ISTANBUL OKAN UNIVERSITY

INSTITUTE OF SCIENCES

THESIS FOR THE DEGREE OF MASTER OF AUTOMOTIVE MECHATRONICS AND INTELLIGENT VEHICLES

Bartu TUNA

THE EVALUATION OF BATTERY ELECTRIC VEHICLE AND ITS IMPACT ON CLIMATE CHANGE

ADVISOR

Prof. Dr. Ramazan Nejat TUNCAY

ISTANBUL, December 2022

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PİLLİ ELEKTRİKLİ ARACIN DEĞERLENDİRİLMESİ VE ONUN İKLİM DEĞİŞİKLİĞİNDEKİ ETKİSİ

Bu tezde elektrikli araç incelendi ve onun iklim değişikliğindeki etkisi değerlendirildi. İlk olarak pilli elektrikli araç ve onun fosil yakıtlı araçlar ile karşılaştırılarak avantajları ve dezavantajları ifade edildi. İkinci olarak pilli elektrikli araçların markaları ele alındı ve dünya çapındaki ve Çin'deki elektrikli araç satışları ile birlikte gelecekteki elektrikli araç satışlarından söz edildi. Üçüncü olarak elektrikli araçların karbon dioksit emisyonu üzerine kuyudan tekerleğe bakış açısıyla bir çalışma yapıldı. Elektrikli bir aracın yolda seyir halindeyken elektrik tükettiği bilinmiştir. Ancak elektrik üretimi sırasında fosil yakıtlar kullanıldı ve çevreye karbon dioksit salındı. Bu doğrultuda doğal gaz, petrol, ve kömür gibi farklı birincil enerjiler için elektrik üretilirken karbon dioksit emisyon faktörleri hesaplanmıştır. Fosil yakıtların elektrik üretiminde kullanımının ülkeden ülkeye farklılık gösterdiği ve elektrikli araçların tükettiği elektriğin bu açıdan değerlendirilmesi gerektiği belirtilmiştir. Bu çalışma, çeşitli ülkeler için elektrik enerjisi üretirken ortaya çıkan karbon dioksit emisyonlarını sunmuş ve 2019, 2020, 2021, 2030 ve 2040 yılları için sunulmuştur. Dördüncü olarak yukarıda bahsedilen çalışmalar ve çeşitli ülkelerde yıldan yıla istatistiksel değişimler değerlendirilmiştir. Son olarak farklı ülkelerde aynı araç için 100 kilometrede karbon dioksit emisyonu tabloda gösterilmiştir.

Anahtar Kelimeler: Enerji Karışımı, Karbon Dioksit Emisyonu, Karbon Dioksit Emisyon Faktörü, Pilli Elektrikli Araç

Tarih: 14.12.2022

ABSTRACT

THE EVALUATION OF BATTERY ELECTRIC VEHICLE AND ITS IMPACT ON CLIMATE CHANGE

In this thesis, the evaluation of battery electric vehicle and its impact on climate change was studied. First of all, battery electric vehicles and their advantages and disadvantages comparing with fossil fueled cars have been expressed. Secondly, the brands of battery electric vehicles have been handled and electric vehicle sellings which are in the future have been mentioned together with electric vehicle sellings which are both worldwide and in China. Thirdly, a study on the carbon dioxide emission of the electric vehicles from the Well to Wheel point of view has been conducted. It has been known that an electric vehicle consumes electricity while it is travelling on the road. Nevertheless, the fossil fuels were used and carbon dioxide was emitted during the generation of electricity. In this respect, the carbon dioxide emission factors have been calculated while producing electricity for different primary energies, such as natural gas, oil, and the coal. It has been noted that the use of fossil fuels in electricity production varies from country to country and the electricity consumed by electric vehicle must be considered from this point of view. This study presented the carbon dioxide emissions while electric energy producing for various countries and was presented for the years of 2019, 2020, 2021, 2030, and 2040. Fourthly, the above mentioned studies and the year by year statistical changes in various countries have been evaluated. Finally, carbon dioxide emission per 100 kilometers for same vehicle in different countries has been showed in table.

Keywords: Battery Electric Vehicle, Carbon Dioxide Emission, Carbon Dioxide Emission Factor, Energy Mix

Date: 14.12.2022

ABBREVIATIONS

BEV : Battery Electric Vehicle

BMW : Bavarian Motor Works

BP : British Petroleum

CO2 : Carbon Dioxide

DC : Direct Current

EU : European Union

EV : Electric Vehicle

ICE : Internal Combustion Engine

SUVs : Sports Utility Vehicles

UK : United Kingdom

US : United States

ZEVs : Zero Emissions Vehicles

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CHAPTER 1. INTRODUCTION

EV is known as vehicle which utilizes either one or more electric motors for propulsive power. It may be made work either by battery that is charged by transforming fuel to electricity by making use of either generator or fuel batteries or by system which is collector (Faiz vd., 1996).

Electric vehicles were common at the beginning of 1900s. In automobile moving, electricity was preferred at this time. The energy crisis gave new interest in electric cars in both 1970s and 1980s (Shrivastava, 2011).

1.1 THE POSITIVE SIDES OF EV COMPARED TO FOSSIL FUELED CARS

EV, which is also known as BEV that means Battery Electric Vehicle, has a few positive sides over traditional ICE vehicles. These advantages are explained below:

- Extermination of detrimental tailpipe polluters like diverse oxides of nitrogen that kill many people from year to year (WEB_8, 2017).
- While electric vehicles use 38 MJs per 100 kilometers, internal combustion engine vehicles use 142 MJs per 100 kilometers (WEB_2, 2017).
- Battery electric cars have less carbon dioxide emissions than fossil fueled cars. Therefore, climate change is limited (International Energy Agency, 2020).

1.2 THE NEGATIVE SIDES OF EV COMPARED TO FOSSIL FUELED CARS

EV has negative sides together with positive sides. These disadvantages are explained below:

- Although the amount of unusual metals shows dissimilarity per car, it is thought that there is reliance on unusual earth elements like terbium, lanthanum, dysprosium, and neodymium, and other important elements like cobalt and lithium (WEB_10, 2019; WEB_6, 2010).
- There are pollution which is emitted in production, and the quantities which increase from production of battery.
- There are particulate substance emissions which increase because of tires. This is due to the fact that many electric automobiles have heavy battery. This means that tires of the automobile are exposed to more corrosion. If there is regenerative braking, the brake pads in electric automobiles may be used less than non-electric automobiles. Therefore, particulate pollution can be produced less than brakes which are in non-electric automobiles by the brake pads (WEB_1, 2017; WEB_7, 2017). Moreover, some electric automobiles can have incorporation of disc brakes and drum brakes. If we compare disc brakes with drum brakes, disc brakes lead to more particulate emissions than drum brakes (WEB_4, 2022).

This thesis initially explains the brands of the electric vehicle, and electric vehicle sellings that are in the future together with electric vehicle sellings that are both worldwide and in China. Secondly, CO2 emission is going to be explained, and unit emission values of natural gas, coal, and oil will be calculated dividing the world CO2 emissions in terms of these sources by the world electricity productions in terms of these sources. CO2 emissions of fossil fuels like coal, natural gas, and oil in Asian and European countries are going to be calculated for 2019, 2020, 2021, 2030, and 2040 and total CO2 emissions are going to be obtained. Thirdly, the statistical changes of both total carbon dioxide emission and unit emission value from 2019 to 2020, from 2020 to 2021 and from 2030 to 2040

will be shown with charts. Finally, CO2 emission per 100 km for same vehicle in different countries will be showed in chart.

CHAPTER 2. BRANDS and SELLINGS OF ELECTRIC VEHICLES

2.1 BMW i4

The BMW i4 was German brand's third battery electric vehicle in 2021, which was immediately after both iX and iX3 SUVs. Nevertheless, this vehicle has been the most significant electric vehicle of BMW so far because this is both zero emissions alternative to popular 3 Series sedan of the brand and direct rival to both Tesla Model 3 and Polestar 2. Moreover, BMW based the i4 upon 4 Series Gran Coupe with combustion engine. Therefore, it has abundantly visual existance (WEB_3, 2022).

The i4 M50 has estimated range until 386.24 km whereas the i4 eDrive40 has estimated range until 482.8 km. The battery of this vehicle is 108 mm long, which consists of both three 12 cell modules and 4 modules with 72 cells. For high-power DC charging, the battery pack of this vehicle whose voltage is 398 V has charging capacity which is 200 kW. As BMW says, charging from 10 % to 80 % must take thirty-one minutes (WEB_5, 2021).

2.2 VOLKSWAGEN ID.4

The Volkswagen ID.4 is sports utility vehicle with electric, which is brand's well-known. This vehicle rivals with electric sports utility vehicles which sell most worldwide such as Tesla Model Y. In the future, this vehicle will become the most popular electric car worldwide. This vehicle reaches 394.29 km of driving range. Moreover, there is abundantly cabin area in this vehicle. This vehicle charges at a logical speed. Also, this vehicle has a silent driving (WEB_9, 2022).

2.3 ELECTRIC VEHICLE SELLINGS WORLDWIDE

Electric vehicles were initially sold in many parts of the world in 2012, and the selling number of these vehicles was 120000. The sellings of electric vehicles which are worldwide continued to increase extremely in 2022. 2000000 electric vehicles were sold in worldwide in the first three months of this year, and the sellings of electric vehicles increased 75 % in worldwide according to the same period of 2021 (International Energy Agency, 2022).

2.4 ELECTRIC VEHICLE SELLINGS IN CHINA

In China, 3.3 million electric vehicles were sold in 2021, which was 0.3 million more than the number of electric vehicle selling which was worldwide in 2020. Moreover, the fleet of this country about electric vehicles whose amount is 7.8 million continued to be the world's largest in 2021. This doubled up the stock belonging to 2019. Also, battery electric vehicles were sold in this country in 2021, which was over 2.7 million. This created 82 % of new electric vehicle sellings (International Energy Agency, 2022).

2.5 ELECTRIC VEHICLE SELLINGS IN THE FUTURE

BMW purposes that 50 % of its cars which are sold until 2030 will be completely electric. Hyundai which is Korean manufacturer aims sellings of 1.9 million electric vehicles every year until 2030 not only in order to assure 7 % universal market share but also in order to end sellings of internal combustion engine vehicles in Europe in 2035. Volkswagen that is German manufacturer explained that whole EVs will pass over 50 % of the US and Chinese, and 70 % of European sellings until 2030, which should be almost 100 % ZEVs (International Energy Agency, 2022).

CHAPTER 3. CALCULATION OF TOTAL CO2 EMISSIONS and CO2 EMISSION FACTORS

Carbon dioxide emission which is based on burning of fossil fuels such as coal, natural gas or petrolium while producing electricity, is the major source of global climate change (Ritchie and Roser, 2020). It occurs not only in Turkey but in other European and Asian countries as well. Since percentage of the fossil fuels used in electricity production varies from country to country, it is necessary to calculate the CO2 per kWh ratio separately for each country. First, we need to know the CO2 emission factor for each fossil fuel. Then we have to obtain the power mix for each country and calculate the produced electricity by using each fossil fuel. Then the emitted CO2 for each fossil fuel could be calculated by multiplying kWh electricity produced by the relevant fossil fuel. Finally, CO2 emitted by each fossil fuel are summed and the total CO2 emitted during the electricity production per year is obtained. In order to find CO2/kWh value for each country, the total CO2 produced by fossil fuels is divided by total electricity production including renewables and nuclear too.

