

Five-Year Energy Consumption Perspective in Iran and Required Scenarios for Its Supply [†]

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Abstract: In this century, with increasing society's population and Gross Domestic Product (GDP) trend, energy demand is increased in the countries of the whole world. Nowadays, the use of different Renewable Energy Sources (RESs) in the network has become commonplace and, of course, has been challenged. In this way, forecasting energy demand plays a key role in the development of different parts of a country. In this study, firstly a prediction of consumption and fluctuations in the sources of energy is made, and secondly, regarding different parts of the industry, agriculture, and households, two different scenarios have been analyzed to provide this demand in the future. An Artificial Neural Network (ANN) method has been used to predict energy consumption level, and also the two factors of the increase in population and GDP have been considered. Prediction of population increase rate, with respect to its statistical complexities, is derived from a literature review of other references; the GDP prediction is derived with a conventional method of the Grey method. Then, with the prediction of the aforementioned factors, energy consumption is predicted by a metaheuristic algorithm. Afterwards, scenarios related to the energy consumption are predicted and priorities are given, such as environmental impacts, in order to provide the predicted consumption level. Scenarios will considerably show that the supply and demand should be managed by fossil fuel energy production replaced with RESs in the supply side, and providing products with higher energy efficiency in the demand side.

Keywords: renewable energy sources (RESs); artificial neural network (ANN); grey method; reference energy system; LEAP software

1. Introduction

Energy is a subset of the economic and social system that has a major impact on the process of economic development. Increasing importance and role of energy in the sectors of production, services, as well as the creation of extensive economic, political and even social interactions, which will result in such things as job creation, increase revenues from energy trade, etc., for the country, growing Economics and the urgent need for energy reflect the need to estimate energy demand. Doing any planning, designing in the field of energy supply, requires full knowledge of energy demand. In other words, the prerequisite for the design and construction of energy facilities is to estimate the amount of demand for those facilities.

Currently, due to the statistics and figures available in the energy sector, as well as the growing problems in the energy sector of the world, the need for modeling and planning in this sector is felt more and more. In the meantime, despite issues such as uncontrolled increase in consumption, limited supply by refineries, increased air pollution in large cities, the need to use clean and renewable energy, prevention of energy loss, saving, energy management in industries, coordination.

With global sustainable development programs to reduce greenhouse gases, expand non-fossil fuels, and reduce the use of underground resources, the importance of this sector is on the agenda.

According to the information available for this project, which is limited to the energy balance between the years 1970 to 2019 and only contains information about the annual production and consumption of different carriers by segments [1]:

- 1 Home, public and commercial
- 2 Industry
- 3 Transportation
- 4 Agriculture
- 5 Non-energetic uses

In order to predict the consumption of the above five sections, the first section uses the neural network method. The information is taken from the ministry of power website until 2019 and the consumption by segments until 2044 is predicted. In the second part, the modeling of the energy balance will be done in 2019, and then the RES curve of the energy balance in 2019 will be presented in this section. Also, the results obtained from the transfer matrices are analyzed by LEAP software [2] and the 2019 balance sheet is extracted from it. In the last step, by applying scenarios, the rate of reduction of energy consumption will be calculated by LEAP software as a result of implementing the scenarios, and finally the conclusion of this research will be presented.

In this study, scenarios using LEAP software will be designed and analyzed for long-term power supply planning. LEAP software is a complete and comprehensive system that includes both energy demand and production. The software also examines the price and analysis of the release, taking into account environmental data such as widespread publishing factors, the applied database, and the ability to import data directly from Excel software. The input information to the LEAP software is from bottom to top, so the specifications of the energy consumed at the end of the demand chain are given to the software to perform the calculations on it. Given the software's connection to the environmental database, LEAP can assess the amount of greenhouse gas emissions from the extraction, processing, distribution, and combustion activities of different fuels.

2. Gathering the Information Needed to Conduct Studies

Different levels of energy consumers

Home section

This part of energy consumers varies according to the population of each country and at the same time the highest energy consumption is in the same sector. Households, both urban and rural, where the main consumption in this sector is related to lighting. This section includes: cooling (cooler-refrigerator), heating (electric heater-hair dryer-chiller, etc.), cooking (oven, microwave, barbecue, etc.), air conditioning and other electrical appliances such as meat grinder-water Fruit picking, laundry, vacuum cleaner, etc. which have a significant share in electricity consumption

Commercial sector

This segment of energy consumers varies according to the economic growth of each country. These times mainly include lighting, shopping malls, passages, hotels, restaurants, supermarkets, shops, government offices, and so on. And also, like home use, it includes all kinds of electrical equipment such as appliances and air conditioning, cooling and heating uses, etc., and are the main consumers of electricity during peak times.

Industrial sector

This segment of energy consumers varies according to the economic growth of each country. The sectors in this sector, which use more than half of the electricity generated to meet industrial needs, mainly include a variety of large and small factories and various workshops. . The equipment that is mainly used in this section is electric motors in different dimensions and also large electromagnets in cranes are responsible for moving large metal parts. The next part is the lighting of these places.

Agriculture section

Due to the geographical situation in each country and also having fertile agricultural lands, the consumption of electricity in this sector is different. Most of the electricity consumption in this sector is related to the commissioning of water pump motors. The consumption in this section is different in different ways.

Transportation

Consumption in this sector varies according to the progress of that country in the automotive industry and also progress in the use of advanced electrical equipment such as electric cars, electric trains, electric motors, etc. Electricity consumption in this sector is different.

Other uses

In this section, where the main consumers are public and in fact public sectors, such as military centers, government offices, mosques, street lighting, hospitals and medical centers, street lighting and traffic lights, etc., the share is significant of the total electricity consumption of a country.

Index expression

In this section, we introduce socio-economic indicators such as GDP and POP, which are very effective in predicting energy consumption. We will first introduce each of the indicators and then define a statistical tool (correlation coefficient (to check the accuracy and accuracy of the interaction between energy consumption and gross domestic product and population growth).

1- GDP growth (GDP)

One of the measurement scales in economics. GDP represents the total value of goods and services produced in a country over a period of time, usually one year. In other words, GDP is the monetary value of all final goods and services produced within the borders of a country over a period of time. GDP is usually calculated on an annual basis. There are several ways to calculate gross domestic product. Calculating the total value added, calculating the consumption attitude and calculating the income attitude are three common ways to do this. For example, calculating the consumption attitude is as follows:

$$GDP = \text{private consumption} + \text{investment} + \text{government spending} + (\text{exports} - \text{imports})$$

2- Population

In statistical terms, any set of distinct elements or sets of human and plant individuals that have at least one common attribute is called a statistical community.

3. Predicting the Energy Consumption of Various Sections with the Help of an Artificial Neural Network

At the outset, we need to predict population and GDP (GDP) variables as neural network inputs. Linear approximation is used in the Curve Fitting Tool to predict population. The results are as presented in Figure 1:

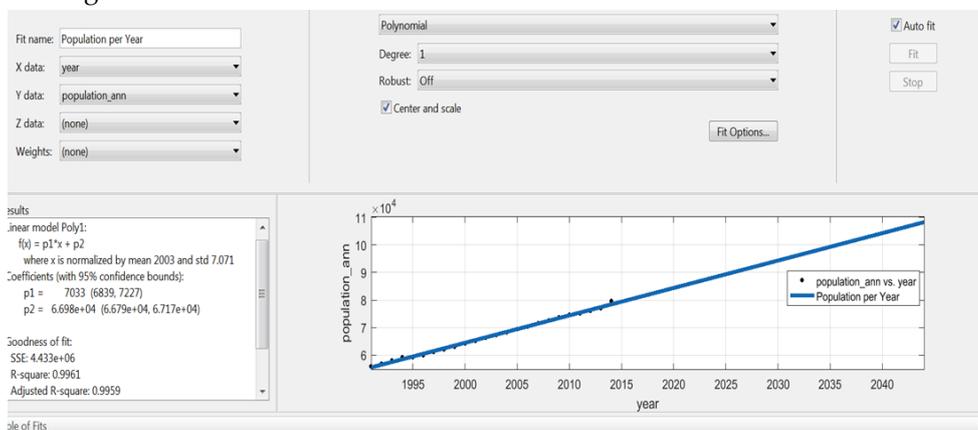


Figure 1. Population prediction in Iran until 2044.

To predict GDP from the Gray-Verhulst model * according to the reference [3], there are values that must be predicted.

The GDP chart for the year 1991 to 2044 is as follows according to the Gray-Verhulst method. Figure 2 shows the values. Note that the amount of GDP is in the amount of billions of rials.

