this study, the most suitable way as an alternative to oil heating is heat pumps, though they are more expensive and have longer payback times compared to wood fuels. Nevertheless, "*they produce no emissions on-site, and present dramatically reduced GHG and pollutant emissions on a global scale; besides, they do not require fuel storage"* (Cassaso et al., 2019, p.13).

Using clean fuels in transportation, production, and residential areas create a cycle in which each stage affects the others positively. Air quality management strategies can reduce pollution and provide clean air and the environment. Mena-Carrasco et al. (2012) state that with these strategies and policies, emissions can reduce, so the pollutant concentrations in the air also decrease.

Mena-Carrasco et al. (2012) study use chemical transport model for Santiago-Chile to demonstrate that reduction in emissions have impacts on human health. They aim to estimate the health benefits owing to expanding natural gas use in transportation systems and residential heating. Replacing wood burning that is the most common fuels in Santiago with the mix of kerosene, natural gas and propane reduced the total

$PM_{2.5}$ concentration 671 t/year and 2.07 μg/m^3 in annual average concentrations (Mena-Carrasco et al., 2012, p.265). While residential heating causes seasonal fluctuations, emissions from transportation do not depend on the seasons. Nevertheless, using natural gas in both areas make a significant contribution to air quality.

Tayanç (2000) made in İstanbul, Turkey, to assess the spatial and temporal distribution of SO_2 emissions shows that it mostly depends on house heating. In this study, SO_2 emission values and observed an increase in SO_2 concentration between 1985 and 1991 years, and decrease in 1995 and 1996 years. It is known that the fuel types for heating have changed during this period, and the emissions have increased. Thus he searched the reason behind this fluctuation of emissions and use kriging method to find out the spatial distribution of emissions. The results show that while the highest level of concentrations observed in the heating season, the spatial distribution concentrated in the area where urban density is high. Moreover, Tayanç (2000) also explained the decrease in the concentration of SO_2 emissions after 1995. When effect of meteoroidal changes isolated, ventilation has increased and so concentration of SO_2 in the air has decreased. On the other hand, the dispersion of the natural gas network provided people to be able to use cleaner fuels. Besides, prohibiting low-quality coal usage provided diminishing air pollution. Briefly, ventilation, switching fuel from coal to natural gas, and the treatment of coal, which aims to avoid using the high sulfur content coal, had an impact on this reduction.

Lessening the consumption of fossil fuels and disposing of existing greenhouse gases with natural or artificial carbon sinks are the two most basic ways to reduce air pollution (Balaban, 2017). Hence, the damaging environmental impacts of energy consumption can be prevented.

2.3.1 Air Quality Standards in the World and in Turkey

Air quality is directly related to the sustainability of the ecosystem. Clean air is considered as a fundamental requirement of human health by WHO, and the organization also has air quality guidelines to regulate air quality. The first air quality guideline was published in 1987, and later revised in 1997. WHO released the last guidelines and set measures to air pollutant concentrations in 2005 with the help of scientific evidence and assessments related to air pollution health effects. European Environment Agency (EEA) is other institution that set goals to raise air quality, and aim to manage air pollution problems. However, their thresholds values are different from the WHO's one. WHO has more restrictive limits than the EEA.

There are also several legislations to promote air quality and reduce the pollution levels since the 1980's by the European Commission. Council Directive 85/203/EEC, Council Directive 80/779/EEC, Commission Decision 2004/224/EC, Commission Decision 2004/461/EC, Directive 2002/3/EC, Directive 2000/69/EC, Council Directive 1999/30/EC, Council Decision 97/101/EC and Council Directive 96/62/EC were the previous legislations of the European Commission for air quality management. From the 1980s, these legislations aimed at assessing and managing air quality. Today there are three directives and an implementation decision set for the EU countries (Directive 2008/50/EC , Directive 2004/107/EC , Directive 2015/1480/EC and Commission Implementing Decision 2011/850/EU) providing an actual framework for the control of ambient air pollution concentrations in the EU (EEA, 2019).

These directives set standards and limit values for pollutants including sulphur dioxide, nitrogen dioxide and oxides of nitrogen and particulate matter, of which concentrations should not be exceeded in a given period. Particulate matters ($PM_{2.5}$ and PM_{10}), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and ozone (O_3) are the primary pollutants in the air. Industrial facilities, power plants, traffic, and fuel consumption for heating in the winter season are primary air pollution sources. While SO_2 is emitted mostly from industrial facilities, NO_X, CO and VOC are from traffic, and lastly, PM is emitted from residential heating (Elbir and Müezzinoğlu, 2004).

Particulate Matters ($PM_{2.5}$ and PM_{10}):

Particle matters are mixtures of solid particles and liquid droplets found in the air. While PM_{10} are inhalable particles, sized 10 micrometers and smaller, $PM_{2.5}$ are finely inhalable that are sized 2.5 micrometers and smaller (EPA, n.d.). These pollutants can be emitted directly from nature such as volcanic eruptions and dust storms, or human activities such as power plants, factories, fuel residues from motor vehicles and airplanes, fuel consumption in houses, forest fires and agricultural combustion. Since breathing these substances can cause damage to the lungs and severe health problems, governments attempt to reduce and control air pollution with legislative regulations.

According to the EU Air Quality Directive and WHO, the hourly limit value of PM_{10} equals to 50 µg/m³. However, the object of the EU Air Quality directive is not to be exceeded on more than 35 days per year, while this limit is three days in a year in WHO. The annual limit value of PM10 is 40 µg/m³ in Air Quality Directive and 20µg/m³ in WHO guidelines.

The government of Turkey accepted the threshold values of the EU Air Quality Directive. The limit values are published in 2008 with the number of 26898 official gazette.

Nitrogen Dioxide (NO_2)

Nitrogen Dioxide (NO_2) is one of a group of highly reactive gases known as oxides of nitrogen or nitrogen oxides (NO_x) (EPA, n.d.). Burning fossil fuels causes NO_2 emissions. Breathing air with high concentrations of NO_2 can irritate airways in the human respiratory system. Moreover, if NO_2 interacts with other chemicals in the atmosphere, it leads to acid rain and damages the ecosystem. The pollutant of nitrogen dioxide limit values is the same for the WHO and EU Air Quality Directive. While targeting the hourly value of NO_2 is 200µg/m³, the annual value is 40µg/m³. Turkey has also set the same threshold values, but it has aimed to reach as of 2024.

Sulfur Dioxide (SO_2):

Sulfur dioxide is a toxic gas that is emitted from the burning of fossil fuels. Like NO_2, SO_2 can also be emitted from natural sources and human activities. Being exposed to high SO_2 concentrations causes respiratory illnesses and cardio-vascular diseases (EPA, n.d &Minnesota Pollution Control Agency). Its hourly and daily limit values are 350 $\mu g/m^3$ and 125 $\mu g/m^3$, respectively. The permitted exceedance days of limit value in a year are 24. Notwithstanding, the threshold of SO_2 for 24 hours in WHO guidelines are 20 $\mu g/m^3$. The limit values of Turkey are also the same as the EU Air Quality Directive.

Pollutant Limit Values in Turkey

To protect the environment, to reduce air pollution, and to support healthy living areas, these thresholds are set on, and the authorities are expected to make air quality management plans which aim to meet the limits and target values. In Turkey, Air Quality Assessment and Management Regulation was published in 2008 to prevent harmful effects of air pollution on the environment and human health, and define air quality objectives to reduce and create defined methods and criteria to assess air quality. According to this regulation, from 2013 until 2019, air pollutant limit values in Turkey have gradually reached European Union standards. As of January 2019, the limit values of pollutants are the same as the European Union standards, and these values are as shown in the table below.

Table 2.2 Limit Values of Air Pollutions by Year in Turkey (Air Quality Assessment and Management Regulation, 2008)

Pollutant	Avg Period	Limit Values ($\mu g/m^3$)							
		2013	2014	2015	2016	2017	2018	2019	2020
PM10	daily	100	100	90	80	70	60	50	50
	annual	60	60	56	52	48	44	40	40
SO2	hourly	500	500	470	440	410	380	350	350
	daily	250	250	225	200	175	150	125	125
	annual	20	20	20	20	20	20	20	20
NO2	daily	300	300	290	280	270	260	250	240
	annual	60	60	56	52	48	44	40	40
NOX	annual	30	30	30	30	30	30	30	30

In this study, these limitation values are used while investigating the air pollution levels as a result of residential heating.

CHAPTER 3

STUDY AREA AND NATURAL GAS DEVELOPMENT

3.1 Location

İzmir is the third largest city with approximately 4 370 000 inhabitants are located in the Western part of Turkey (TUIK, 2019). İzmir is a coastal city, which has thirty districts in the Aegean Region that has fertile agricultural lands, steams, and ports, which are essential for the transportation of agricultural and commercial products. The area of the city covers 12012 km^2 that lies between 37^o 45 'and 39^o 15' North latitudes and 26^o 15 'and 28^o 20' East longitudes (Izmir Governorship). It is placed in a basin and urban settlements are surrounded by a rugged topography of approximately 1000- 1500 meters height which both limits and determines the direction of the urban growth. İzmir has prominent economic power in industry, services, and agricultural sectors within this geography.

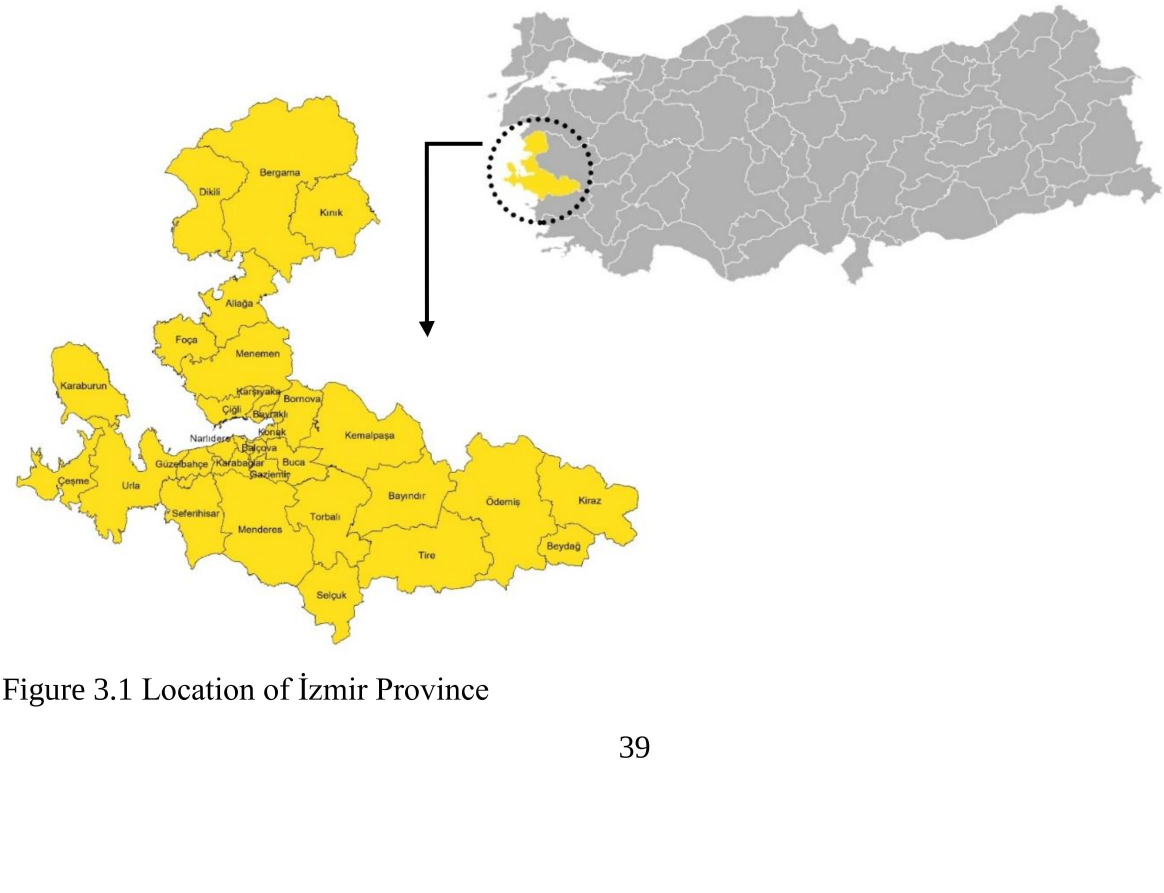

Figure 3.1 Location of İzmir Province

The history of the city is dating back to more than five thousand years. Throughout history, İzmir has always been an attraction point due to its geographic location, natural assets, and rapidly growth dynamic economy. Settlements started as a port city which was located at the edge of a wide and sheltered gulf in the Aegean region. It is still receiving migration and has a high urban density with 360 per/km^2. (Türkçü et al., 1996; Oral, 2010; TUIK, 2019). İzmir has Mediterranean climate conditions characterized by hot and dry weather during summer, and mild and rainy weather in winter seasons. In addition to mild climate conditions, having airline, road, railway and marine transportation and having a significant employment capacity İzmir attracts populations. Although the geological and hydrographic structure of the city set some limitations on the physical expansion of urban settlement, fertile agricultural lands, railway networks, and geographical features contributed to the growth with increased accessibility and city attractiveness (Koçman, 1989).

3.2 Historical Background of İzmir Urbanization Process

Thanks to its geographical location, İzmir has made enormous spatial and economic development as of 3rd century BC. Settlement had expanded from inner port that corresponds to today's Bayraklı location to the castle that corresponds to today's Kadifekale until the 11th century. Production of agricultural raw material and international commercial activities enhanced the importance of the port. From the 14th to the 18th century, as commercial activities increased, the demographic structure also changed and European traders had migrated. Urban settlements has spread along the coast.

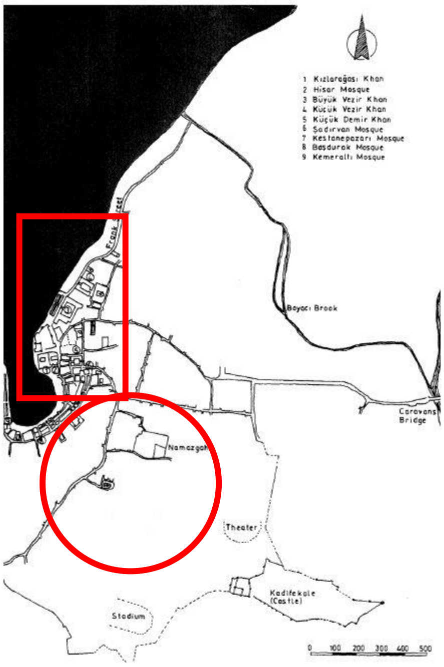

Figure 3.2 Izmir in the 17th century (Design Strategy Report of İzmir History Project, 2017, p.27)

The need for agricultural products and raw materials due to the industrial revolution in Europe and locating between the Europe and Asia and being a bridge were the reasons that supported the growth of İzmir as a port city in the 18th century (Yılmaz &Yetkin, 2002).

By the end of the 19th century, the city, which increased its commercial power owing to railway and port, had spread over an area that includes today's Karataş, Güzelyalı and Göztepe districts. In the early republic period, increased industrial investments in Halkapınar, Daraağaç, Tilkilik, Eşrefpaşa, and Kemeraltı, and enhanced agricultural activities required more labor force (Karataş, 2006). New industrial and agricultural activities led migration flows to the city. The city was lacking affordable housing stock for the new comers, so that migrants settled in illegal self-housing neighborhoods, namely squatter areas. While settlements were expanding, lacking sufficient physical conditions in residential areas have become evident for workers in Daraağaç Halkapınar, Kızılçullu (Şirinyer) and Tepecik (Yılmaz & Yetkin, 2002).

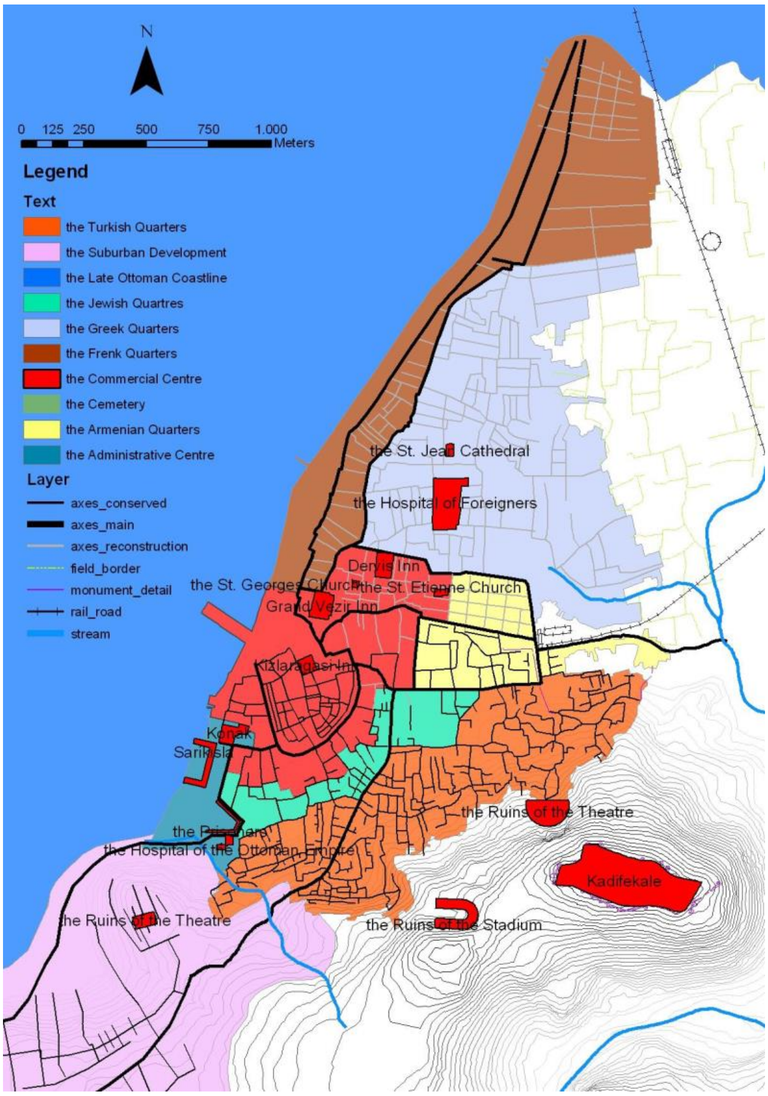

Figure 3.3 Izmir in the early 20th century (Belge, 2005, p.102)

Spatial segregation became evident in the city, which led to socio-economic, cultural and physical problems in the forthcoming years. Since the 1950s, with rapid growth in industrialization, the urban population has increased fast, and the settlement area has grown uncontrollably (Oral, 1996). Urban population doubled, while the population living in city center was approximately 240 000 in 1950, it reached 554

000 in the 1970s (Ünverdi, 2002). While industrial developments were enhancing, urban settlements expanded accordingly. This rapid growth brought about spatial problems and increasing need for additional infrastructure. Furthermore, with the spread of uncontrolled urban land use between 1950 and 1970 owing to the industrial investments around the transportation arteries and growing squatter settlements particularly in the periphery, urban areas exceeded topographic thresholds. Kadifekale, Kadriye, Yeni İstiklal, Zeytinlik, Yeşildere, Cumhuriyet, and Naldöken squatter neighborhoods emerged in this period (Karataş, 2006). The city was not ready for that rapid urban expansion in terms of the housing stock, infrastructure and urban services. Although electricity service and public transportation started in the 1930s, these services could not meet the needs in 1960s (Becerik, 2008). Moreover, having poor physical conditions of Kemeraltı, İkiçeşmelik, Eşrefpaşa, Basmahane, and Tepecik surrounding central business district has incited the development of

additional slum areas. Railway to Bayraklı and newly established industries in Mersinli and Çamdibi brought about the squatter belt around the city (Figure 3.4).