The formula that belongs to the carbon dioxide emission is shown below (Özdemir and Yatarkalkmaz, 2019):

CO2 Emission= Electricity Production * Emission Factor (3.1)

3.1 CO2 EMISSIONS and CO2 EMISSION FACTOR in VARIOUS COUNTRIES in 2019

The carbon dioxide emission factor is available in various countries together with carbon dioxide emission. According to 2019, the energy mix values of various countries about coal, gas, oil, renewables, nuclear, hydro, and others which I found are shown below:

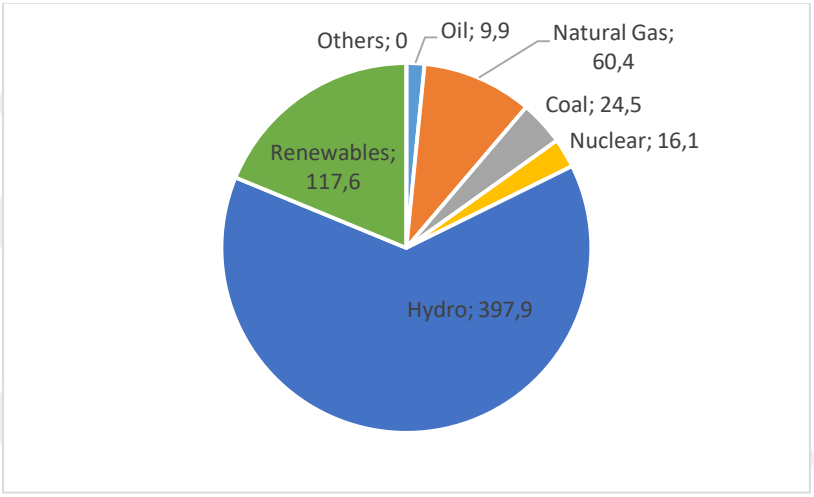

Figure 3.1. Energy Mix Values in Brazil in 2019 (BP Statistical Review of World Energy, 2021)

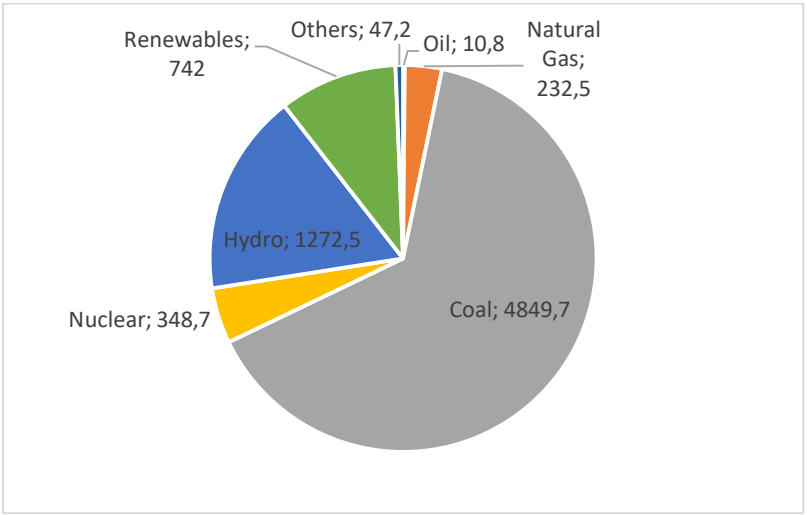

Figure 3.2. Energy Mix Values in China in 2019 (BP Statistical Review of World Energy, 2021)

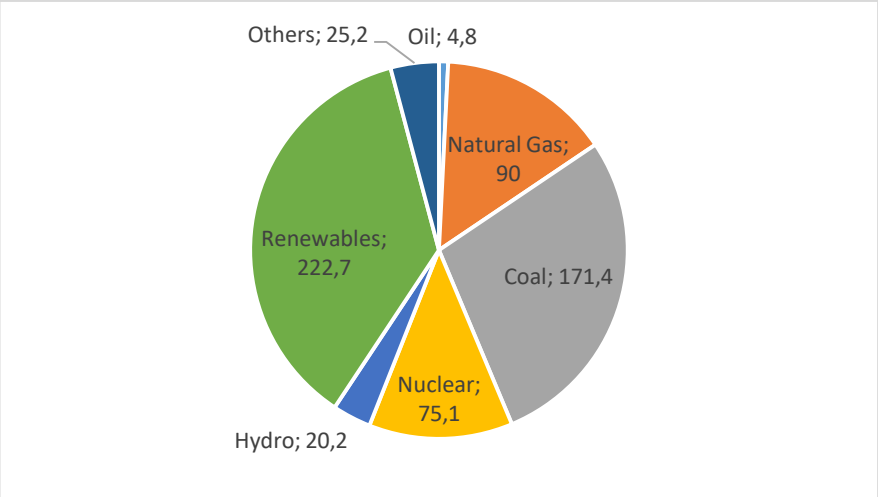

Figure 3.3 (Continuation). Energy Mix Values in Germany in 2019 (BP Statistical Review of World Energy, 2021)

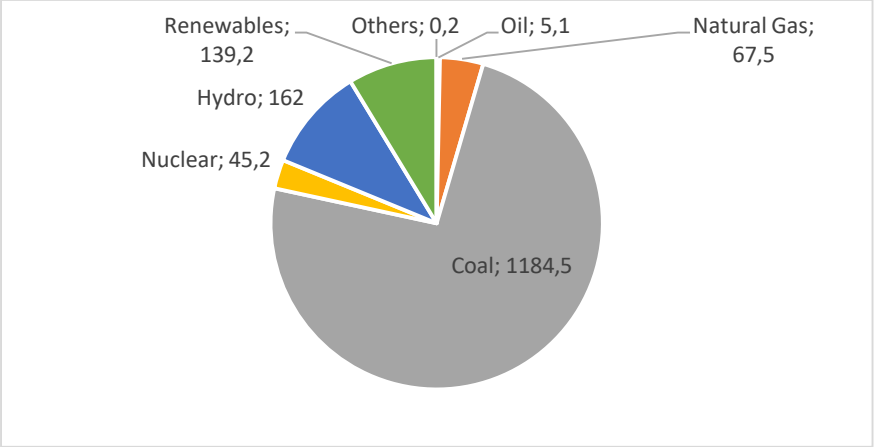

Figure 3.4 (Continuation). Energy Mix Values in India in 2019 (BP Statistical Review of World Energy, 2021)

3.1.1. Total Electricity Production of Various Countries in 2019 (BP Statistical Review of World Energy, 2021)

Brazil: 626,4 Twh

China: 7503,4 Twh

Germany: 609,4 Twh

India: 1603,7 Twh

Italy: 293,9 Twh

Japan: 1030,3 Twh

Russia: 1118,1 Twh

Spain: 267,5 Twh

Turkey: 303,8 Twh

US: 4411,2 Twh

3.1.2. Unit Carbon Dioxide Emission per kWh for Coal, Natural Gas, and Oil Worldwide in 2019 (International Energy Agency, 2021)

Coal:

Unit CO2 Emission per kWh = (10171*10^12 gr) / (9911*10^9 kWh)

Unit CO2 Emission per kWh = 1026 gr/kWh

The numerator is the World's total carbon dioxide emission while producing electricity by coal. On the other hand, the denominator is the World's total electricity production by coal. When they are divided each other, the unit emission value for the coal can be found as gr CO2 emission per kWh electricity production.

Natural Gas:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh = (3136*10^12 gr) / (6356*10^9 kWh)

Unit CO2 Emission per kWh = 493 gr/kWh

The numerator is the World's total carbon dioxide emission of the natural gas in terms of electricity production, whereas the denominator is the World's total electricity production by the natural gas. When they are divided each other, the unit emission value of the natural gas can be found as gr CO2 emission per kWh electricity production.

Oil:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh = (626*10^12 gr) / (752*10^9 kWh)

Unit CO2 Emission per kWh = 832 gr/kWh

The numerator is the World's total carbon dioxide emission of the oil in terms of electricity production, whereas the denominator is the World's total electricity production by the oil. When they are divided each other, the unit emission value of the oil can be found as gr CO2 emission per kWh electricity production.

3.1.3. Calculations of CO2 Emission and CO2 Emission Factor in Various Countries in 2019

Brazil: The electricity production of this country from coal is 24.5 Twh, from oil is 9.9 Twh, from renewables is 117.6 Twh, from hydro is 397.9 Twh, from natural gas is 60.4 Twh, from nuclear is 16.1 Twh. However, there is no electricity production from others in this country for this year (BP Statistical Review of World Energy, 2021). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

Since the electricity production of others is zero, CO2 emission from others is going to be zero. Furthermore, CO2 emission from nuclear, hydro and renewables like wind and solar will be zero.

CO2 emission for natural gas = (60,4*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 29777,2*10^9 grCO2

CO2 emission for coal = (24,5*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 25137*10^9 grCO2

CO2 emission for oil = (9,9*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 8236,8*10^9 grCO2

Total CO2 emission = 63151*10^9 grCO2

Unit Emission Value = (63151*10^9 grCO2) / (626,4*10^9 kWh)

Unit Emission Value = 100,81 gr/kWh

China: The electricity production of this country from natural gas is 232.5 Twh, from coal is 4849.7 Twh, from hydro is 1272.5 Twh, from renewables is 742 Twh, from oil is 10.8 Twh, from nuclear energy is 348,7 Twh, and from others is 47.2 Twh (BP Statistical

Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, hydro, nuclear, and others are zero.

CO2 emission for coal = (4849,7*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 4975792,2*10^9 grCO2

CO2 emission for oil = (10,8*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 8985,6*10^9 grCO2

CO2 emission for natural gas = (232,5*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 114622,5*10^9 grCO2

Total CO2 emission = 5099400,3*10^9 grCO2

Unit Emission Value = (5099400,3*10^9 grCO2) / (7503,4*10^9 kWh)

Unit Emission Value = 679,61 gr/kWh

Germany: The electricity production of this country from hydro is 20.2 Twh, from oil is 4.8 Twh, from natural gas is 90 Twh, from coal is 171.4 Twh, from renewables is 222.7 Twh, from nuclear is 75.1 Twh, and from others is 25.2 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from hydro, renewables, nuclear, and others are zero.

CO2 emission for oil = (4,8*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 3993,6*10^9 grCO2

CO2 emission for coal = (171,4*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 175856,4*10^9 grCO2

CO2 emission for natural gas = (90*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 44370*10^9 grCO2

Total CO2 emission = 224220*10^9 grCO2

Unit Emission Value = (224220*10^9 grCO2) / (609,4*10^9 kWh)

Unit Emission Value = 367,93 gr/kWh

India: The electricity production of this country from nuclear is 45.2 Twh, from coal is 1184.5 Twh, from natural gas is 67.5 Twh, from renewables is 139.2 Twh, from oil is 5.1 Twh, from hydro is 162 Twh, and from others is 0.2 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables and hydro are zero.

CO2 emission for coal = (1184,5*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 1215297*10^9 grCO2

CO2 emission for natural gas = (67,5*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 33277,5*10^9 grCO2

CO2 emission for oil = (5,1*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 4243,2*10^9 grCO2

Total CO2 emission = 1252817,7*10^9 grCO2

Unit Emission Value = (1252817,7*10^9 grCO2) / (1603,7*10^9 kWh)

Unit Emission Value = 781,2 gr/kWh

Italy: The electricity production of this country from coal is 21.3 Twh, from oil is 11.8 Twh, from hydro is 46.4 Twh, from natural gas is 141.7 Twh, from renewables is 69.5 Twh, and from others is 3.2 Twh. Unfortunately, there is no nuclear in this country (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

Since the electricity production of nuclear is zero, CO2 emission from nuclear will be zero. Moreover, CO2 emissions from not only renewbles but also hydro, and others are going to be zero.