$$a = -0.63, b = -0.061$$

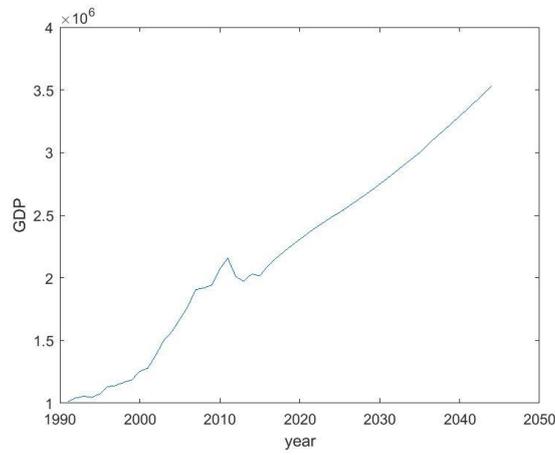
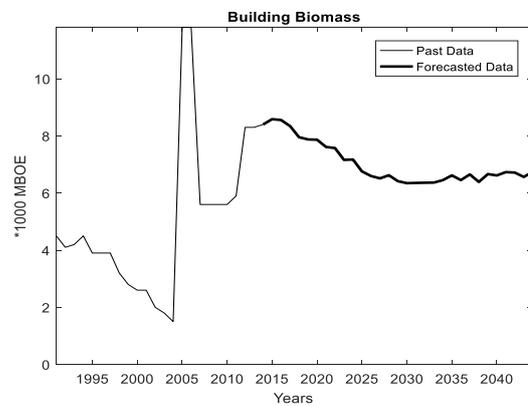
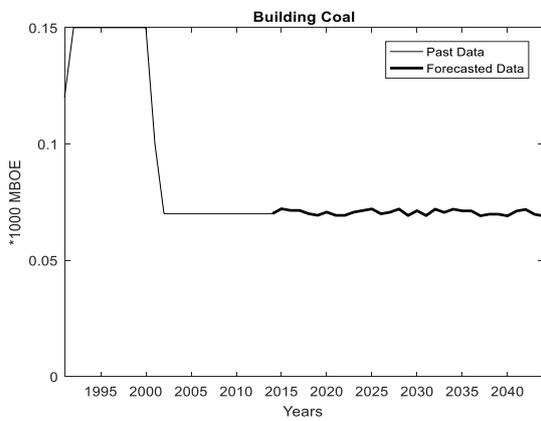
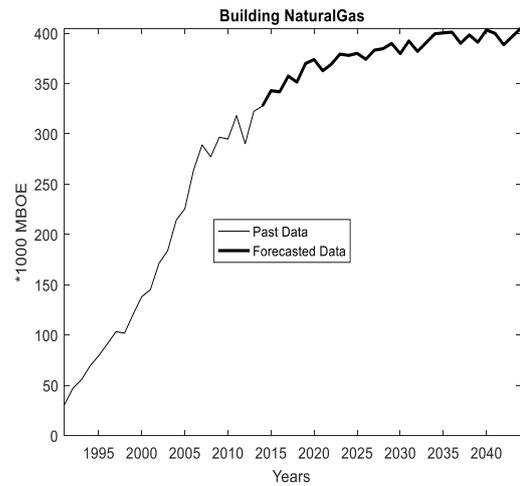
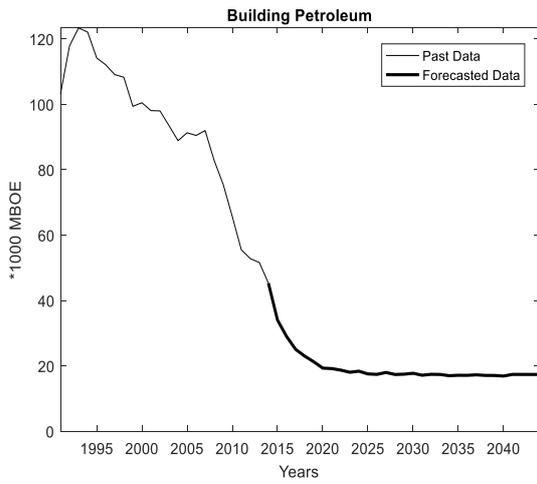
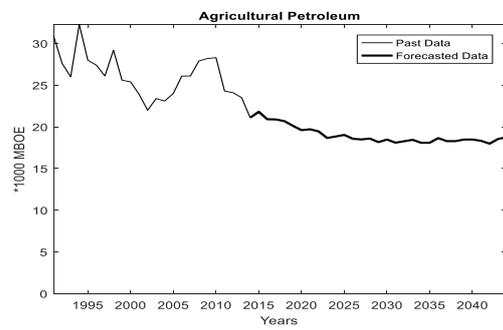
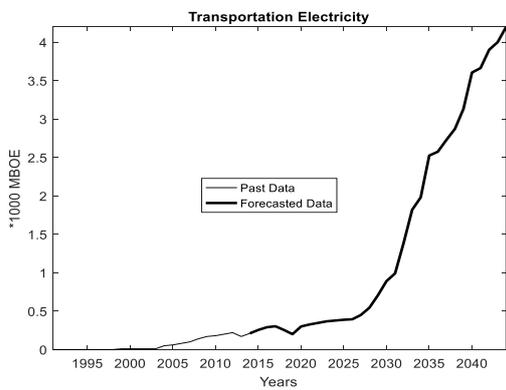
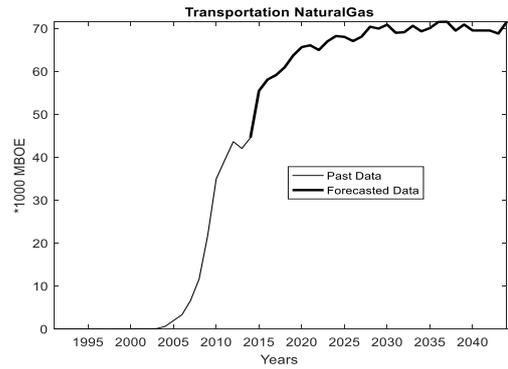
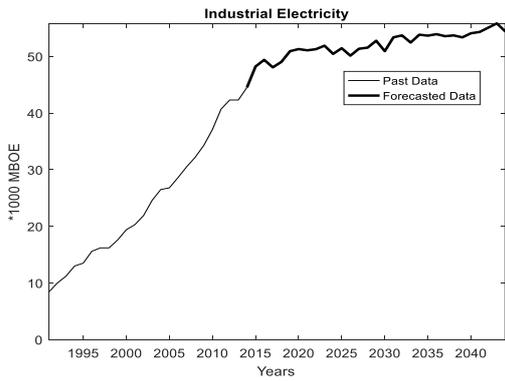
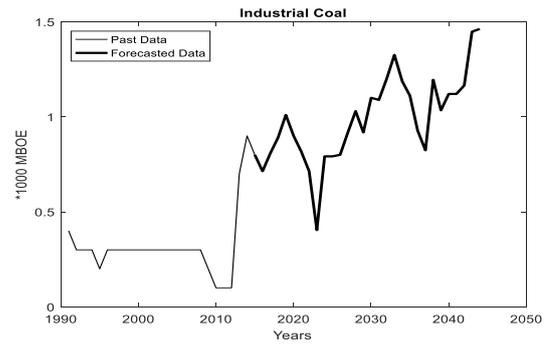
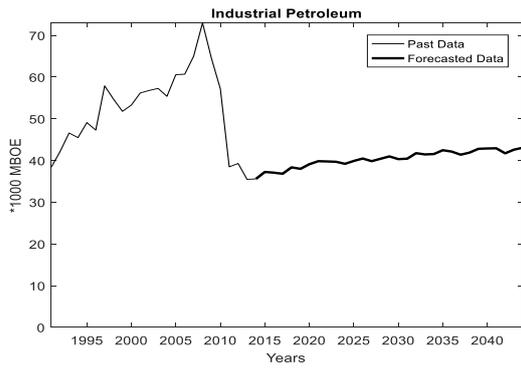
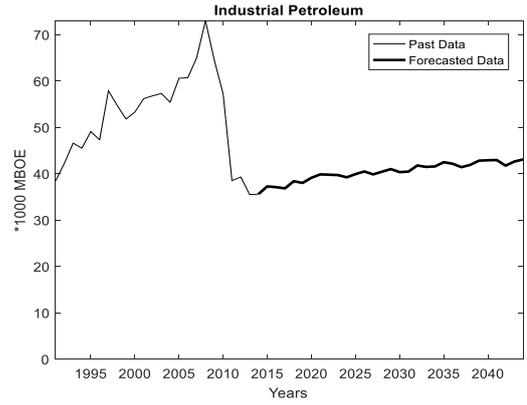
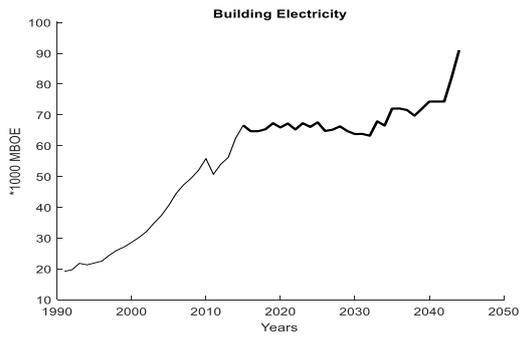
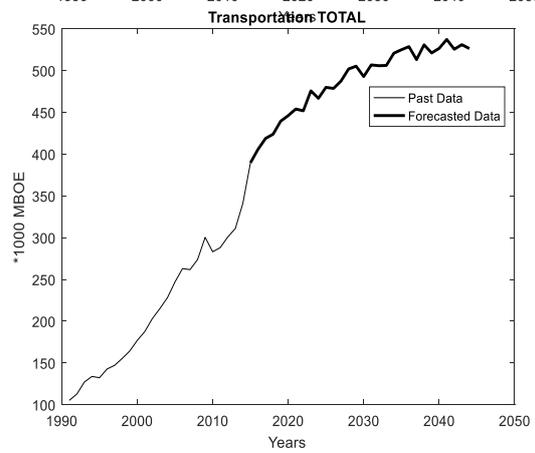
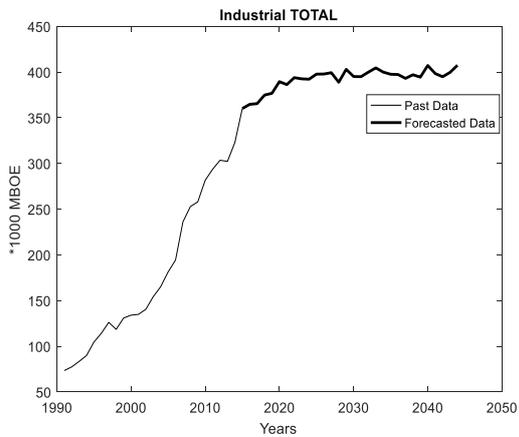
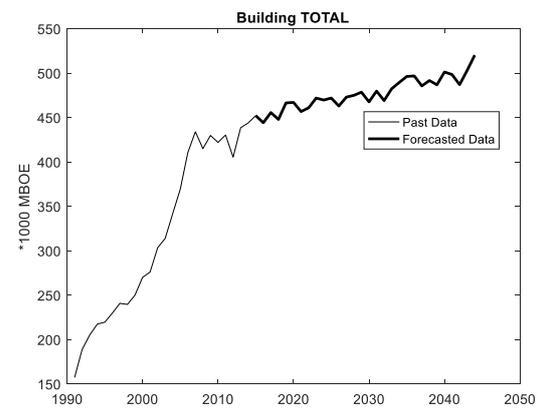
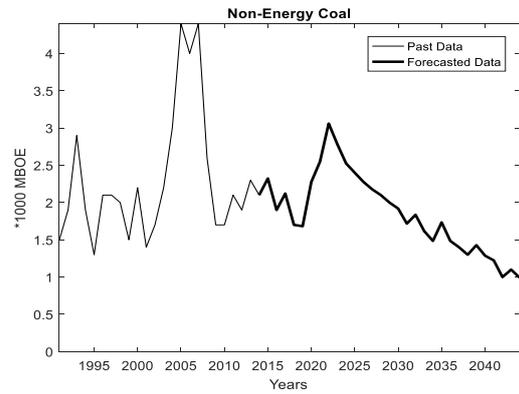
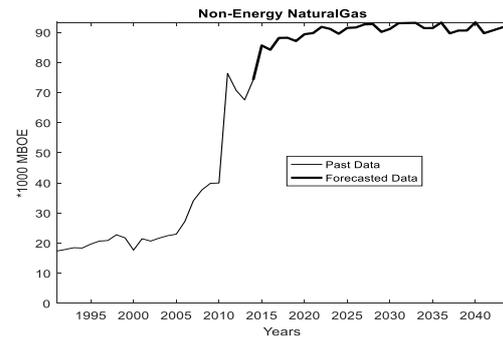
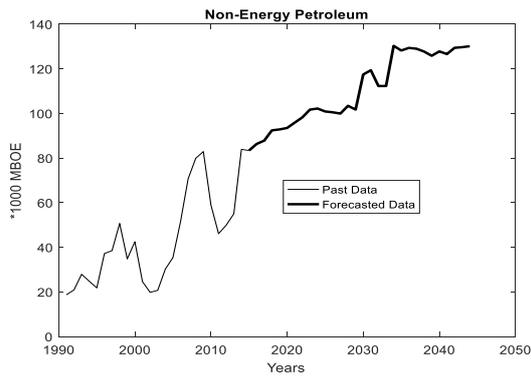
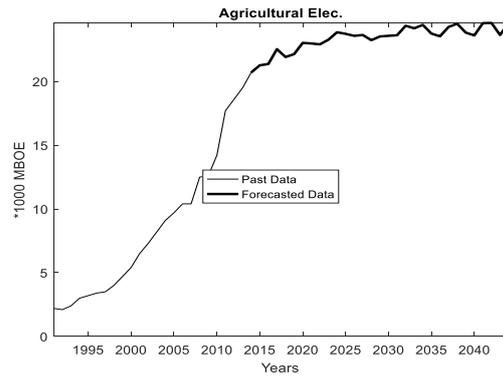
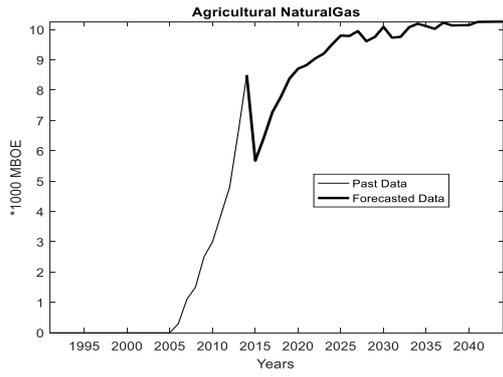


Figure 2: GDP chart

Predictions







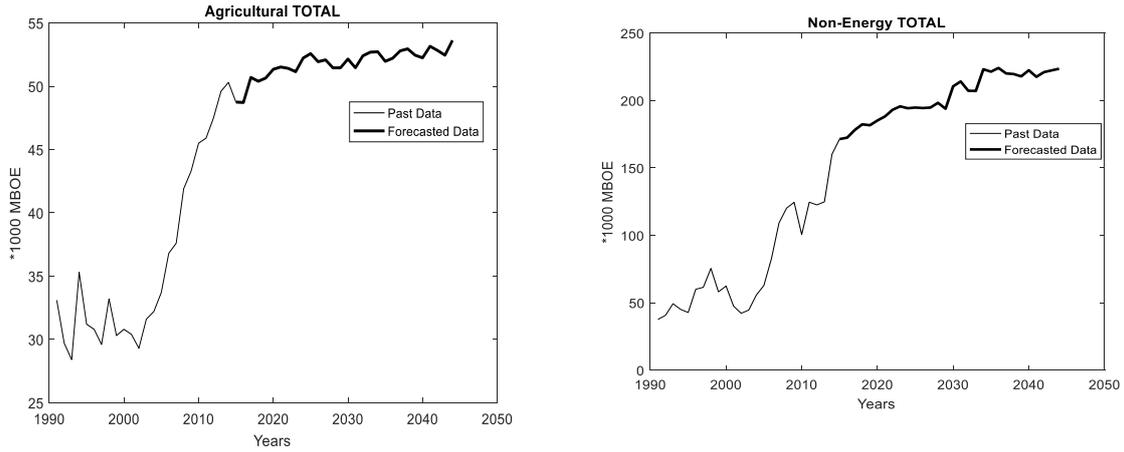


Diagram 1: The predictions.

4. Calculation of Transfer Matrices Based on the Balance Sheet of 2019 and Creation of Balance Sheet for the 30-Year Horizon

At this stage of the project, transfer matrices are calculated from the balance sheet of 2019, and with the help of these matrices and calculations, we get the initial production values of energy resources. Also, using LEAP software, we obtain the energy balance of the years 2020 to 2044 using the predicted data. First, we calculate the transfer matrices from the energy balance in 2020.