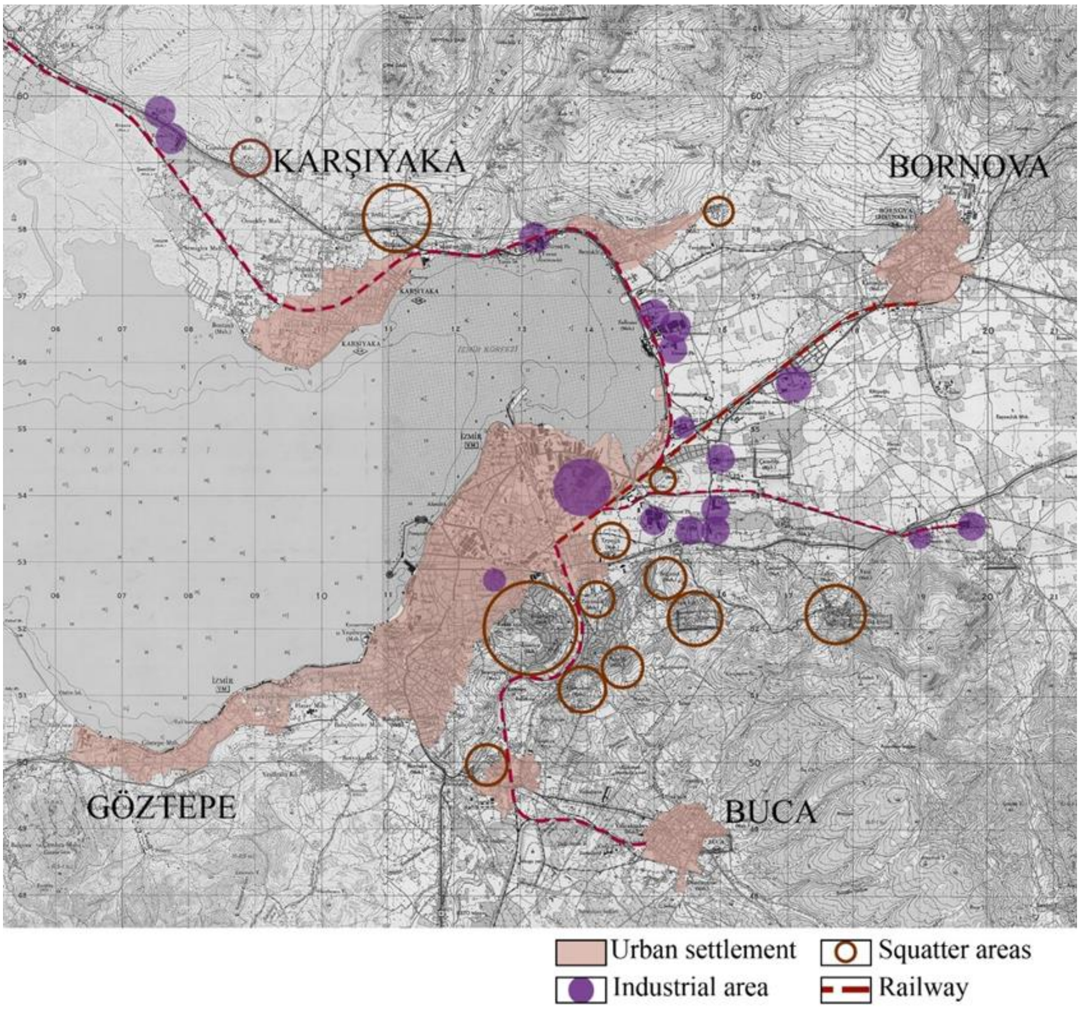

Figure 3.4 Urban Macroform and Squatter Areas in the 1960s

After the 1960s, squatter areas expanded throughout the North and the Northeast part of the metropolitan area, which covered Çay, Çiçek, Muhittin Erener neighborhoods in Bayraklı district, Yamanlar in Karşıyaka district and at the South and Southeast part o the metropolitan, which covered Bozyaka, Yeşilyurt, Cennetoğlu, Vezirağa, Altındağ, Çamdibi, and Mersinli neighborhoods. In the 1970s and the 1980s, as production capacity increased, İzmir continued to be an attractive destination for immigrants, and the population continued to increase. Net migration rate was 8‰ between the 1960s and 6.5 ‰ in 1970s and 1980s respectively (Kocaman, 2008).

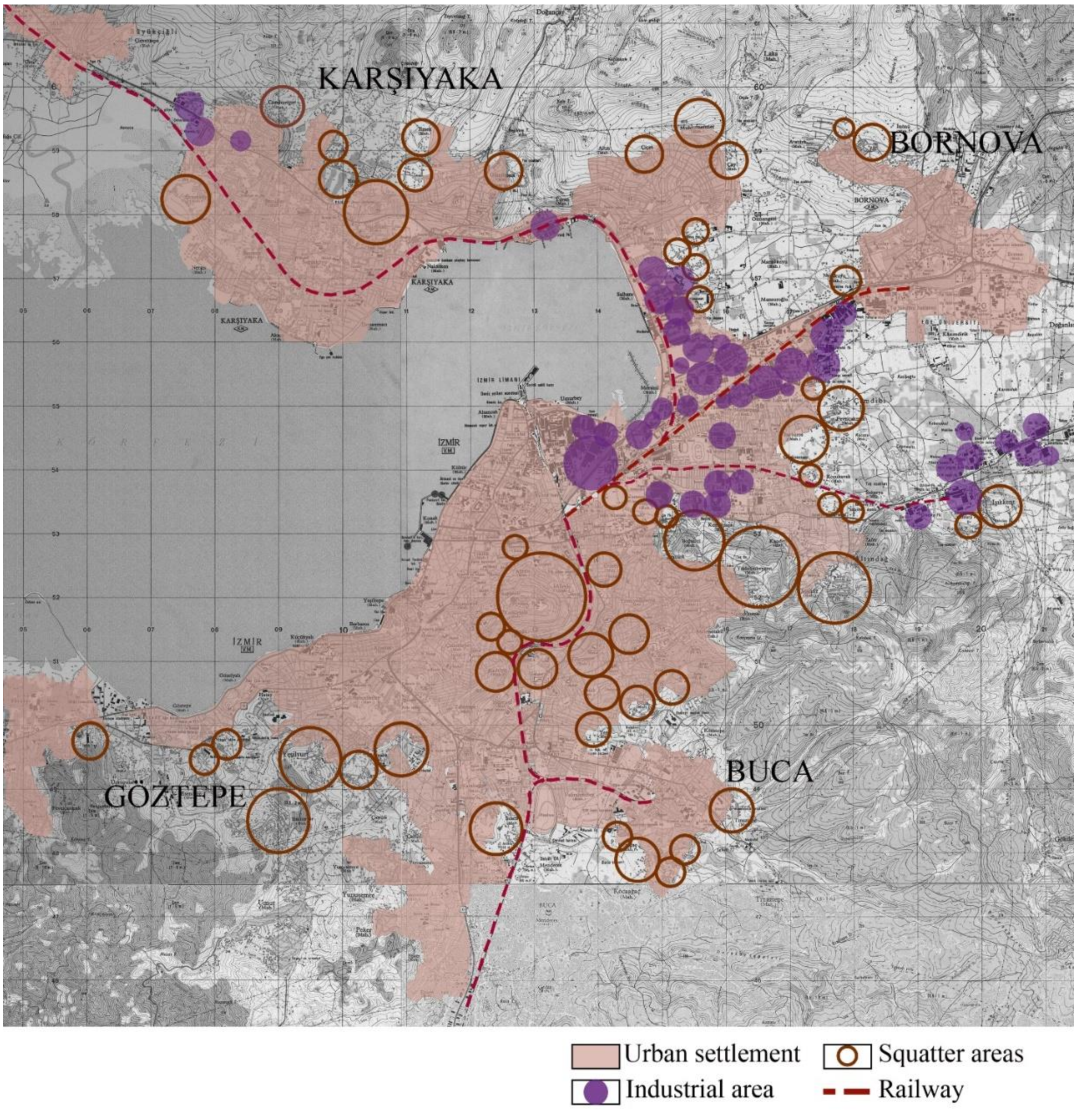

Figure 3.5 Urban Macroform and Squatter Areas in the 1980s

Industrial areas and urban settlements had spread from the core of the metropolitan area to Buca, Bornova, and Kemalpaşa placed just in the East and Northeast of the city center (Ünverdi, 2002). However, in the 1980s, excluding from the priority regions for development that regions take incentives for investment and its failure to enter the global market causes a drastic decline in industrial activities in İzmir. Production activities were limited to the local market, while being located as large industrial enterprises at the periphery and small-scale enterprises in the city center. While this situation led to the spread of slums between the periphery and the center to cover the house stock needs for the labor class, the industry's capital accumulation came to a standstill.

Table 3.1 Historical Development of Squatter Neighborhoods (Karataş, 2006; Ünverdi, 2002; Koçman, 1989; Yılmaz & Yetkin, 2002)

Period	Squatter and depriated Neighbourhoods
Before Republic	Daraağacı, Tepecik, Şirinyer, Naldöken
1920-1940	Yeni istiklal, Zeytinlik, Yeşildere, Cumhuriyet, Naldöken
1941-1960	Gürçeşme, Samantepe,Kadifekale, Boğaziçi, Gültepe, Ferahlı, İmraniye , İstiklal, Ballıkuyu, I. Kadriye, II. Kadriye
1961-1980	Yamanlar, Çay, Çiçek, Muhittin Erener, Bozyaka, Yeşilyurt, Cennetoğlu, Vezirağa Altındağ, Çamdibi, Mersinli,
1981-2000	Emek, Örnekköy, Gümüşpala, Balatçık, Güzeltepe, Yeşildere, Çiğli-Menemen,Işıkkent, Pınarbaşı, Kavaklıdere

In contrast to the declining production activities, construction sector started to gain importance to facilitate capital accumulation and prevent economic stagnation. Besides, amnesty laws and legal regulations enacted in the 1980s turned squatter settlements an investment tool. This approach led to urban sprawl and occurring new development areas. Until the 1980s, unauthorized housing was occurred generally in public property land located at the periphery of the macroform and closed to industrial areas. In the 1980s, for the first time, slum areas appeared in Buca, Narlıdere and Güzelbahçe which were far from industrial activities but offered cheap land prices (Ünverdi, 2002). Even though production activities focused only in local market not regional scale, the population growth rate did not decrease. Total population reached 1,976,763 in 1980. At that time, approximately 45% of the population lived in these slum neighborhoods (Ünverdi, 2002). (Figure3.5)

In İzmir, built-up areas became a prevailing landuse type by expanding through agricultural land and urban area grew threefold from the 1960s to 2005 (Hepcan et al., 2013).

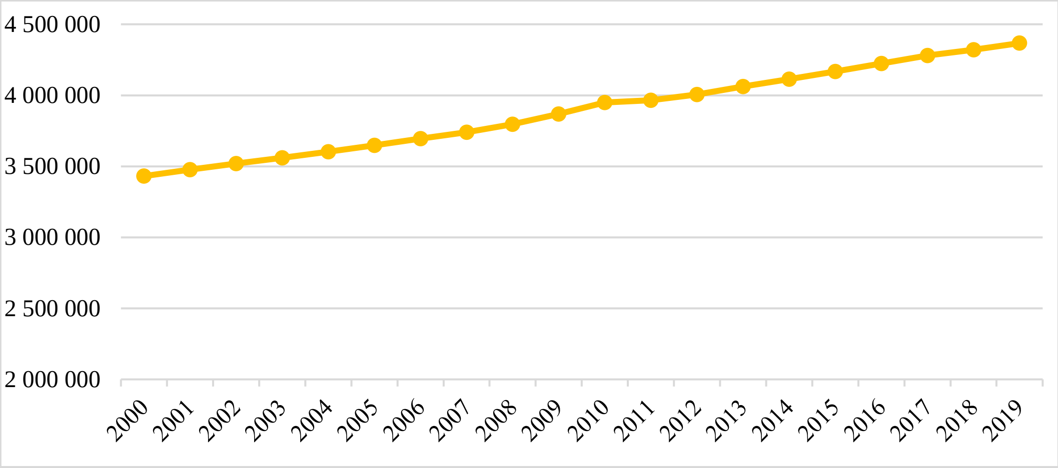

Figure 3.6 Population growth from 2000 to 2019 (TUIK, 2019)

In parallel to the expanding built-up areas, from 2000 to 2019, total population increased approximately 27%.

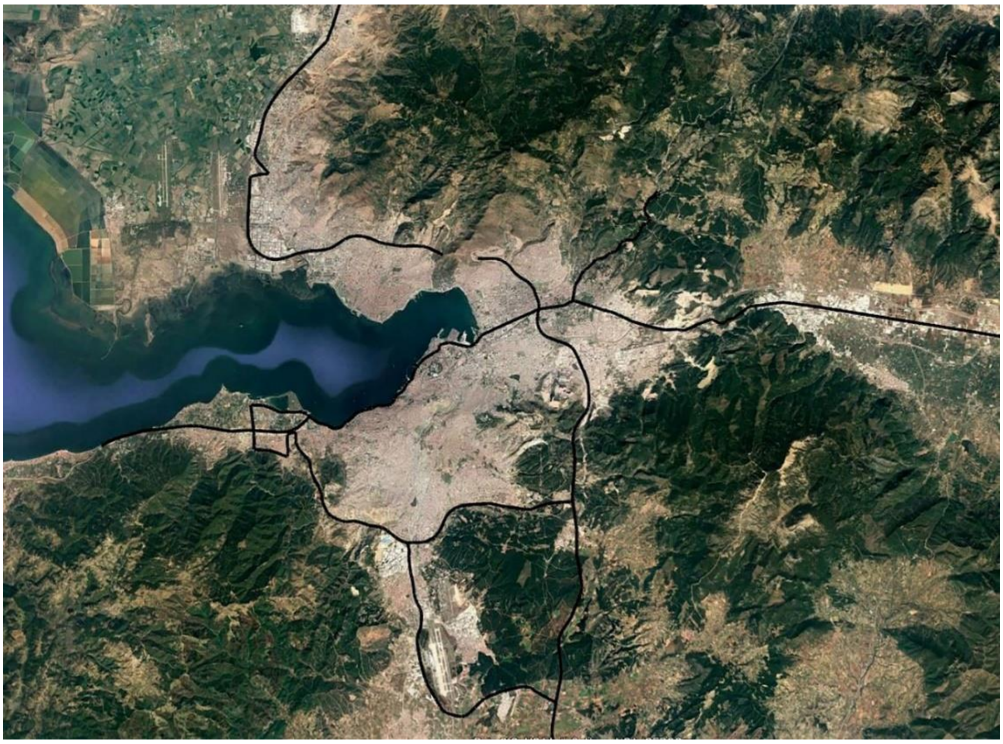

Figure 3.7 İzmir Metropolitan Area in 2020 (Google Earth Pro, November, 7, 2020)

Today, besides fertile agricultural areas and vast residential settlements, there are thirteen organized industrial zones and more than hundred power plants in İzmir. The city makes a significant contribution to the National economy. The share of the Gross Domestic Product was 6.23% in 2017, ranking the third in Turkey (TUIK, 2019). However İzmir still has some issues regarding widespread squatter settlements and poor physical conditions in some neighborhoods. According to the Ministry of Environment and Urbanization, Izmir Infrastructure and Urban Transformation Provincial Directorate, the areas that need rehabilitation and renovation constitute 46.5% of the total housing area (2013).

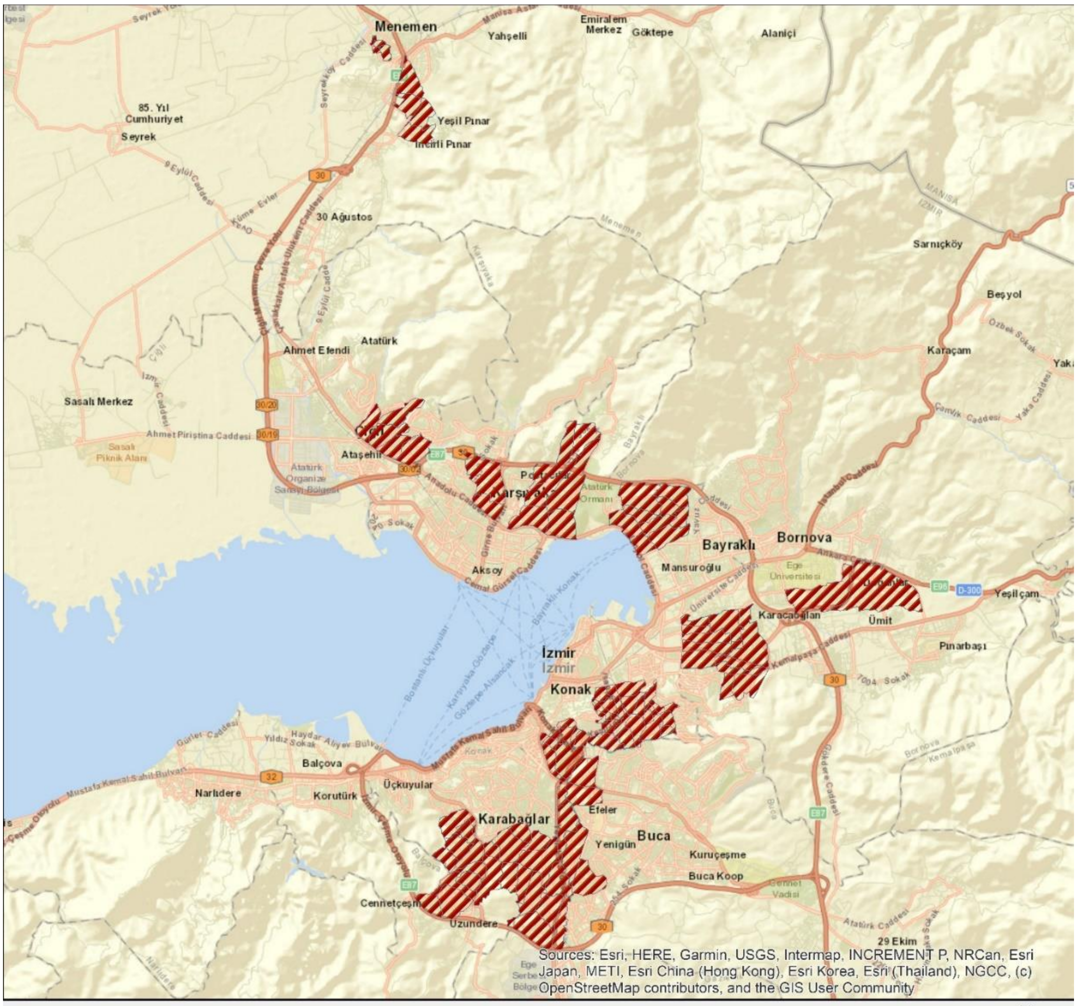

Figure 3.8 Slum and Deprivation Areas in Metropolitan Area in 2018 (İzmir Great Municipality,2009; Çınar& Penbecioğlu, 2018; Ministry of Environment and Urbanism, 2013)

As a large metropolitan city, with thirty districts, İzmir has a significant housing stock within a large built-up area, a developed transportation network, industrial zones and agricultural areas. To maintain the sustainable functioning of these urban components, social and technical infrastructure is vital. Urban energy network is one of the main technical infrastructure to sustain daily life and industrial production.

3.3 Natural Gas Systems as One of the Urban Energy Services

There is a broad literature related to urban energy systems that contain different dimensions of energy. Notwithstanding, the share of natural gas systems has relatively small. Socio-spatial impacts of energy, especially natural gas, are among the current issues which are recently started to be discussed. In these analyses, multivariate regressions were performed using cross-sectional data or panel data; and it has been found out that in addition to unit price, sales volumes, number of subscribers variables density, height, employee wages, regional differences, and characteristics of sectoral consumers also have an impact on costs of transmission and distribution lines (Guldman 1983, 1985, 1989; Klein, 1993; Kim & Lee, 1995; Fabbri et al., 2000; Bernard et al., 2002)

In the economic efficiency analysis, on the other hand, it was revealed that some socio-economic, urban and environmental factors such as apartment/building ratios, average winter temperatures in addition to the input and output variables and densities of the system are also influential in the factors that play a role in the differentiation of costs (Rossi, 2001; Hollas et al., 2002; Farsi et al., 2007; Erbetta & Rappuoli, 2008; Ertürk & Türüt-Aşık, 2011). While some studies examining the relationship of natural gas systems with urbanization focusing on urbanization and the energy demand brought together (Shen et al. 2005; Madlener and Altar, 2011; O'Neill et al. 2012; Fan et al. 2017), there are also studies focusing on dual causality relationship of variables such as natural gas consumption, income, urbanization and carbon emissions (Poumanyvong & Kaneko, 2010; Solarin & Lean, 2016).

