Research Article

ENERGY SYSTEM MODELING IN URBAN SCALE: CASE OF ÇANAKKALE[1*]

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ABSTRACT

As a result of the rapidly increasing urbanization in the last decades, 55% of the world population lived in cities in 2018. While this rate is approximately three-quarters of the total population in the European Union (EU), it is expected that by 2050, approximately 85% of the EU population will live in the cities. As a result of this rapid population increase in cities, the number of regions with relatively high energy needs is increasing. Being able to provide this intense energy need without interruption in cities also increases the importance of city-scale energy modeling studies. The case city of this study is Çanakkale, which is located in western Turkey, it has over 500 thousand of the population and a great potential for renewable energy production. In this study, a detailed Reference Energy System (RES) was created by determining the sources, process and conversion technologies, demands, energy carriers, and demand technologies of Çanakkale. Then, by collecting data, a base scenario and alternative scenarios were developed with Answer-TIMES. "20% More Efficient Technologies" and "Shutdown of Lignite Power Plants" are alternative scenarios of this study that are tailored from the base scenario.

Keywords *Energy Modeling, Answer-TIMES, Urban Scale Modeling*

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1. INTRODUCTION

It is becoming more difficult to manage the energy needs of regions, where there is a dense population in small areas. Being able to provide this intense energy need without interruption in cities also increases the importance of city-scale energy modeling studies.

Due to the rapid development of technology, electricity generation from renewable energy sources has become relatively more cost-effective than conventional power plants. The fact that renewable energy sources are inexhaustible, economic and most importantly not damaging ecological balance by following an environmental production method has led to the emergence of the concept "100% Renewable Energy ". When it comes to 100% renewable energy; a process that depends on renewable sources, does almost no damage to the environment and greenhouse gas emissions are close to zero and do not use any fossil fuels to produce energy.

In recent years, many countries have created renewable energy action plans, both because it is becoming feasible and because of its local and global environmental contributions. These countries have begun to set achievable targets with these local or national energy action plans and increase the share of renewable energy in energy production. Many projects, which are mostly prepared by local governments for the transition to 100% renewable energy on an urban scale, are progressing confidently within the framework of the plans created.

Energy modeling studies can show us the results of all scenarios that will be created by modeling regions where alternative sources are added to the system, where production with fossil resources is stopped, and even with the potential to produce energy with fully renewable resources. Various energy modeling tools can be used in such an action plan. These tools can be selected from dozens of programs according to the model to be installed and the desired results. In this study, the Answer-TIMES program was selected as the most appropriate modeling tool for the case city. Technologies, commodities and commodity flows are three types of assets that the TIMES energy model includes.

In this context, the chosen city was examined from a minimal cost and environmentally friendly perspective. The case city of this study is Çanakkale, which is located in western Turkey, it has over 500 thousand of the population and a great potential for renewable energy production. The city, which has a high potential for wind and solar energy in particular, already houses many renewable and fossil power plants. The city, which imports a large part of the electricity (Turkey's most industrialized cities, centers and metropolises are very close, and more than 26 million people live up to 400 kilometers away) generated from all these sources, has an important share in meeting Turkey's electric energy needs. In this study, a detailed Reference Energy System (RES) was created by determining the sources, process and conversion technologies, demands, energy carriers and demand technologies of Çanakkale. Then, by collecting data, a base scenario and alternative scenarios were developed with Answer-TIMES. The base scenario is based on 2016 data. A time horizon beginning in 2016 and ending in 2030 was deemed appropriate for the study. When the current situation (base scenario) is continued, alternative scenarios have been created by examining the changes in the balance of energy production and consumption of the city and the total cost of the system in 2030. In addition to the base scenario, 2 different alternative scenarios have been created that address different perspectives. These scenarios are: "closure of lignite power plants" and "20% more efficient technologies"

In the first section, general information about the importance of city-scale energy modeling, the chosen city and the method used for this study are given. Section 2 describes the methodology and development of the TIMES-Çanakkale model, also the assumptions of scenarios. Results of the base scenario and alternative scenarios are discussed in section 3. And the conclusion of the study is given in section 4.