1 - The total consumption matrix of each section V1: This matrix expresses the consumption of each part of the consumers. This means that this matrix is equal to the total energy consumption of each of the sub-sections of the balance sheet. This matrix is calculated from the energy balance.

$$V 1 = \begin{bmatrix} \textit{Building} \\ \textit{Industry} \\ \textit{Transportation} \\ \textit{Agriculture} \\ \textit{Other} \\ \textit{NonEnergy} \end{bmatrix} = \begin{bmatrix} 443.8 \\ 322.9 \\ 341.3 \\ 50.3 \\ 2.3 \\ 160 \end{bmatrix}$$

2- Separator transfer matrix to subdivisions T12: This matrix converts the amount of previous matrix consumption to the fuel carriers used in each section. This matrix is calculated based on the percentage of each fuel in the consumption of each of the sections that is obtained from the energy balance of 2019. The numbers in this matrix are expressed in percentages.

$$T_{12} = \begin{bmatrix} 10.207 & 0 & 0 & 0 & 0 & 0 \\ 73.817 & 0 & 0 & 0 & 0 & 0 \\ 0.022 & 0 & 0 & 0 & 0 & 0 \\ 1.892 & 0 & 0 & 0 & 0 & 0 \\ 14.082 & 0 & 0 & 0 & 0 & 0 \\ 0 & 11.025 & 0 & 0 & 0 & 0 \\ 0 & 74.914 & 0 & 0 & 0 & 0 \\ 0 & 0.278 & 0 & 0 & 0 & 0 \\ 0 & 13.781 & 0 & 0 & 0 & 0 \\ 0 & 0 & 86.903 & 0 & 0 & 0 \\ 0 & 0 & 13.038 & 0 & 0 & 0 \\ 0 & 0 & 0.058 & 0 & 0 & 0 \\ 0 & 0 & 0 & 41.948 & 0 & 0 \\ 0 & 0 & 0 & 16.898 & 0 & 0 \\ 0 & 0 & 0 & 41.153 & 0 & 0 \\ 0 & 0 & 0 & 0 & 100 & 0 \\ 0 & 0 & 0 & 0 & 0 & 52.404 \\ 0 & 0 & 0 & 0 & 0 & 46.346 \\ 0 & 0 & 0 & 0 & 0 & 1.311 \end{bmatrix}_{19 \times 6} = \begin{bmatrix} Oil \\ NaturalGas \\ Coal \\ Biomass \\ Electricity \\ \hline Oil \\ NaturalGas \\ Coal \\ Electricity \\ \hline Oil \\ NaturalGas \\ Electricity \\ \hline Oil \\ NaturalGas \\ Electricity \\ \hline Electricity \\ \hline Oil \\ NaturalGas \\ Coal \end{bmatrix}$$

3- Sub-segments consumption matrix by carriers V2: This matrix includes the consumption of each type of fuel in each of the sub-sectors of energy consumption, which is obtained from the following relationship:

$$V_2 = T_{12} \times V_1 \times \frac{1}{100}$$

Multiplying the number one hundredth in this regard is because the matrix numbers are calculated as a percentage.

$$V 2 = \begin{bmatrix} 45.29 \\ 327.59 \\ 0.09 \\ 8.39 \\ 62.49 \\ 35.59 \\ 241.89 \\ 0.89 \\ 44.49 \\ 296.59 \\ 44.49 \\ 0.19 \\ 21.09 \\ 8.49 \\ 20.7 \\ 2.3 \\ 83.89 \\ 74.19 \\ 2.09 \end{bmatrix}_{19 \times 1} = \begin{bmatrix} Oil \\ NaturalGas \\ Coal \\ Biomass \\ Electricity \\ \dots \\ Oil \\ NaturalGas \\ Coal \\ Electricity \\ \dots \\ Oil \\ NaturalGas \\ Electricity \\ \dots \\ Oil \\ NaturalGas \\ Coal \end{bmatrix}$$

4- Transfer matrix for aggregating the costs of each carrier T23: This matrix is for converting matrix V1 to matrix V2, which includes the total consumption of each carrier.

$$T 23 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \end{bmatrix}_{5 \times 19} = \begin{bmatrix} Oil \\ \dots \\ NaturalGas \\ \dots \\ Coal \\ \dots \\ Biomass \\ \dots \\ Electricity \end{bmatrix}$$

5- Total fuel consumption matrix V3: According to the method of defining matrices V2 and T23, this matrix is obtained from the following formula:

$$V 3 = T 23 \times V 2$$

$$V 3 = \begin{bmatrix} 482.49 \\ 696.69 \\ 3.09 \\ 8.39 \\ 130.19 \end{bmatrix}_{5 \times 1} = \begin{bmatrix} Oil \\ \dots \\ NaturalGas \\ \dots \\ Coal \\ \dots \\ Biomass \\ \dots \\ Electricity \end{bmatrix}$$

6- Efficiency matrix T34: This matrix shows transmission and distribution losses. It should be noted that in this matrix, coke and furnace losses in coal fuel have also been considered. The elements of this matrix are one on efficiency.

$$T_{34} = \begin{bmatrix} \frac{1}{0.93} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{0.9} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{0.34} & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{0.82} \end{bmatrix}_{5 \times 5}$$

7 -Total fuel consumption matrix including distribution and transmission losses V4:

$$V_4 = T_{34} \times V_3$$

$$V_4 = \begin{bmatrix} 518.81 \\ 774.10 \\ 9.10 \\ 8.39 \\ 158.77 \end{bmatrix}_{5 \times 1} = \begin{bmatrix} \textit{Oil} \\ \textit{NaturalGas} \\ \textit{Coal} \\ \textit{Bio} \\ \textit{Electricity} \end{bmatrix}$$

8- Total fuel consumption matrix with impact of electricity imports and exports V4*: Because electricity is one of the secondary energies, before going to the next steps, it is necessary to add the difference between the amount of exports and imports, plus the change in reserves and the statistical difference.

$$V_4^* = V_4 + W$$

That W is the difference between exports and changes in electricity reserves and statistical differences with electricity imports. The result of these two matrices is as follows:

$$W = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 4.1 \end{bmatrix}, \quad V_4^* = \begin{bmatrix} 518.81 \\ 774.10 \\ 9.10 \\ 8.39 \\ 162.87 \end{bmatrix}$$

9- Separation matrix T45: This matrix is used to convert the amount of electricity consumed to the fuels that produce it. This matrix is calculated from the balance sheet data and according to the efficiency of each fuel in electricity generation.

$$T_{45} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0.1112 \\ 0 & 0 & 0 & 0 & 0.7829 \\ 0 & 0 & 0 & 0 & 0.0039 \\ 0 & 0 & 0 & 0 & 0.0006 \\ 0 & 0 & 0 & 0 & 0.0507 \\ 0 & 0 & 0 & 0 & 0.0012 \\ 0 & 0 & 0 & 0 & 0.0492 \end{bmatrix}_{11 \times 5}$$

10 -Matrix of total fuel consumption V5: There is no power consumption in this matrix. Because we have divided electricity consumption between the sources of its production. This matrix is calculated by multiplying the two matrices T45 and V4*:

$$V_5 = T_{45} \times V_4$$

$$V_5 = \begin{bmatrix} 518.81 \\ 774.1 \\ 9.1 \\ 8.39 \\ 18.1 \\ 127.5 \\ 0.63 \\ 0.09 \\ 8.2 \\ 0.2 \\ 8 \end{bmatrix}_{11 \times 1} = \begin{bmatrix} Oil \\ \dots \\ NaturalGas \\ \dots \\ Coal \\ \dots \\ Biomass \\ \dots \\ Oil \\ \dots \\ NaturalGas \\ \dots \\ Coal \\ \dots \\ Biomass \\ \dots \\ Hydro \\ \dots \\ Renewable \\ \dots \\ Nuclear \end{bmatrix}$$

11- Power plant efficiency matrix T56: This matrix represents the efficiency of each of the power plants. The efficiency of power plants is considered in accordance with the average values expressed in the energy balance sheet.

$$T\ 56 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{0.1415} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{0.4} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{0.35} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{11 \times 11}$$

12 -Consumption matrix of each fuel including power plant efficiency V6: This matrix expresses the amount of fuel consumed, taking into account the efficiency of each power plant.

$$V\ 6 = T\ 56 \times V\ 5$$

$$V\ 6 = \begin{bmatrix} 518.81 \\ 774.10 \\ 9.10 \\ 8.39 \\ 127.9 \\ 318.8 \\ 1.8 \\ 0.09 \\ 8.2 \\ 0.2 \\ 8 \end{bmatrix}_{11 \times 1}$$

13 -Collector transfer matrix Consumption of any type of fuel T67: By multiplying in the V6 matrix, this matrix calculates the sum of the consumption values of each fuel that are in the different rows of the V6 matrix.

$$T 67 = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{7 \times 11}$$

14-Total consumption matrix of any type of primary fuel V7: According to the description, this matrix is obtained by multiplying the matrices V6 and T67.

$$V 7 = \begin{bmatrix} 646.8 \\ 1092.8 \\ 10.9 \\ 8.5 \\ 8.2 \\ 0.2 \\ 8 \end{bmatrix}_{7 \times 1}$$

15- Oil Transfers and Refineries Matrix T78: This matrix is to consider the impact of crude oil losses on transfers and refineries or refinery costs. In this matrix, only the diameter elements have a value, and only the non-one diameter element is related to the first line and is equal to one divided by the efficiency of the oil transfers and refineries.

$$T 78 = \begin{bmatrix} \frac{1}{0.94} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}_{7 \times 7}$$

16- Matrix of resource expenditures including transfer returns and oil refineries V8: This matrix is obtained by multiplying the matrices V7 and T78:

$$V_8 = \begin{bmatrix} 688.1 \\ 1092.8 \\ 10.9 \\ 8.5 \\ 8.2 \\ 0.2 \\ 8 \end{bmatrix}_{7 \times 1}$$

17- Total initial supply matrix V9: This matrix is the first line of energy balance. If we consider the effects of exports and imports in the V8 matrix and the change in statistical reserves and differences and the fuel of ships and international aircraft, we will reach the V9 matrix. If we define the S matrix as follows:

$$S = \text{Export} - \text{Im port} + \text{ships} + \text{Airplanes} + \text{Stock_Changes}$$

Then, by adding it to the V8 matrix, the V9 matrix is obtained:

$$S = \begin{bmatrix} 560 \\ 23.2 \\ -5.8 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}_{7 \times 1}$$

$$V_9 = V_8 + S$$

$$V_9 = \begin{bmatrix} 1248.1 \\ 1116 \\ 5.1 \\ 8.5 \\ 8.2 \\ 0.2 \\ 8 \end{bmatrix}_{7 \times 1}$$

In the continuation of this stage of the article, the goal is to calculate the energy balance with the help of LEAP software. After determining the sub-branches and placing the values related to the Demand sub-branch, as well as the coefficients (efficiency) of transmission and fuel of power plants in accordance with the energy balance of 2019 and according to the data predicted with the help of artificial neural network in MATLAB, we can Calculate the energy balance from 2019 to 2044. The calculated balance sheets are listed below.

The energy balance in their corresponding years are provided in the appendixes.

5. Examining Different Scenarios and Examining Their Impact on Improving Energy Efficiency and Conserving the Country's Energy Reserves

Today, due to the emergence of various technologies to generate electricity, including fuel cells, wind turbines with the ability to be installed in different areas, high-efficiency solar panels, as well

as the possibility of controlling and changing the way of consumption, arose many issues in finding the best way to respond to consumption.

These include testing different scenarios to improve energy efficiency and reduce demand and production losses. Here is an example of the work done in this area.

In [5], the electric stove scenario is used as a demand side scenario (DSM) for energy planning and pollution control in Nepal. The results of this study show that the seasonal plan is economically and environmentally seem good, but in order to attract the attention of consumers to participate in this scenario, it is necessary to reduce electricity tariffs.

In a study [6], it was shown that free basic electrical energy encourages more poor consumers to use electricity for cooking. While liquefied petroleum gas can provide the same service to consumers at a lower cost to society.

In [7], the authors studied the generation of electrical energy in Indonesia and considered uncertainty in the scenario planning method. The study showed that the use of gas-coal-fired power plants with combined cycle and advanced gas power plants with combined cycle resulted in savings of \$ 3.5 billion over a 15-year period with a 230-million-ton reduction in emissions of greenhouse gases.

In this part of the study, we intend to examine the impact of each scenario on improving energy efficiency, conserving natural resources and reducing environmental pollutants by considering different scenarios in both sides of demand and production. The following scenarios are given.

5.1. Basic Scenario

This scenario will be used to import the predicted data into LEAP software and find the balance sheet for the coming years until 2044. In this scenario, the method of energy supply in different sectors, such as the base year of 2019, is. This scenario is also used to compare the results of the application of each of the other scenarios. This scenario is defined as Business as Usual (BAU) in LEAP software. The balance sheets for this scenario are abovementioned.