CO2 emission for natural gas = (141,7*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 69858,1*10^9 grCO2

CO2 emission for oil = (11,8*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 9817,6*10^9 grCO2

CO2 emission for coal = (21,3*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 21853,8*10^9 grCO2

Total CO2 emission = 101529,5*10^9 grCO2

Unit Emission Value = (101529,5*10^9 grCO2) / (293,9*10^9 kWh)

Unit Emission Value = 345,45 gr/kWh

Japan: The electricity generation of this country from natural gas is 363.7 Twh, from nuclear is 65.6 Twh, from coal is 307.2 Twh, from renewables is 111.2 Twh, from hydro is 73.6 Twh, from oil is 53.5 Twh, and from others is 55.5 Twh (BP Statistical Review of

World Energy, 2021). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

Since the unit emission value of hydro is zero, CO2 emission from hydro will be zero. Also, CO2 emissions from not only nuclear but also renewables, and others will be zero.

CO2 emission for oil = (53,5*10^9 kWh) * (832 gr/kWh)

CO2 emission for oil = 44512*10^9 grCO2

CO2 emission for coal = (307,2*10^9 kWh) * (1026 gr/kWh)

CO2 emission for coal = 315187,2*10^9 grCO2

CO2 emission for natural gas = (363,7*10^9 kWh) * (493 gr/kWh)

CO2 emission for natural gas = 179304,1*10^9 grCO2

Total CO2 emission = 539003,3*10^9 grCO2

Unit Emission Value = (539003,3*10^9 grCO2) / (1030,3*10^9 kWh)

Unit Emission Value = 523,15 gr/kWh

Russia: The electricity production of this country from coal is 176.8 Twh, from natural gas is 519.2 Twh, from oil is 12 Twh, from nuclear is 209 Twh, from hydro is 194.4 Twh, from renewables is 1.8 Twh, and from others is 4.9 Twh (BP Statistical Review of World Energy, 2021). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

Since the unit emission values of nuclear, hydro, renewables, and others are zero, CO2 emissions of these sources will be zero.

CO2 emission for natural gas = (519,2*10^9 kWh)*(493 gr/kWh)

CO2 emission for natural gas = 255965,6*10^9 grCO2

CO2 emission for coal = (176,8*10^9 kWh)*(1026 gr/kWh)

CO2 emission for coal = 181396,8*10^9 grCO2

CO2 emission for oil = (12*10^9 kWh)*(832 gr/kWh)

CO2 emission for oil = 9984*10^9 grCO2

Total CO2 emission = 447346,4*10^9 grCO2

Unit Emission Value = (447346,4*10^9 grCO2)/(1118,1*10^9 kWh)

Unit Emission Value = 400,09 gr/kWh

Spain: The electricity production of this country from nuclear is 58.3 Twh, from renewables is 73.8 Twh, from oil is 12.3 Twh, from natural gas is 83.2 Twh, from coal is 14.1 Twh, from hydro is 22.5 Twh, and from others is 3.3 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from hydro, renewables, nuclear, and others are zero.

CO2 emission for coal = (14,1*10^9 kWh)*(1026 gr/kWh)

CO2 emission for coal = 14466,6*10^9 grCO2

CO2 emission for natural gas = (83,2*10^9 kWh)*(493 gr/kWh)

CO2 emission for natural gas = 41017,6*10^9 grCO2

CO2 emission for oil = (12,3*10^9 kWh)*(832 gr/kWh)

CO2 emission for oil = 10233,6*10^9 grCO2

Total CO2 emission = 65717,8*10^9 grCO2

Unit Emission Value = (65717,8*10^9 grCO2)/(267,5*10^9 kWh)

Unit Emission Value = 245,67 gr/kWh

Turkey: The electricity production of this country from natural gas is 57.3 Twh, from coal is 112.9 Twh, from renewables is 43.3 Twh, from oil is 0.3 Twh, from hydro is 88.8 Twh, and from others is 1.2 Twh. There is no nuclear in this country just as in Italy (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

Because the electricity production of nuclear is zero, CO2 emission from nuclear will also be zero. Furthermore, CO2 emissions from hydro, renewables, and others will be zero.

CO2 emission for coal = (112,9*10^9 kWh)*(1026 gr/kWh)

CO2 emission for coal = 115835,4*10^9 grCO2

CO2 emission for natural gas = (57,3*10^9 kWh)*(493 gr/kWh)

CO2 emission for natural gas = 28248,9*10^9 grCO2

CO2 emission for oil = (0,3*10^9 kWh)*(832 gr/kWh)

CO2 emission for oil = 249,6*10^9 grCO2

Total CO2 emission = 144333,9*10^9 grCO2

Unit Emission Value = (144333,9*10^9 grCO2)/(303,8*10^9 kWh)

Unit Emission Value = 475,09 gr/kWh

The US: The electricity production of this country from hydro is 285.5 Twh, from nuclear is 852 Twh, from natural gas is 1705.2 Twh, from coal is 1051.1 Twh, from renewables is 483.7 Twh, from oil is 19.7 Twh, and from others is 14 Twh (BP Statistical Review of

World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from hydro, renewables, and others will be zero.

CO2 emission for oil = (19,7*10^9 kWh)*(832 gr/kWh)

CO2 emission for oil = 16390,4*10^9 grCO2

CO2 emission for coal = (1051,1*10^9 kWh)*(1026 gr/kWh)

CO2 emission for coal = 1078428,6*10^9 grCO2

CO2 emission for natural gas = (1705,2*10^9 kWh)*(493 gr/kWh)

CO2 emission for natural gas = 840663,6*10^9 grCO2

Total CO2 emission = 1935482,6*10^9 grCO2

Unit Emission Value = (1935482,6*10^9 grCO2)/(4411,2*10^9 kWh)

Unit Emission Value = 438,76 gr/kWh

3.2 CO2 EMISSIONS and CO2 EMISSION FACTOR in VARIOUS COUNTRIES in 2020

The energy mix values of various countries about nuclear, renewables, gas, coal, hydro, oil, and others I found are shown below:

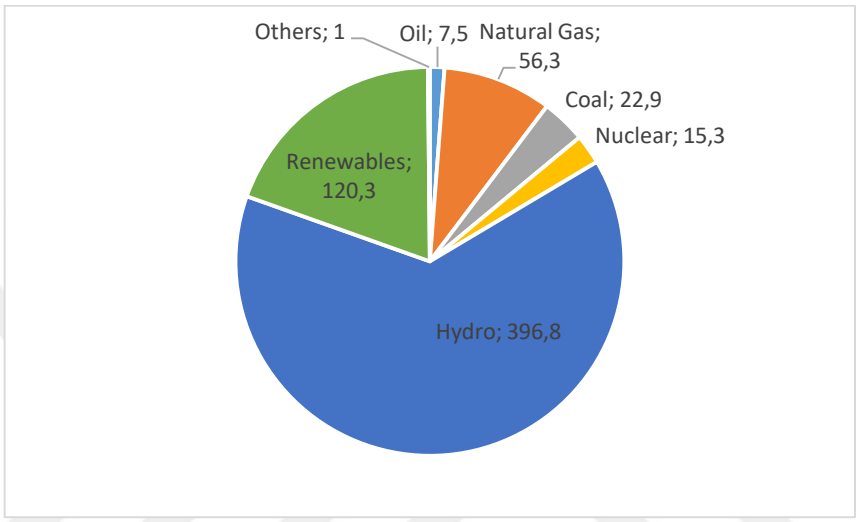

Figure 3.5. Energy Mix Values in Brazil in 2020 (BP Statistical Review of World Energy, 2021)

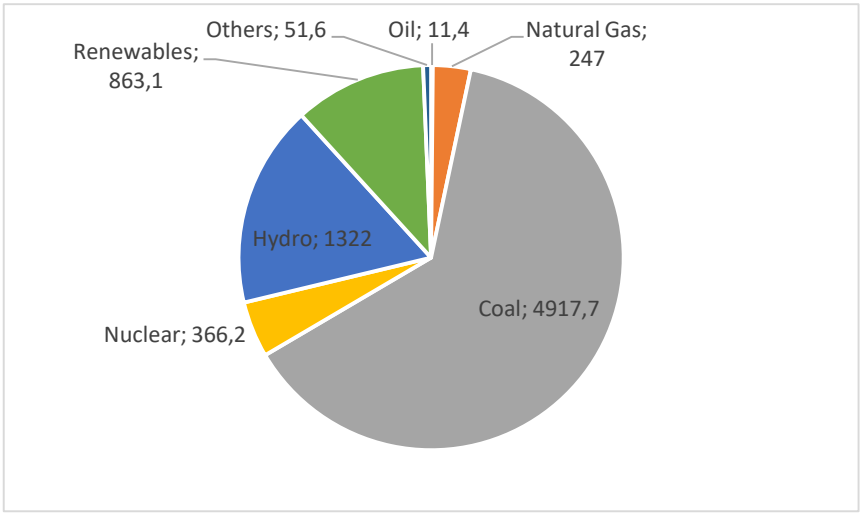

Figure 3.6. Energy Mix Values in China in 2020 (BP Statistical Review of World Energy, 2021)

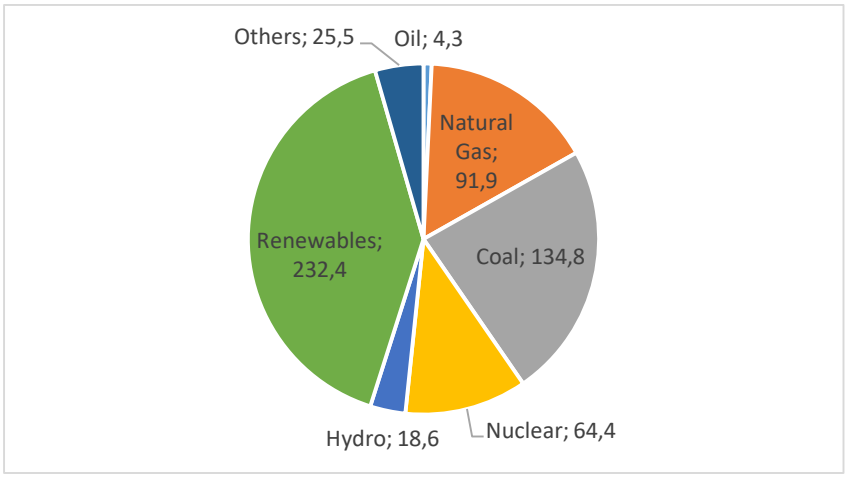

Figure 3.7 (Continuation). Energy Mix Values in Germany in 2020 (BP Statistical Review of World Energy, 2021)

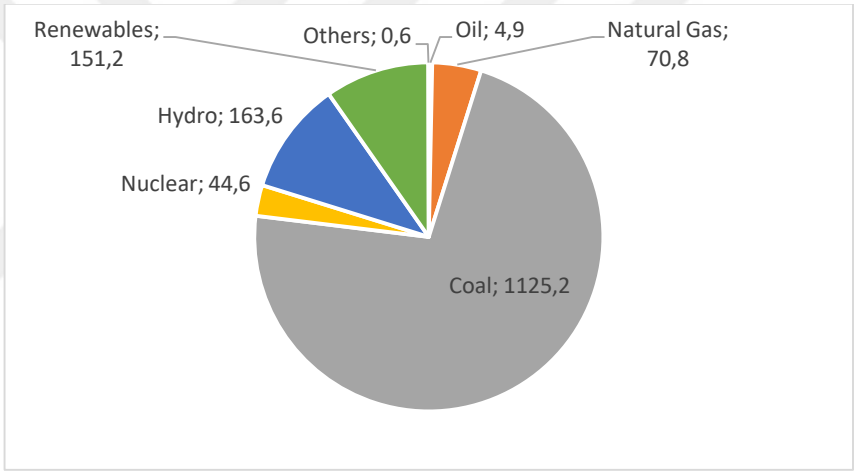

Figure 3.8 (Continuation). Energy Mix Values in India in 2020 (BP Statistical Review of World Energy, 2021)

3.2.1. Total Electricity Production of Various Countries in 2020 (BP Statistical Review of World Energy, 2021)

Brazil: 620,1 Twh

China: 7779 Twh

Germany: 571,9 Twh

India: 1560,9 Twh

Italy: 282,7 Twh

Japan: 1004,8 Twh

Russia: 1085,4 Twh

Spain: 255,8 Twh

Turkey: 305,4 Twh

US: 4286,6 Twh

3.2.2. Unit Carbon Dioxide Emission per kWh for Coal, Natural Gas, and Oil Worldwide in 2020 (International Energy Agency, 2021)

Coal:

Unit CO2 Emission per kWh = (9832*10^12 gr)/(9467*10^9 kWh) = 1039 gr/kWh

The numerator is the World's total carbon dioxide emission while producing electricity by coal. On the other hand, the denominator is the World's total electricity production by the coal. When they are divided each other, we find the unit emission value for the coal as gr CO2 emission per kWh electricity production.