3.4 Hıstorical Background of the Natural Gas in Turkey

In Turkey, the presence of natural gas was first discovered in 1970 in Kırklareli. It has started to be used in Pınarhisar Cement Factory. In 1975, natural gas extracted from Mardin Çamurlu region was started to be used in the Mardin Cement Factory. Electricity generation from natural gas took place in 1985 at the Hamitabat Natural

Gas Cycle Power Plant, for the first time. All of the consumption from the 1970s to the mid-1980s was from local sources and was used for industrial purposes (Yardimci, 2011).

The first agreement to import natural gas to Turkey was made with the Soviet Union in 1984. Transmission lines starting from Malkoçlar on the Bulgarian border, following the Hamitabat-Ambarlı route initially reached Istanbul, and then passed the Izmit Gulf and reached to Ankara via Gemlik-Bursa and Bozüyük-Eskişehir. (Chamber of Mechanical Engineers, 1996). In 1987, Turkey carried out its first gas imports (Petform). Natural gas was used for urban domestic and commercial purposes for the first time in Ankara in 1988 (Yardimci, 2011). Then, it has started to be used in Istanbul and Bursa in 1992, and in Eskişehir and Izmit in 1996.

The transmission and distribution of natural gas were done by the public sector, until the 2000s. Pipelines and Petrol Transportation Corporation (BOTAŞ), established in 1974, had the authority to determine the sales prices and transmission of imported and domestic natural gas. However, liberalization of the economy brought forward the quality, reliability, affordability and environmental challenges in the natural gas market. In that sense, The Natural Gas Market Law was enacted in 2001 asserting to create a financially sound, stable and transparent natural gas market. By this law, storage and distribution processes other than transmission have been transferred to the private sector. As of 2009, four private importers and other wholesale companies have started their activities, and the share of the private sector has increased to 4 billion m^3 (Petform). The amount of imported natural gas has increased approximately 26% and reached up 45 211.47 million sm^3 since 1988 (EMRA, 2020). To meet natural gas demand for the long run, Turkey has made agreements with Russia, Iran and Azerbaijan and import natural gas from these countries (Figure 3.9).

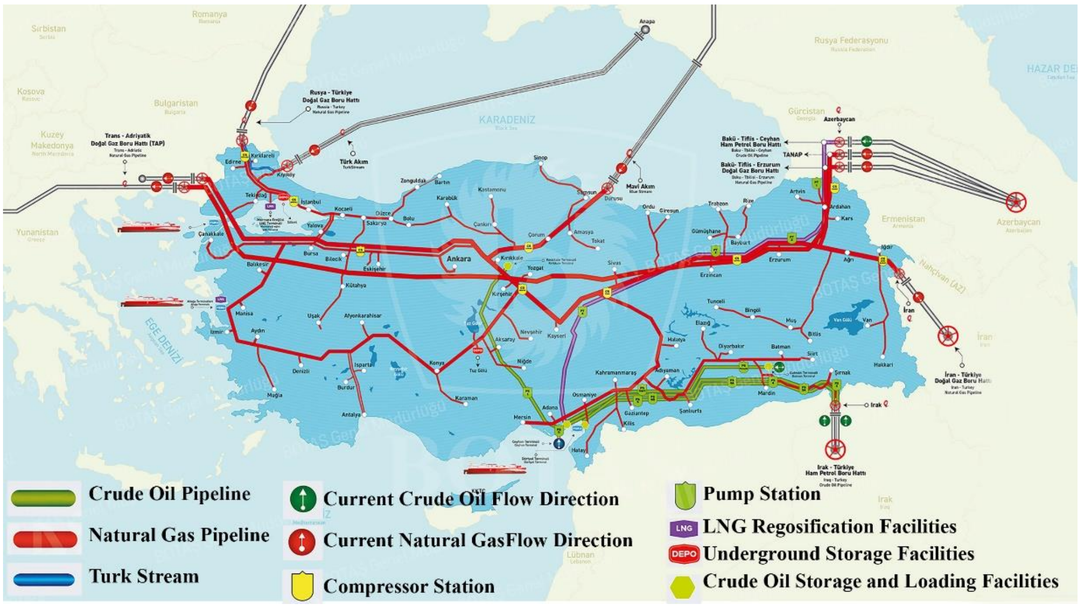

Figure 3.9 Natural Gas and Oil Transmission Lines (BOTAŞ, 2020)

In Turkey, as of 2019, natural gas is distributed to 81 provinces and 62 million people have access to the gas network (SHURA Energy Transition Center and Buildings Performance Instıtute Europe, 2019, p.10), and 50, 6 million people actively use the natural gas. Private firms undertake the distribution of natural gas in urban areas. The total natural consumption of natural gas in 2019 is approximately 42.28 million sm^3 (EMRA, 2019). The number of natural gas subscribers is approximately 15 500 000, 96% of which is using natural gas for residential purposes (GAZBİR, 2018, p.8). According to the distribution of sectoral natural gas consumption in 2019, the largest share (31.79%) belongs to residential sector, followed by industry(27.43) and natural gas transformation sector (24.86%), respectively (EMRA, 2019).

3.5 Natural Gas Investments in İzmir

In İzmir, natural gas investment has started in 2005. İzmirGaz firm is authorized to distribute natural gas and the local gas pipeline network and transportation activities. After receiving the license and opening a subscriber center, natural gas was first used in residences in Karşıyaka Mavişehir in 2006. From 2006 to 2018, the natural gas distribution network has been distributed to 25 districts of the city.

Table 3.2 First Natural Gas Usage Dates (İzmir Gaz, n.d.)

Districts	Date
Karşiyaka	July 2006
Kemalpaşa	October 2006
Torbali	December 2006
Gaziemir	December 2006
Aliağa	March 2007
Konak	June 2007
Bornova	June 2007
Bayrakli	June 2007
Karabağlar	July 2007
Buca	July 2007
Tire	July 2007
Çiğli	October 2007
Menemen	August 2010
Balçova	October 2010
Menderes	November 2010
Narlidere	October 2011
Kinik	March 2017
Bayındır	March 2017
Ödemiş	August 2017
Bergama	December 2017
Selçuk	December 2017
Güzelbahçe	July 2018
Urla	November 2018
Seferihisar	November 2018
Foça	November 2018

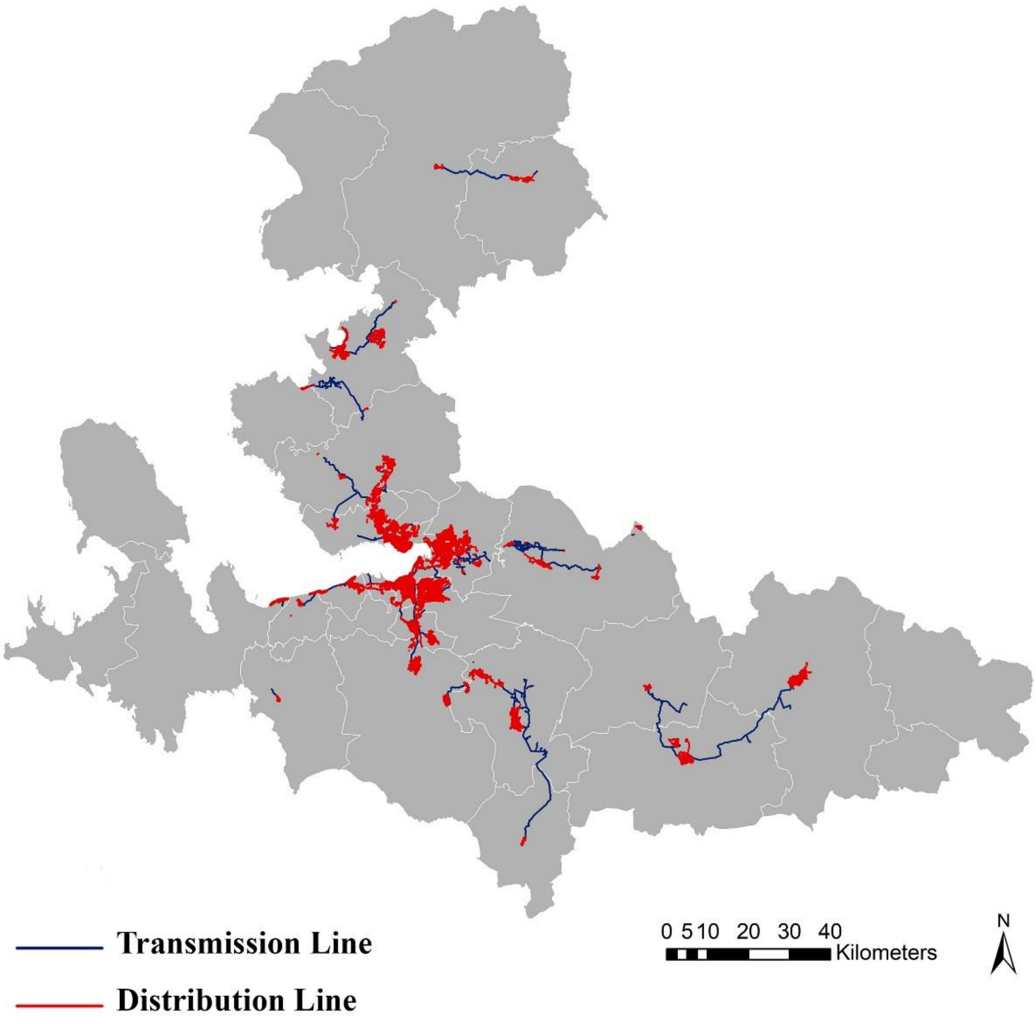

Figure 3.10 İzmir Natural Gas Network (İzmir Gaz, 2008)

Nowadays, infrastructure natural gas distribution investment plans continue for the remaining districts, namely Beydağ, Dikili, Kiraz, Karaburun and Çeşme.

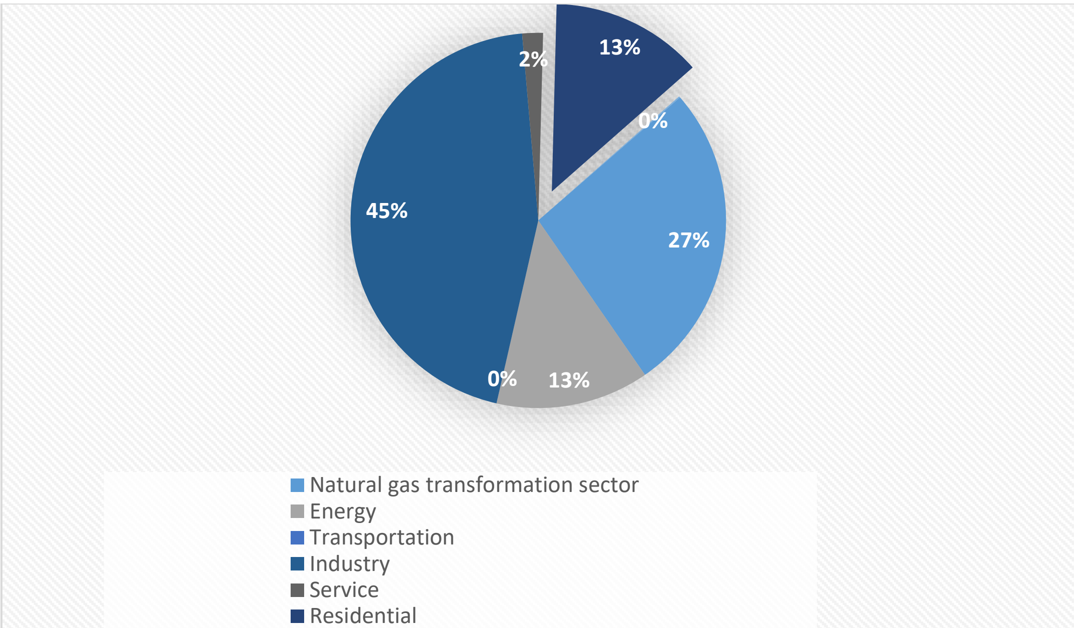

Figure 3.11 Natural Gas Consumption by Sector (EMRA, 2019)

With the expansion of distribution areas, the amount of natural gas consumption increased, as well. The total natural gas consumption was 4.3 million sm3, approximately 70% of which is used in industry (45%) and service sector(27%), while 13% is used in residences in 2019 (EMRA, 2019).

3.6 Environmental Degradation and Air Pollution in İzmir

Population growth, uncontrolled urbanization, dense industrial activities and unauthorized housing areas lead to environmental problems in İzmir.

According to Turkey Environmental Problems and Priorities Assessment Report prepared by the Ministry of Environment and Urbanization (2019, p.8), waste management, water pollution, and air pollution are the most critical problems in order of priorities in İzmir as of 2017. The primary cause of air pollution is domestic heating, followed by manufacturing industries and thermal power plants using fossil fuels. Although Turkey ranked the last in fossil fuel consumption (44.2 %) among the OECD countries in the 1960s, it moved to the fourth place (86.84%) in 2015. Air pollution became a critical problem of İzmir after the 1950s due to rapid urbanization (Sarı & Bayram, 2014). There are some difficulties in solving air pollution problem due to lack of inspection, institutional and legal deficiencies, using poor quality fuels as a result of unaffordability/low levels of purchasing power, the difficulty of access to high-quality fuels, unawareness, and meteorological and topographic factors (Marufu et al. 1999: Douthitt, 1989: Turkey Environmental Problems and Priorities Assessment Report, 2019). Emission inventories are crucial to understand how human activities affect the air quality in the urban area and to be able to control pollution, and several studies have prepared air pollutant emissions inventory for İzmir (Elbir & Müezzinoğlu, 2004: Yatkın & Bayram, 2008: Sarı, 2011: Bayram & Sarı, 2014). The studies made by Sarı (2011) and Sarı & Bayram (2014) demonstrate that due to meteorological conditions and demographic structure, domestic heating emissions have mostly affected central districts where the population is concentrated, and the share of coal-burning is high.

Stationary combustions are sources of PM_{10}, SO_2, NO_X, NO_2, CO, and CO_2 pollutants that are emitting from residential, commercial, and industrial consumption. Muezzinoğlu and Elbir (2004), researched the source of major pollutants in İzmir, finding out that the share of the sectors in the air pollution varies according to the pollutants. While industrial plants were the most polluting sources for SO_2 (88 %), domestic heating was for PM (56%), and traffic for NO_X, NO_2, and CO in 2000 (Elbir, Muezzinoğlu, 2004). Emissions from domestic heating were high in the central districts, Alsancak, Konak, Karsiyaka, and Bornova, where the urban population was dense. Moreover, Sarı and Bayram made a study to quantify the amount of domestic heating emissions for PM_{10}, SO_2, NO_2 VOC, and CO together with greenhouse gases- CO_2, CH_4, and N_20 in 2008-2009 winter season. They also found out that Konak and Karabağlar were the most polluted districts, while Güzelbahçe was the least located in the southeastern part of the city (Sarı, 2011). The reasons for being less polluted of the eastern region are meteorological factors: stable atmospheric stratification, low wind speed, and ground-based inversion for the efficient mixing of air pollutants and less urban population and density. Because wind direction determines the areas that the pollutants will be transported and the dominant wind direction is southeast and west, this region is less polluted. In İzmir, poor metrological conditions *occur during the winter season, and these conditions lead to less dispersion of the pollutants resulting in higher pollution concentrations in air (Elbir, 2003).* The level of pollutant concentration also varies by seasons and settlements. Yatkın's study covering June 2004 and May 2005 period showed that PM concentrations was higher in winter in urban areas, whereas it was higher in summer in suburban areas (Yatkın, 2006, p.9).)

When the studies of Müezzinoğlu et al. (2000) and Bayram &Sarı (2011) are compared, it was pointed out that the PM10 and SO2 emissions from domestic heating decreased in a significant way from the 1999 to 2008-2009 winter season. There is a critical decrease (80%) in emission. This decrease stems from local policies that force residents to use more qualified coal and less coal consumption than before, and increase natural gas usage (Sarı & Bayram, 2014: Sarı, 2011). Even Müezzinoğlu's study comprises the year 1999 and the other only winter season, these both studies had been measured the emissions from domestic heating and the heating season in İzmir is almost the same as the winter season in the metropolitan region where both studies area include.

The above-mentioned studies showed that air pollution has been a problem in İzmir. Measures are needed to reduce air pollution, ensure the use of quality solid/liquid fuel, provide information and awareness, and provide monitoring.

There is a global attempt to reduce carbon emissions and air pollution. The European Union asserts the requirement of participation of local authorities to mitigate climate change. The commitment of "*The Covenant of Mayors"* is a way of an incentive of the European Union that encourages the local authorities who are close to the citizens and non-governmental organizations (The European Union, 2020). İzmir Metropolitan Municipality is also one of the participants of transnational municipal networks, and it has signed the Covenant of Mayors. As a part of the Covenant of

Mayer (CoM), İzmir Metropolitan Municipality prepared İzmir Metropolitan Municipality Sustainable Energy Action Plan (İMMSEAP), which aims to reduce 20 % of the CO_2 emissions by the year 2020 (Covenant of Mayor's, n.d.). 2014 was accepted as the base year, to prepare the GHG Emission Inventory, for İMMSEAP. The stationary combustion emissions from residential and commercial fuel consumption (Tier 1) were 880,561-ton CO_{2e} CO_2, 5,457-ton CO_{2e} CH_4, 5,379-ton CO_{2e} N_2O, and 891,396-ton CO_{2e} total greenhouse gas emissions. (IMMSEAP, 2016). Moreover, the total fuel and electricity consumptions in the residential area caused 2,725,513 tons of CO_{2e} emissions. The emission per capita was 5.31 tons CO_{2e} in İzmir, in 2014. Residential energy consumption comprised 31% of the total greenhouse gas emissions in İzmir (ISAP, 2016, p.53)

In Turkey, most of the municipalities who take climate change action have more tendency to mitigation rather than adaptation (Gedikli & Balaban, 2018). As an initial goal, reducing the emission of CO_2 by 2020 is also demonstrates this approach.

According to the International Energy Agency, the total natural gas consumption in Turkey was 1 170 038 TJ in 2017. Its 44 % has been used in the residential sector, 40 % in the industry sector, 11 % in the commercial and public sector, and the rest of it used in transportation and agriculture. (IEA Data and Statistics, 2019).

CHAPTER 4

ASSESSTMENT OF ECONOMIC SOCIAL AND ENVIRONMENTAL IMPACT OF NATURAL GAS SYSTEMS IN İZMİR

In this part of the study, the impact of natural gas system on sustainability is analyzed in terms of the three pillars: economy, equity and environment. First, the economic analysis is conducted with respect to the comparison of the costs of alternative fuels in residential heating. Then, social equity is analyzed in terms of fuel poverty and the accessibility of alternative fuels. Third, environmental impact is analyzed with the comparison of air quality before and after the natural gas service become widespread, through the spatial interpolation of air pollution in 2009-2010 and 2018-2019 winter seasons.

4.1 Comparison of Residential Heating Costs

House heating costs depend on climate conditions, physical characteristics of the houses (degree of insulation, wind orientation, home attachment, and house size), heating methods, fuel price, efficiency of fuel combustion, and socio-economic structure of the households such as demographic composition of the household, household size and mode of tenure (Douthitt, 1989: Scott, 1980; Sardianou, 2008: Rosas et al. 2010: Nesbakken, 1999). While colder outdoor temperature forces households to consume more fuel (Scott, 1980), household's income, energy-saving measures in the dwelling stock, and the availability of heating technology alternatives also have an impact on energy consumption (Nesbakken, 1999: Rosas et al.2010). In this study, household attributes and structural housing characteristics are disregarded due to data limitations. Instead, air temperature data is utilized to calculate average heating costs of alternative fuels for an average housing unit of 100 m^2.

Annual average air temperature is 18 °C (Turkish State Meteorological Service) in İzmir, and it rarely falls below 0 °C thanks to the relatively mild weather and high humidity. The coldest months are January (9°C) and February (9.2 °C), whereas the warmest months are July (27.3 °C) and August (27.6 °C). According to İzmir Geothermal Energy (2019), 8 million kilocalories of energy are required annually to heat 100m^2 indoor space in this climate zone. In light of this information, the average housing unit size is accepted as 100 m^2, and different fuel alternatives are considered to calculate the heating costs of a 100m2 housing unit in İzmir.

Lignite, import coal, natural gas, fuel oil, wood, LPG, diesel fuel, and geothermal energy are being used for space heating in the city. Unit prices, lower heating values, and average operation efficiency rates are utilized to calculate each fuels annual heating cost.