5.2. Demand-Side Scenarios (DSM)

1- Optimal lighting of home and commercial sector: In this scenario, the goal is to improve the home and commercial lighting system of the energy balance and use higher-efficiency LED lamps instead of incandescent and low-efficiency fluorescent lamps. This scenario is defined as Efficient Lighting (EFL) in LEAP software. According to Figure 3, taken from [8], LED lamps consume 68% less energy than fluorescent lamps and 90% less energy than conventional incandescent lamps. As shown in Figure 3, LED lamps have a longer service life and lower cost than the other two types of lamps. So, it is quite economical to use these lamps. Of course, these scenarios will not discuss economic issues, and economic issues are beyond the scope of this study.

Comparison Chart
LED Lights vs. Incandescent Light Bulbs vs. CFLs

Energy Efficiency & Energy Costs	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Life Span (average)	50,000 hours	1,200 hours	8,000 hours
Watts of electricity used (equivalent to 60 watt bulb). <small>LEDs use less power (watts) per unit of light generated (lumens). LEDs help reduce greenhouse gas emissions from power plants and lower electric bills</small>	6 - 8 watts	60 watts	13-15 watts
Kilo-watts of Electricity used (30 Incandescent Bulbs per year equivalent)	329 KWh/yr.	3285 KWh/yr.	767 KWh/yr.
Annual Operating Cost (30 Incandescent Bulbs per year equivalent)	\$32.85/year	\$328.50/year	\$76.65/year

Figure 3. Comparison between LED and fluorescent and incandescent lamps [8].

According to [9], 30% of household and commercial electricity consumption is related to lighting. Equally, incandescent and fluorescent lamps make up about 80 percent of all light bulbs. [10] As a result, 24% of total household and commercial electricity demand consists of incandescent and fluorescent lamps. Assuming that the share of incandescent and fluorescent lamps is the same, LED lamps consume 26% of the energy of incandescent and fluorescent lamps.

To apply this scenario to the basic energy balance sheet, we divide the household and commercial electricity consumption subdivisions into three parts. These include non-electric power consumption, electric power consumption including fluorescent and incandescent lamps, and power consumption includes LED lamps (Electricity Efficient Lighting). The penetration level of LED lamps is 4 steps with values of 20% in 2020, 50% in 2025, 80% in 2030 and 100% in 2035. In other words, in 2035, all the lamps will be replaced, and from then on, only the LED lamp will be used in the lighting.

Considering the electricity consumption predicted in the coming years and also the level of penetration introduced, the amount of consumption of each of these three parts in the Excel file has been calculated and entered into LEAP software. The effect of LED lamps is to reduce the electricity consumption of the home and commercial sector in the coming years.

Figure 4 shows the rate of change in total electricity consumption in this scenario compared to the baseline scenario.

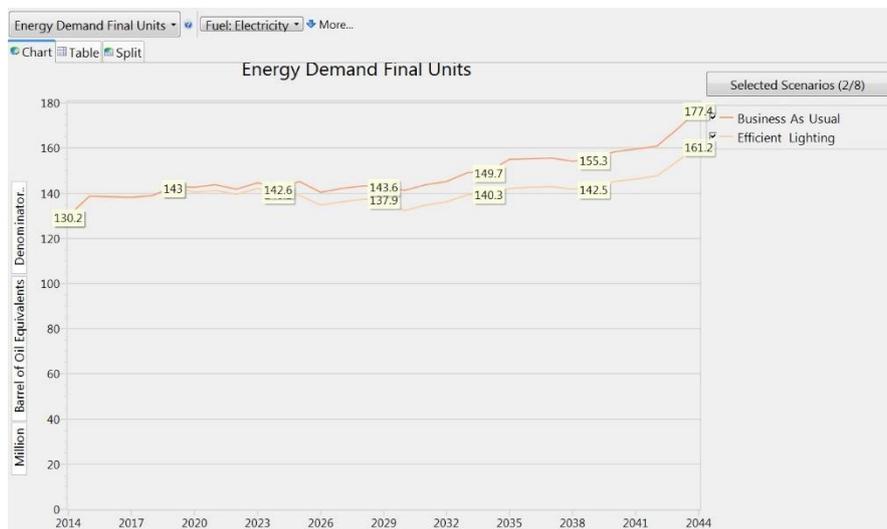


Figure 4. Total electricity consumption in the optimal lighting scenario of the home and commercial sector and the base scenario.

As shown in Figure 4, applying this scenario will significantly reduce the amount of electrical energy consumed.

Energy balance sheets in different years can be obtained for this scenario as well as the basic scenario. In this section, to prevent the addition of content, we will put only the balance sheets of 2044.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	3.8	1,394.8	1,474.6	10.1	0.2	9.9	6.9	-	2,900.3
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.6	1,371.6	914.6	10.1	0.2	9.9	6.9	-4.1	2,318.8
Oil Transfers	-	-	-30.9	-	-	-	-	-	-30.9
Oil Refinery	-	-	-18.4	-	-	-	-	-	-18.4
PowerPlants	-2.2	-389.5	-156.4	-10.1	-0.2	-9.9	-0.1	199.0	-369.4
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-48.8	-	-	-	-	-33.7	-178.1
Total Transformation	-7.1	-483.9	-254.5	-10.1	-0.2	-9.9	-0.1	165.3	-600.4
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	74.8	504.0
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	450.8	-	-	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	660.2	-	-	-	6.7	161.2	1,718.4
Unmet Requirements (Waste)	0.0	0.0	-	-	-	-	0.0	0.0	0.0

Figure 5. Energy level for 2044 related to the optimal lighting scenario of the domestic and commercial sectors.

2- Creating and expanding transportation with hydrogen vehicles:

Hydrogen cars are a type of car that uses hydrogen fuel instead of fossil fuels such as gasoline and diesel [7]. European countries have recently resorted to using this fuel in cars in order to protect the environment and reduce air pollution. On the other hand, in accordance with the Kyoto Treaty, all industrialized countries are required to reduce greenhouse gas emissions [11].

In this scenario, it is assumed that hydrogen vehicles will be transported with 20% penetration level by 2022, and by 2042 this amount will reach 35%. The rate of change in the level of penetration of hydrogen vehicles is such that every 4 years, 5% is added to the level of penetration of these vehicles. The added share of hydrogen vehicles is reduced by the share of fuel-derived vehicles. The fuel required for hydrogen vehicles comes from renewable sources with water electrolysis.

To apply this scenario, we add another section to the Demand branch and the Transportation sub-branch called Hydrogen, with Solar Fuel, which in LEAP software represents renewable energy. And as the level of penetration of hydrogen vehicles increases, the amount of oil consumption in the transportation sector will decrease. This scenario is implemented under the name of Hydrogen Transportation (HT) in LEAP software.

Figures 6 and 10 show the total demand (production) of crude oil and the total demand for renewable energy in the two basic scenarios, respectively, and the creation and expansion of transportation with hydrogen vehicles.

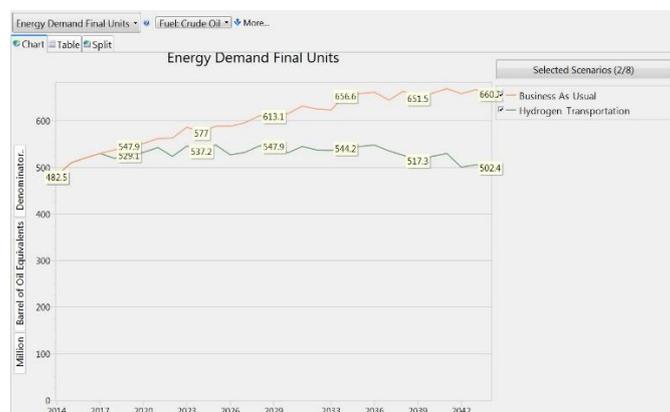


Figure 6. Total demand for (production) of crude oil in two basic scenarios and the creation and expansion of transportation by hydrogen vehicles.



Figure 7. Total demand (production) of renewable energy in two basic scenarios and the creation and expansion of transportation by hydrogen vehicles.

It is observed that the production of crude oil under this scenario has decreased significantly compared to the base state.

Also, according to the results of other scenarios, five sample energy balance sheets are given here in Figure 8.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.0	1,433.1	1,311.8	11.1	100.0	10.8	6.9	-	2,877.6
Imports	2.6	47.4	23.8	-	58.0	-	-	2.2	134.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.8	1,409.9	751.8	11.1	158.0	10.8	6.9	-4.1	2,354.2
Oil Transfers	-	-	-25.4	-	-	-	-	-	-25.4
Oil Refinery	-	-	-15.1	-	-	-	-	-	-15.1
PowerPlants	-2.4	-427.7	-171.7	-11.1	-0.3	-10.8	-0.1	218.5	-405.7
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-37.1	-	-	-	-	-37.1	-169.8
Total Transformation	-7.3	-522.1	-249.4	-11.1	-0.3	-10.8	-0.1	181.5	-619.6
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	91.0	520.2
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	293.0	-	157.8	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	502.4	-	157.8	-	6.7	177.4	1,734.5
Unmet Requirements (Waste)	0.0	0.0	-	-	0.0	-	0.0	0.0	0.0

Figure 8. Energy Balance of 2044 related to the scenario of creation and expansion of transportation with hydrogen vehicles.

5.3. Production and Demand Side Scenario (DSM & SSM)

1- Creating direct current transmission lines and reducing power transmission losses: Due to the high losses in electricity transmission and distribution networks [12] as well as the low efficiency of power plants in Iran, reducing the losses of transmission lines and electricity distribution will have a great impact on reducing fossil fuel consumption. In this scenario, the goal is to reduce transmission and electricity loss losses by developing direct current transmission lines (HVDC) and replacing alternating current (AC) lines with high losses with direct current transmission lines with low losses. Direct current transmission lines also have other advantages, such as lower investment costs, reduced air pollution, and lower material consumption per capita [13]. According to Figure 9, long-distance direct current transmission lines have far fewer losses.

Also, direct current transmission lines do not have effects such as franchise effect and low power factor, etc.

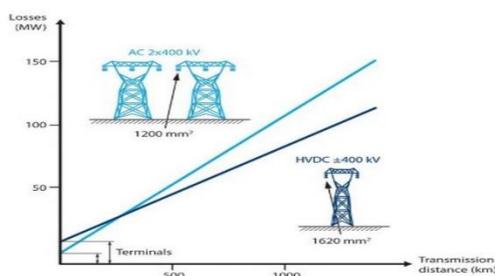


Figure 9. Comparison of direct current and alternating current transmission line losses.

Based on the issues raised in this scenario, it is assumed that the efficiency of electricity transmission and distribution will reach linearly from 82.7 in the base year (2019) to 90% by 2044. This scenario has been implemented with the help of Interp function in LEAP software and under the name of HVDC.

Figure 10 shows the change in transmission efficiency and distribution in the two basic scenarios and the creation of direct current transmission lines and the reduction of power transmission losses.

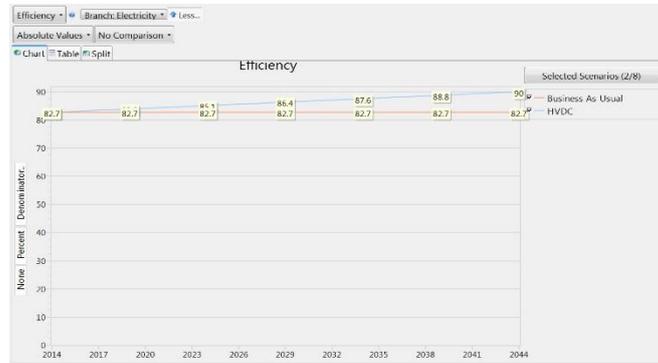


Figure 10. Power transmission and distribution efficiency in two basic scenarios and the creation of direct current transmission lines and reduction of power transmission losses.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	3.8	1,399.1	1,476.4	10.2	0.2	10.0	6.9	-	2,906.6
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.6	1,375.9	916.4	10.2	0.2	10.0	6.9	-4.1	2,325.1
Oil Transfers	-	-	-31.0	-	-	-	-	-	-31.0
Oil Refinery	-	-	-18.4	-	-	-	-	-	-18.4
PowerPlants	-2.2	-393.7	-158.1	-10.2	-0.2	-10.0	-0.1	201.2	-373.4
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-48.8	-	-	-	-	-	-19.7
Total Transformation	-7.1	-488.1	-256.3	-10.2	-0.2	-10.0	-0.1	181.5	-590.6
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	91.0	520.2
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	450.8	-	-	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	660.2	-	-	-	6.7	177.4	1,734.5
Unmet Requirements (Waste)	0.0	0.0	0.0	-	-	-	0.0	0.0	0.0

Figure 11. Energy level for 2044 related to the scenario of creating direct current transmission lines and reducing power transmission losses.

5.4. Supply Scenarios (SSM)

1- Increasing the share of water power plants with storage pump system in electricity generation

In the base year, the share of hydropower plants in electricity supply was 5.07 percent [12]. Water power plants are important because they have a very low operating cost and are free from environmental pollution. The effect of the hydropower plant of the storage pump is that it can be used as a storage system in periods when electricity consumption is low [14]. By creating two upper and lower reservoirs, the network can be used to carry water to the upstream reservoir in the off-peak hours, and in the peak hours, the upstream reservoir enters the circuit as a dam and provides part of the network load [15]. In this section, since the purpose is to investigate the amount of energy consumed, we will not examine the effects of this type of power plant on the power system.