Natural Gas:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh = (3097*10^12 gr)/(6257*10^9 kWh) = 495 gr/kWh

The numerator is the World's total carbon dioxide emission of the natural gas in terms of electricity production, while the denominator is the World's total electricity production by the natural gas. When they are divided each other, the unit emission value of the natural gas can be found as gr CO2 emission per kWh electricity production.

Oil:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh = (601*10^12 gr)/(716*10^9 kWh) = 839 gr/kWh

The numerator is the World's total carbon dioxide emission of the oil in terms of electricity production, while the denominator is the World's total electricity production by the oil. We find the unit emission value of the oil as gr CO2 emission per kWh electricity production when they are divided each other.

3.2.3. Calculations of CO2 Emission and CO2 Emission Factor in Various Countries in 2020

Brazil: The electricity production of this country from renewables is 120.3 Twh, from nuclear is 15.3 Twh, from hydro is 396.8 Twh, from coal is 22.9 Twh, from natural gas is 56.3 Twh, from oil is 7.5 Twh, and from others is 1 Twh (BP Statistical Review of

World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from hydro, renewables, nuclear, and others will be zero.

CO2 emission for oil= (7,5*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 6292,5*10^9 grCO2

CO2 emission for coal= (22,9*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 23793,1*10^9 grCO2

CO2 emission for natural gas= (56,3*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 27868,5*10^9 grCO2

Total CO2 emission= 57954,1*10^9 grCO2

Unit Emission Value= (57954,1*10^9 grCO2)/(620,1*10^9 kWh)

Unit Emission Value= 93,46 gr/kWh

China: The electricity production of this country from coal is 4917.7 Twh, from natural gas is 247 Twh, from hydro is 1322 Twh, from oil is 11.4 Twh, from renewables is 863.1 Twh, from nuclear is 366.2 Twh, and from others is 51.6 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, hydro, renewables, and others are going to be zero.

CO2 emission for natural gas= (247*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 122265*10^9 grCO2

CO2 emission for coal= (4917,7*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 5109490,3*10^9 grCO2

CO2 emission for oil= (11,4*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 9564,6*10^9 grCO2

Total CO2 emission= 5241319,9*10^9 grCO2

Unit Emission Value= (5241319,9*10^9 grCO2)/(7779*10^9 kWh)

Unit Emission Value= 673,77 gr/kWh

Germany: The electricity production of this country from nuclear is 64.4 Twh, from renewables is 232.4 Twh, from oil is 4.3 Twh, from coal is 134.8 Twh, from hydro is 18.6 Twh, from natural gas is 91.9 Twh, and from others is 25.5 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, nuclear, hydro, and others are zero.

CO2 emission for coal= (134,8*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 140057,2*10^9 grCO2

CO2 emission for oil= (4,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 3607,7*10^9 grCO2

CO2 emission for natural gas= (91,9*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 45490,5*10^9 grCO2

Total CO2 emission= 189155,4*10^9 grCO2

Unit Emission Value= (189155,4*10^9 grCO2)/(571,9*10^9 kWh)

Unit Emission Value= 330,74 gr/kWh

India: The electricity production of this country from natural gas is 70.8 Twh, from coal is 1125.2 Twh, from hydro is 163.6 Twh, from oil is 4.9 Twh, from nuclear is 44.6 Twh, from renewables is 151.2 Twh, and from others is 0.6 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, hydro, nuclear, and others are zero.

CO2 emission for natural gas= (70,8*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 35046*10^9 grCO2

CO2 emission for coal= (1125,2*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 1169082,8*10^9 grCO2

CO2 emission for oil= (4,9*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 4111,1*10^9 grCO2

Total CO2 emission= 1208239,9*10^9 grCO2

Unit Emission Value= (1208239,9*10^9 grCO2)/(1560,9*10^9 kWh)

Unit Emission Value= 774,06 gr/kWh

Italy: The electricity production of this country from coal is 16.7 Twh, from hydro is 46.7 Twh, from natural gas is 136.2 Twh, from renewables is 70.3 Twh, from oil is 9.7 Twh, and from others is 3.1 Twh. There is no nuclear in this country just as in 2019 (BP Statistical Review of World Energy, 2021). The calculations of both CO2 emission and CO2 emission factor are shown below:

Since the electricity production of nuclear is zero, CO2 emission from nuclear is going to be zero. Moreover, CO2 emissions from renewables, hydro, and others are going to be zero.

CO2 emission for oil= (9,7*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 8138,3*10^9 grCO2

CO2 emission for coal= (16,7*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 17351,3*10^9 grCO2

CO2 emission for natural gas= (136,2*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 67419*10^9 grCO2

Total CO2 Emission= 92908,6*10^9 grCO2

Unit Emission Value= (92908,6*10^9 grCO2)/(282,7*10^9 kWh)

Unit Emission Value= 328,64 gr/kWh

Japan: The electricity production of this country from renewables is 125.6 Twh, from hydro is 77.5 Twh, from coal is 298.8 Twh, from natural gas is 353.5 Twh, from oil is 41.6 Twh, from nuclear is 43 Twh, and from others is 64.8 Twh (BP Statistical Review of World Energy, 2021). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

CO2 emission from hydro, nuclear, renewables, and others will be zero.

CO2 emission for coal= (298,8*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 310453,2*10^9 grCO2

CO2 emission for natural gas= (353,5*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 174982,5*10^9 grCO2

CO2 emission for oil= (41,6*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 34902,4*10^9 grCO2

Total CO2 emission= 520338,1*10^9 grCO2

Unit Emission Value= (520338,1*10^9 grCO2)/(1004,8*10^9 kWh)

Unit Emission Value= 517,85 gr/kWh

Russia: The electricity generation of this country from coal is 152.3 Twh, from oil is 10.7 Twh, from renewables is 3.5 Twh, from hydro is 212.4 Twh, from nuclear is 215.9 Twh, from natural gas is 485.5 Twh, and from others is 4.9 Twh (BP Statistical Review of World Energy, 2021). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from nuclear, renewables, hydro, and others will be zero.

CO2 emission for oil= (10,7*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 8977,3*10^9 grCO2

CO2 emission for natural gas= (485,5*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 240322,5*10^9 grCO2

CO2 emission for coal= (152,3*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 158239,7*10^9 grCO2

Total CO2 emission= 407539,5*10^9 grCO2

Unit Emission Value= (407539,5*10^9 grCO2)/(1085,4*10^9 kWh)

Unit Emission Value= 375,47 gr/kWh

Spain: The electricity production of this country from natural gas is 68.7 Twh, from oil is 10.7 Twh, from coal is 5.6 Twh, from renewables is 80.5 Twh, from hydro is 27.5 Twh, from nuclear is 58.2 Twh, and from others is 4.6 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, hydro, nuclear, and others are going to be zero.

CO2 emission for oil= (10,7*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 8977,3*10^9 grCO2

CO2 emission for natural gas= (68,7*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 34006,5*10^9 grCO2

CO2 emission for coal= (5,6*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 5818,4*10^9 grCO2

Total CO2 emission= 48802,2*10^9 grCO2

Unit Emission Value= (48802,2*10^9 grCO2)/(255,8*10^9 kWh)

Unit Emission Value= 190,78 gr/kWh

Turkey: The electricity production of this country from hydro is 78.1 Twh, from natural gas is 70 Twh, from coal is 106.1 Twh, from oil is 0.1 Twh, from renewables is 49.8 Twh, and from others is 1.3 Twh. Also, there is no nuclear in this country (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

Because the electricity production of nuclear is zero, CO2 emission from nuclear is going to be zero just as in Italy. Also, CO2 emissions from hydro, renewables, and others are zero.

CO2 emission for coal= (106,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 110237,9*10^9 grCO2

CO2 emission for natural gas= (70*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 34650*10^9 grCO2

CO2 emission for oil= (0,1*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 83,9*10^9 grCO2

Total CO2 emission= 144971,8*10^9 grCO2

Unit Emission Value= (144971,8*10^9 grCO2)/(305,4*10^9 kWh)

Unit Emission Value= 474,69 gr/kWh

The US: The electricity production of this country from nuclear is 831.5 Twh, from coal is 844.1 Twh, from hydro is 288.7 Twh, from oil is 18.8 Twh, from natural gas is 1738.4 Twh, from renewables is 551.7 Twh, and from others is 13.4 Twh (BP Statistical Review of World Energy, 2021). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, hydro, renewables, and others will be zero.

CO2 emission for natural gas= (1738,4*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 860508*10^9 grCO2

CO2 emission for coal= (844,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 877019,9*10^9 grCO2

CO2 emission for oil= (18,8*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 15773,2*10^9 grCO2

Total CO2 emission= 1753301,1*10^9 grCO2

Unit Emission Value= (1753301,1*10^9 grCO2)/(4286,6*10^9 kWh)

Unit Emission Value= 409,01 gr/kWh

3.3 CO2 EMISSIONS and CO2 EMISSION FACTOR in VARIOUS COUNTRIES in 2021

The energy mix values of various countries about gas, coal, oil, hydro, renewables, nuclear, and others I found are shown below:

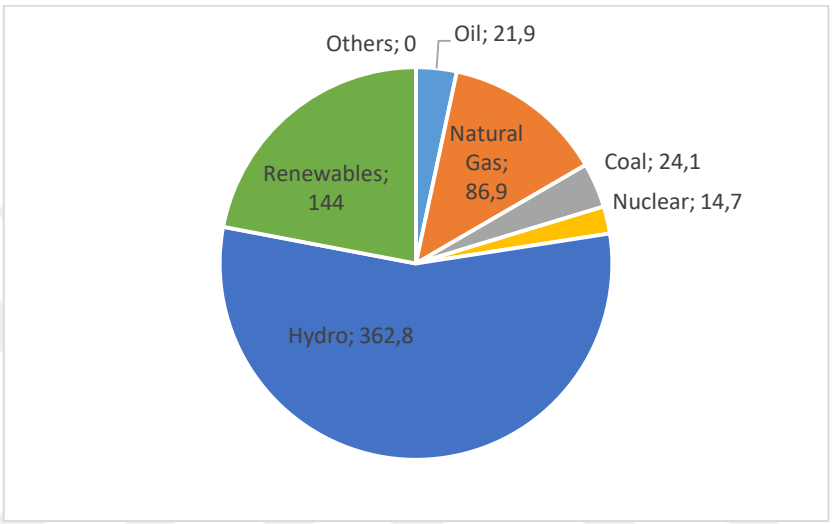

Figure 3.9. Energy Mix Values in Brazil in 2021 (BP Statistical Review of World Energy, 2022)