Calorific value/ Heating value is the amount of heat produced during the combustion of a unit volume of any fuel, which is wholly burned (Woodyard, 2009; Rena et al., 2019; Sarkar, 2015). Sarkar (2015, p.93) explains the difference between the low and high heating value as follows;

> *When a fuel is burned in oxygen saturated with water vapor, the quantity of heat released is known as the high heating value (HHV) of fuel. When the latent heat of water vapor contained in the combustion products is subtracted from the HHV, the low heating value (LHV) or net calorific value (NCV) of fuel is obtained.*

The latent heat of water vaporization affects the heat of combustion. The heat is reported as low heating value (LHV) or high heating value (HHV) according to the account of water vaporization (Adhiksri et al., 2018).

According to the US Department of Energy (2012), combustion efficiency is a measure of how effectively a fuel is transforming to adaptable heat. While combusting fuels, there is a loss of heat due to some technical reasons. Sensible flue gas, latent flue gas, and unburned gases like CO are some of the reasons for heat loss (Stamper & Koral, 1965). Therefore, combustion efficiency also depends on operating efficiency. Fuel preparation, storage, operational costs, and fuel combustions are some factors affecting operational efficiency. Automatic control system usage, maintenance, and the quality of operating service can enhance efficiency, so more heat can be achieved with fewer costs (Comparison of various fuel types costs, 2018). This re-calculated efficiency is called as average operation efficiency. Thus, low heating value and average operation efficiency rates are necessary to calculate the heating costs more precisely.

The unit price of geothermal, lignite, import coal, fuel oil, electricity, wood, LPG and diesel-fuel have been obtained from Izmir Geothermal Energy (2020), Izmir Natural gas (2020), The Turkish Coal Operations Authority (2018), Ulusoy Coal Firm (2020) and Energy Market Regulatory Authority and Gediz Electricity, respectively, and each fuel type data has been transformed into Turkish lira per 1000 kilocalories for comparison. The transformation requires multiplication of unit prices are with 1000 and then division of the value with the multiplication of low heat value and average operation efficiency rate.

$$P_i = \frac{Pu_i * 1000}{LH_i * OE_i}$$

Where i=fuel type, Pi= 1000 kilocalories fuel price, Pui= Unit price of fuel i, LHi= lower heating value of fuel i, and OEi=average operation efficiency rate of fuel i.

Calculated heating costs display variations across different fuel types (Table 5.1). While the cheapest way of heating is geothermal energy that costs 926 TL, annually, and the most expensive fuel is diesel that costs 6186 TL, annually. The cost of diesel fuel is approximately seven times and six times overpriced than geothermal and natural gas respectively. The second cheapest fuel for heating is natural gas, followed by lignite, import coal, fuel oil, electricity, wood and LPG. In addition to being economic, heat transmission in natural gas appliances is faster than coal and oil burning systems, so it enables further efficiency in heating and more economic usage (IZGAZ). Coal (lignite and imported coal), oil (fuel-oil, LPG and diesel fuel), electricity and wood require great expenditures to reach the heating standards for indoor space. Although wood is not the one of the primary fuel used for heating, it is necessary to ignite the coal to burn (Sarı & Bayram, 2014). It can be deduced that if residents do not have floor heating systems, wood is an extra charge in the houses where coal is burned. Households who could not afford coal may prefer wood for heating, when they collect firewood free in some cases.

Table 4.1 Investment Costs and Unit Price of Different Fuel Types

FUEL TYPES	Low Heat Value	Unit	Unit price (krs)	Unit	Avg Operation Efficiency	TL/1000kcal	Capital invt cost (tl)
Geothermal	1000	kcal/kWh	0.1158	TL/kcal	100%	0.1158	2750
Natural gas	8250	kcal/m3	1.17845	TL/m3	107%	0.133497	1210
Lignite	4889	kcal/kg	0.431	TL/kg	65%	0.135626	0[1]
Import Coal	7000	kcal/kg	1.325	TL/kg	65%	0.291209	0*
Fuel-oil	9875	kcal/kg	3.1	TL/kg	80%	0.392405	0*
Electricity	860	kcal/kwh	0.4751	TL/kwh	99%	0.55802	196
Wood	2500	kcal/kg	0.95	TL/kg	60%	0.633333	0*
LPG	11100	kcal/kg	7.75232	TL/kg	106%	0.658875	0*
Diesel fuel	10256	kcal/kg	6.662	TL/kg	84%	0.773299	0*

[1] The cost of boiler, stove and additional appiances are excluded.

Although it is the cheapest way, geothermal energy is available only in Narlıdere and Bolçova districts for house heating and approximately eighty-three thousand people can benefit from this service .(İzmir Geothermal Energy, 2019), which constitutes only 2% of the total population of İzmir. Lignite which is the third cheapest fuel is the most health-harming form of coal, given the higher amount of pollution resulting from its combustion (Heal Briefing, 2018).

On the other hand, the second cheapest fuel natural gas is only 142 TL more expensive than geothermal annually, but serves in a larger geography (Figure 4.1).

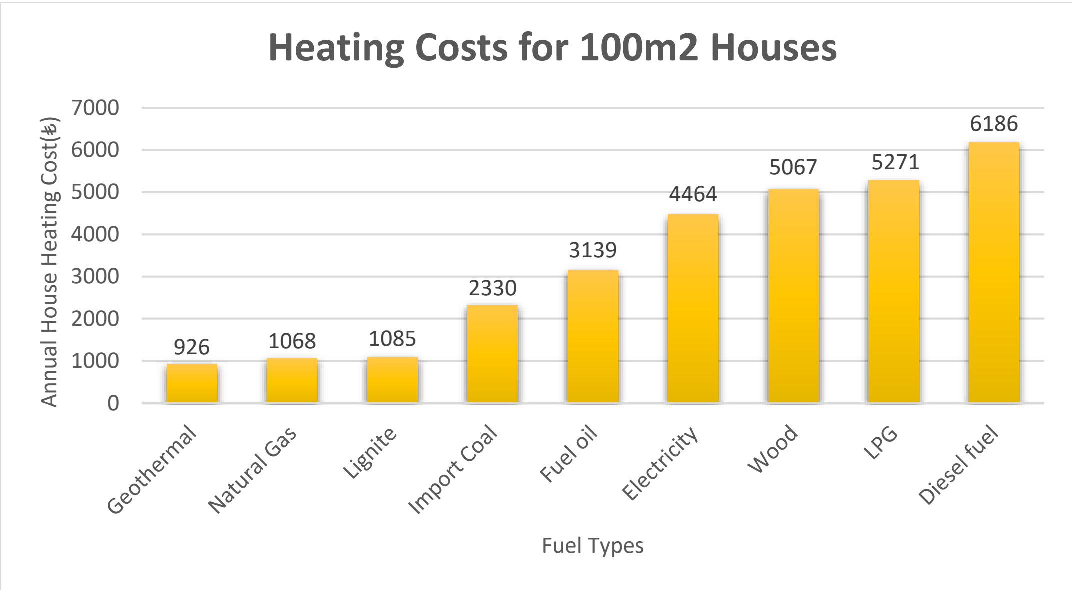

Figure 4.1 Annual Heating Costs of Different Fuel Types

Natural gas network has expanded to whole province except Beydağ, Çeşme, Dikili, Karaburun and Kiraz districts, which are located at the periphery, since the first natural gas service started in 2006 (İZMİRGAZ, 2020).

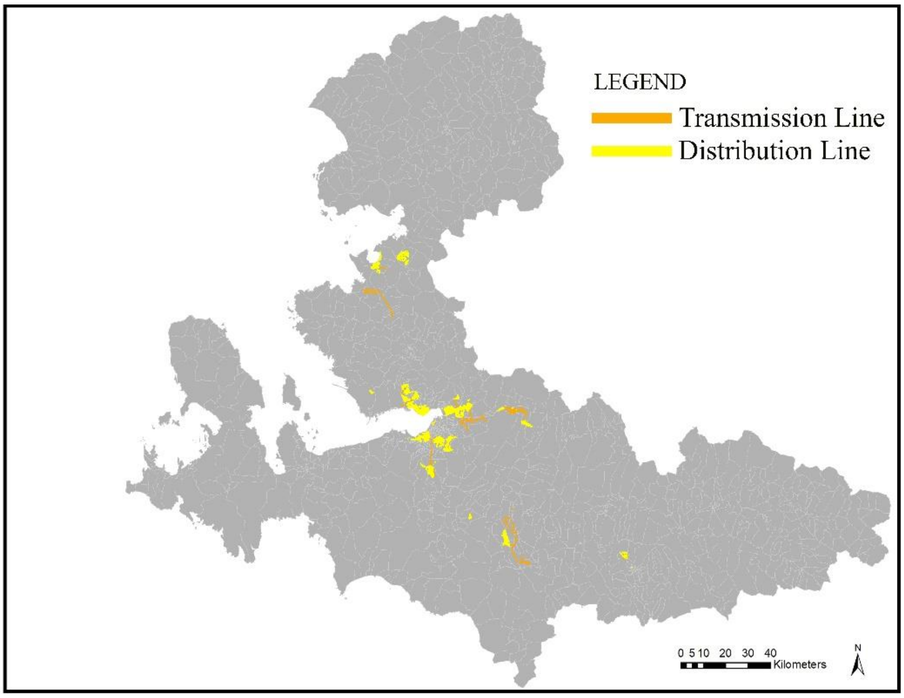

Figure 4.2 Natural Gas Network 2005-2009

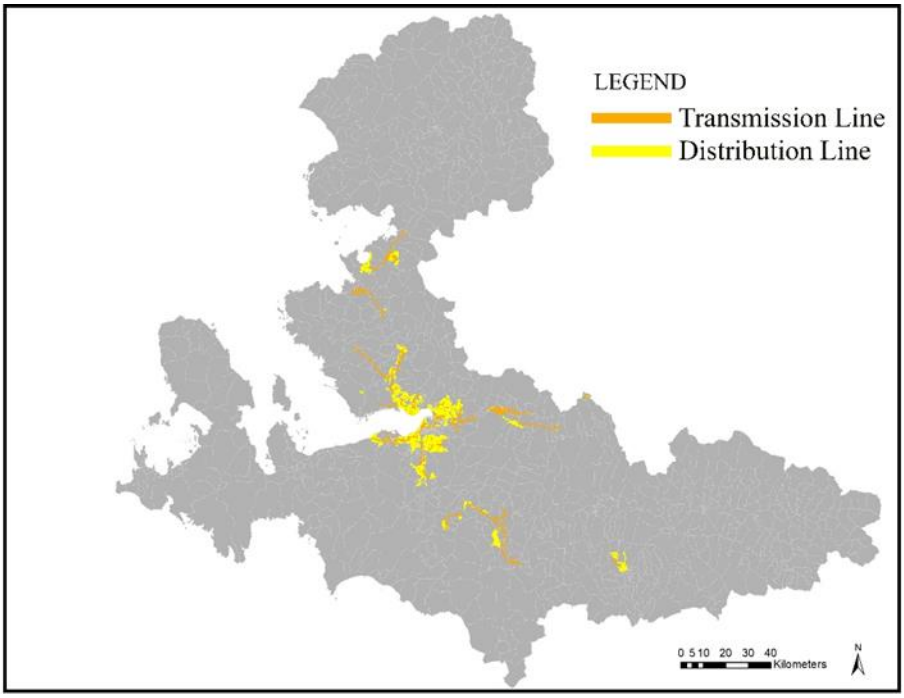

Figure 4.3 Natural Gas Network 2010-2014

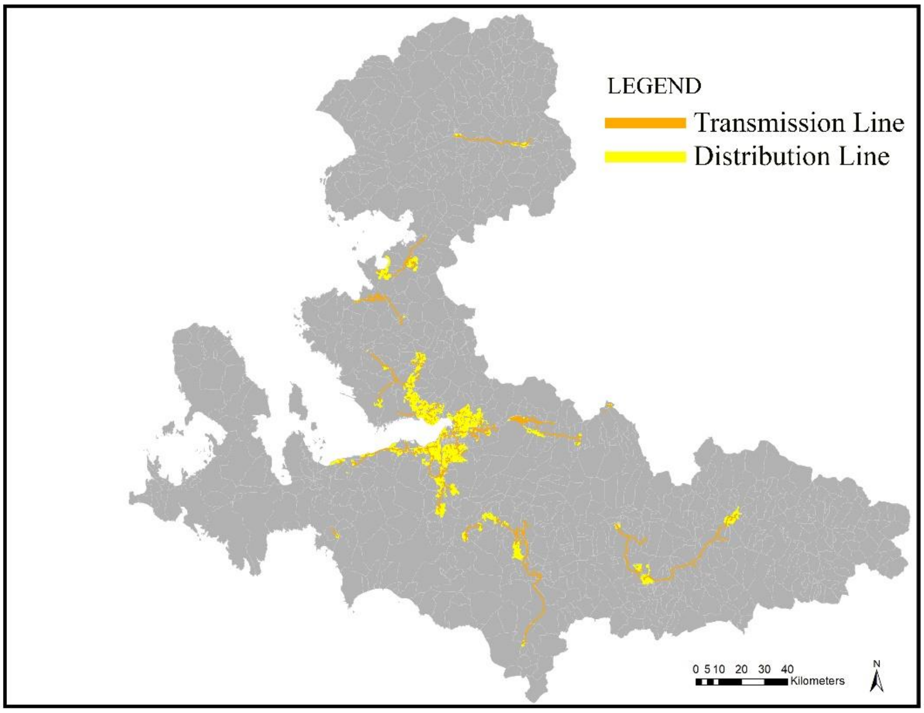

Figure 4.4 Natural Gas Network 2015-2018

While natural gas subscribes were approximately 739000 in 2018 (İZMİRGAZ, 2018) the contractor company İZMİRGAZ has reach to more than one million subscribers as of 2019 (IZMIRGAZ, 2019; IZMIRGAZ, n.d.). Natural gas was only 6% of total fuel consumption for residential heating in 2008-2009 winter season, whereas coal was the most common fuel used (Sarı & Bayram, 2014, p.432). In the past decade, 49 % of the population gained physical access to natural gas by 2018 with the expansion of the network (IZMIRGAZ). Natural gas has replaced coal in the residences in heating. From 2015 to 2019, total residential natural gas consumption has increased by 58% (Figure 4.5). Transition to using natural gas has reduced the share of house heating in the household budget.

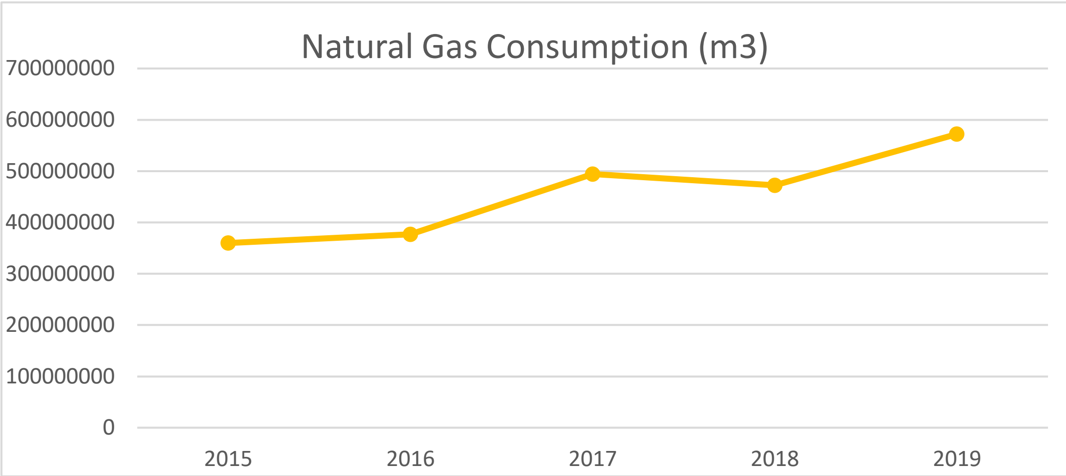

Figure 4.5 Distribution of Natural Gas Consumption by Years (Source; İZMİRGAZ, 2020)

Despite natural gas requires the highest deposit value and subscription fee in addition to installation cost, it should be noted that it can be used for hot water and cooking. Total cost for heating, cooking and hot water can be provided within a system, and significantly cost less than electricity and household gas cylinder. Other systems, however, do not provide fuels for heating, hot water and kitchen together except electricity. Fuel types used for cooking can be classified as traditional (animal dung, agricultural residues and fuelwood), intermediate (wood pellets, charcoal, briquettes, lignite, coal and kerosene), and modern (solar, LPG, biogas, natural gas, electricity, plant oils and dimethyl ether) according to the energy development level of the country (Malla &Timilsina, 2014). In Izmir, household gas cylinders, electricity, and solar energy are prevalent fuels for hot water and cooking, but these services become an additional burden on the household budget. To compare the cost of total energy requirements in residential sector, different alternatives for hot water, cooking and heating were calculated. While annual heating costs were calculating, it was assumed that 8 million kilocalories were used. To meet the monthly hot water need per person, 5.41m3 natural gas, 0.4 household gas cylinder or 33.75 kWh electricity is required (İzgaz, n.d). On the other hand, for cooking purposes, monthly 3.16 m^3 natural gas or 0.2 household gas cylinder per person is necessary. When the costs of different alternatives for heating, hot water and cooking were compared, it has been pointed out that using natural gas for hot water and cooking costs five times cheaper than a household gas cylinder and three times than electricity (Table 5.2).

Table 4.2Table 5.2 Cost Comparison of Fuels for Different Purpose in House (EMRA, 2018; İzmirgaz, 2018;İzgaz; The Turkish Coal Operations Authority ,2018; Ulusoy Coal Firm, 2020;Gediz Electricity, 2018)

Heating	Hot water	Cooking	Total Cost (TL)
Natural gas	Natural gas	Natural gas	
1068.00	229.51	134.06	**1431.57**
Coal	Electricity	HH gas cylinder	
1085	770.00	676.80	**2531,80**
Coal	HH gas cylinder	HH gas cylinder	
1085	1150.56	676.80	**2912,36**
Import Coal	Electricity	HH gas cylinder	
2330	577.00	676.80	**3583.80**
Import Coal	HH gas cylinder	HH gas cylinder	
2330	1150.56	676.80	**4057,36**
Electricity	Electricity	Electricity	
4464	577.00	43.30	**5084.3**

It can be concluded that in addition to heating, natural gas is also more cost-effective than other fuels for hot water and cooking in terms of the total cost.

4.2 Energy Distribution and Fuel Poverty

As mentioned in the literature, energy justice is on the agenda of most of the European countries. Gillard et al. (2017) examine inequalities that arise during the distribution of goods and services among groups in society, the procedure of determining and making decisions related to energy distribution, and the recognition of the needs and rights of different groups in society under the concept of energy justice. There are several studies that using different indicators to investigate the energy poverty issues. The 10% fuel cost ratio indicator is the most common used for measuring the energy poverty in these studies. On the other hand, Robinson et al. (2018) examined fuel poverty in England with 10% of fuel cost ratio indicator, which is the most used and low-income high-cost indicators (LIHC) which is the relatively new compared to others. However, to be used these methods, detailed data related to householders' social, economic, and spatial information are necessary.

In this part, to be find out the fuel poverty tendency of households, the income data and house heating costs are required. In this regard, the income data taken from the survey that was conducted by the Greater Municipality of İzmir. This survey was made in 2015 that includes income and household size in around main transportation zone which are mostly match the neighborhood level except large size land usage purposes such as university, industry zone. Although the income data exist, household expenditures and energy consumption patterns are not available. Therefore, while energy consumption costs are calculating, it is accepted that households are consuming 8 million calories for domestic heating in a year. According to this data, a 10% fuel cost ratio indicator, which examines if the cost of energy consumption exceeds the 10% of households' income or not, has been used to analyze the fuel poverty pattern in İzmir. It is required to know total fuel costs and total household income to determine the fuel poverty ratio with the 10% indicator.

$$\frac{\text{Total Fuel Costs}}{\text{Total income}} = \text{Fuel Poverty Ratio}$$

If households spend more than 10% of their income to maintain the house adequately warm, they are called fuel poor.