In this scenario, it is assumed that the share of hydropower plants in electricity generation will increase from 5.07 percent in the base year of 2019 to 15 percent by 2028. This increase in share is in the following steps: (2020, 11), (2022, 12), (2024, 13), (2026, 14), (2028, 15). This is done with the help of the Step function in LEAP software. In this scenario, as the share of the hydroelectric power plant increases, the share of the power plants with the fuel of the oil derivatives decreases. This scenario is called Hydro Pump Storage (HPS).

Figure 12 shows the increase in production of hydropower plants compared to the base scenario.

Figure 13 also shows the amount of crude oil production in these two scenarios. Due to the low efficiency of electricity generation from oil derivatives, with a slight change in the percentage of electricity production by these power plants, it can be seen that a large amount of its primary production is reduced.

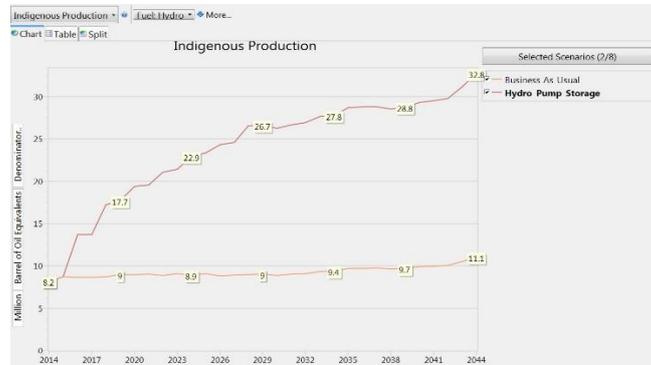


Figure 12. The difference between the amount of production of hydropower plants in two basic scenarios and increase the share of hydropower plants with the storage pump system in electricity generation.

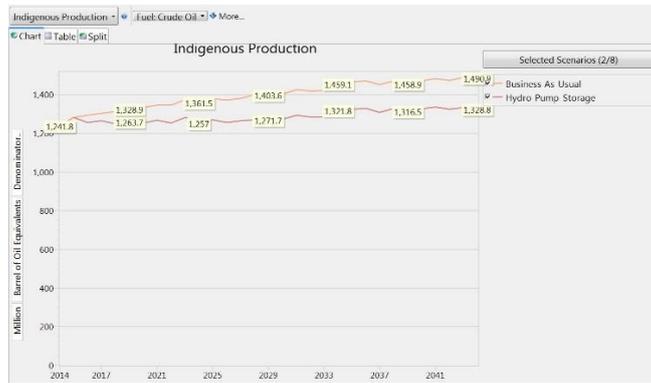


Figure 13. The difference between crude oil production in the two basic scenarios and the increase in the share of hydropower plants with the storage pump system in electricity generation.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.0	1,433.1	1,328.8	32.8	0.3	10.8	6.9	-	2,816.6
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.8	1,409.9	768.8	32.8	0.3	10.8	6.9	-4.1	2,235.1
Oil Transfers	-	-	-26.0	-	-	-	-	-	-26.0
Oil Refinery	-	-	-15.4	-	-	-	-	-	-15.4
PowerPlants	-2.4	-427.7	-18.4	-32.8	-0.3	-10.8	-0.1	218.5	-274.0
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-48.8	-	-	-	-	-37.1	-181.5
Total Transformation	-7.3	-522.1	-108.6	-32.8	-0.3	-10.8	-0.1	181.5	-500.5
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	91.0	520.2
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	450.8	-	-	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	660.2	-	-	-	6.7	177.4	1,734.5
Unmet Requirements (Waste)	0.0	0.0	0.0	-	-	-	0.0	-	0.0

Figure 14. Energy balance for 2044 related to the scenario of increasing the share of hydropower plants with the storage pump system in electricity generation.

2- Replacing gas power plants with combined cycle: Due to the huge gas reserves in Iran [12], the main production of electricity in Iran by gas power plants. Gas power plants have low efficiency and therefore burn more fuel in exchange for producing the same amount of energy as combined cycle power plants.

According to the above, the conversion of low-efficiency gas power plants into combined cycles can have a significant impact on reducing natural gas consumption. In the base year of 2019, gas power plants provide 78.29% of the country's electricity needs with an average return of 40%. [12] Some of these plants are still in the combined cycle. In this scenario, it is assumed that the efficiency of gas power plants and combined gas combustion cycle will change from 40% in 2019 to Table 1. This scenario, called NG to Combined Cycle (NGTCC), has been implemented in LEAP software.

Table 1. The rate of change in the efficiency of gas-fired power plants in the scenario of replacing gas-fired power plants with a combined cycle.

Efficiency of gas-fired power plants(%)	Year
46	2020
48	2022
50	2024
52	2026
54	2028
56	2030
58	2032
60	2034

Figure 15 shows the change in efficiency of gas-fired power plants in the planning period.

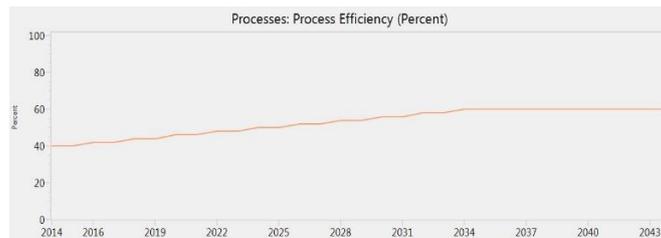


Figure 15. The rate of change in the efficiency of gas-fired power plants in the scenario of replacing gas-fired power plants with a combined cycle.

5.5. All Scenarios Together

Energy level for the year 2044 according to corresponding scenario is presented in Figure 16.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.0	1,290.5	1,490.9	11.1	0.3	10.8	6.9	-	2,814.4
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.8	1,267.3	930.9	11.1	0.3	10.8	6.9	-4.1	2,232.9
Oil Transfers	-	-	-31.5	-	-	-	-	-	-31.5
Oil Refinery	-	-	-18.7	-	-	-	-	-	-18.7
PowerPlants	-2.4	-285.2	-171.7	-11.1	-0.3	-10.8	-0.1	218.5	-263.1
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-48.8	-	-	-	-	-37.1	-181.5
Total Transformation	-7.3	-379.5	-270.7	-11.1	-0.3	-10.8	-0.1	181.5	-498.4
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	91.0	520.2
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	450.8	-	-	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	660.2	-	-	-	6.7	177.4	1,734.5
Unmet Requirements (Waste)	0.0	0.0	-	-	-	-	0.0	0.0	0.0

Figure 16. Energy level for 2044 related to the scenario of replacing gas power plants with combined cycle.

This is not a new scenario. In this scenario, we apply all the changes we made to the said scenarios. The purpose of this scenario is to investigate the effect of simultaneously performing the above scenarios. This scenario is defined in LEAP software as All Together (ALL). The results are presented in Figure 17.

	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	53.9	1,218.1	1,132.8	27.5	100.0	9.1	6.9	-	2,548.3
Imports	2.6	47.4	23.8	-	58.0	-	-	2.2	134.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	59.7	1,194.9	572.8	27.5	158.0	9.1	6.9	-4.1	2,024.8
Oil Transfers	-	-	-19.4	-	-	-	-	-	-19.4
Oil Refinery	-	-	-11.5	-	-	-	-	-	-11.5
PowerPlants	-52.3	-212.8	-2.5	-27.5	-0.2	-9.1	-0.1	183.2	-121.2
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-37.1	-	-	-	-	-17.9	-150.7
Total Transformation	-57.2	-307.2	-70.5	-27.5	-0.2	-9.1	-0.1	165.3	-306.4
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	74.8	504.0
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	293.0	-	157.8	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	502.4	-	157.8	-	6.7	161.2	1,718.4
Unmet Requirements (Waste)	0.0	-	0.0	-	0.0	-	0.0	-	0.0

Figure 17. The energy level of 2044 is related to the scenario of all scenarios together.

6. Conclusions

According to the data in the above tables, it can be said that in terms of consumption of natural resources and reserves of crude oil and natural gas, the ALL scenario is the best scenario. That is, when we apply all the scenarios together, the consumption of these two energy reserves is the lowest. After this scenario, the HPS scenario will cause the least amount of crude oil consumption. Also, the NGTCC scenario after the ALL scenario causes the least amount of natural gas consumption.

In terms of coal fuel, HVDC and EFL scenarios have the lowest coal consumption. In terms of environmental pollution, the ALL scenario is the best scenario, followed by the HPS scenario. Also, the scenarios that have the lowest consumption of natural resources cause the depletion of the country's natural reserves to be postponed.

Also, by comparing the tables, we find that after the ALL scenario, the NGTCC scenario has the greatest effect on reducing the initial supply of natural gas. And from the point of view of reducing crude oil supply after the ALL scenario, the HT scenario is the best scenario.

Appendix A

Gary-Verhulst model

$$X^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(n)), \quad n \geq 4,$$

Then the accumulated values of x (1) are calculated.

$$x^{(1)}(k) = \sum_{i=1}^k x^{(0)}(i), \quad k = 1, 2, 3, \dots, n.$$

Then we get the average.

$$z^{(1)}(k) = 0.5x^{(1)}(k) + 0.5x^{(1)}(k - 1), \quad k = 2, 3, \dots, n.$$

The Gray-Verhulst equation will be as follows.

$$\frac{dx^{(1)}}{dx} + ax^{(1)} = b(x^{(1)})^2$$

This will be the case with Gray-Verhulst differential equations.

$$\begin{aligned} x^{(0)}(k) + az^{(1)}(k) &= b(z^{(1)}(k))^2, \\ x^{(0)}(k) &= -az^{(1)}(k) + b(z^{(1)}(k))^2 \end{aligned}$$

Like GM (1,1):

$$[a, b]^T = (B^T B)^{-1} B^T Y,$$

where:

$$Y = [x^{(0)}(2), x^{(0)}(3), \dots, x^{(0)}(n)]^T,$$

$$B = \begin{bmatrix} -z^{(1)}(2) & (z^{(1)}(2))^2 \\ -z^{(1)}(3) & (z^{(1)}(3))^2 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ -z^{(1)}(n) & (z^{(1)}(n))^2 \end{bmatrix}.$$

This will be the collective answer:

$$x_p^{(1)}(k + 1) = \frac{ax^{(0)}(1)}{bx^{(0)}(1) + (a - bx^{(0)}(1))e^{ak}}$$

And in the end, the answer will be:

$$\begin{aligned} x_p^{(0)}(k) &= \frac{ax^{(0)}(1)(a - bx^{(0)}(1))}{(bx^{(0)}(1) + (a - bx^{(0)}(1))e^{a(k-1)}} \\ &\quad * \frac{(1 - e^a)e^{a(k-2)}}{(bx^{(0)}(1) + (a - bx^{(0)}(1))e^{a(k-2)}} \end{aligned}$$

Artificial neural network

Neurological networks are needed to predict the future. Multilayer Perceptron (MLP) is used for this purpose. The Levenberg-Marquardt Network Training Algorithm is considered (80% data for training and 20% for testing). As can be seen in Figure A1, the neural network consists of three layers: Input, Hidden, and Output. The neural network in the project consists of a maximum of two hidden layers.

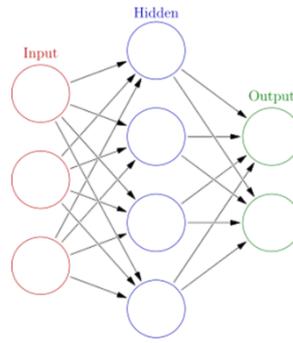


Figure A1: Neural network layers

In the Figure A2, the mechanism of a neural network is shown.