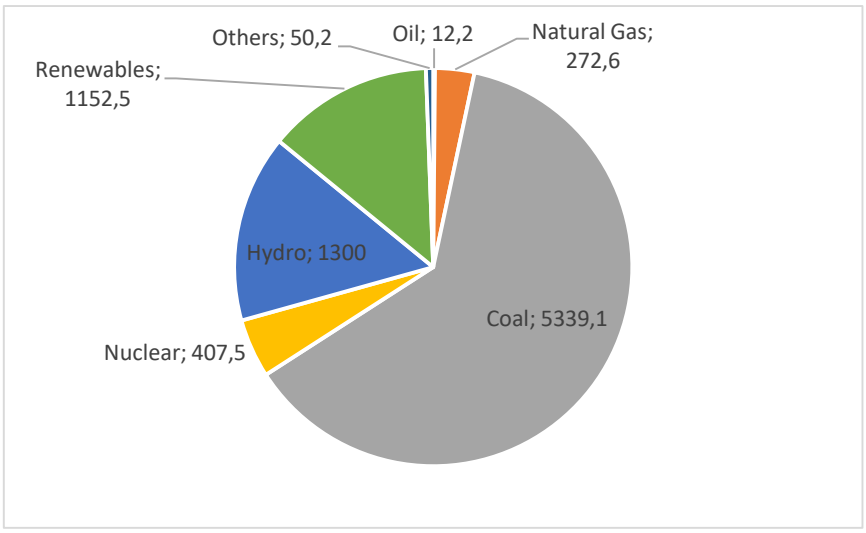

Figure 3.10. Energy Mix Values in China in 2021 (BP Statistical Review of World Energy, 2022)

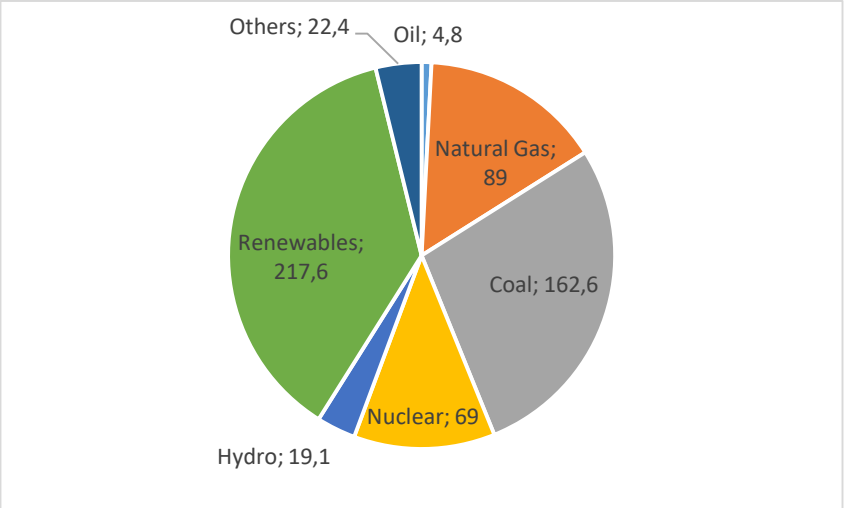

Figure 3.11 (Continuation). Energy Mix Values in Germany in 2021 (BP Statistical Review of World Energy, 2022)

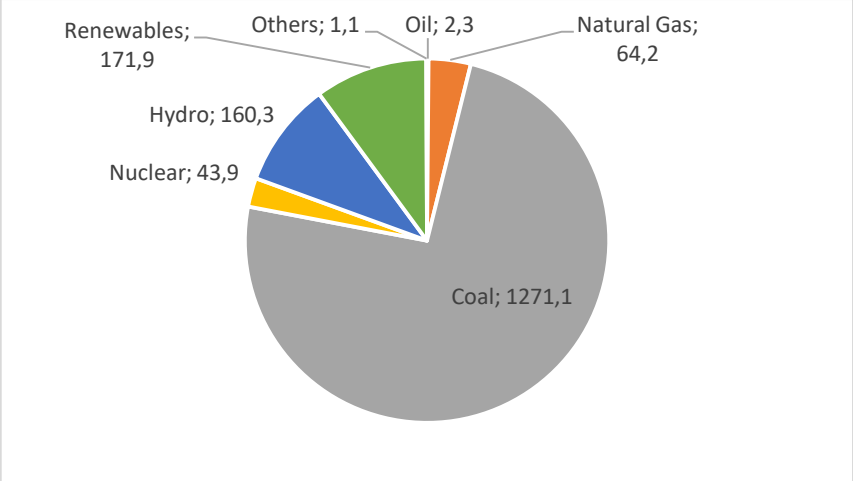

Figure 3.12 (Continuation). Energy Mix Values in India in 2021 (BP Statistical Review of World Energy, 2022)

3.3.1. Total Electricity Production of Various Countries in 2021 (BP Statistical Review of World Energy, 2022)

Brazil: 654,4 Twh

China: 8534,3 Twh

Germany: 584,5 Twh

India: 1714,8 Twh

Italy: 287,2 Twh

Japan: 1019,7 Twh

Russia: 1157,1 Twh

Spain: 272,1 Twh

Turkey: 333,3 Twh

US: 4406,4 Twh

3.3.2. Unit Carbon Dioxide Emission per kWh for Coal, Natural Gas, and Oil Worldwide in 2021 (International Energy Agency, 2021)

Coal: We can take the unit carbon dioxide emission per kWh as 1039 gr/kWh.

Natural Gas: We can take the unit carbon dioxide emission per kWh as 495 gr/kWh.

Oil: We can take the unit carbon dioxide emission per kWh as 839 gr/kWh.

3.3.3. Calculations of CO2 Emission and CO2 Emission Factor in Various Countries in 2021

Brazil: The electricity generation of this country from natural gas is 86.9 Twh, from oil is 21.9 Twh, from hydro is 362.8 Twh, from nuclear is 14.7 Twh, from coal is 24.1 Twh, and from renewables is 144 Twh. However, there are no others in this country (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, renewables, hydro, and others will be zero.

CO2 emission for coal= (24,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 25039,9*10^9 grCO2

CO2 emission for oil= (21,9*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 18374,1*10^9 grCO2

CO2 emission for natural gas= (86,9*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 43015,5*10^9 grCO2

Total CO2 emission= 86429,5*10^9 grCO2

Unit Emission Value= (86429,5*10^9 grCO2)/(654,4*10^9 kWh)

Unit Emission Value= 132,07 gr/kWh

China: The electricity production of this country from renewables is 1152.5 Twh, from hydro is 1300 Twh, from natural gas is 272.6 Twh, from oil is 12.2 Twh, from nuclear is 407.5 Twh, from coal is 5339.1 Twh, and from others is 50.2 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, nuclear, hydro, and others will be zero.

CO2 emission for oil= (12,2*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 10235,8*10^9 grCO2

CO2 emission for natural gas= (272,6*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 134937*10^9 grCO2

CO2 emission for coal= (5339,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 5547324,9*10^9 grCO2

Total CO2 emission= 5692497,7*10^9 grCO2

Unit Emission Value= (5692497,7*10^9 grCO2)/(8534,3*10^9 kWh)

Unit Emission Value= 667,01 gr/kWh

Germany: The electricity generation of this country from renewables is 217.6 Twh, from natural gas is 89 Twh, from hydro is 19.1 Twh, from oil is 4.8 Twh, from nuclear is 69 Twh, from coal is 162.6 Twh, and from others is 22.4 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, hydro, renewables, and others will be zero.

CO2 emission for natural gas= (89*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 44055*10^9 grCO2

CO2 emission for coal= (162,6*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 168941,4*10^9 grCO2

CO2 emission for oil= (4,8*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 4027,2*10^9 grCO2

Total CO2 emission= 217023,6*10^9 grCO2

Unit Emission Value= (217023,6*10^9 grCO2)/(584,5*10^9 kWh)

Unit Emission Value= 371,29 gr/kWh

India: The electricity production of this country from coal is 1271.1 Twh, from nuclear is 43.9 Twh, from renewables is 171.9 Twh, from natural gas is 64.2 Twh, from hydro is 160.3 Twh, from oil is 2.3 Twh, and from others is 1.1 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, renewables, hydro, and others will be zero.

CO2 emission for oil= (2,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 1929,7*10^9 grCO2

CO2 emission for natural gas= (64,2*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 31779*10^9 grCO2

CO2 emission for coal= (1271,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 1320672,9*10^9 grCO2

Total CO2 emission= 1354381,6*10^9 grCO2

Unit Emission Value= (1354381,6*10^9 grCO2)/(1714,8*10^9 kWh)

Unit Emission Value= 789,81 gr/kWh

Italy: The electricity production of this country from hydro is 43.1 Twh, from coal is 14.5 Twh, from oil is 8.3 Twh, from natural gas is 146.4 Twh, from renewables is 71.4 Twh, and from others is 3.5 Twh. However, there is no nuclear in this country (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from hydro, renewables, nuclear, and others will be zero.

CO2 emission for oil= (8,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 6963,7*10^9 grCO2

CO2 emission for coal= (14,5*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 15065,5*10^9 grCO2

CO2 emission for natural gas= (146,4*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 72468*10^9 grCO2

Total CO2 emission= 94497,2*10^9 grCO2

Unit Emission Value= (94497,2*10^9 grCO2)/(287,2*10^9 kWh)

Unit Emission Value= 329,03 gr/kWh

Japan: The electricity generation of this country from nuclear is 61.2 Twh, from coal is 301.9 Twh, from oil is 31.3 Twh, from hydro is 77.6 Twh, from natural gas is 326.1 Twh, from renewables is 130.3 Twh, and from others is 91.3 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, nuclear, hydro, and others will be zero.

CO2 emission for natural gas= (326,1*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 161419,5*10^9 grCO2

CO2 emission for oil= (31,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 26260,7*10^9 grCO2

CO2 emission for coal= (301,9*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 313674,1*10^9 grCO2

Total CO2 emission= 501354,3*10^9 grCO2

Unit Emission Value= (501354,3*10^9 grCO2)/(1019,7*10^9 kWh)

Unit Emission Value= 491,66 gr/kWh

Russia: The electricity production of this country from oil is 8.5 Twh, from renewables is 5.4 Twh, from nuclear is 222.4 Twh, from coal is 204.7 Twh, from natural gas is 496.8 Twh, from hydro is 214.5 Twh, and from others is 4.7 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, hydro, renewables, and others will be zero.

CO2 emission for coal= (204,7*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 212683,3*10^9 grCO2

CO2 emission for oil= (8,5*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 7131,5*10^9 grCO2

CO2 emission for natural gas= (496,8*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 245916*10^9 grCO2

Total CO2 emission= 465730,8*10^9 grCO2

Unit Emission Value= (465730,8*10^9 grCO2)/(1157,1*10^9 kWh)

Unit Emission Value= 402,49 gr/kWh

Spain: The electricity production of this country from coal is 6.1 Twh, from oil is 10.3 Twh, from natural gas is 69.2 Twh, from hydro is 29.6 Twh, from nuclear is 56.5 Twh, from renewables is 95.8 Twh, and from others is 4.7 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from nuclear, hydro, renewables, and others will be zero.

CO2 emission for coal= (6,1*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 6337,9*10^9 grCO2

CO2 emission for natural gas= (69,2*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 34254*10^9 grCO2

CO2 emission for oil= (10,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 8641,7*10^9 grCO2

Total CO2 emission= 49233,6*10^9 grCO2

Unit Emission Value= (49233,6*10^9 grCO2)/(272,1*10^9 kWh)

Unit Emission Value= 180,94 gr/kWh

Turkey: The electricity generation of this country from natural gas is 110.4 Twh, from coal is 104.2 Twh, from renewables is 62.7 Twh, from oil is 0.3 Twh, and from hydro is 55.7 Twh. However, there are no nuclear and others in this country (BP Statistical Review

of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions of renewables, hydro, nuclear, and others will be zero.