2. MATERIAL AND METHODS

2.1. ANSWER-TIMES

Answer-Times is an energy system modeling program that enables the creation of economic models for energy systems of various sizes with a rich technology base to show the change in energy supply and demand over a specified time period. With Answer-TIMES, models can be created to analyze the entire energy system or single energy line on a large scale from local to global. In order to produce a reference scenario in the program, the current energy sources/stocks and technologies as well as potential resources and technologies, end-user energy demands and estimations must be provided by the user. [2]

Answer-TIMES is a mouse-controlled, visual-based and interactive windows operating system interface developed to increase the understandability and usability of any TIMES energy system model. [3]

Energy system modeling with Answer-TIMES has a complex structure. The collected data are entered into the TIMES model generator program by the researcher using the Answer-TIMES interface. Modeling is optimized and solved in TIMES by GAMS and other solvers to create suitable solutions for different scenarios predetermined by the researcher. Finally, suitable solutions for end-user evaluation and the feasibility of the scenario are displayed through the Answer-TIMES interface. [2] [3]

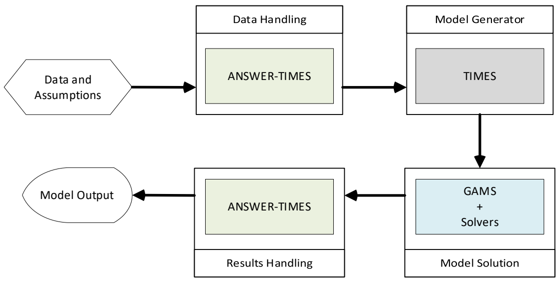


Figure 1. Mechanism of Answer-TIMES with TIMES Energy Model. [4]

Four different input types are required for any TIMES model: energy sources, energy demands, process&conversion technologies and current energy policies. [2]

2.2. DEVELOPMENT OF BASE SCENARIO FOR ÇANAKKALE

2.2.1. CASE CITY; ÇANAKKALE

Çanakkale, located in the northwest of Turkey, in the region of Marmara, located in between 25° 40′ - 27° 30′ east longitude and 39° 27′ - 40° 45′ north latitude. It has a total length of 671 km along the Marmara and Aegean Sea coasts. [5] Çanakkale Province has an area of 9,817 km² and a population of 519,793. Population density is 52 people per km² according to 2016 data. While the urbanization rate of the city is around 59.28%, its population is expected to reach 836,290 people in 2040. [6]

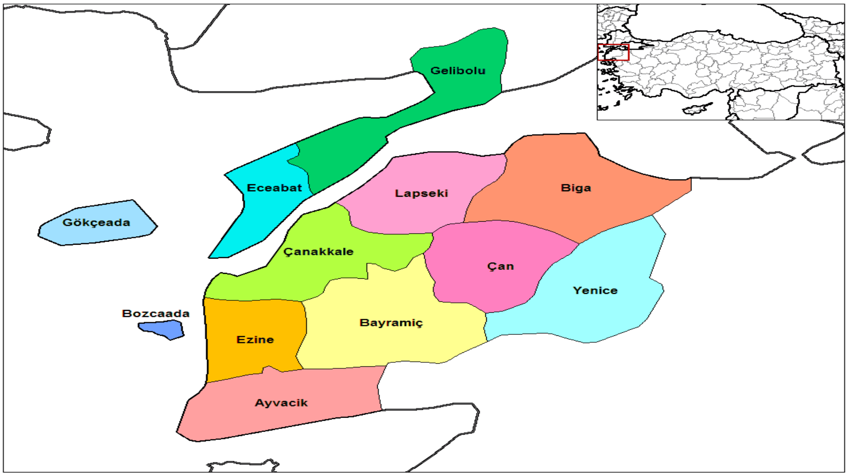


Figure *2*. Map of Çanakkale. [7]

Çanakkale, which has 2 airports and 5 ports, is close to many metropolises and industrial zones. The city also has a high potential for many renewable energy sources such as solar, biomass and wind. [5] [6]

2.2.2. DATA COLLECTION

The data needed for the Answer-TIMES energy model of Çanakkale was collected as a result of one-on-one interviews with the city's institutions and organizations (Provincial Directorate of Agriculture and Rural Affairs, Chamber of Industry, Special Provincial Administration, Çanakkale Municipality, electricity distribution company, non-governmental organizations, chamber of electrical engineers, etc.). Besides, data announced by institutions such as the Ministry of Energy and Natural Resources were used. The World Bank's forecast was used for the rate of economic growth and population growth projections are based on the statistical agency of Turkey. All data refer to 2016.