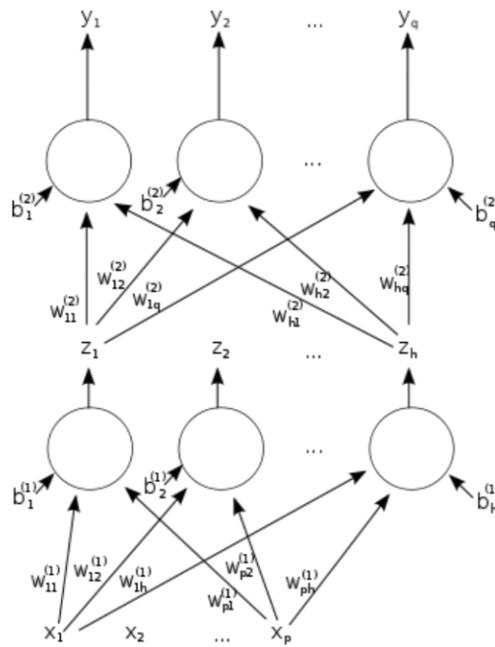


Figure A2 Mechanism of a neural network

$$z_i = \sum_{j=1}^p (w_{ij} * x_j + b_j)$$

$$y_i = \sum_{j=1}^p (w_{ij} * z_j + b_j)$$

The three excitation functions are used:

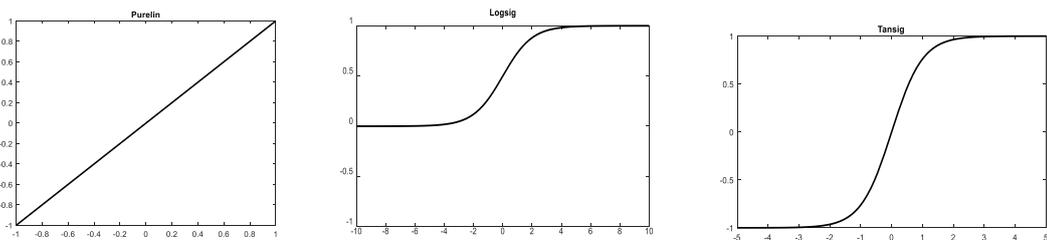


Figure A3. Excitation functions.

Where, from left to right:

$$y=x$$

$$y = \frac{1}{1 + e^{-x}}$$

$$y = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

According to [4], minimum and maximum neurons of each layer can be founded as:

$$2((n_i + n_o) + 1) \leq n \leq \left[\frac{K(n_i + n_o) - n_o}{n_i + n_o + 1} \right] + 1$$

n_i (number of inputs) = 2

GDP & POP n_i

(number of outputs) = 1

Energy Forecast n_o

K (number of samples) = 24

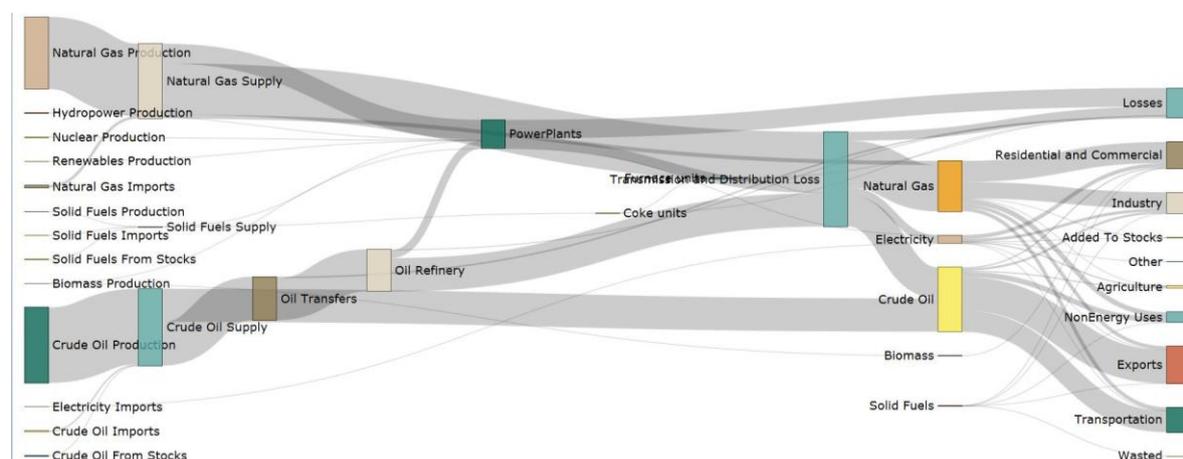
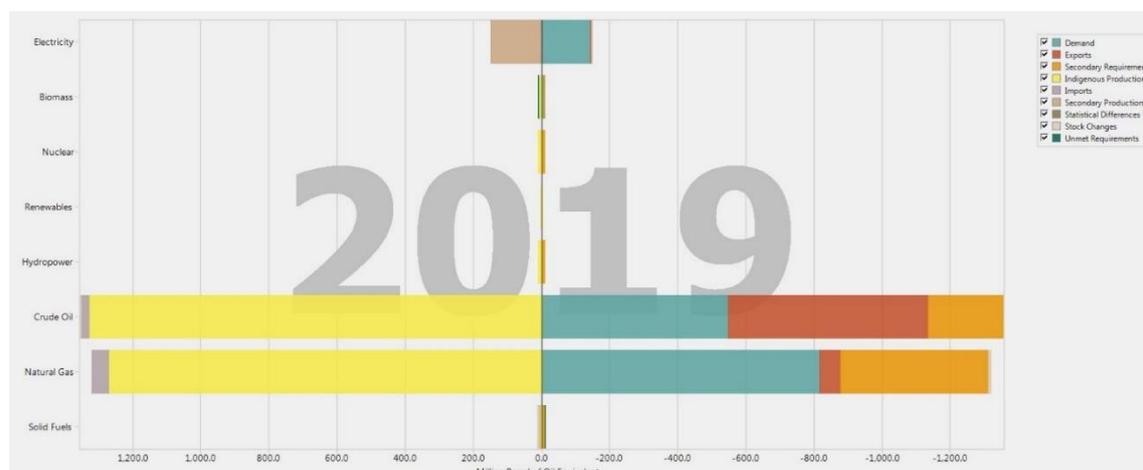
Samples from 1970-2019

n (number of neurons in hidden layers)

Therefore, the hidden layer neurons is $7 \leq n \leq 18$.

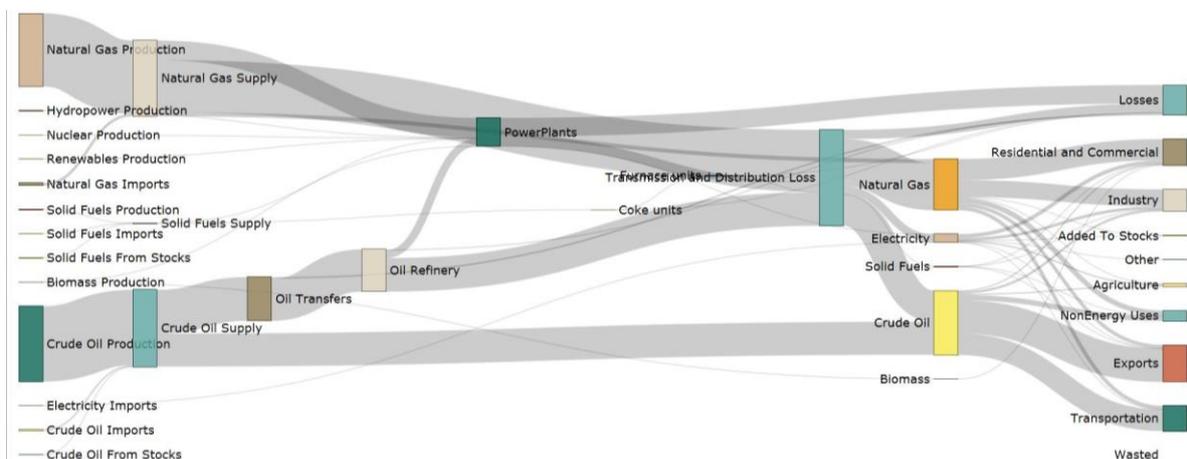
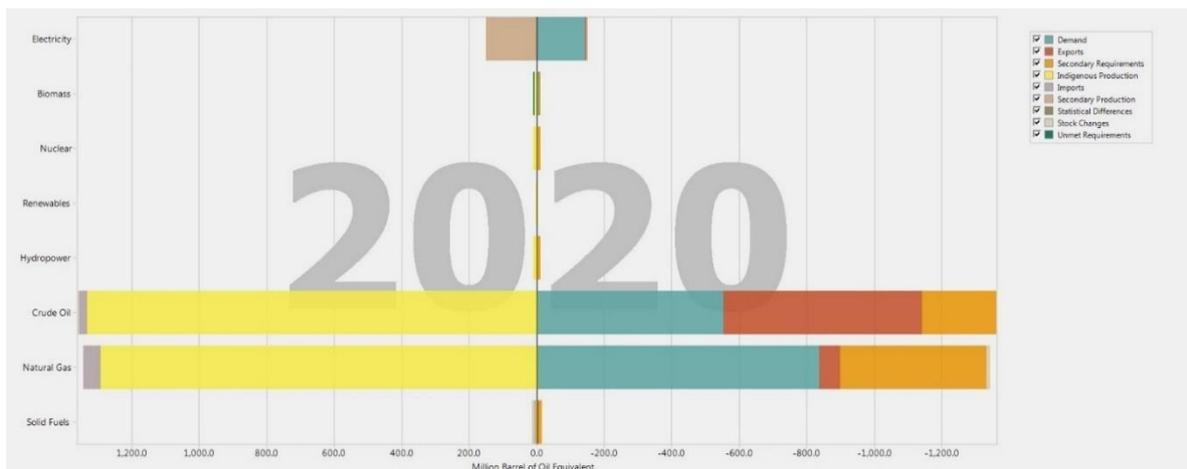
Energy balances

The following figures show the energy balance in 2019 based on the previous approach (without any scenario).



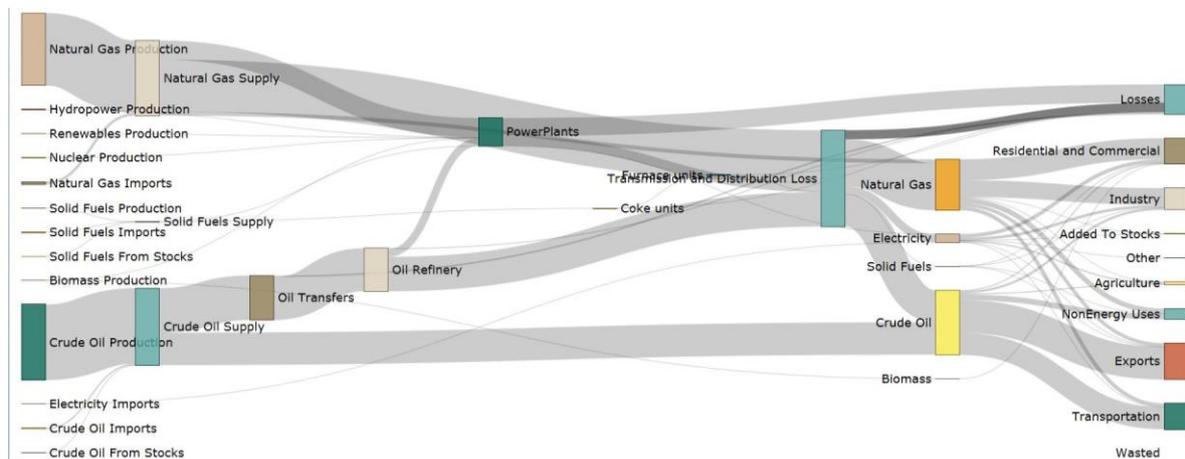
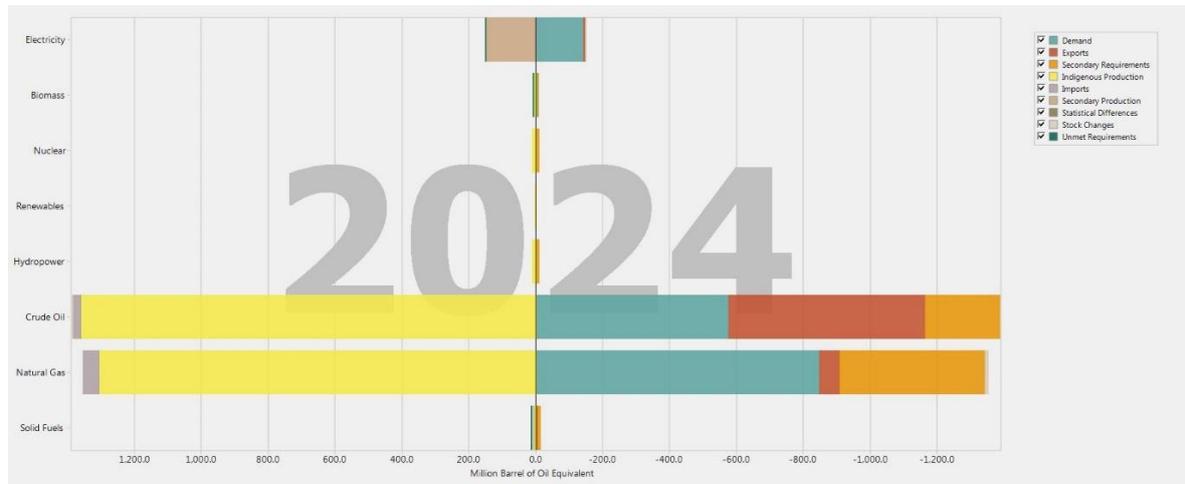
	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.3	1,272.2	1,328.9	9.0	0.2	8.8	8.0	-	2,631.3
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	10.1	1,249.0	768.9	9.0	0.2	8.8	8.0	-4.1	2,049.8
Oil Transfers	-	-	-26.0	-	-	-	-	-	-26.0
Oil Refinery	-	-	-15.5	-	-	-	-	-	-15.5
PowerPlants	-2.0	-346.3	-139.1	-9.0	-0.2	-8.8	-0.1	176.9	-328.5
Coke units	-1.6	-	-	-	-	-	-	-	-1.6
Furnace units	-2.4	-	-	-	-	-	-	-	-2.4
Transmission and Distribution Loss	-1.4	-86.7	-40.5	-	-	-	-	-29.9	-158.5
Total Transformation	-7.3	-433.1	-221.0	-9.0	-0.2	-8.8	-0.1	147.1	-532.3
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	369.9	21.3	-	-	-	7.9	67.3	466.4
Industry	1.0	286.9	38.0	-	-	-	-	50.9	376.8
Transportation	-	63.6	375.7	-	-	-	-	0.2	439.5
Agriculture	-	8.4	20.1	-	-	-	-	22.1	50.7
Other	-	-	-	-	-	-	-	2.4	2.4
NonEnergy Uses	1.7	87.2	92.8	-	-	-	-	-	181.7
Total Demand	2.8	815.9	547.9	-	-	-	7.9	143.0	1,517.4
Unmet Requirements (Waste)	0.0	-	-	-	-	-	0.0	-	-

The following figures show the energy balance in 2020 based on the previous approach (without any scenario).