In the light of this information, the survey data was used for spatial distribution and income information. The survey covering all districts of the İzmir province was conducted in 586 neighborhoods. Firstly, household income in 2018 was calculated according to the inflation ratio. Housing heating cost was adjusted with the annual average heat energy required for İzmir. The amount of heat required for each fuel type was considered constant, and the heating cost was calculated for each fuel type. Then, the share of heating costs in winter season for each fuel type (geothermal, natural gas, lignite, import coal, fuel oil, electricity, LPG and diesel fuel) in the household income was calculated. The calculation of fuel poverty is currently based on annual fuel costs set against annual income, but the ratio of fuel costs to income usually be much greater during the winter than in the spring and summer seasons (Moore, 2012). While in European countries, households can make pre-payments for their electricity and gas usage; there is no such kind of implementation in Turkey. Thus, fuel poverty proportions were calculated based on the winter season period.

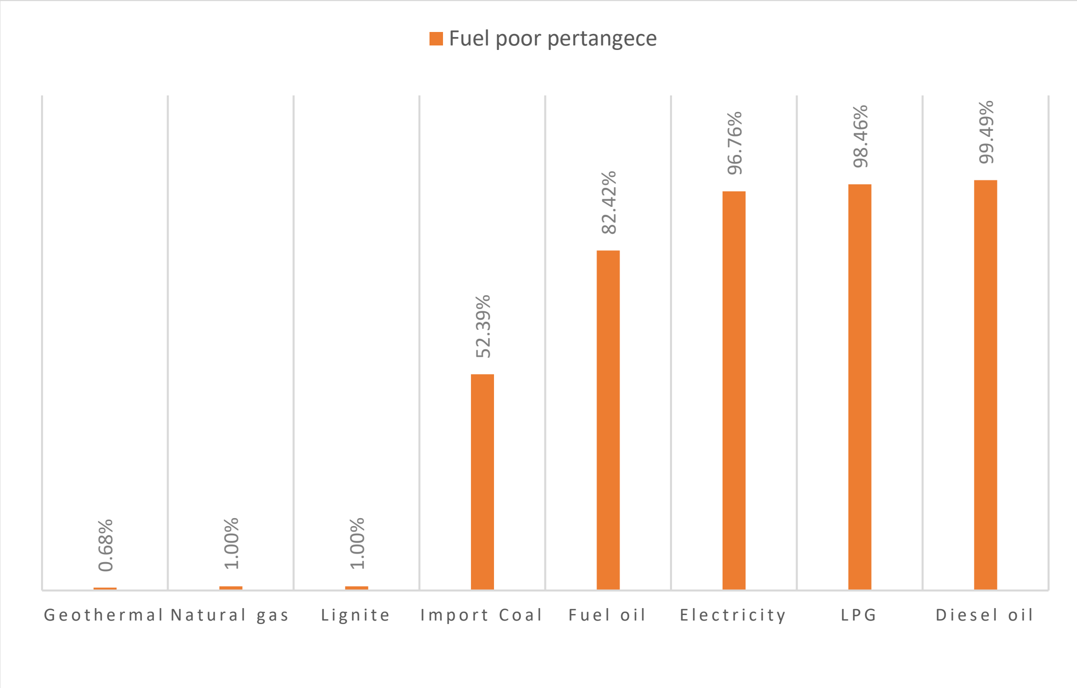

Figure 4.6 Probability of Being Fuel Poor According To Different Fuel Types

According to fuel types, the annual domestic heating costs vary considerably. This differences also impact the probability of being fuel poor. In case of the availability of all fuels types, the percentage of the fuel poverty is given in figure 4.6, with respect to the use of only one fuel type in the study area. In the case of using geothermal natural gas and lignite, approximately 1% of residents are faced with being fuel poor, whereas more than 50% become fuel poor when they use imported coal, and more than 80% when they use fuel oil, electricity, LPG and diesel. The spatial distribution of the households' tendency to be fuel poor was investigated with the help of Geographical Information Systems (GIS). The spatial distribution of fuel poverty tendency for each fuel types is demonstrated in figures 5.7-5.12. If whole households were be able to use the natural gas, out of the whole study area, only 8 neighborhoods that are Kemal Atatürk neighborhood in Torbalı, Dolaplıkuyu in Konak, Ovakent, Bademli, Konaklı, Bıçakçı in Ödemiş and Atmaca in Bergama would be fuel poor (Figure 4.7).

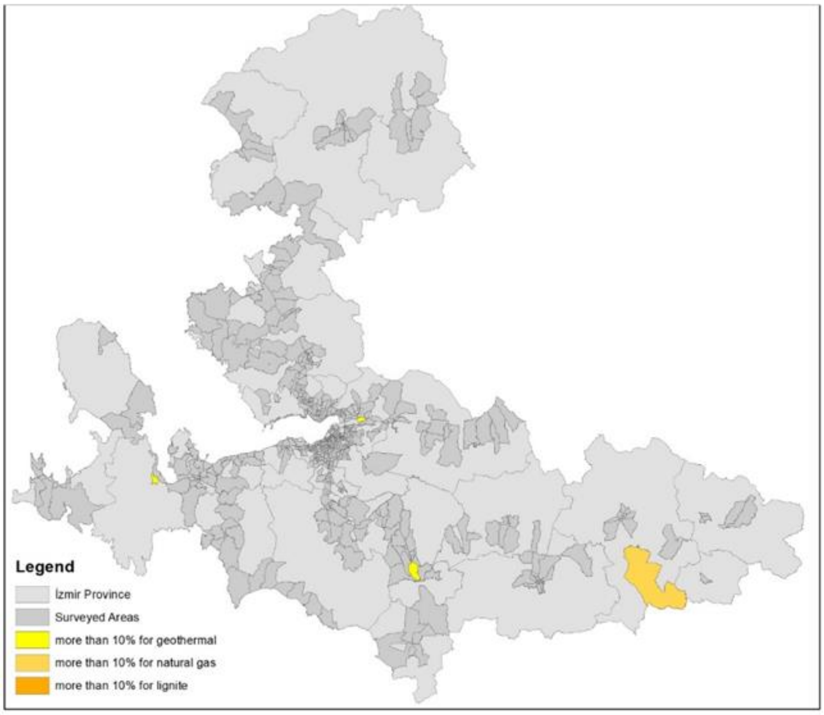

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Figure 4.7 Fuel Poor Neighborhoods In Case Of Using Geothermal Energy, Natural Gas and Lignite For Domestic Heating

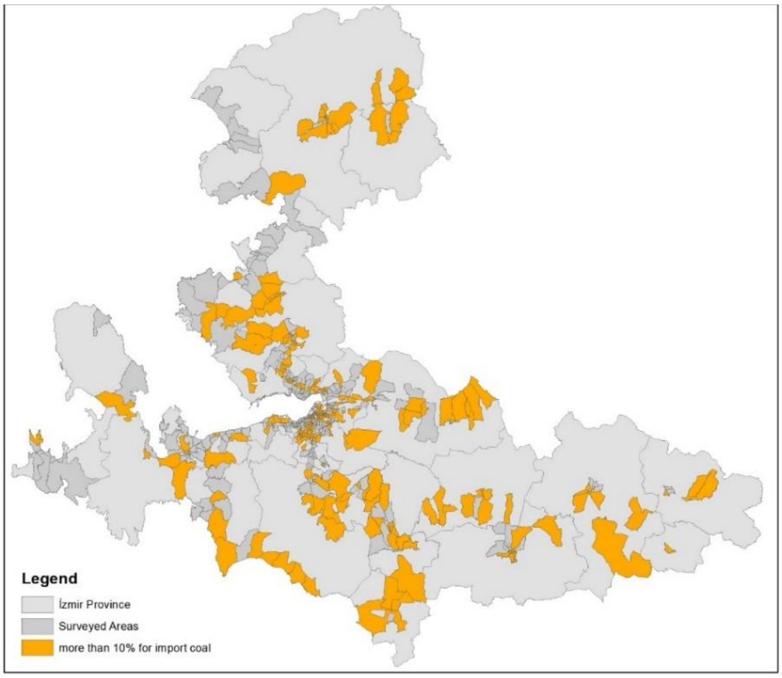


Figure 4.8 Fuel Poor Neighborhoods In Case Of Using İmport Coal for Domestic Heating

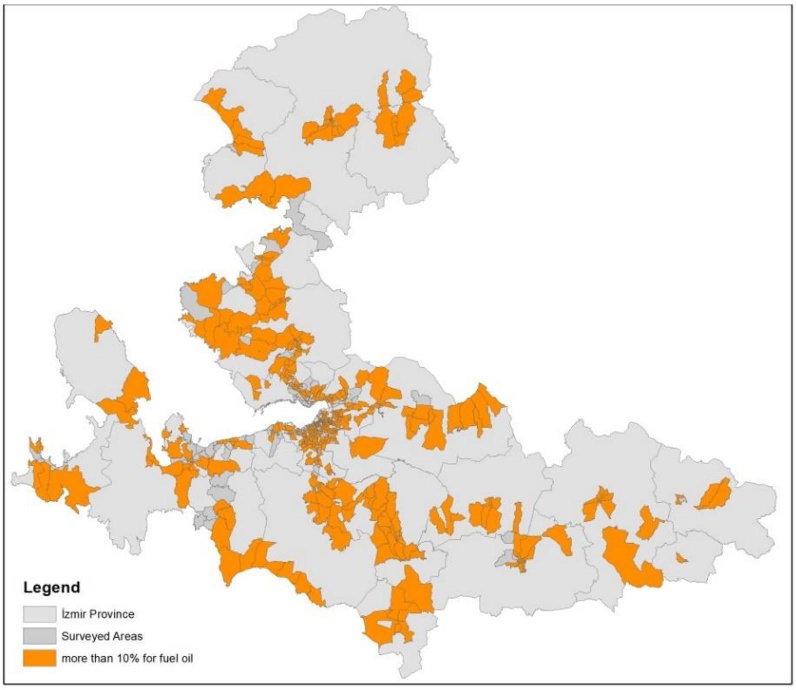


Figure 4.9 Fuel Poor Neighborhoods In Case Of Using Fuel-Oil for Domestic Heating

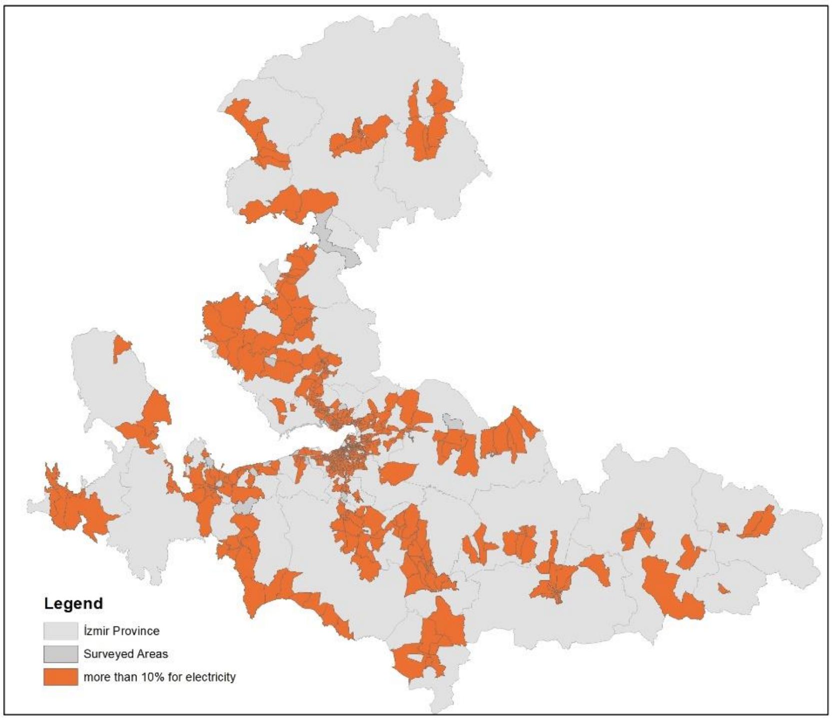


Figure 4.10 Fuel Poor Neighborhoods in Case of Using Electricity for Domestic Heating

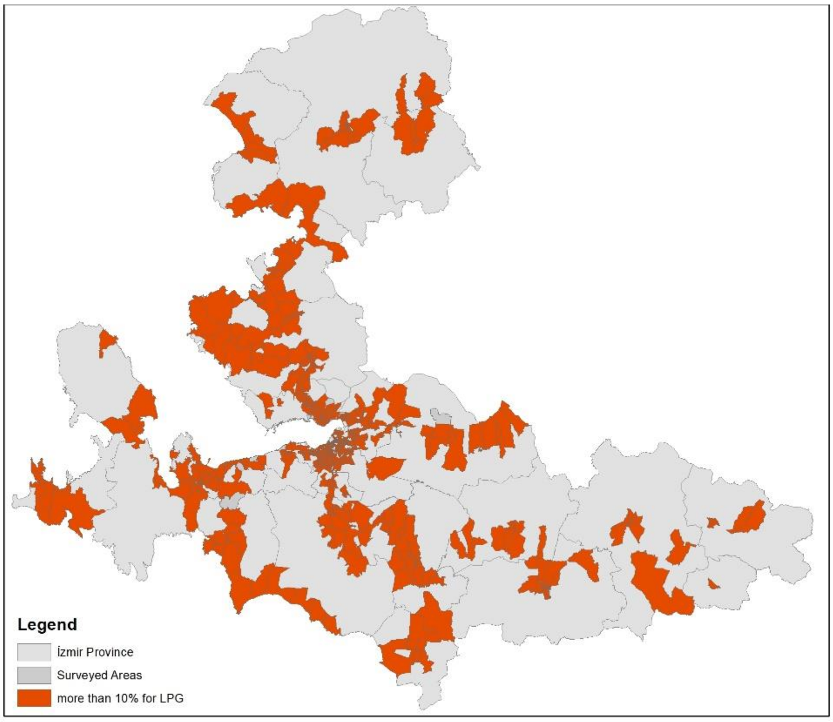


Figure 4.11 Fuel Poor Neighborhoods in Case of Using LPG for Domestic Heating

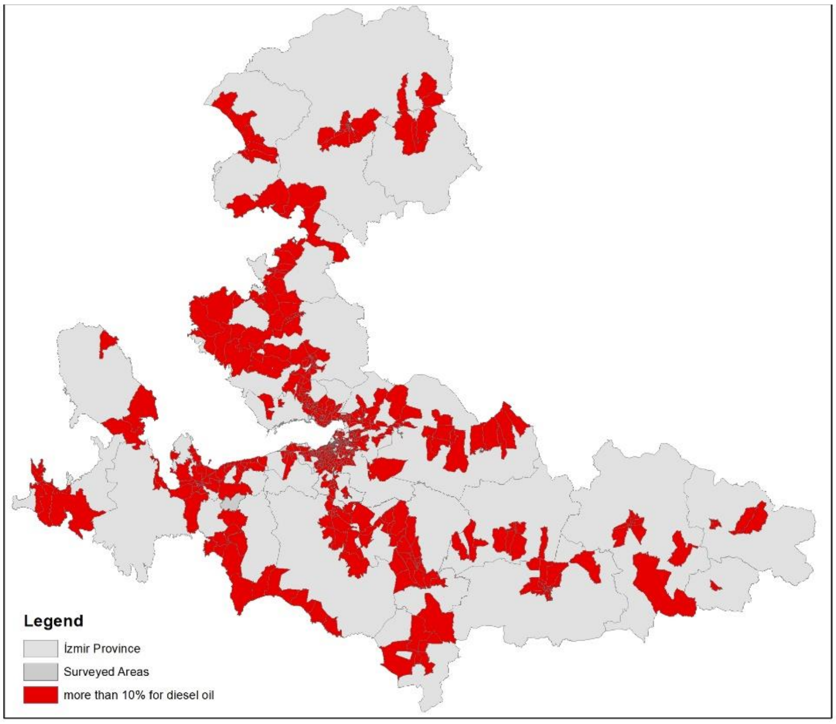


Figure 4.12 Fuel Poor Neighborhoods in Case of Using Diesel Oil for Domestic Heating

As shown in the figures above, apart from the natural gas and geothermal energy, other fuel types are not affordable for most of the household living in study area.

Altıevler, Mavişehir and Bademler are the only three neighborhoods that pay less than 10% of their income for heating no matter what fuel they use.

House heating cost is one of the main household expenditures and residents have to pay fuel to keep their houses warm. Although there are nine different fuel types, not all households have access to them. Some fuels such as geothermal and natural gas are not available due to geographical conditions and lack of physical infrastructure; others could not be used due to high cost.

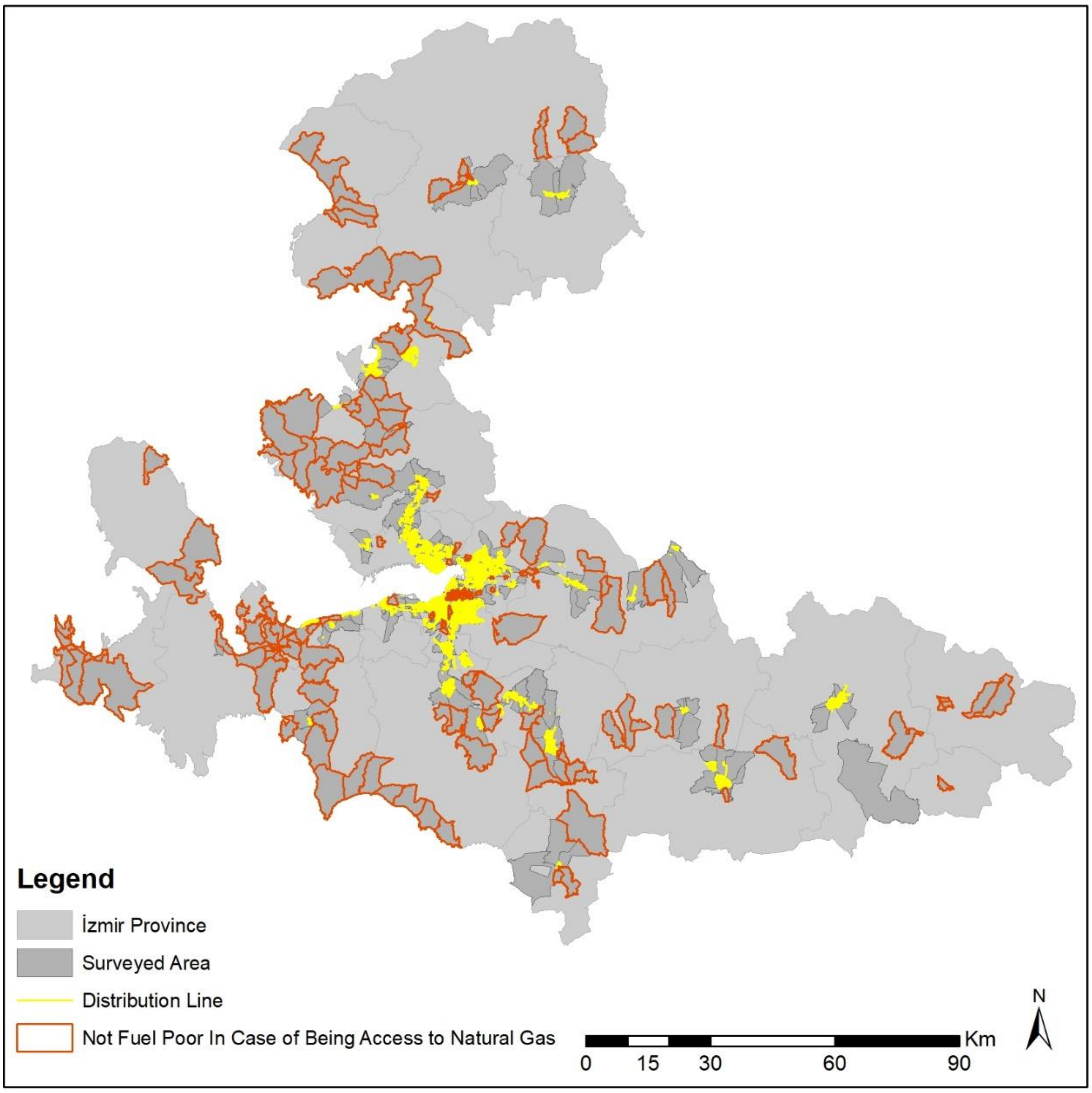


Figure 4.13 Not Fuel Poor Neighborhoods in Case of Natural Gas Distribution is Supplied

In the study area, only 32% of the neighborhoods have access to natural gas service. However, if natural gas were available in the whole study area, only six neighborhoods could be faced with becoming fuel poor.