2.3. REFERENCE ENERGY SYSTEM

The TIMES energy model includes three types of assets: technologies, commodities and commodity flow. Technologies, which can also be called processes, include tools, devices or methods that transform goods into other types of goods. Commodities: It includes goods, energy providers and carriers, emissions and money flows. Commodity flow refers to the link between technologies and commodities. The diagram showing the relationships between technologies, commodities and commodity flow is called the Reference Energy System (RES). [2]

As shown in Figure 3, RES contains six columns. The first column contains the sources showing all the energy resources of the region. The second column shows the primary energy carriers, while the third column shows the process and conversion technologies. The fourth column indicates the final energy carriers and the fifth column indicates the demand technologies. Finally, the sixth column addresses the demand groups.

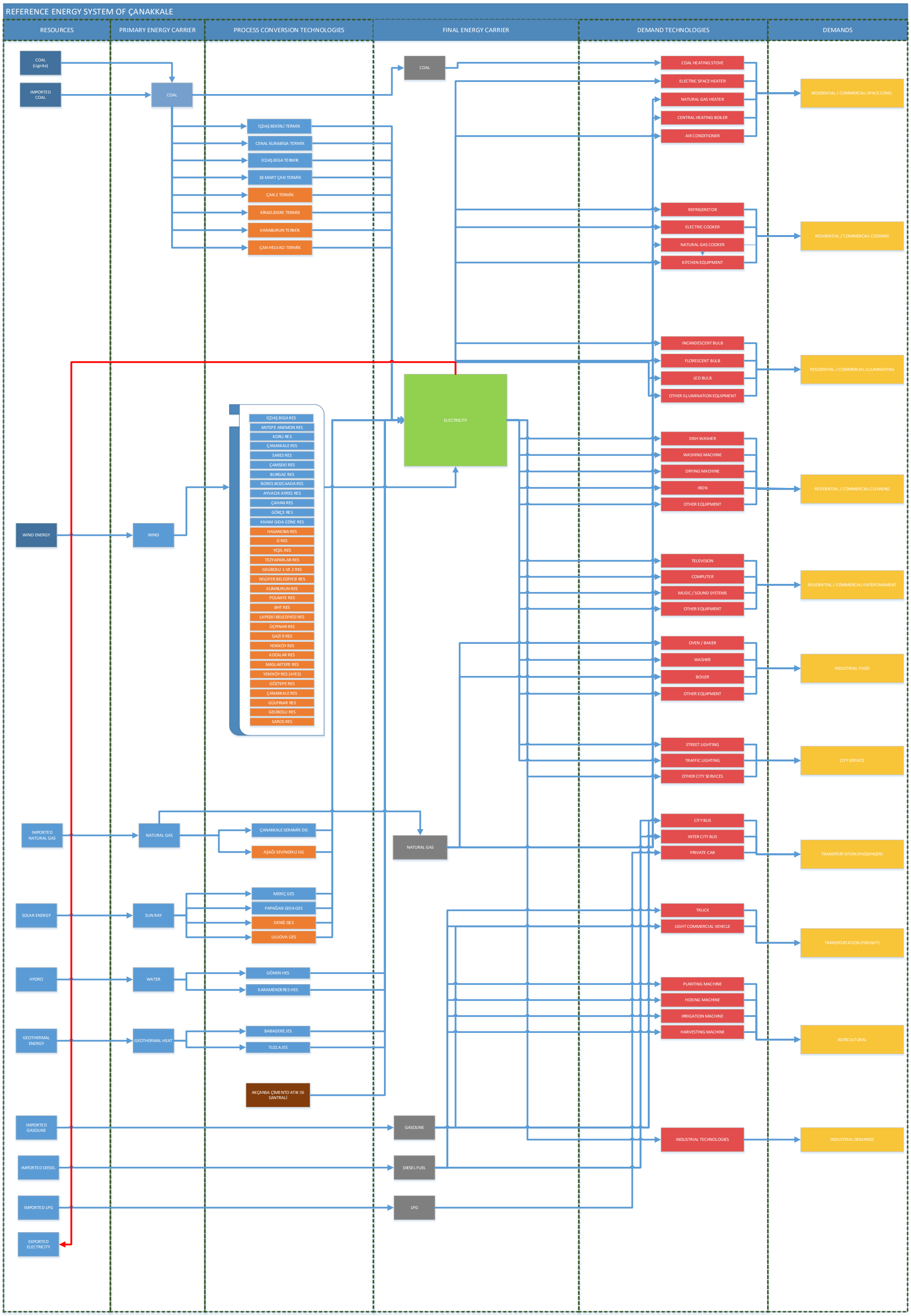


Figure 3. Reference Energy System of Çanakkale Province

2.4. DESCRIPTION OF BASE SCENARIO

To create a base scenario; the collected data, obtained by conducting interviews with various institutions in Çanakkale, information and documents, as well as by using online sources were classified and a data set was created. This data was entered into the database step by step and the base scenario was created. In short, the base scenario expresses the equivalent of the current situation of Çanakkale in 2030 as a result of the increase in energy demand due to the projected population growth and economic changes.