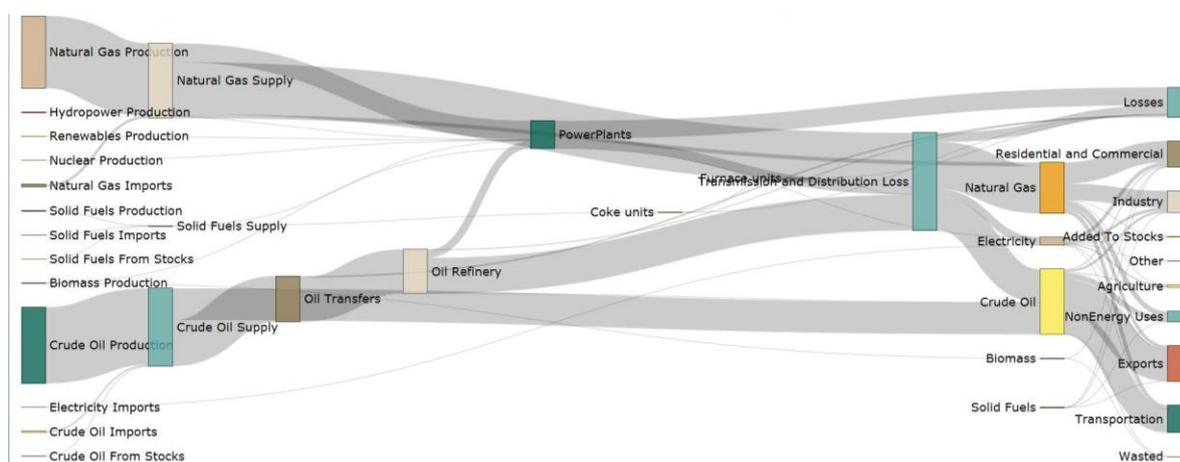
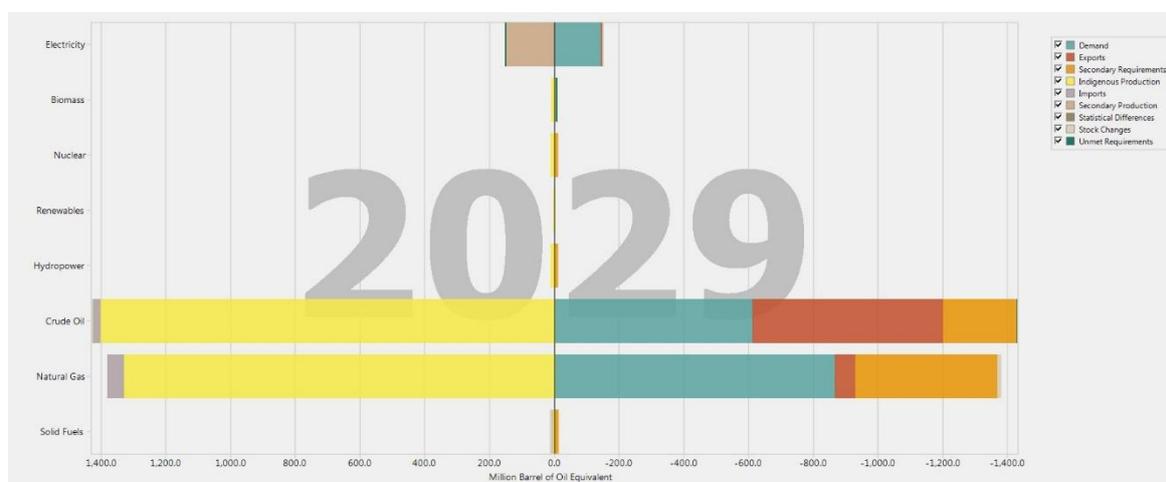
	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	5.7	1,293.8	1,333.2	9.0	0.2	8.7	8.0	-	2,658.5
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	11.5	1,270.6	773.2	9.0	0.2	8.7	8.0	-4.1	2,077.0
Oil Transfers	-	-	-26.1	-	-	-	-	-	-26.1
Oil Refinery	-	-	-15.5	-	-	-	-	-	-15.5
PowerPlants	-2.0	-346.0	-138.9	-9.0	-0.2	-8.7	-0.1	176.8	-328.1
Coke units	-1.8	-	-	-	-	-	-	-	-1.8
Furnace units	-2.8	-	-	-	-	-	-	-	-2.8
Transmission and Distribution Loss	-1.6	-88.9	-40.8	-	-	-	-	-29.9	-161.1
Total Transformation	-8.2	-434.8	-221.4	-9.0	-0.2	-8.7	-0.1	146.9	-535.5
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	373.8	19.3	-	-	-	7.9	65.9	467.0
Industry	0.9	298.2	39.1	-	-	-	-	51.3	389.5
Transportation	-	65.6	380.3	-	-	-	-	0.3	446.2
Agriculture	-	8.7	19.6	-	-	-	-	23.0	51.3
Other	-	-	-	-	-	-	-	2.3	2.3
NonEnergy Uses	2.3	89.4	93.5	-	-	-	-	-	185.2
Total Demand	3.2	835.7	551.9	-	-	-	7.9	142.8	1,541.5
Unmet Requirements (Waste)	-	-	-	-	-	-	0.0	-	0.0

The following figures show the energy balance in 2024 based on the previous approach (without any scenario).



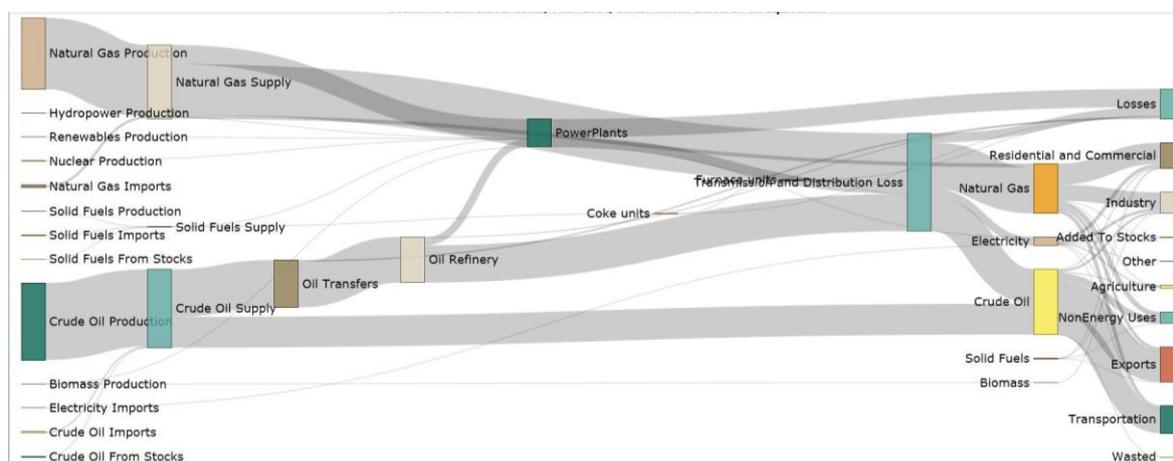
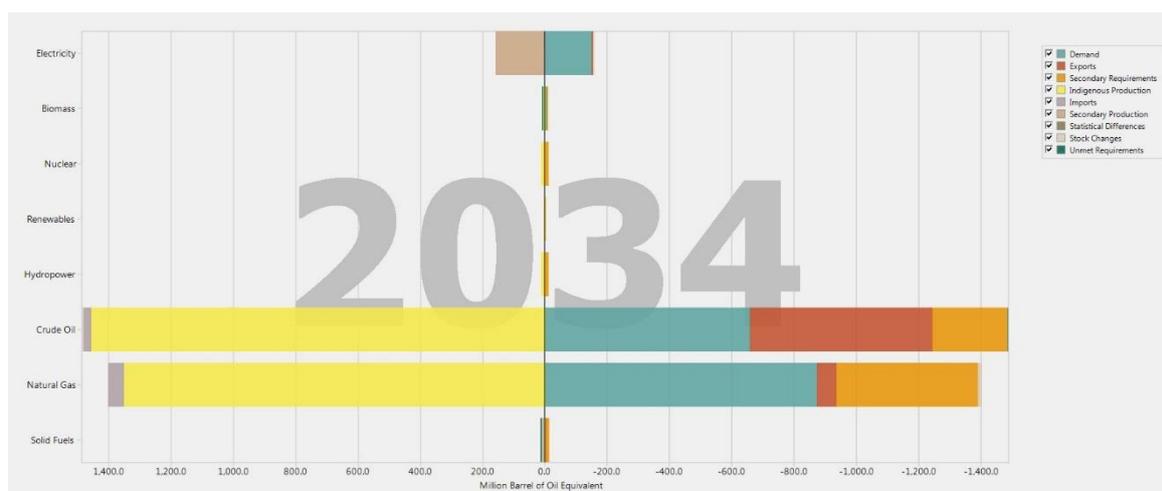
	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	6.1	1,305.5	1,361.5	8.9	0.2	8.7	7.3	-	2,698.3
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	11.9	1,282.3	801.5	8.9	0.2	8.7	7.3	-4.1	2,116.8
Oil Transfers	-	-	-27.1	-	-	-	-	-	-27.1
Oil Refinery	-	-	-16.1	-	-	-	-	-	-16.1
PowerPlants	-2.0	-345.4	-138.7	-8.9	-0.2	-8.7	-0.1	176.5	-327.6
Coke units	-1.9	-	-	-	-	-	-	-	-1.9
Furnace units	-2.9	-	-	-	-	-	-	-	-2.9
Transmission and Distribution Loss	-1.7	-90.0	-42.6	-	-	-	-	-29.8	-164.2
Total Transformation	-8.5	-435.4	-224.5	-8.9	-0.2	-8.7	-0.1	146.7	-539.8
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	377.9	18.4	-	-	-	7.2	66.1	469.6
Industry	0.8	301.7	39.2	-	-	-	-	50.4	392.2
Transportation	-	68.2	398.3	-	-	-	-	0.4	466.9
Agriculture	-	9.5	18.8	-	-	-	-	23.9	52.2
Other	-	-	-	-	-	-	-	1.8	1.8
NonEnergy Uses	2.5	89.6	102.2	-	-	-	-	-	194.3
Total Demand	3.4	846.9	577.0	-	-	-	7.2	142.6	1,577.0
Unmet Requirements (Waste)	0.0	-	-	-	-	-	0.0	0.0	0.0

The following figures show the energy balance in 2029 based on the previous approach (without any scenario).