4.3 Kriging Model for Estimation of Air Pollution

Spatial analysis is used to evaluate the spatial information and interpreting observed or measured original data (Bailey & Gatrell, 1995). Using geostatistical analysis unknown values where observation is not made can be estimated with the generation of estimated surfaces and error surfaces. Kriging is one of the geostatistical analysis tools which interpolates the unknown data points with observed values through semivariograms (Crissie, 1990).

It was originated by Kridge in 1950s and developed by Matheron who derived the formulas and established the linear geostatistics (Hengl, 2009). Kriging was originated firstly for geostatistical purposes but it has also being used in different fields such as mining, geographical mapping and environmental assessment of site (Schaugh, 1993: Crissie, 1990). In spatial statistics, Kriging is used synonymously with "optimally predicting" or "optimal prediction" in space, using observations taken at known nearby locations (Cressie, 1990). This technique has been discovered many times and it is still being implemented using numerous approaches (Hengl, 2009). Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface (Esri, 2019). Matheron (1963) states that "kriging consist of predicting the grade of a panel by computing the weighted average of available sample, some being located inside others outside the panel, and the grade of the panel is obtained by averaging over a volume". It also provides a measure of the estimation error (kriging variance) associated with the estimates. If the kriging errors which are the differences between the true values and the kriging estimates are normally distributed, this kriging variance can be used to put confidence bands about lines of constant concentration (Gilbert & Simpson, 1985:114). In Kriging method, the weight is not only based on the distance between the measured points and the prediction points but also the overall spatial arrangement of the measured points.

At known locations $s_1, s_2, \ldots, s_n,$ it is aimed to predict $\hat{Z}(s_i)$, based on data $Z(s_i)$ and the prediction are based on the following model:

$$Z(s) = \mu + \varepsilon'(s)$$

Here, the model is composed of two parts: trend or the mean and the residuals or the autocorrelated error. The predictions are made based in Equation;

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i \cdot Z(s_i)$$

Where $Z(s_i)$the measured value at *i*th location, λ_i is an unknown weight for the measured value at the *i*th location, s_0 is the prediction location and *N* is the number of measured values.

$Z = (Z(s_1), Z(s_2), \ldots\ldots, Z(s))$ can be thought as observation from a random process.

Kriging has an advantage over the deterministic interpolation methods since it creates both a prediction surface and a related error surface. It is not possible to collect data for every point in an area, thus, the method can be considered as a powerful tool to estimate the unobserved values using mathematical/statistical assumptions.

There are different techniques available for the method such as Simple Kriging, Ordinary Kriging, Universal Kriging, and Indicator kriging. The mean is assumed to be a known constant in Simple Kriging, whereas it is considered as an unknown constant in Ordinary Kriging. In Universal Kriging a trend which can be indicated by a deterministic function is evident. Indicator Kriging is utilized for observed binary data.

To be able to make prediction with the kriging method, there are two steps; spatial modeling (semivariogram) and kriging. Semivariogram is a measure of the variation of sample variance with distance. It is a graphical representation of the variance of data pairs with regard to distance. In that sense, it shows autocorrelation among observed values. Samples that are close to each other show similar variance values compared to distant ones, and generally, the variance increases with the distance between samples. Firstly, variograms are created to estimate the weights in an objective way. A variogram expresses the degree of similarity between two observations separated by a given distance, so the weights reflect the true spatial autocorrelation structure (Matheron, 1963; Wong et al., 2004). If statistical dependence is provided with spatial autocorrelation, then, the second step is making a prediction for unknown values (Matheron, 1963; Esri, 2019).

To compute the semivariogram from sampled data, the following equation is used:

$$\gamma(\mathrm{h}) = \frac{1}{2\mathrm{M(h)}} \sum_{i=1}^{M(h)} [\,(z(s_i\,) - z(s_i + h))^2\,]$$

where $\gamma(\mathrm{h})$ is the estimated semivariance at a separation distance, or lag h which is separated given distance, h is the distance between two observation sites, $z(s_i)$ is the value of a target variable at sampled location, $z(s_i + h)$ is the value of the neighbor at distance $s_i + h$, and lastly, M(h) is the number of pairs of data at distance. It is assumed that if there are n point observations, n. n(n-1)/ 2 semivariance can be calculated (Hengl, 2009; Wong et al., 2004). In a semivariogram, three components are observed: the nugget, the range and the sill. The distance where the model first flattens out is known as range. While sample locations separated by distance closer than range are spatially autocorrelated, locations that far away the range are not spatially autocorrelated. The sill is the value on the y-axis that the semivariogram model touches at the range. The partial sill is the sill minus the nugget. If the separation distance is 0, the semivariogram value is also 0. Nugget refers to the measurement errors or variations at distances smaller than the sampling interval (ArcgisPro, n.d). It is the point where the semivariogram graph cuts the y-axis.

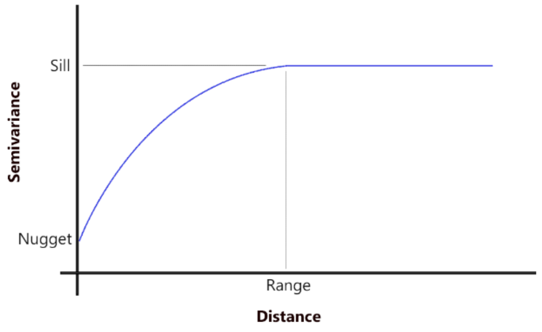


Figure 4.14 Semivariogram Graph (ArcgisPro, n.d)

The Semivariogram model is used to fit the empirical data that predicted at unsampled locations. Empirical semivariogram provides information on values, whether they are spatially autocorrelated or not. However, it does not give a result for all distances and directions. The semivariogram modeling is performed on experimental data to get a continuous function (Fanchi, 2018). There are several semivariogram models: Circular, Exponential, Gaussian, Spherical, Tetraspherical, Pentaspherical, Stable, Hole Effect, K-Bessel, and J-Bessel, of which fit changes according to the data. The most used five models are given below:

The circular model is

$$\gamma = C_0 + C_1\left(1 - \frac{2}{\pi}\cos^{-1}(\frac{h}{a}) + \sqrt{1 - \frac{h^2}{a^2}}\right)$$

The hole-effect model is

$$\gamma = C_0 + C(1 - e^{n}.\cos\theta)$$

The exponential model is

$$\gamma = C_0 + C_1\left\{1 - \exp(-\frac{h}{a})\right\}$$

The gaussian model is

$$\gamma = C_0 + C_1 \left\{ 1 - \exp(-\frac{h^2}{a^2}) \right\}$$

And the spherical model is

$$\gamma = C_0 + C_1 \left(\frac{3h}{2a} - \frac{1}{2} (\frac{h}{a})^3 \right)$$

Where $h \geq 0$ is lag, C_0 is the nugget, C_1 is the sill, n is the pairs of point and a is the range of influence (Fanchi, 2018; Yaprak &Arslan, 2008).

While model fitting, Root Mean Square (RMS), Root-Mean-Square Standirdized and Average Standard Error (ASE) are main selection criteria.

The root mean square (RMS) prediction error estimated by the expression:

$$\sqrt{\frac{\sum_{a=1}^{n} [(\hat{Z}(s_0) - Z(s_0)]^2}{n}}$$

And another criteria the root mean square standardized (RMSS) prediction errors is defined by:

$$\sqrt{\frac{\sum_{a=1}^{n} [(\hat{Z}(s_0) - Z(s_0))/\hat{\sigma}(s_0)]^2}{n}}$$

Where $\hat{Z}(s_0)$is the kriging estimation, $Z(s_0)$ is the observed value and $\hat{\sigma}(s_0)$ is the prediction standard error for s_0 location (Alves & Pozza, 2010: Pasini et al., 2014).

In order to decide the best fitting model, RMS error values are compared for all models, and the model giving the smallest RMS value is preferred. The smaller the RMS error value, the lower the interpolation error rate. The minimum value of RMS, the value of RMSS which is the closest to 1 and the value of ASE which is the closest to RMS value among the models indicate a better model fit. The proximity of the RMSSE value to one indicates the high interpolation accuracy (Kale, 2018).

4.4 Spatial Distribution of Air Pollutants in İzmir

This part of the study investigates the contribution of natural gas consumption for domestic heating to air pollution. The change in the spatial distribution of the pollutants was examined over the years. There were four air monitoring stations between 1996 -1998 in İzmir. Four more stations were established with the Air Quality Assessment and Management directive in 2008, (Chamber of Environmental Engineering, 2013). As of 2019, air quality is measured by 22 stations, six of which are constructed by the İzmir Greater Municipality and the others by the Ministry of Environment and Urbanism. Daily pollutant values are taken from the National Network of Air Quality Monitoring for the analysis of the change in the air quality in 2009-2018 period. However, PM_{10} and emissions are not measured regularly by all stations. Thus, the emissions concentration were obtained from Alsancak, Bayraklı, Bornova, Çiğli, Gaziemir, Karşıyaka, and Şirinyer stations that make regular hourly and daily measurement and located in the metropolitan region. Thus, air quality analysis is limited to the metropolitan area, rather than the whole province.

Table 4.3 Average PM10 Emissions, Observed Maximum Values During the Year and the Number of Days Exceeding Limit Values

		Alsancak	Bayraklı	Bornova	Çiğli	Gaziemir	Güzelyalı	Karşıyaka	Şirinyer
2009	Avg	54.5		39.6	61.3	57.4	42.0	48.2	64.3
	NED	23		3	32	5	5	16	42
	Max.	172.7		111.5	175.2	134.3	199.0	181.2	264.4
2010	Avg	43.6	66.6	50.2	46.6	55.5	44.0	44.3	56.0
	NED	13	35	7	9	15	2	6	24
	Max.	161.7	196.3	164	125.3	177	127.8	132.5	231.5
2011	Avg	97.4	140.8	98.0	100.0	134.4	104.8	89.2	123.5
	NED	31	59	8	19	32	26	18	39
	Max.	242.1	308.9	139.9	195.4	199	161.7	176.3	253.5
2012	Avg	41.5	60.7	44.9	44.3	34.3	39.7	51.7	57.4
	NED	14	41	9	5	0	6	14	25
	Max.	207.6	242.9	372	140.8	71.6	126.7	637.1	227.1
2013	Avg	41.1	58.9	40.6	41.2	23.6	55.1	38.4	56.8
	NED	13	40	3	13	1	20	8	36
	Max.	189.9	248.1	154.9	168.1	122	1314	131.9	312.4
2014	Avg	33.2	63.2	40.0	37.1	17.9	51.1	38.9	46.9
	NED	6	55	3	10	0	23	12	26
	Max.	204.4	201.2	130.9	132.2	55.8	834.3	298.9	185.7
2015	Avg	32.3	56.8	46.3	39.8	33.4	40.9	28.7	46.2
	NED	6	51	16	14	22	15	4	29
	Max.	883.2	222.4	344.2	127.7	172	145.9	548.5	182.2
2016	Avg	42.2	53.8	44.2	35.4	51.1	38.5	19.6	46.2
	NED	39	50	15	15	37	17	3	31
	Max.	160.6	185.5	128.2	129.6	189	153.7	128.9	186.9
2017	Avg	36.5	49.4	42.4	34.5	59.5	36.1	32.6	41.3
	NED	24	66	27	18	94	18	12	33
	Max.	133.9	140.7	89.05	112.1	169	126	93.53	152.5
2018	Avg	35.9	51.8	48.6	37.3	45.2	36.1	28.7	42.1
	NED	30	99	92	41	64	35	25	52
	Max.	165.2	190.2	225.2	131.4	149	130.8	123.2	168.9

Daily emission values of PM_{10} diversify considerably throughout the year. The observed maximum values were much more than approximately 2-3 times the average daily emission values during the year. Daily average emissions of the pollutants were used between the 2009 and 2018 years to analyze the differentiation among the years. Winter season's average daily PM_{10} emissions were used to understand domestic heating's contribution to air pollution. Average PM_{10} emissions had fluctuated for the last eleven years. Emissions had increased from 2008-2009 winter season to 2010-2011 winter season. PM_{10} concentration had peaked at all stations in 2013-2014 winter season, and Güzelyalı had registered the highest emission value (124.23 µg/m³).

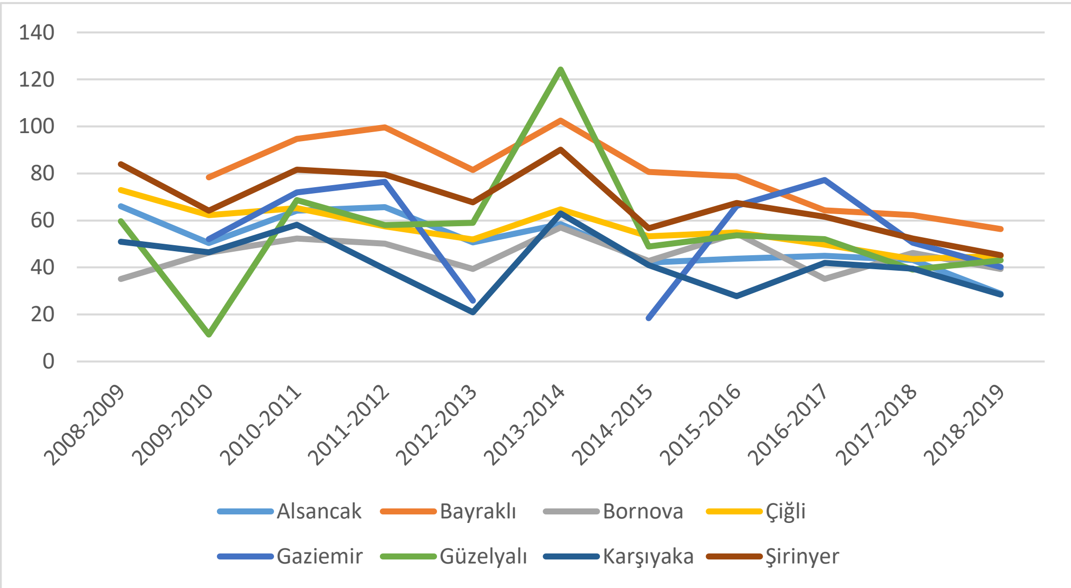
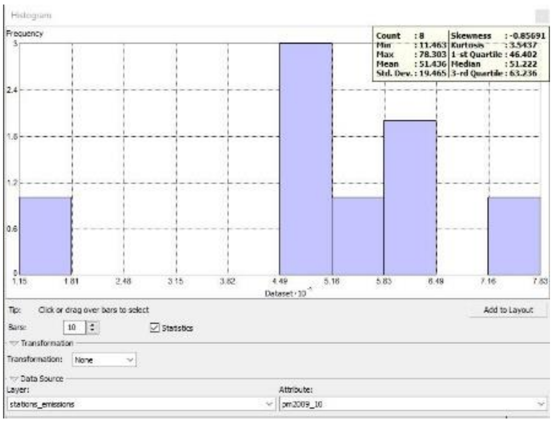


Figure 4.15 Changing PM10 Emissions by Stations from 2008-2009 to 2018-2019 winter seasons (National Network of Air Quality Monitoring)

Firstly, winter seasons' average daily PM_{10} concentration values were received (Table 4.4). Then, ArcMap GIS (10.7) Geostatistical Analyst Extension was used for the creation of semivariogram and the subsequent spatial estimations of averaged daily location-specific PM_{10}. Then, the root mean square error (RMSE) is calculated to quantitatively describe each map's estimation error when performing spatial interpolation for unmeasured locations.

Table 4.4 Winter Season Average PM10 Emission Measurements

	2008-9	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19
Alsancak	66.05	50.41	64.17	65.64	50.66	58.51	42.09	43.73	45.01	43.24	28.82
Bayraklı	-	78.3	94.69	99.54	81.54	102.49	80.65	78.79	64.26	62.29	56.35
Bornova	35.11	46.32	52.29	50.16	39.31	57.03	42.79	54.48	35.2	46.17	39.41
Çiğli	72.94	62.28	65.28	57.51	51.91	64.78	53.23	54.89	49.68	43.59	44.99
Gaziemir	-	52.03	71.96	76.45	25.93	-	48.44	66.18	77.22	50.54	40.12
Güzelyalı	59.62	11.46	68.61	58.11	59	124.23	48.88	53.66	52.09	39.1	43.02
Karşıyak -	51.01	46.48	58.16	39.41	20.94	62.99	41.07	27.83	42	39.45	28.48
Şirinyer	83.9	64.19	81.68	79.61	67.76	90.14	56.71	67.44	61.55	52.36	45.23



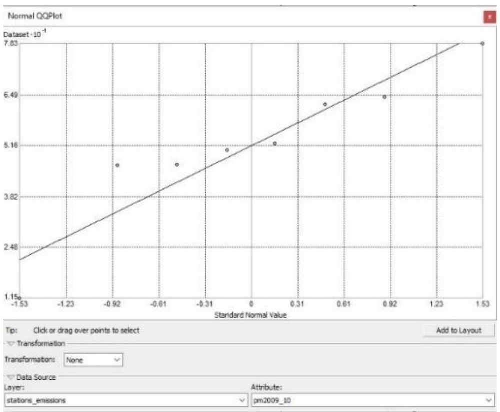


Figure 4.16 Normal QQ Plot and histogram graphics of 2009-2010 year PM_{10} emissions

In identical distribution, QQ Plot is a straight line and points are clustering along the line. The skewness is equal to -0.85691, Kurtosis is 3.5437 and standard deviation is 19.465. When normality test was performed for emission data, it is found out that the data is normally distributed for the 2009-2010 winter season, and ordinary Kriging has been applied. During 2009-2010 winter season emissions, the average minimum value of PM_{10} measurement was 11.463 µg/m³ in Güzelyalı, the average maximum measurement was 78.303 µg/m³ in Bayraklı, and the median was 51.22 µg/m³.

Ordinary Kriging (OK) was used to estimate and create pollutant surface. Ordinary Kriging is used in the interpretation of the air pollution analysis in several studies including Huang et al. (2020), Nunez-Alonso et al. (2019), Son et al. (2010), Shad et al (2009), and Bayraktar and Turalioğlu (2005) Although more observations give better results, the number of stations were 22, 13 and 6 in the studies of Nunez-Alonso et al (2019), Son et al (2010), and Bayraktar and Turalioğlu (2005), respectively.

The research was carried out by performing different semivariogram models until the most suitable theoretical model was found. The RMS and RMSS error values were compared to determine the theoretical semivariogram model (Table 5.5).

Considering RMS and RMSS error values, the Hole-effect semivariogram model which has the smallest RMS error value and RMSS error value closest to 1 was chosen as a suitable function that represents the pairs best.

Table 4.5 Theoretical Semivariogram Models and Error Values

	Circular	Gaussian	Hole Effect	Spherical	Exponential
RMS	20.8176	22.1887	19.7219	21.7347	21.2494
RMSS	1.0004	1.1954	1.0003	1.0974	1.0405

The estimation surfaces depict that PM_{10} emission was concentrated around Bayraklı station, where the highest pollution measurement was made in the 2009-2010 heating season. East of the gulf that was the most polluted region. Bayraklı, east part of the Konak and the northern part of the Buca was region exposing high level pollution. The south of the gulf, where Güzelyalı and Balçova located was the least polluted region (Figure 4.17).