3. ANALYSIS OF THE SCENARIOS RESULTS

3.1. BASE SCENARIO

The base scenario is based on the reference energy system shown in Figure 3. In the figure, process-conversion technologies shown in column 3, the power plants are shown in blue represent the power plants currently in production. The orange ones are the plants that are planned to start production after 2016. The scenario was created in such a way that these plants will start production in the planned year. In the base scenario, our time horizon starts from 2016 and continues until 2030. The years 2020 and 2025 were determined as the years in which intermediate results were obtained and 2030 was the year in which the last results were obtained. Results are in millions of dollars (million $) and petajoules (PJ).

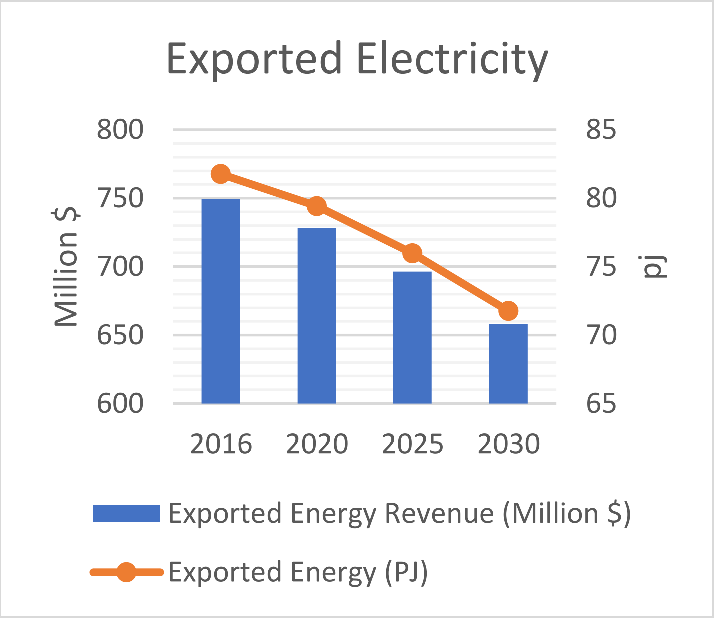


Figure 4. Base Scenario Exported Electricity Values.

As can be seen in figure 4, while the energy exported by the city decreased by approximately 10 petajoules by 2030 in the base scenario, the gain from the energy it exports decreased by approximately 90 million dollars accordingly. The reason for this is that despite the projected growth rate of 4%, the increase in energy production was not enough to meet this consumption. The energy needed by the city is higher in 2030 compared to 2016, and the share used by it has increased.

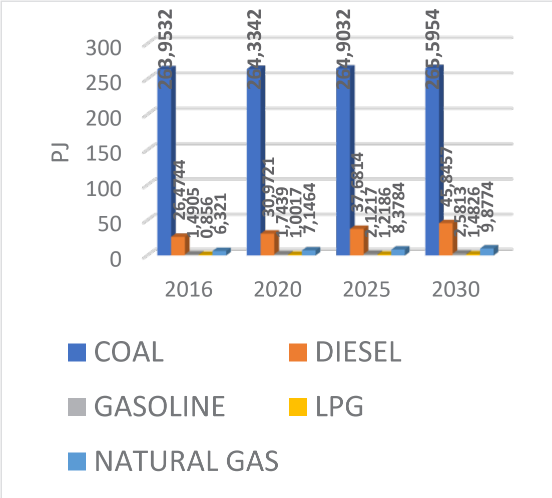


Figure 5. Base Scenario Imported Fossil Resources (PJ).