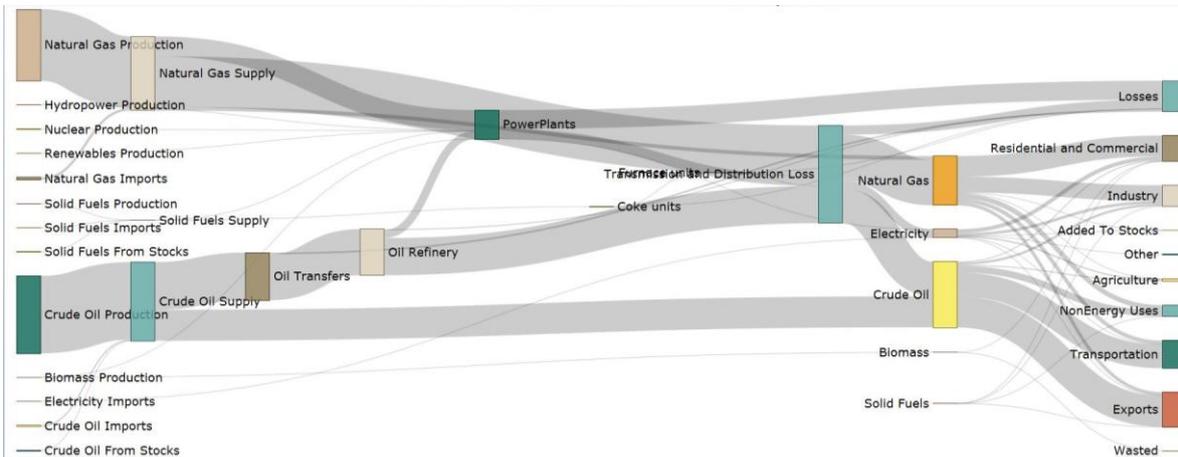
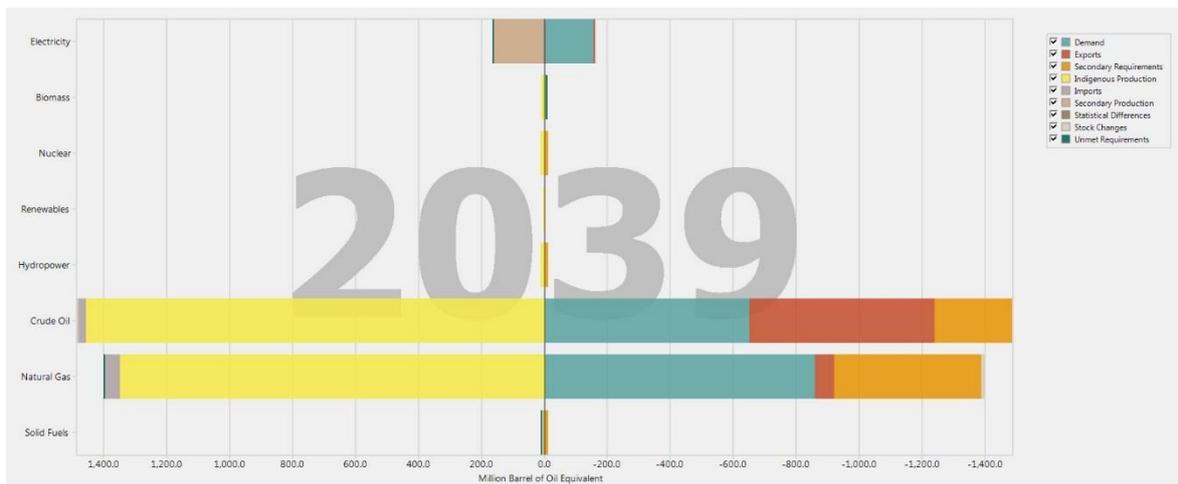


	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.9	1,331.3	1,403.6	9.0	0.2	8.8	6.5	-	2,764.4
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	10.7	1,308.1	843.6	9.0	0.2	8.8	6.5	-4.1	2,182.9
Oil Transfers	-	-	-28.5	-	-	-	-	-	-28.5
Oil Refinery	-	-	-17.0	-	-	-	-	-	-17.0
PowerPlants	-2.0	-347.9	-139.7	-9.0	-0.2	-8.8	-0.1	177.7	-329.9
Coke units	-1.7	-	-	-	-	-	-	-	-1.7
Furnace units	-2.6	-	-	-	-	-	-	-	-2.6
Transmission and Distribution Loss	-1.5	-92.3	-45.3	-	-	-	-	-30.0	-169.1
Total Transformation	-7.8	-440.2	-230.4	-9.0	-0.2	-8.8	-0.1	147.7	-548.8
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	389.8	17.5	-	-	-	6.4	64.7	478.5
Industry	0.9	308.3	41.0	-	-	-	-	52.8	403.0
Transportation	-	69.9	434.7	-	-	-	-	0.7	505.4
Agriculture	-	9.8	18.2	-	-	-	-	23.5	51.5
Other	-	-	-	-	-	-	-	1.9	1.9
NonEnergy Uses	2.0	90.2	101.7	-	-	-	-	-	193.9
Total Demand	3.0	868.0	613.1	-	-	-	6.4	143.6	1,634.1
Unmet Requirements (Waste)	-	-	0.0	-	-	-	0.0	0.0	0.0

The following figures show the energy balance in 2034 based on the previous approach (without any scenario).

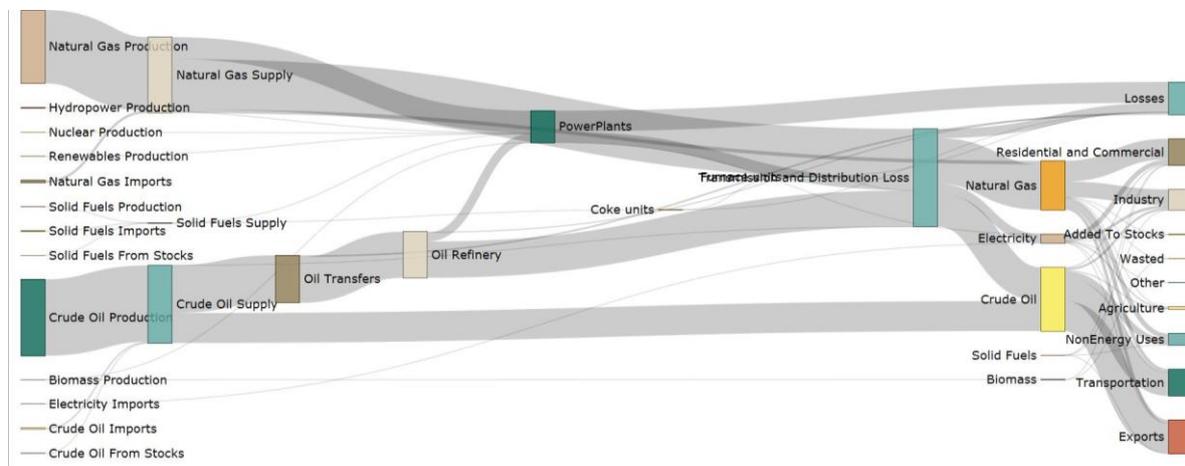
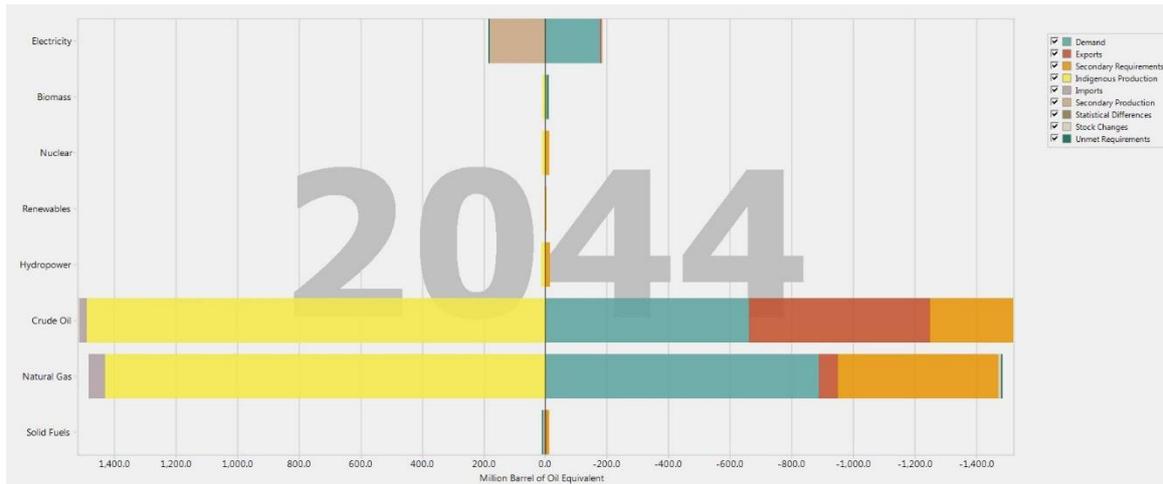


	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.3	1,352.0	1,459.1	9.4	0.2	9.2	6.6	-	2,840.8
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	10.1	1,328.8	899.1	9.4	0.2	9.2	6.6	-4.1	2,259.3
Oil Transfers	-	-	-30.4	-	-	-	-	-	-30.4
Oil Refinery	-	-	-18.1	-	-	-	-	-	-18.1
PowerPlants	-2.1	-362.3	-145.5	-9.4	-0.2	-9.2	-0.1	185.1	-343.6
Coke units	-1.6	-	-	-	-	-	-	-	-1.6
Furnace units	-2.4	-	-	-	-	-	-	-	-2.4
Transmission and Distribution Loss	-1.4	-92.9	-48.5	-	-	-	-	-31.3	-174.1
Total Transformation	-7.4	-455.2	-242.4	-9.4	-0.2	-9.2	-0.1	153.8	-570.1
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	399.4	17.0	-	-	-	6.5	66.5	489.4
Industry	1.2	303.4	41.6	-	-	-	-	53.8	399.9
Transportation	-	69.3	449.7	-	-	-	-	2.0	520.9
Agriculture	-	10.2	18.1	-	-	-	-	24.4	52.7
Other	-	-	-	-	-	-	-	3.0	3.0
NonEnergy Uses	1.5	91.4	130.3	-	-	-	-	-	223.2
Total Demand	2.7	873.6	656.6	-	-	-	6.5	149.7	1,689.2
Unmet Requirements (Waste)	0.0	-	0.0	-	-	-	0.0	-	-



	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	3.8	1,350.1	1,458.9	9.7	0.2	9.5	6.8	-	2,838.9
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.6	1,326.9	898.9	9.7	0.2	9.5	6.8	-4.1	2,257.4
Oil Transfers	-	-	-30.4	-	-	-	-	-	-30.4
Oil Refinery	-	-	-18.1	-	-	-	-	-	-18.1
PowerPlants	-2.1	-375.6	-150.8	-9.7	-0.2	-9.5	-0.1	191.9	-356.2
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-91.4	-48.1	-	-	-	-	-32.5	-173.3
Total Transformation	-7.0	-467.0	-247.4	-9.7	-0.2	-9.5	-0.1	159.4	-581.6
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	391.0	17.1	-	-	-	6.7	72.0	486.8
Industry	1.0	297.2	42.8	-	-	-	-	53.4	394.4
Transportation	-	70.8	447.2	-	-	-	-	3.1	521.2
Agriculture	-	10.1	18.5	-	-	-	-	23.8	52.5
Other	-	-	-	-	-	-	-	3.0	3.0
NonEnergy Uses	1.4	90.6	125.9	-	-	-	-	-	217.9
Total Demand	2.5	859.9	651.5	-	-	-	6.7	155.3	1,675.9
Unmet Requirements (Waste)	0.0	0.0	0.0	-	-	-	0.0	0.0	0.0

The following figures show the energy balance in 2044 based on the previous approach (without any scenario).



	Solid Fuels	Natural Gas	Crude Oil	Hydropower	Renewables	Nuclear	Biomass	Electricity	Total
Production	4.0	1,433.1	1,490.9	11.1	0.3	10.8	6.9	-	2,957.0
Imports	2.6	47.4	23.8	-	-	-	-	2.2	76.0
Exports	-1.0	-61.1	-587.4	-	-	-	-	-5.7	-655.2
From Stock Change	4.2	-9.5	3.6	-	-	-	-	-0.6	-2.3
Total Primary Supply	9.8	1,409.9	930.9	11.1	0.3	10.8	6.9	-4.1	2,375.5
Oil Transfers	-	-	-31.5	-	-	-	-	-	-31.5
Oil Refinery	-	-	-18.7	-	-	-	-	-	-18.7
PowerPlants	-2.4	-427.7	-171.7	-11.1	-0.3	-10.8	-0.1	218.5	-405.7
Coke units	-1.4	-	-	-	-	-	-	-	-1.4
Furnace units	-2.2	-	-	-	-	-	-	-	-2.2
Transmission and Distribution Loss	-1.3	-94.4	-48.8	-	-	-	-	-37.1	-181.5
Total Transformation	-7.3	-522.1	-270.7	-11.1	-0.3	-10.8	-0.1	181.5	-641.0
Statistical Differences	-	-	-	-	-	-	-	-	-
Residential and Commercial	0.1	405.0	17.4	-	-	-	6.7	91.0	520.2
Industry	1.5	308.5	43.1	-	-	-	-	54.4	407.4
Transportation	-	71.5	450.8	-	-	-	-	4.2	526.5
Agriculture	-	10.3	18.8	-	-	-	-	24.6	53.6
Other	-	-	-	-	-	-	-	3.2	3.2
NonEnergy Uses	1.0	92.5	130.1	-	-	-	-	-	223.6
Total Demand	2.5	887.7	660.2	-	-	-	6.7	177.4	1,734.5
Unmet Requirements (Waste)	0.0	0.0	0.0	-	-	-	0.0	0.0	0.0

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