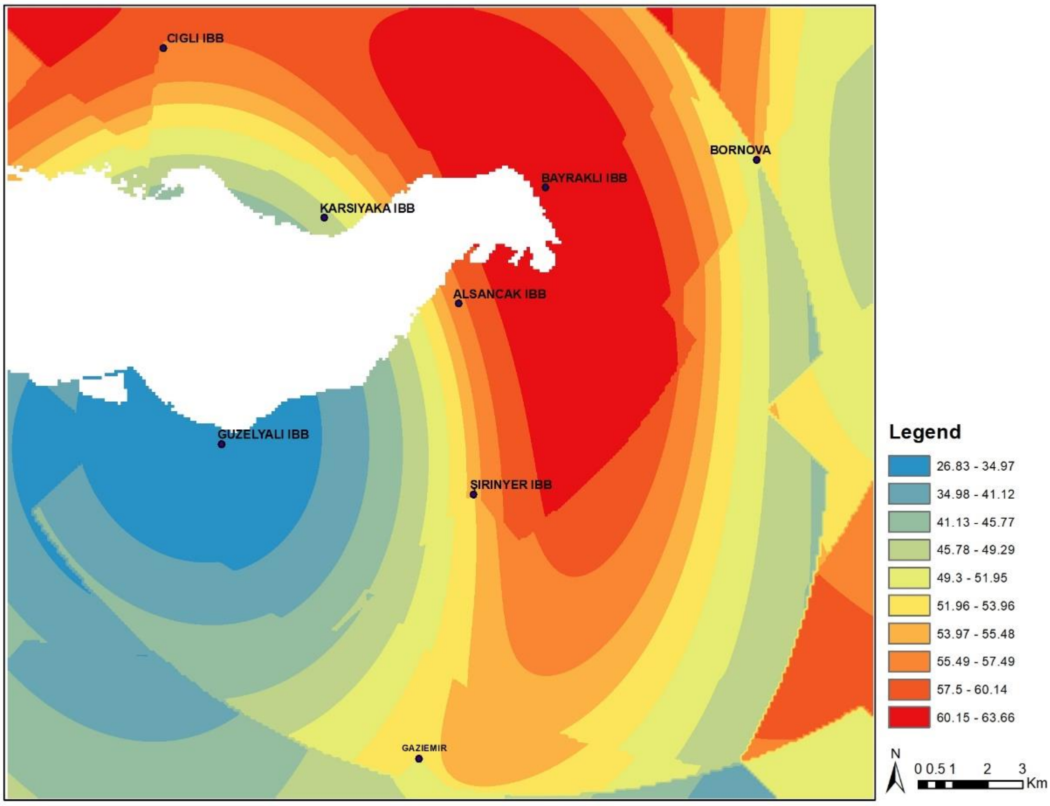


Figure 4.17 Spatial Distribution of PM10 Pollutant in 2009-2010 Winter Season

The air quality of Çiğli the northern of the Karşıyaka, Şirinyer locating southern of the Alsancak and Bornova was moderate.

To be able to compare the change of the spatial pattern of PM_{10} concentration, the distribution of recently measured PM_{10} emissions was also analyzed. 2018-2019 winter season average PM_{10} concentrations for seven stations were obtained. The skewness is equal to 0.067, Kurtosis is 2.432 and the standard deviation is 9.115. Since the data normally distributed without transformation, Ordinary Kriging was performed. The Circular semivariogram model, which has the smallest RMS error value and RMSS error value closest to 1, was picked as a fitting function representing the pairs precisely. During the 2018-2019 heating season, the minimum average emission was measured from Karşıyaka (28.4 $\mu g/m^3$) and Alsancak (28.8$\mu g/m^3$), and the maximum average value of the PM_{10} emissions were measured in Bayraklı (56.35 $\mu g/m^3$) station.

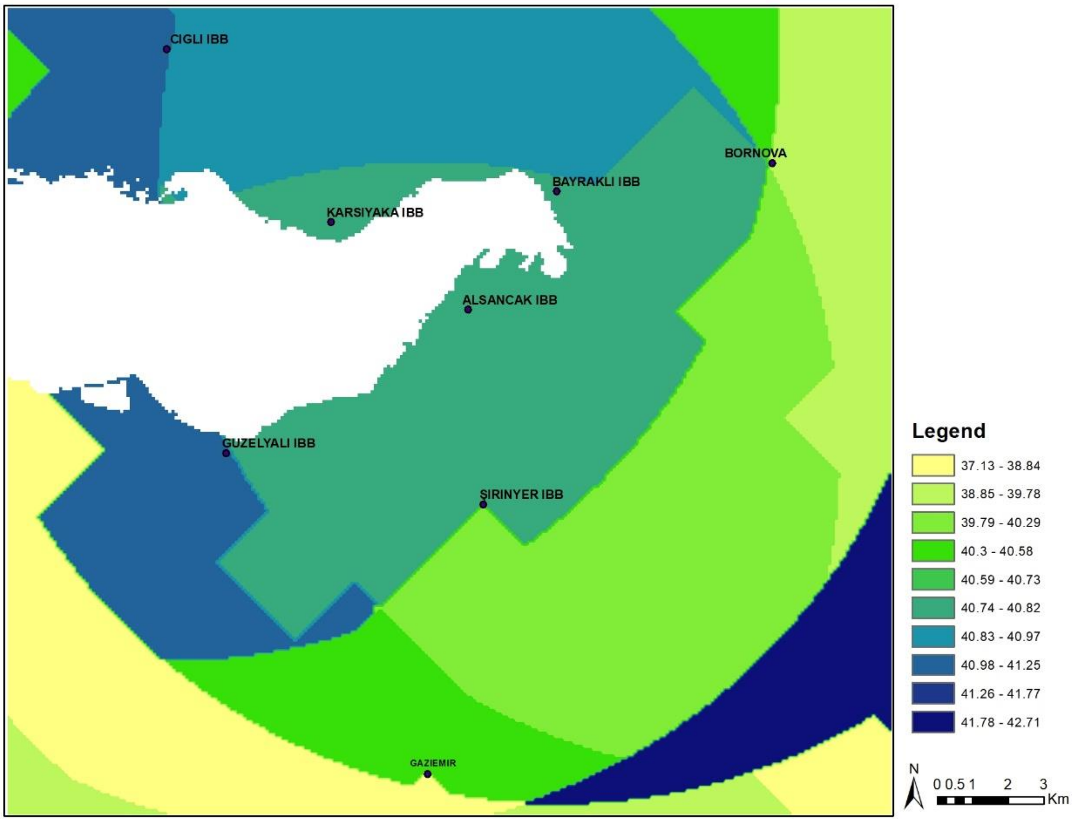


Figure 4.18 Spatial Distribution of PM10 Pollutant in 2018-2019 Winter Season

The air quality estimation surface demonstrates that the spatial distribution of PM_{10} concentration has changed. The PM_{10} emission has diminished considerably in Alsancak, Bayraklı, Karşıyaka, Şirinyer and Çiğli after nine years. The decrease in PM10 levels can be observed as high as 22 µg/m³. However, the highest value of PM_{10} emission was monitored again in Bayraklı station. Although it was significantly less than the value measured in 2009-2010, it exceeded the limit value set for protecting human health and environmental sustainability (50 µg/m³ annual mean). On the other hand, in Güzelyalı the PM_{10} concentration level has increased. The highest level of PM_{10} increase is observed 14 µg/m³. The estimations show that almost all area meets the PM10 standards in 2018-2019 estimations. When two spatial patterns of air pollution are compared with the extent of the Raster Difference in ArcMap, the changes is seen in figure 4.19.

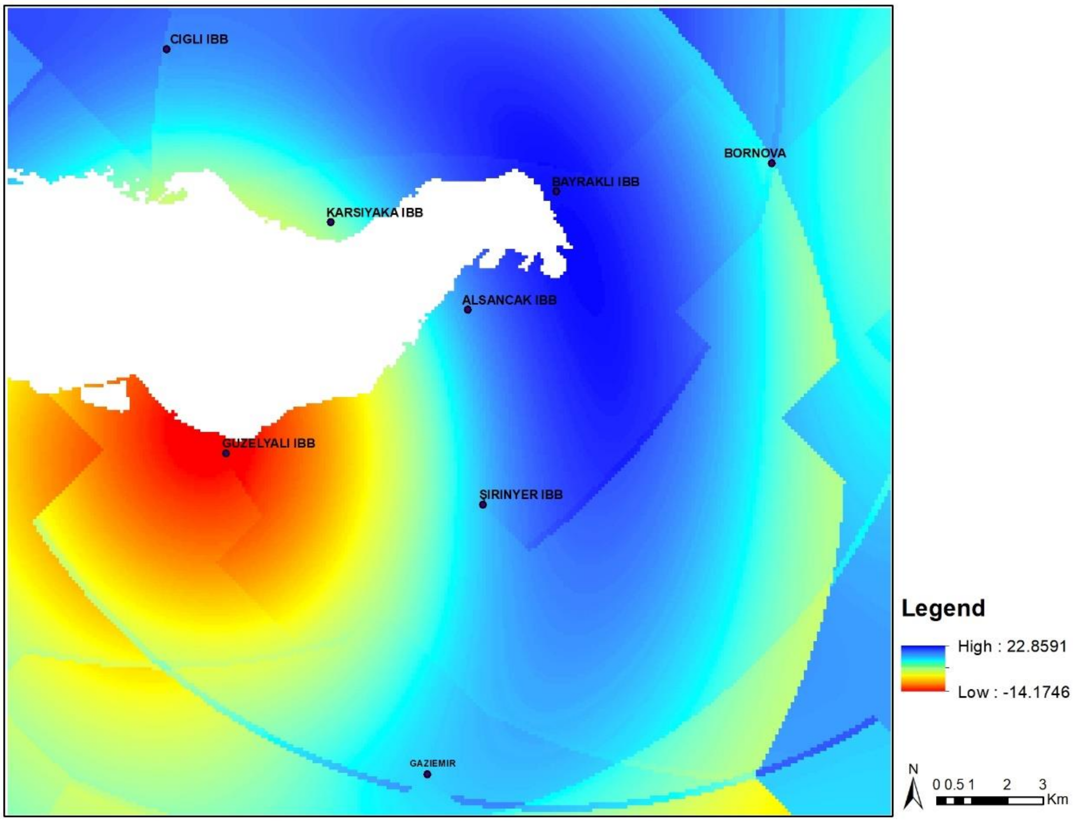


Figure 4.19 Decrease in Air Pollution in terms of the differences of the PM_{10} Emissions between 2009-2010 and 2018-2019 Heating Season

It is observed that from the 2009-2010 winter season to the 2018-2019 winter season, the spatial distribution of air pollution has decreased throughout the city. PM_{10} emissions have significantly reduced around the Bayraklı and Bornova stations located in the northeast of the gulf, Karşıyaka, and Çiğli in the north and Şirinyer and Gaziemir in the southern part of the city.

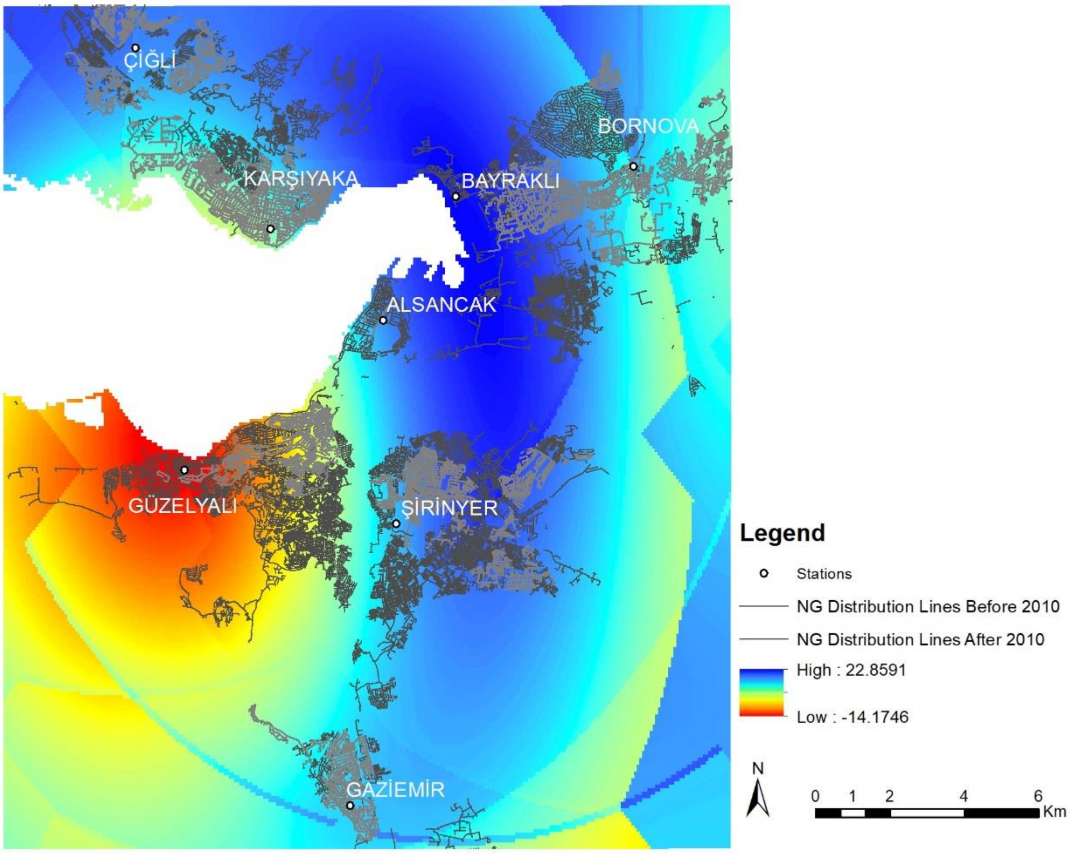


Figure 4.20 Decrease in Air Pollution in terms of the differences of the PM_{10} Emissions and Natural Gas Distribution Lines

The new natural gas distribution lines after 2010 has also supported the diminishing air pollution in the North, East and the Southeast part of the gulf.

However, an increase in the amount of PM_{10} concentrations is observed in Güzelyalı station and its surroundings. However, it still either meets or slightly exceeds the standards (40 μg/m³), thus can be considered as having an acceptable pollution level.

4.5 Further Analysis on the Change in Air Quality Regarding Population Dynamics

Change in air quality can be affected by population change. Regarding that, the population change in districts between 2010 and 2018 is analyzed. The total metropolitan area population increased by 5.75% from 2010 to 2018. While the population living in the metropolitan area constituted 70.5% of the total population in 2010, this share declined to 68.2% in 2018 (TUIK, n.d.). When the investment years are considered, it is observed that 72% of the distribution line and 67% of the transmission lines were constructed after 2010 out of the 2005-2018 investment period.

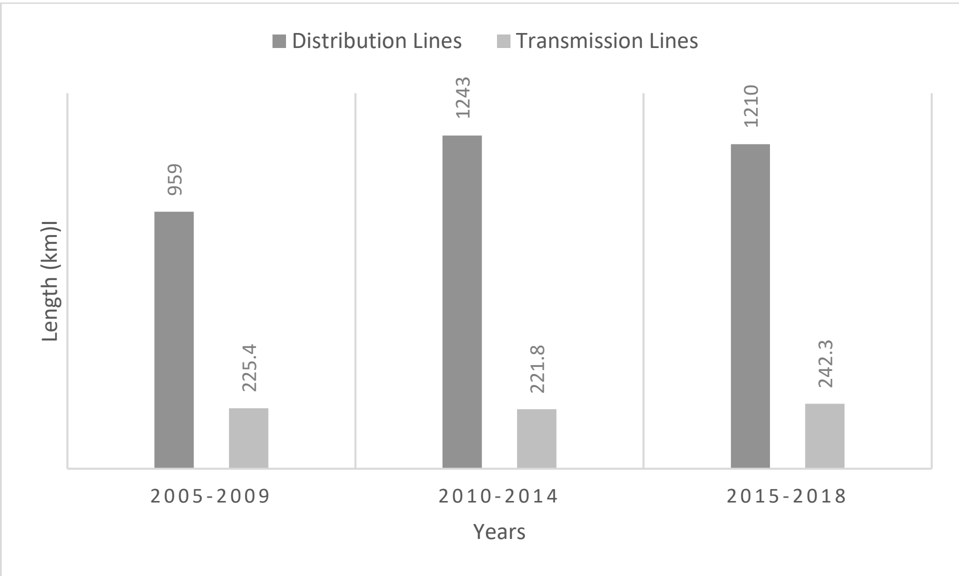


Figure 4.21 Length of Natural Gas Transmission and Distribution Lines (İzmir Gaz, 2018)

A decrease in population is observed only in Konak (-12.09%) and Narlıdere (-9.10%) districts (Figure 4.22). The decrease in population is expected to be parallel to the reduction of the air pollution. Nevertheless, the impact of the expansion of natural gas pipelines on air quality should not be ignored. As of 2018, the total length of the distribution line was 3412 km and the transmission was 689 km. Moreover, although population increased in the remaining districts, air pollution concentrations decreased in the overall between the two periods except for Güzelyalı area.

The investment of natural gas distribution lines had started in 2010 in Narlıdere and the total length of the distribution pipelines had reach approximately 78 km in 2018. However, there is not any air pollution monitoring stations in or around Narlıdere area, and the district is beyond the range value, thus, ignored in terms of the effect of natural gas investments in air pollution.

In Konak, on the other hand, the natural gas investments started in 2005, but 76% of total natural gas pipelines length had expanded after 2010 and reach approximately 18 km in 2018.

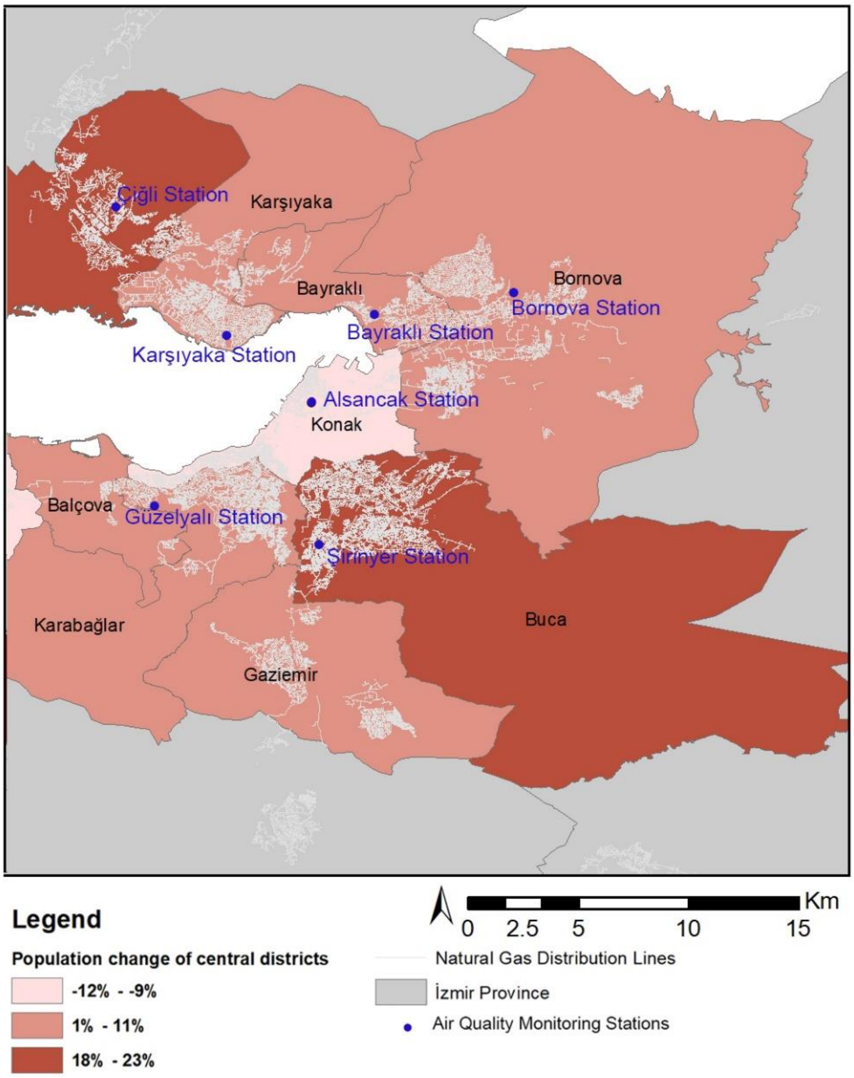


Figure 4.22 Population Change From 2010 to 2018 in Central Districts (TUIK, n.d.)

It is worth to discuss Kadifekale case in Konak, which might have been contributed to the decrease in air pollution, apart from natural gas investments. In addition to expansion of natural gas pipelines, İzmir Greater Municipality has expropriated Kadifekale and its surrounding region (48 ha) which is located close to Alsancak air monitoring station in Konak of which average daily PM_{10} emissions decreased by 21.6 µg/m³ throughout the study period (Figure 4.22). Since Kadifekale had been a squatter settlement prior to the expropriation, it could be expected for the area the extensive use of coal. After the clearance of the area, both the decrease in population pressure and the cease in the use of low-quality fuels are likely contributed to the decline in PM_{10} concentrations.