Figure 5 shows the imported fossil energy resources in terms of petajoules over the years. In the established model, while there is no significant increase in the production of coal plants over the years, there is a significant increase in the exports of other fossil resources due to the increase in demands.

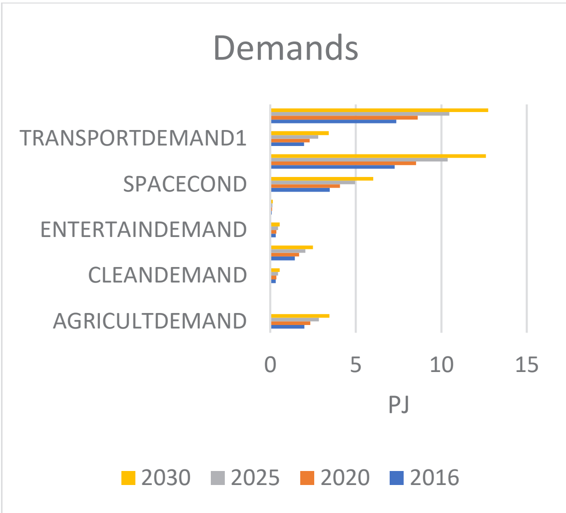


Figure *6*. Base Scenario Demands (PJ)

Figure 6 shows the change in demands. For example, the increase in transport and industrial demand has nearly doubled in 2030. These demand increases are also the main reason for the increases in fossil resource exports in the previous figure. For example, the increase in transportation demand is the main reason for the increase in diesel fuel requirements.

3.2. ALTERNATIVE SCENARIOS

3.2.1. SHUTDOWN OF LIGNITE POWER PLANTS SCENARIO

In this scenario, it is envisaged that 2 lignite-sourced fossil power plants in Çanakkale will be shut down until 2030. The total installed power of these closed power plants is 550MW.

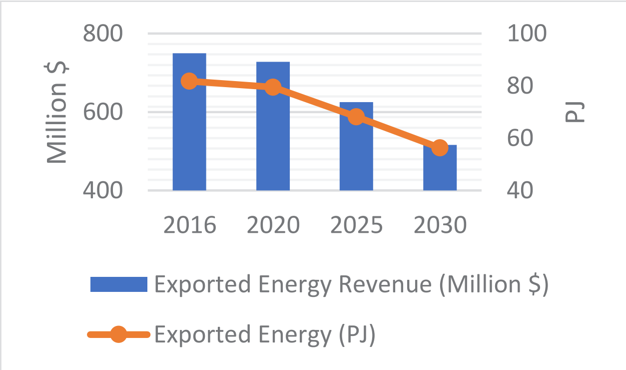


Figure 7. The shutdown of Lignite Power Plants Scenario-Exported Electricity Values.

As can be seen in figure 7, closing lignite power plants without any generation plants placed in their places significantly increases the cost of the system compared to the base scenario. Because the energy exported has decreased, and as a result, earnings have decreased by about 140 million dollars.

3.2.2. 20% MORE EFFICIENT TECHNOLOGIES SCENARIO

In this scenario, it is aimed to examine the effects of energy efficiency in houses on total consumption. For this reason, it is foreseen that all electrical devices in the residences will be replaced with 20% more efficient devices.

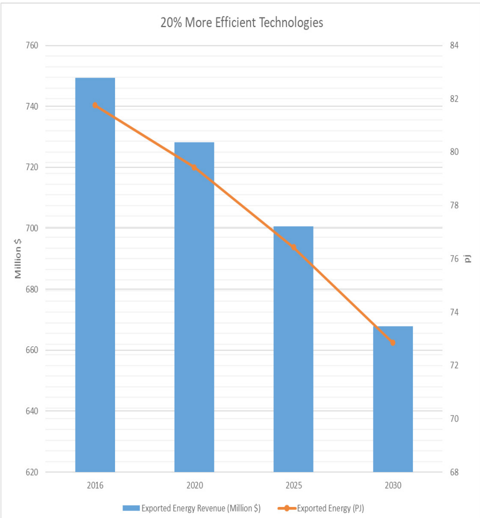
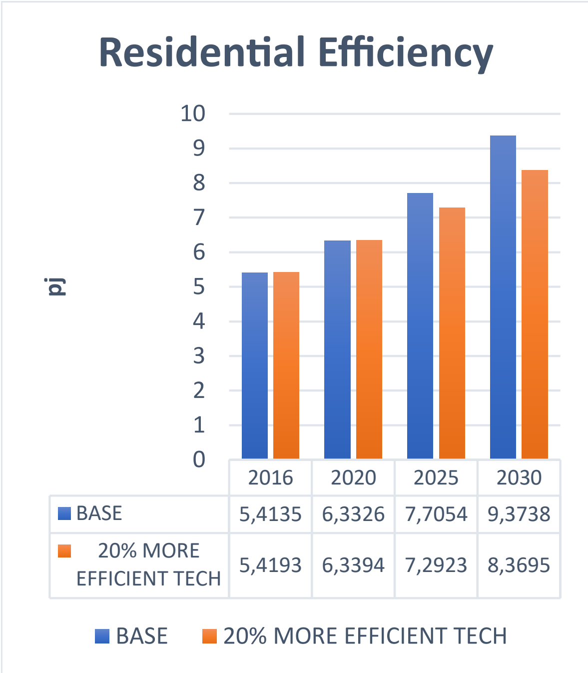