CO2 emission for oil= (0,3*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 251,7*10^9 grCO2

CO2 emission for natural gas= (110,4*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 54648*10^9 grCO2

CO2 emission for coal= (104,2*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 108263,8*10^9 grCO2

Total CO2 emission= 163163,5*10^9 grCO2

Unit Emission Value= (163163,5*10^9 grCO2)/(333,3*10^9 kWh)

Unit Emission Value= 489,54 gr/kWh

The US: The electricity production of this country from nuclear is 819.1 Twh, from oil is 20.2 Twh, from coal is 978.5 Twh, from hydro is 257.7 Twh, from natural gas is 1693.8 Twh, from renewables is 624.5 Twh, and from others is 12.7 Twh (BP Statistical Review of World Energy, 2022). The calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emissions from renewables, hydro, nuclear, and others will be zero.

CO2 emission for coal= (978,5*10^9 kWh)*(1039 gr/kWh)

CO2 emission for coal= 1016661,5*10^9 grCO2

CO2 emission for natural gas= (1693,8*10^9 kWh)*(495 gr/kWh)

CO2 emission for natural gas= 838431*10^9 grCO2

CO2 emission for oil= (20,2*10^9 kWh)*(839 gr/kWh)

CO2 emission for oil= 16947,8*10^9 grCO2

Total CO2 emission= 1872040,3*10^9 grCO2

Unit Emission Value= (1872040,3*10^9 grCO2)/(4406,4*10^9 kWh)

Unit Emission Value= 424,84 gr/kWh

3.4 CO2 EMISSIONS and CO2 EMISSION FACTOR in VARIOUS COUNTRIES in 2030

The energy mix values of various countries about coal, hydro, oil, gas, renewables, nuclear, and others I found are shown below:

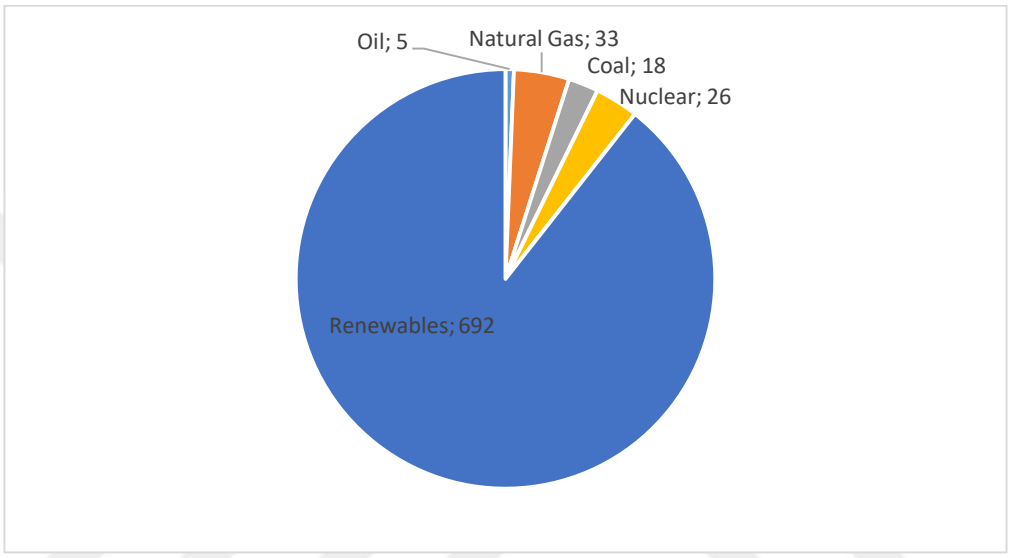

Figure 3.13. Energy Mix Values in Brazil in 2030 (International Energy Agency, 2019)

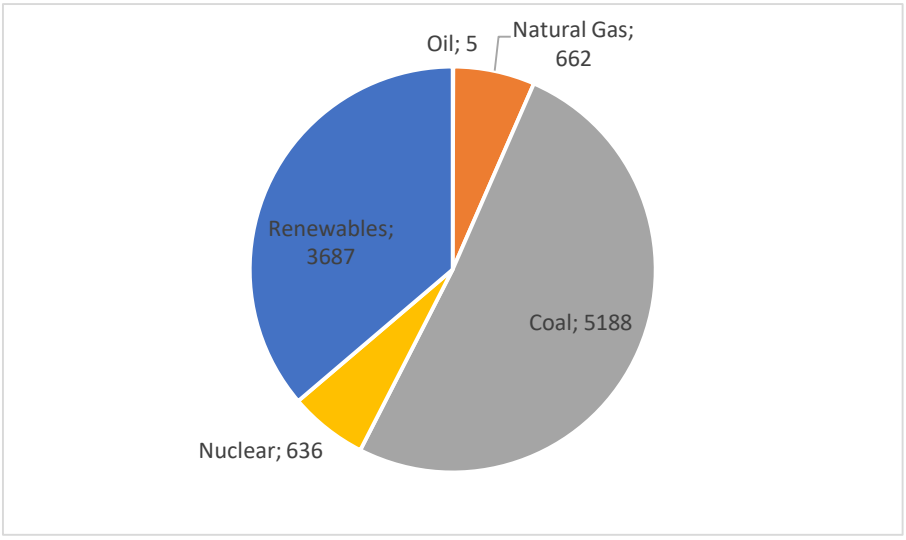

Figure 3.14. Energy Mix Values in China in 2030 (International Energy Agency, 2019)

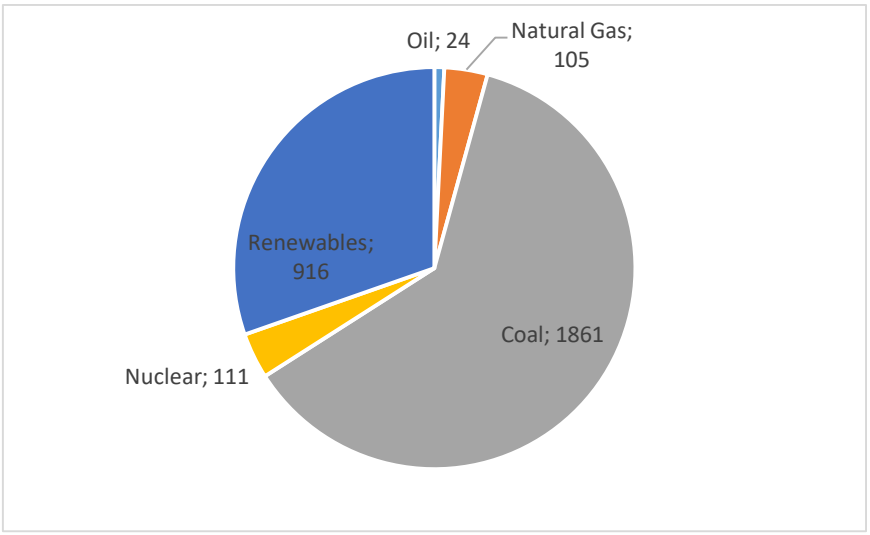

Figure 3.15 (Continuation). Energy Mix Values in India in 2030 (International Energy Agency, 2019)

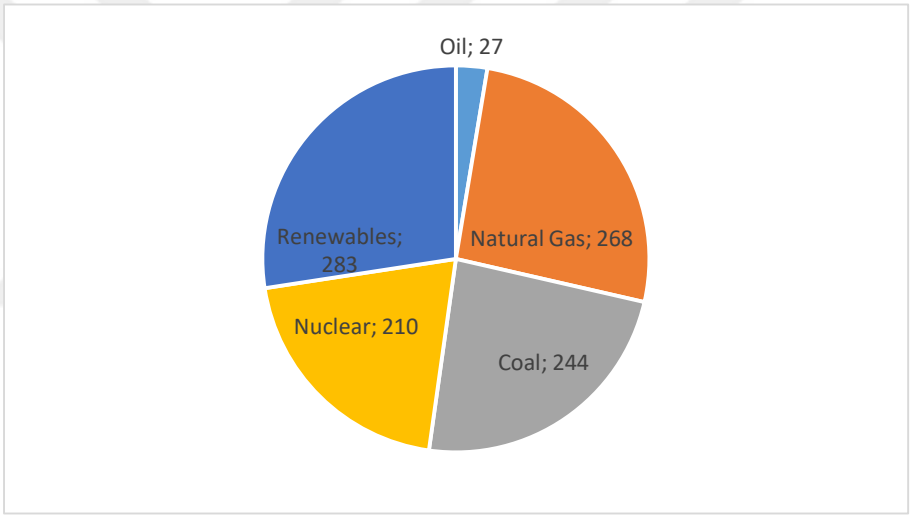

Figure 3.16 (Continuation). Energy Mix Values in Japan in 2030 (International Energy Agency, 2019)

3.4.1. Total Electricity Production of Various Countries in 2030 (International Energy Agency, 2019)

Brazil: 774 Twh

China: 10178 Twh

India: 3017 Twh

Russia: 1232 Twh

Japan: 1032 Twh

3.4.2. Unit Carbon Dioxide Emission per kWh for Coal, Natural Gas, and Oil Worldwide in 2030 (International Energy Agency, 2021)

Coal:

Unit CO2 Emission per kWh= (8791*10^12 gr)/(8733*10^9 kWh)=1006 gr/kWh

The numerator is the World's total carbon dioxide emission while producing electricity by coal. On the other hand, the denominator is the World's total electricity production by the coal. When they are divided each other, the unit emission value for the coal can be found as gr CO2 emission per kWh electricity production.

Natural Gas:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh= (3222*10^12 gr)/(7112*10^9 kWh)= 453 gr/kWh

The numerator is the World's total carbon dioxide emission of the natural gas in terms of electricity production, while the denominator is the World's total electricity production by the natural gas. When they are divided each other, the unit emission value of the natural gas can be found as gr CO2 emission per kWh electricity production.

Oil:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 Emission per kWh= (412*10^12 gr)/(500*10^9 kWh)= 824 gr/kWh

The numerator is the World's total carbon dioxide emission of the oil in terms of electricity production, while the denominator is the World's total electricity production by the oil. When they are divided each other, the unit emission value of the oil can be found as gr CO2 emission per kWh electricity production.

3.4.3. Calculations of CO2 Emission and CO2 Emission Factor in Various Countries in 2030

Brazil: The electricity generation of this country from natural gas is 33 Twh, from coal is 18 Twh, from nuclear is 26 Twh, from oil is 5 Twh, and from renewables is 692 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for oil= (5*10^9 kWh)*(824 gr/kWh)

CO2 emission for oil= 4120*10^9 grCO2

CO2 emission for coal= (18*10^9 kWh)*(1006 gr/kWh)

CO2 emission for coal= 18108*10^9 grCO2

CO2 emission for natural gas= (33*10^9 kWh)*(453 gr/kWh)

CO2 emission for natural gas= 14949*10^9 grCO2

Total CO2 emission= 37177*10^9 grCO2

Unit Emission Value= (37177*10^9 grCO2)/(774*10^9 kWh)

Unit Emission Value= 48,03 gr/kWh

China: The electricity production of this country from coal is 5188 Twh, from natural gas is 662 Twh, from nuclear is 636 Twh, from oil is 5 Twh, and from renewables is 3687 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from nuclear, and renewables will be zero.