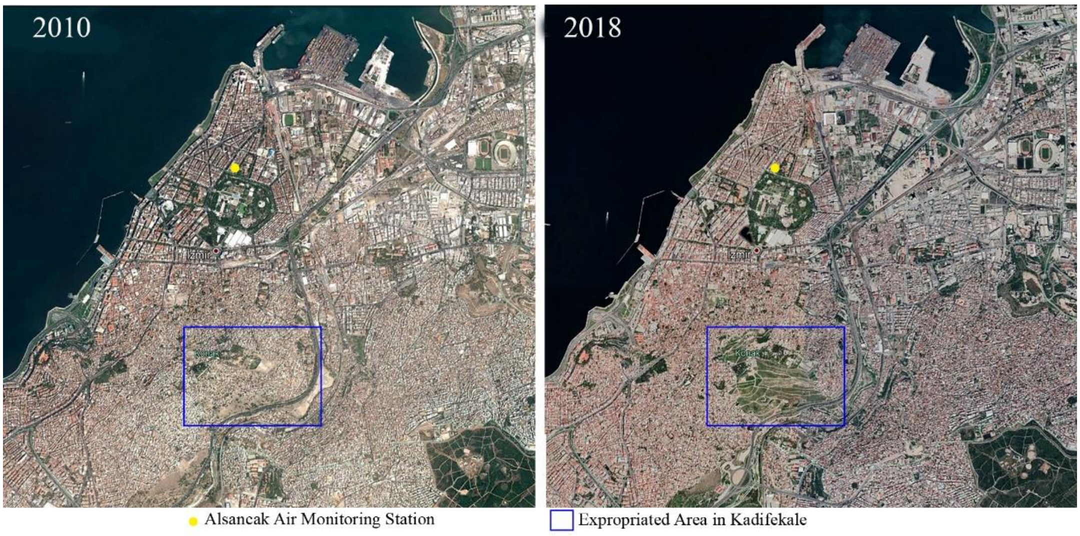


Figure 4.23 Expropriated Area in Kadifekale (Google Earth Pro, 2010& 2018)

In the remaining districts of the metropolitan area, however, population increased to a certain extent, and in spite of that increase, air pollution decreased over time.

In Bayraklı, even though the population has increased 1% from 2010 to 2018, the natural gas distribution lines' total length increased by 59%, and air quality increased. The station that average emissions decreased the most is Bayraklı, where winter season average PM_{10} emissions reduced significantlyfrom 2009-2010 until the 2018-2019 winter season.

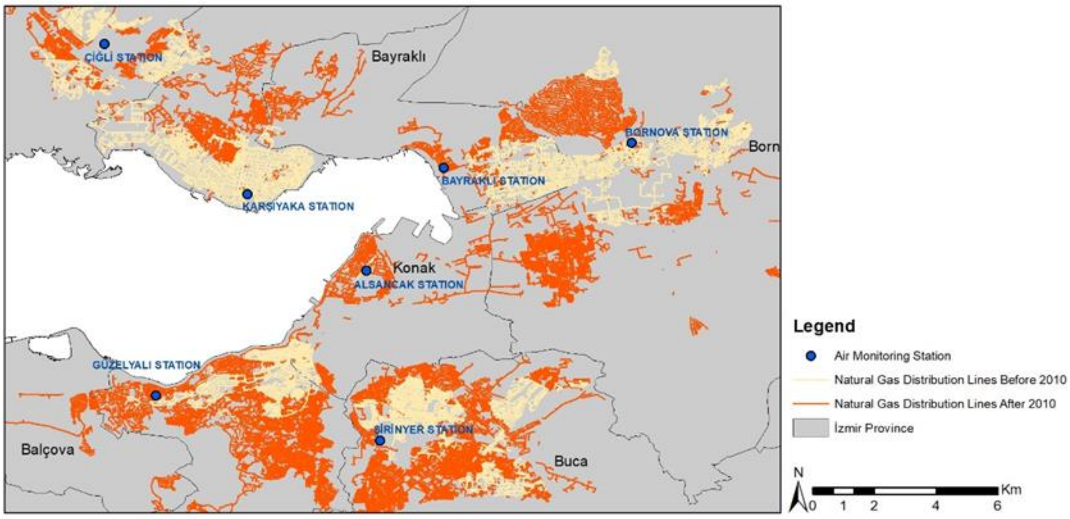


Figure 4.24 Natural Gas Investments after 2010 and Air Monitoring Stations

Winter season average PM_{10} emissions reduced approximately 18 µg/m³ in Şirinyer and Karşıyaka station. In ten years period, the population increased in Buca (18%), where the Şirinyer air monitoring station exists and Karşıyaka (10%), where Alsancak station exists, PM_{10} emissions have reduced. From 2010 to 2018, the natural gas distribution lines' total length increased 72% and 41% and reached approximately 479 km and 284 km in Buca and Karşıyaka districts, respectively. It can be interpreted that, despite population growth in metropolitan area, air pollution has decreased likely with the contribution of the extension of natural gas lines.

CHAPTER 5

CONCLUSION

5.1 A Summary of Thesis

Due to the multi-dimensional aspects of energy investments; economic, social and environmental impacts of the natural gas service are studied for İzmir in this study. Investigating whether natural gas is economically preferable, socially equitable and environmentally friendly in terms of sustainability of the energy services have been the main concerns of the research.

Initially, energy and energy systems for human life and urbanization process are discussed and energy usage fields are examined considering its fundamental relation with the human needs. It is observed that energy is an indispensable requirement in human life and has multi-dimensional impacts.

Second chapter includes literature review that analyze the economic, social and environmental dimensions of natural gas network investments as a type of urban energy system. Natural gas can be used in the residential sector, transportation, industrial activities, and produce electrical energy. In the first section of the literature review, the factors that depend on the amount of energy used in residences and the conditions influencing the household’s energy consumption behavior have been discussed. Then, under the equity of energy title, energy justice, energy poverty, and energy vulnerability concepts have been discussed respectively. Recognizing the energy needs of different groups in the society, deciding how and when these energy needs are distributed, and the spatial distribution of the service are three essential stages defined to ensure energy justice. Then, what makes people fuel poor and how fuel poverty can be measured are discussed. Lastly, energy vulnerability notion is examined. The situations that face households with energy deprivation and who constitute vulnerable groups are asserted.

The following chapter explains the development of the urban settlement from the ancient period until now in İzmir. How urban settlements areas expanded with the impact of the industrialization after the foundation of the Republic of Turkey and how rail ways and industrial region affected these settlement and population movements are highlighted, and the relationship among urbanization, industrialization and energy needs are critically discussed. Then, the development of natural gas investments in Turkey and Izmir the study area are summarized. Natural gas is a relatively new urban energy investment in İzmir, and the service provision has been expanded in larger geographic area throughout time.

The fourth chapter covers three sub-sections where analyses have been made to examine economic, social and environmental effects. In the first section, nine different fuel types; geothermal energy, natural gas, lignite, import coal, fuel oil, wood, LPG and diesel fuel using for heating purposes were handled and annual heating costs for each fuel type was calculated. It should be noted that geothermal energy is available in a particular area, rather than the whole province. In the second section, according to the calculated annual costs, the tendency of being fuel poor is calculated with the help of 10% fuel cost ratio indicator. In the last section, the spatial distribution of PM_{10} emissions is estimated by Kriging method for the 2009-2010 winter season and 2018-2019 winter season. Then, the difference of the interpolated surfaces of two periods is calculated to demonstrate the spatial distribution of PM_{10} emission changes.

5.2 Reflections of the Findings

As a result of the analysis of the economic, social and environmental impact of the natural gas in İzmir, following outcomes can be identified as the main findings of the study:

First, natural gas is the second most economic fuel types for domestic heating, hot water and cooking among the other fuel types. The residential heating cost of natural gas is respectively 2, 3 and 4 times cheaper than imported coal, fuel oil and electricity, which are the most commonly used fuels. Moreover, wood, LPG and diesel are more expensive than these fuels for heating. Although geothermal energy is cheaper than natural gas, it is available in a limited area in İzmir. Only 2% of the total population of İzmir can benefit from this service, including some parts of Balçova and Narlıdere districts (İzmir Geothermal Energy, 2019). On the other hand, natural gas service has become more accessible since 38.5% of the population has access to natural gas in residences in İzmir by 2019.

Considering the annual heating costs, investment costs, and accessibility of all fuel types, natural gas is more cost-effective and accessible than the other fuel types. It appears that there is less burden on household budget when natural gas is preferred in residential use. Hence, it can be concluded from the domestic heating cost analysis of different fuel types that natural gas is economically more advantageous over other fuel types in terms of costs, accessibility and efficiency.

Second, the proportion of fuel expenditure calculated with the help of income and heating costs in the household budget has shown that households tend to be fuel poor if fuels other than geothermal, natural gas, and lignite are used for domestic heating. The spatial distribution of the fuel poverty by the count of fuel types (Figure 5.1) demonstrate that only 1% of all the neighborhoods would be fuel poor if geothermal energy, natural gas or lignite coal were used throughout the survey area. However, it should be noted that geothermal energy is not available apart from the Balçova and Narlıdere districts as mentioned before, and lignite, which is the third cheapest fuels, is less environmentally friendly due to its high sulfur rate, content of ash and low heating value.

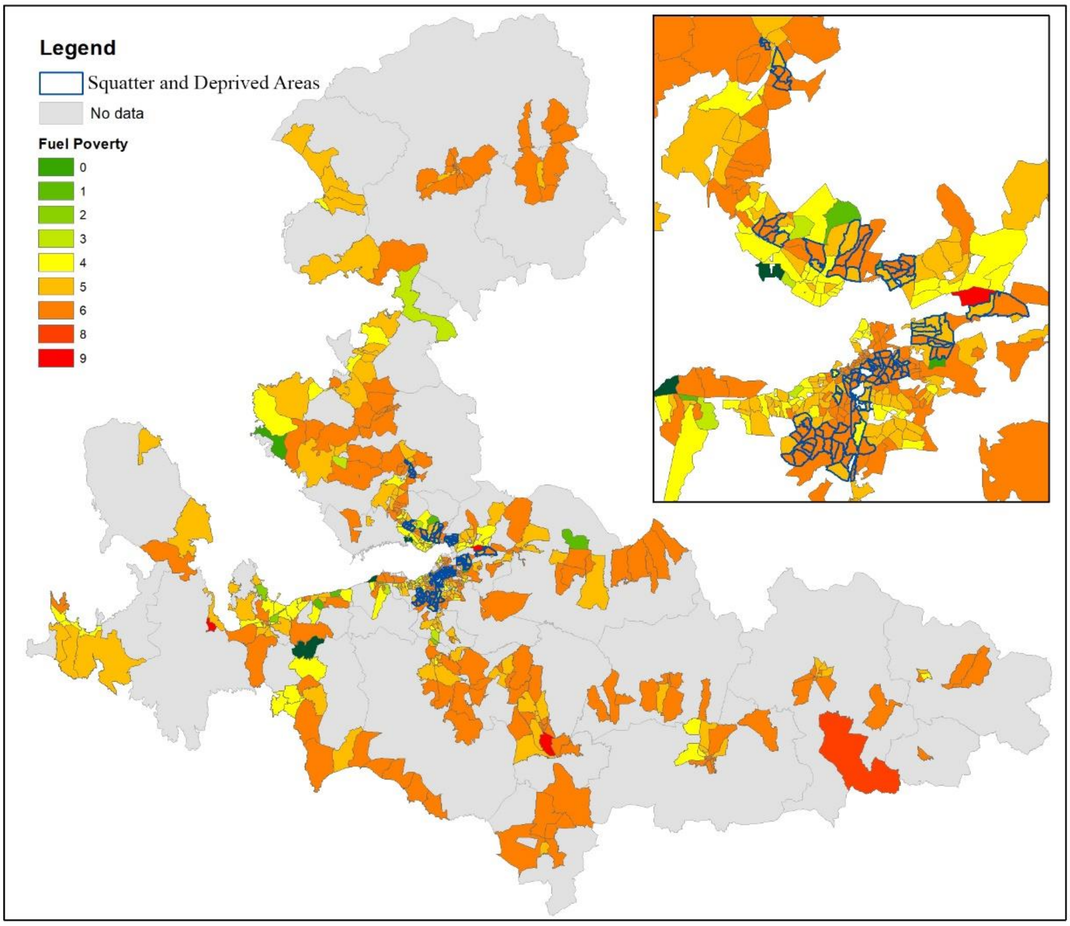


Figure 5.1 Fuel Poor Neighborhoods by the Count of Fuel Types

Natural gas service is not provided in squatter settlements and deprived areas (Figure 5.2) due to being potential urban transformation areas and associated safety concerns. Squatter settlements were developed in an unauthorized way where the physical conditions have been poorer and the average incomes of the residents have been lower when compared to other neighborhoods. The areas would likely have a new street pattern when urban transformation is realized, so it is not rational to build a gas grid in advance. But, if the natural gas was provided in these areas, the tendency of fuel poverty would decrease.

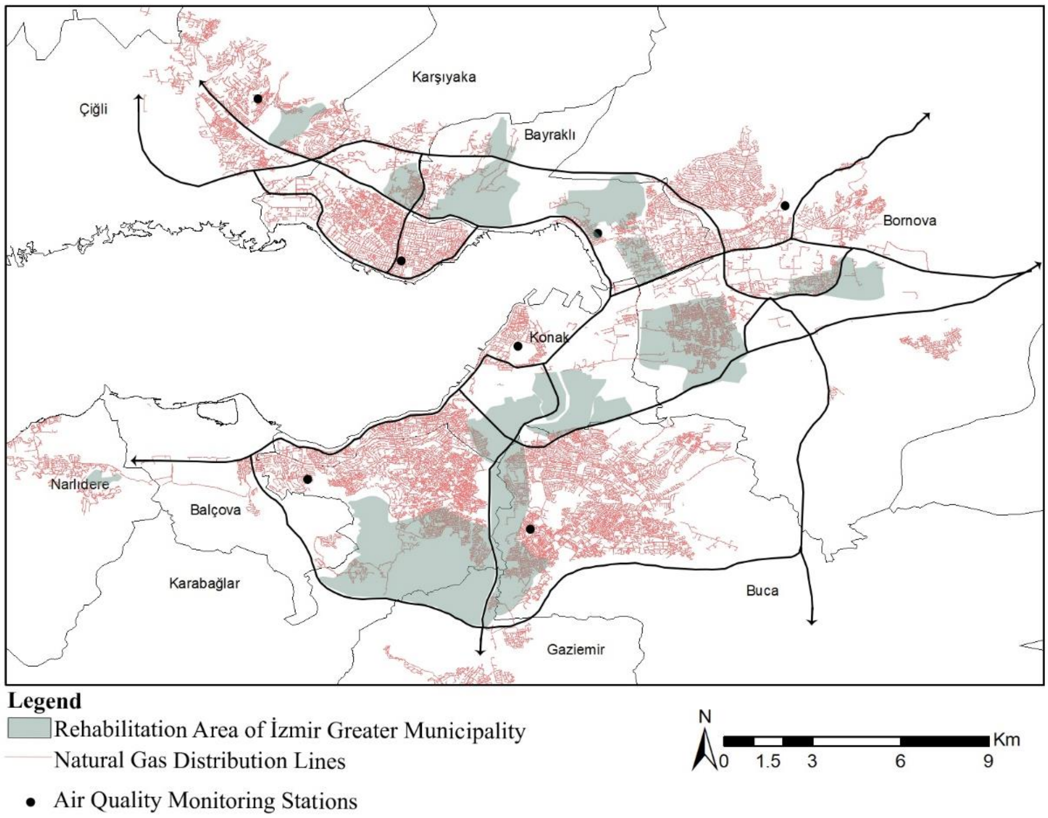


Figure 5.2 Rehabilitation Areas in Metropolitan Districts (İzmir Greater Municipality,2009 & İzmirGaz, 2018)

Bayraklı, Balçova, Bornova, Buca, Çiğli, Gaziemir, Güzelbahçe, Karabağlar, Karşıyaka, Konak and Narlıdere constitute the metropolitan area of İzmir. 67% of the total İzmir province population lives in the metropolitan area and all districts receive natural gas service. However, illegal housing, deprived areas and unauthorized buildings are also present in some of the neighborhoods of the metropolitan area. According to 1/25 000 İzmir Master Plan (2009), 4099 ha area has been declared rehabilitation area by İzmir Greater Municipality, to prevent illegal housing, to prevent urbanization in areas declared endangered to disasters, and to provide sustainable urbanization. Different urban transformation solutions have been proposed for these areas. (İzmir Greater Municipality, 2009).

In Izmir, natural gas is served to approximately 685000 residential subscribers, but those who tend to be fuel poor are clustered in mostly squatter areas, and they are destitute of natural gas services. However, this is directly related to the status and the physical conditions of their neighborhoods. These developments have occurred independently from the planning process. Natural gas is an explosive dangerous energy investments and it is important considering the security of natural gas distribution for public safety. Poisoning from an appliance or flue problem, incidents and explosions due to gas leakages from the pipes in buildings are some probabilities that may causes accident and die (Church & Winckles, 2005). Investors have to take into consideration of these risky conditions. Thus, it could not be directly stated that energy justice is not provided in purpose. Safety is another concern in investment decisions, so that the squatter settlements and physically declined areas are not included in natural gas system expansion plans. However, natural gas can still be considered as the most economic and accessible fuel type in study area, so in case of a transformation is realized, they should be considered in potential investment projects.

Lastly, the comparison of the levels and the spatial distributions of the interpolated air pollution concentrations show that PM_{10} emissions declined within a decade at the overall, after the natural gas service provision started. Since air pollution is linked not only to the residential heating but also traffic and industrial production, PM_{10} is considered as the most related pollutant to the residential heating. Nevertheless, in overall the air pollution has decreased over the years.

Kriging analysis, which provides an interpolated data surface as well as an error surface based on observation points, is utilized to demonstrate spatial distribution of air pollution before and after the natural gas provision has become widespread and physically available in a larger area in İzmir. The results demonstrate that air pollution levels decreased in the metropolitan area over time except for the surrounding area of Güzelyalı air monitoring station. From 2009 to 2018 the air pollution decreased and emission values got close to the limit values. Even in

Güzelyalı area, the estimations either meet or slightly exceeds the limit value of 40 $\mu g/m^3$.for PM_{10} concentrations.

It demonstrates that the use of natural gas in residential heating contribute to the improvement in air quality. The analysis and discussions made throughout the study provided a foothold to show the importance of the energy in residential sector.

For these reason it can be concluded that natural gas has come to the fore as preferable fuel type that is more economic, accessible and less pollutant.

5.3 Limitations of the Study

It is important to mention the limitations of this study. First of all, measure of fuel poverty has some limits. Although fuel consumption depends on the socio-demographic factors such as family composition, marital status, occupancy and socio-economic factors such as employment status, housing tenure, income and lastly housing conditions such as dwelling age, energy saving measurements practically, these factors are neglected due to the lack of data in this study. Instead, unit consumption is assumed for the households while calculating the fuel poverty rate. All households are assumed to have 8 million kilocalories to heat, uniformly.

The fuel costs calculated for different fuel types for annual heating are not how much they actually spend for heating but the required energy to achieve an acceptable level of warmth. Charlier and Legendre (2018) emphasize that there is significant differences between the observed and the expected amounts of fuel consumption. Theoretical fuel costs ensure that the adequate level of warmth achieved by households is subject to a range of dwelling and household characteristics. However, it is not guaranteed that the households would pay this amount, or they might even not prefer to cover such costs. The differences between the required and spent energies indicates that households make concessions on their thermal comfort, thus their fuel poverty may not be precisely measured. In this study, income information is available for a limited area not for the whole province

Moreover, pollutant emissions are received only from eight monitoring stations out of twenty-two, since the remaining stations do not monitor and record pollutant concentrations regularly. Hence, pollution interpolations are done to expand the study area, yet the surface the estimation surfaces cover a limited area where monitoring stations with regular observations are present.

5.4 Recommendation for Future Research

It should be emphasized that there are several difficulties in achieving a reliable database for the actual energy consumption of households. It is considered essential to highlight the restrictions that should be improved for further studies using a similar methodology.

For the future research, it would help to get more sophisticated results with detailed information related to householders' energy consumption behavior and their house characteristics. It is also recommended that more observations with increased number of monitoring points would give more reliable results for estimating pollution patterns.

Last but least, although natural gas is more economical and less polluting than other fossil fuels, it is not a local and a renewable resource. Thus, this study can be expanded within the framework of local and renewable energy alternatives.

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