Figure 8. 20% More Efficient Technologies Scenario-Exported Electricity Values.

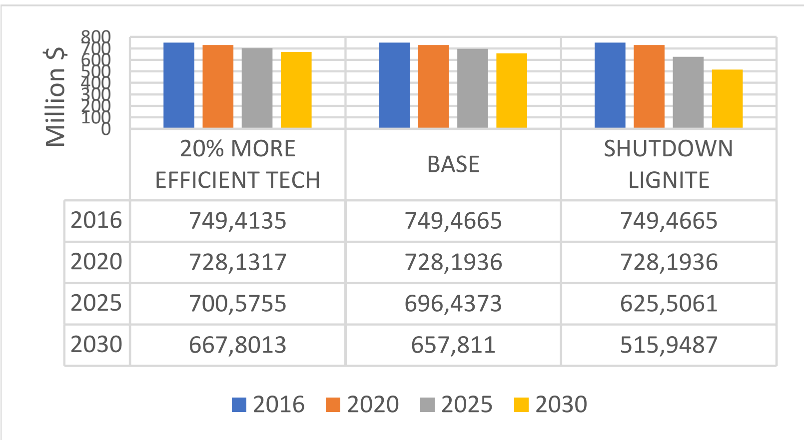
As can be seen in Figures 8 and 9, when devices that consume 20% less electricity are used in houses, an energy saving of approximately 1 petajoule is achieved compared to the base scenario. As a result of these savings, an increase of approximately 10 million dollars has been realized in electricity exports.



	2016	2020	2025	2030
BASE	5,4135	6,3326	7,7054	9,3738
20% MORE EFFICIENT TECH	5,4193	6,3394	7,2923	8,3695

Figure 9. 20% More Efficient Technologies Scenario-Residential Energy Consumption. (PJ)

4. CONCLUSION



	20% MORE EFFICIENT TECH	BASE	SHUTDOWN LIGNITE
2016	749,4135	749,4665	749,4665
2020	728,1317	728,1936	728,1936
2025	700,5755	696,4373	625,5061
2030	667,8013	657,811	515,9487

Figure 10. Exported Electricity

When all three scenarios are compared, as can be seen in figure 10, the model with the highest electricity export is the one in which 20% more efficient technologies are used. In this scenario, by 2030, the amount of surplus electricity has increased, as electricity consumption is less than in other scenarios. In the scenario of shutting down lignite power plants, there was a 550 MW decrease in the installed power, so the biggest decrease in the energy exported occurred in this scenario.

Table 1. Total Imported Fossil Resources Costs for All Scenarios.

	Million $			
	2016	2020	2025	2030
20% More Efficient Technology	864.3445	887.8619	922.9479	965.6411
Base Scenario	864.3445	887.8619	922.9479	965.6411
Shutdown Lignite Power Plants	864.3445	887.8619	862.6003	844.946

From the table showing the value of the total imported fossil resources, it is understood that the base scenario and the scenarios where 20% more efficient technologies are used are the same for fossil resource imports. Total imports for both scenarios increased by approximately 100 million dollars. In the lignite power plants decommissioning scenario, the import of fossil fuel resources decreased by approximately 20 million dollars. This decrease in the import of fossil fuel resources clearly shows that the CO_2 emission will decrease.

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