CO2 emission for coal= (5188*10^9 kWh)*(1006 gr/kWh)

CO2 emission for coal= 5219128*10^9 grCO2

CO2 emission for natural gas= (662*10^9 kWh)*(453 gr/kWh)

CO2 emission for natural gas= 299886*10^9 grCO2

CO2 emission for oil= (5*10^9 kWh)*(824 gr/kWh)

CO2 emission for oil= 4120*10^9 grCO2

Total CO2 emission= 5523134*10^9 grCO2

Unit Emission Value= (5523134*10^9 grCO2)/(10177*10^9 kWh)

Unit Emission Value= 542,7 gr/kWh

India: The electricity production of this country from renewables is 916 Twh, from natural gas is 105 Twh, from coal is 1861 Twh, from nuclear is 111 Twh, and from oil is

24 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for natural gas= (105*10^9 kWh)*(453 gr/kWh)

CO2 emission for natural gas= 47565*10^9 grCO2

CO2 emission for oil= (24*10^9 kWh)*(824 gr/kWh)

CO2 emission for oil= 19776*10^9 grCO2

CO2 emission for coal= (1861*10^9 kWh)*(1006 gr/kWh)

CO2 emission for coal= 1872166*10^9 grCO2

Total CO2 emission= 1939507*10^9 grCO2

Unit Emission Value= (1939507*10^9 grCO2)/(3017*10^9 kWh)

Unit Emission Value= 642,86 gr/kWh

Japan: The electricity production of this country from oil is 27 Twh, from natural gas is 268 Twh, from coal is 244 Twh, from renewables is 283 Twh, and from nuclear is 210 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from nuclear, and renewables will be zero.

CO2 emission for natural gas= (268*10^9 kWh)*(453 gr/kWh)

CO2 emission for natural gas= 121404*10^9 grCO2

CO2 emission for coal= (244*10^9 kWh)*(1006 gr/kWh)

CO2 emission for coal= 245464*10^9 grCO2

CO2 emission for oil= (27*10^9 kWh)*(824 gr/kWh)

CO2 emission for oil= 22248*10^9 grCO2

Total CO2 emission= 389116*10^9 grCO2

Unit Emission Value= (389116*10^9 grCO2)/(1032*10^9 kWh)

Unit Emission Value= 377,05 gr/kWh

Russia: The electricity generation of this country from nuclear is 211 Twh, from oil is 1 Twh, from coal is 158 Twh, from renewables is 239 Twh, and from natural gas is 623 Twh (International Energy Agency, 2019). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for natural gas= (623*10^9 kWh)*(453 gr/kWh)

CO2 emission for natural gas= 282219*10^9 grCO2

CO2 emission for coal= (158*10^9 kWh)*(1006 gr/kWh)

CO2 emission for coal= 158948*10^9 grCO2

CO2 emission for oil= (1*10^9 kWh)*(824 gr/kWh)

CO2 emission for oil= 824*10^9 grCO2

Total CO2 emission= 441991*10^9 grCO2

Unit Emission Value= (441991*10^9 grCO2)/(1232*10^9 kWh)

Unit Emission Value= 358,75 gr/kWh

3.5 CO2 EMISSIONS and CO2 EMISSION FACTOR in VARIOUS COUNTRIES in 2040

The energy mix values of various countries about renewables, oil, nuclear, coal, hydro, natural gas, and others I found are shown below:

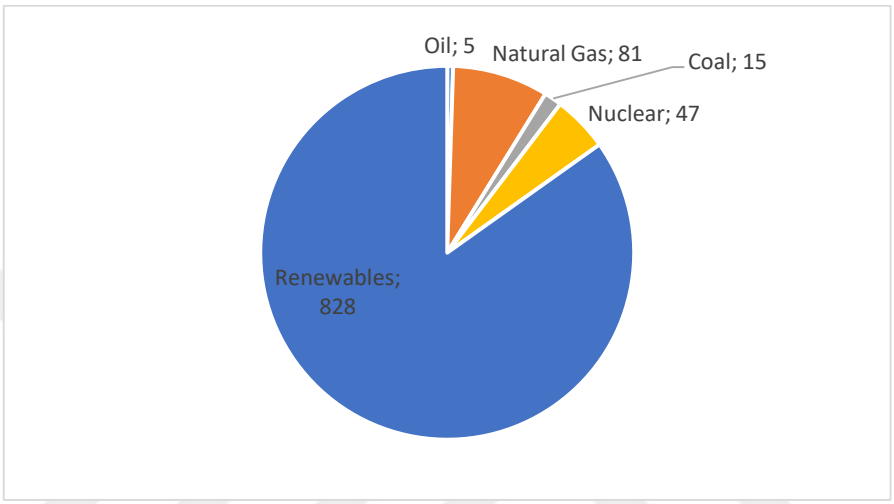

Figure 3.17. Energy Mix Values in Brazil in 2040 (International Energy Agency, 2019)

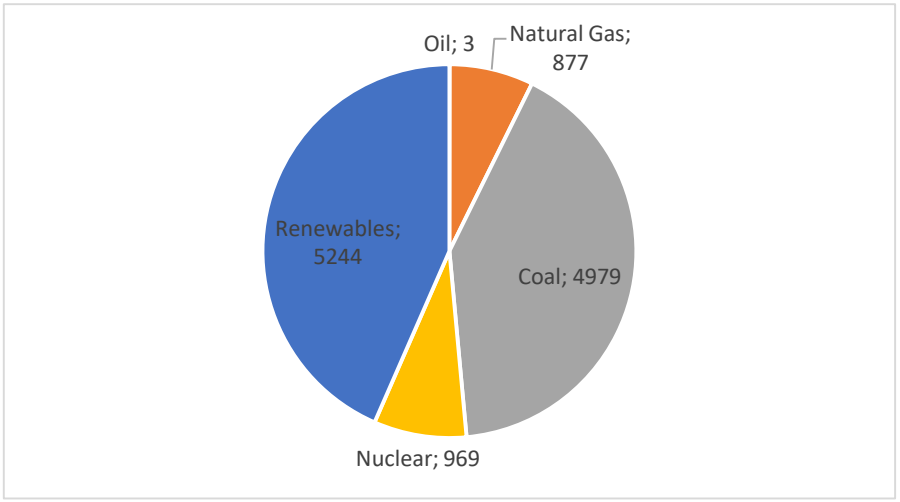

Figure 3.18. Energy Mix Values in China in 2040 (International Energy Agency, 2019)

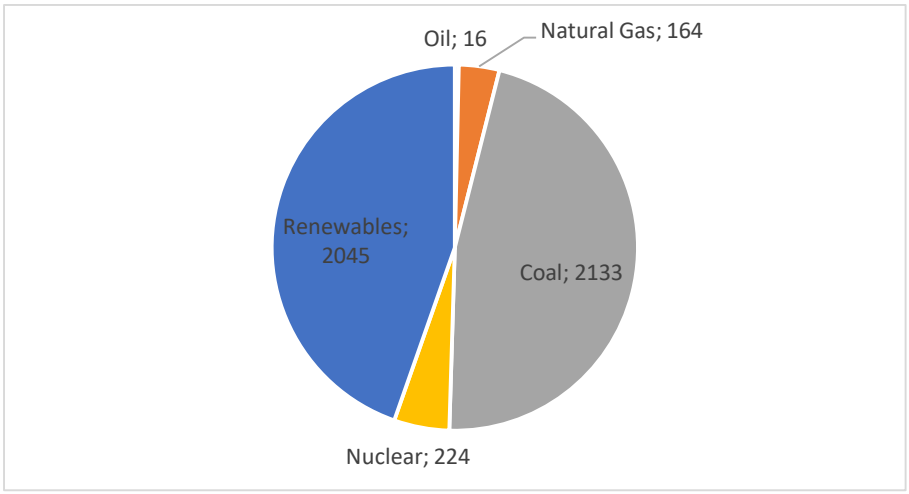

Figure 3.19 (Continuation). Energy Mix Values in India in 2040 (International Energy Agency, 2019)

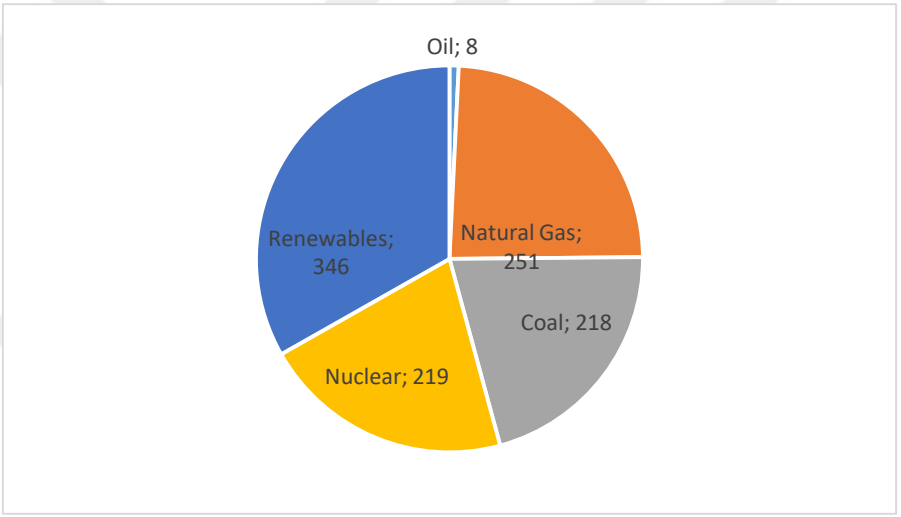

Figure 3.20 (Continuation). Energy Mix Values in Japan in 2040 (International Energy Agency, 2019)

3.5.1. Total Electricity Production of Various Countries in 2040 (International Energy Agency, 2019)

Brazil: 976 Twh

China: 12072 Twh

India: 4582 Twh

Japan: 1042 Twh

Russia: 1346 Twh

3.5.2. Unit Carbon Dioxide Emission per kWh for Coal, Natural Gas, and Oil Worldwide in 2040 (International Energy Agency, 2021)

Coal:

Unit CO2 emission per kWh= (7373*10^12 gr)/(7418*10^9 kWh)= 994 gr/kWh

The numerator is the World's total carbon dioxide emission while producing electricity by coal. On the other hand, the denominator is the World's total electricity production by the coal. When they are divided each other, the unit emission value of the coal is found as gr CO2 emission per kWh electricity production.

Natural Gas:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit CO2 emission per kWh= (3418*10^12 gr)/(7858*10^9 kWh)= 435 gr/kWh

The numerator is the World's total carbon dioxide emission of the natural gas in terms of electricity production, whereas the denominator is the World's total electricity production by the natural gas. When they are divided each other, the unit emission value of the natural gas can be found as gr CO2 emission per kWh electricity production.

Oil:

By applying the similar calculation method, the world's average CO2 emission per kWh value is obtained as,

Unit Emission per kWh= (325*10^12 gr)/(393*10^9 kWh)= 827 gr/kWh

The numerator is the World's total carbon dioxide emission of the oil in terms of electricity production, whereas the denominator is the World's total electricity production by the oil. When they are divided each other, the unit emission value of the oil can be found as gr CO2 emission per kWh electricity production.

3.5.3. Calculations of CO2 Emission and CO2 Emission Factor in Various Countries in 2040

Brazil: The electricity generation of this country from coal is 15 Twh, from natural gas is 81 Twh, from renewables is 828 Twh, from nuclear is 47 Twh, and from oil is 5 Twh (International Energy Agency, 2019). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

CO2 emission from nuclear, and renewables will be zero.

CO2 emission for natural gas= (81*10^9 kWh)*(435 gr/kWh)

CO2 emission for natural gas= 35235*10^9 grCO2

CO2 emission for coal= (15*10^9 kWh)*(994 gr/kWh)

CO2 emission for coal= 14910*10^9 grCO2

CO2 emission for oil= (5*10^9 kWh)*(827 gr/kWh)

CO2 emission for oil= 4135*10^9 grCO2

Total CO2 emission= 54280*10^9 grCO2

Unit Emission Value= (54280*10^9 grCO2)/(976*10^9 kWh)

Unit Emission Value= 55,61 gr/kWh

China: The electricity production of this country from oil is 3 Twh, from nuclear is 969 Twh, from coal is 4979 Twh, from natural gas is 877 Twh, and from renewables is 5244 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for coal= (4979*10^9 kWh)*(994 gr/kWh)

CO2 emission for coal= 4949126*10^9 grCO2

CO2 emission for oil= (3*10^9 kWh)*(827 gr/kWh)

CO2 emission for oil= 2481*10^9 grCO2

CO2 emission for natural gas= (877*10^9 kWh)*(435 gr/kWh)

CO2 emission for natural gas= 381495*10^9 grCO2

Total CO2 emission= 5333102*10^9 grCO2

Unit Emission Value= (5333102*10^9 grCO2)/(12072*10^9 kWh)

Unit Emission Value= 441,77 gr/kWh

India: The electricity production of this country from natural gas is 164 Twh, from oil is 16 Twh, from renewables is 2045 Twh, from nuclear is 224 Twh, and from coal is 2133

Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for coal= (2133*10^9 kWh)*(994 gr/kWh)

CO2 emission for coal= 2120202*10^9 grCO2

CO2 emission for oil= (16*10^9 kWh)*(827 gr/kWh)

CO2 emission for oil= 13232*10^9 grCO2

CO2 emission for natural gas= (164*10^9 kWh)*(435 gr/kWh)

CO2 emission for natural gas= 71340*10^9 grCO2

Total CO2 emission= 2204774*10^9 grCO2

Unit Emission Value= (2204774*10^9 grCO2)/(4582*10^9 kWh)

Unit Emission Value= 481,18 gr/kWh

Japan: The electricity generation of this country from oil is 8 Twh, from natural gas is 251 Twh, from nuclear is 219 Twh, from renewables is 346 Twh, and from coal is 218 Twh (International Energy Agency, 2019). For this country, the calculations of both CO2 emission and CO2 emission factor are shown below:

CO2 emission from nuclear, and renewables will be zero.

CO2 emission for natural gas= (251*10^9 kWh)*(435 gr/kWh)

CO2 emission for natural gas= 109185*10^9 grCO2

CO2 emission for coal= (218*10^9 kWh)*(994 gr/kWh)

CO2 emission for coal= 216692*10^9 grCO2

CO2 emission for oil= (8*10^9 kWh)*(827 gr/kWh)

CO2 emission for oil= 6616*10^9 grCO2

Total CO2 emission= 332493*10^9 grCO2

Unit Emission Value= (332493*10^9 grCO2)/(1042*10^9 kWh)

Unit Emission Value= 319,09 gr/kWh

Russia: The electricity production of this country from coal is 133 Twh, from renewables is 336 Twh, from natural gas is 631 Twh, from oil is 1 Twh, and from nuclear is 245 Twh (International Energy Agency, 2019). For this country, the calculations of CO2 emission and CO2 emission factor are shown below:

CO2 emission from renewables, and nuclear will be zero.

CO2 emission for coal= (133*10^9 kWh)*(994 gr/kWh)

CO2 emission for coal= 132202*10^9 grCO2

CO2 emission for oil= (1*10^9 kWh)*(827 gr/kWh)

CO2 emission for oil= 827*10^9 grCO2

CO2 emission for natural gas= (631*10^9 kWh)*(435 gr/kWh)

CO2 emission for natural gas= 274485*10^9 grCO2

Total CO2 emission= 407514*10^9 grCO2

Unit Emission Value= (407514*10^9 grCO2)/(1346*10^9 kWh)

Unit Emission Value= 302,76 gr/kWh

CHAPTER 4. THE STATISTICAL CHANGES IN CARBON DIOXIDE EMISSION and UNIT EMISSION VALUE FROM 2019 TO 2020

4.1 THE STATISTICAL CHANGES IN TOTAL CARBON DIOXIDE EMISSION

The statistical changes in total carbon dioxide emission from country to country are shown in Table 4.1:

Table 4.1. The Statistical Changes in Total Carbon Dioxide Emission (2019-2020)

Country	Total CO2 Emission in 2019 (grCO2)	Total CO2 Emission in 2020 (grCO2)	Change (%) (+): increase (-): decrease
Brazil	63151*10^9	57954,1*10^9	8,23 (-)
China	5099400,3*10^9	5241319,9*10^9	2,78 (+)
Germany	224220*10^9	189155,4*10^9	15,63 (-)
India	1252817,7*10^9	1208239,9*10^9	3,55 (-)
Italy	101529,5*10^9	92908,6*10^9	8,49 (-)
Japan	539003,3*10^9	520338,1*10^9	3,46 (-)
Russia	447346,4*10^9	407539,5*10^9	8,89 (-)
Spain	65717,8*10^9	48802,2*10^9	25,74 (-)
Turkey	144333,9*10^9	144971,8*10^9	0,44 (+)
US	1935482,6*10^9	1753301,1*10^9	9,41 (-)

4.2 THE STATISTICAL CHANGES IN UNIT EMISSION VALUE

The statistical changes in unit emission value from country to country are shown in Table 4.2:

Table 4.2. The Statistical Changes in Unit Emission Value (2019-2020)

Country	Unit Emission Value in 2019 (gr/kWh)	Unit Emission Value in 2020 (gr/kWh)	Change (%) (+): increase (-): decrease
Brazil	100,81	93,46	7,29 (-)
China	679,61	673,77	0,86 (-)
Germany	367,93	330,74	10,1 (-)
India	781,2	774,06	0,91 (-)
Italy	345,45	328,64	4,86 (-)
Japan	523,15	517,85	1,01 (-)
Russia	400,09	375,47	6,15 (-)
Spain	245,67	190,78	22,34 (-)
Turkey	475,09	474,69	0,084 (-)
US	438,76	409,01	6,78 (-)

CHAPTER 5. THE STATISTICAL CHANGES IN CARBON DIOXIDE EMISSION and UNIT EMISSION VALUE FROM 2020 TO 2021

5.1 THE STATISTICAL CHANGES IN TOTAL CARBON DIOXIDE EMISSION

The statistical changes in total carbon dioxide emission from country to country are shown in Table 5.1:

Table 5.1. The Statistical Changes in Total Carbon Dioxide Emission (2020-2021)

Country	Total CO2 Emission in 2020 (grCO2)	Total CO2 Emission in 2021 (grCO2)	Change (%) (+): increase (-): decrease
Brazil	57954,1*10^9	86429,5*10^9	49,13 (+)
China	5241319,9*10^9	5692497,7*10^9	8,608 (+)
Germany	189155,4*10^9	217023,6*10^9	14,73 (+)
India	1208239,9*10^9	1354381,6*10^9	12,09 (+)
Italy	92908,6*10^9	94497,2*10^9	1,709 (+)
Japan	520338,1*10^9	501354,3*10^9	3,648 (-)
Russia	407539,5*10^9	465730,8*10^9	14,27 (+)
Spain	48802,2*10^9	49233,6*10^9	0,88 (+)
Turkey	144971,8*10^9	163163,5*10^9	12,54 (+)
US	1753301,1*10^9	1872040,3*10^9	6,77 (+)

5.2 THE STATISTICAL CHANGES IN UNIT EMISSION VALUE

The statistical changes in unit emission value from country to country are shown in Table 5.2:

Table 5.2. The Statistical Changes in Unit Emission Value (2020-2021)

Country	Unit Emission Value in 2020 (gr/kWh)	Unit Emission Value in 2021 (gr/kWh)	Change (%) (+): increase (-): decrease
Brazil	93,46	132,07	41,31 (+)
China	673,77	667,01	1,003 (-)
Germany	330,74	371,29	12,26 (+)
India	774,06	789,81	2,03 (+)
Italy	328,64	329,03	0,118 (+)
Japan	517,85	491,66	5,057 (-)
Russia	375,47	402,49	7,19 (+)
Spain	190,78	180,94	5,157 (-)
Turkey	474,69	489,54	3,128 (+)
US	409,01	424,84	3,87 (+)

CHAPTER 6. THE PREDICTIONS OF CARBON DIOXIDE EMISSION and UNIT EMISSION VALUE FOR 2030 and 2040

6.1 THE STATISTICAL CHANGES IN TOTAL CARBON DIOXIDE EMISSION

The statistical changes about prediction in total carbon dioxide emission from country to country are shown in Table 6.1:

Table 6.1. The Statistical Changes in Total Carbon Dioxide Emission (2030-2040)

Country	Total CO2 Emission in 2030 (grCO2)	Total CO2 Emission in 2040 (grCO2)	Change (%) (+): increase (-): decrease
Brazil	37177*10^9	54280*10^9	46 (+)
China	5523134*10^9	5333102*10^9	3,44 (-)
India	1939507*10^9	2204774*10^9	13,67 (+)
Japan	389116*10^9	332493*10^9	14,55 (-)
Russia	441991*10^9	407514*10^9	7,8 (-)

6.2 THE STATISTICAL CHANGES IN UNIT EMISSION VALUE

The statistical changes about prediction in unit emission value from country to country are shown in Table 6.2:

Table 6.2. The Statistical Changes in Unit Emission Value (2030-2040)

Country	Unit Emission Value in 2030 (gr/kWh)	Unit Emission Value in 2040 (gr/kWh)	Change (%) (+): increase (-): decrease
Brazil	48,03	55,61	15,78 (+)
China	542,7	441,77	18,59 (-)
India	642,86	481,18	25,15 (-)
Japan	377,05	319,09	15,37 (-)
Russia	358,75	302,76	15,6 (-)

CHAPTER 7. HOW MUCH AN ELECTRIC VEHICLE EMITTES CO2?

We can assume that an electric vehicle consumes 20 kWh/100 km and travels in different countries.

Table 7.1. CO2 Emission per 100 km for Same Vehicle in Different Countries

Country	Same Vehicle 20 kWh /100 km	Unit Emission Value in 2021 (gr/kWh)	CO2 Emission per km
Brazil	20	132,07	26,414
China	20	667,01	133,402
Germany	20	371,29	74,258
India	20	789,81	157,962
Italy	20	329,03	65,806
Japan	20	491,66	98,332
Russia	20	402,49	80,498
Spain	20	180,94	36,188
Turkey	20	489,54	97,908
US	20	424,84	84,968

CHAPTER 8. CONCLUSION

In this study, the evaluation of battery electric vehicle and its impact on climate change have been studied. Firstly, battery electric vehicles and their positive and negative sides comparing with fossil-fueled cars have been presented. Secondly, two brands of battery electric vehicle and their properties have been discussed. Thirdly, a study on the carbon dioxide emission of the electric vehicles from Well to Wheel point of view has been conducted. It has been expressed that an electric vehicle consumes electricity while it is travelling on the road. However, the fossil fuels were used and carbon dioxide was emitted during the production of this electricity. Also, the carbon dioxide emission factors were calculated for different states by taking their energy-mix values into account. The use of fossil fuels in electricity generation varies from country to country and the electricity which is consumed by electric vehicle must be considered in this point of view too. This study presents the carbon dioxide emissions in electric energy generation for different countries for the years of 2019, 2020, 2021, 2030, and 2040. Fourthly, the above mentioned studies and the year by year statistical changes in different countries have been presented. The statistical changes from year to year are very important to reflect the attitutes of the states energy policy. Finally, carbon dioxide emission per 100 kilometers for same vehicle in different countries has been showed in table.

The rapid growth of the economy after the pandemic period increased the energy demand and also prices. In addition, oil and natural gas prices boomed because of the Ukraine-Russia war. As a result of energy supply shortage, anti-nuclear western economies including Japan and even Germany have considered to change their anti-nuclear policy. As it is known, the CO2 emission in nuclear technology is approximately zero. The 2040 values which are foreseen by the IEA will emerge in the direction of reduction in CO2 emissions for some countries such as Japan. However, for others in which the use of coal will be boosted, CO2 emissions should be expected to increase too. As a result, an electric while travelling in different countries emits different CO2 values.

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APPENDICES

APPENDIX A

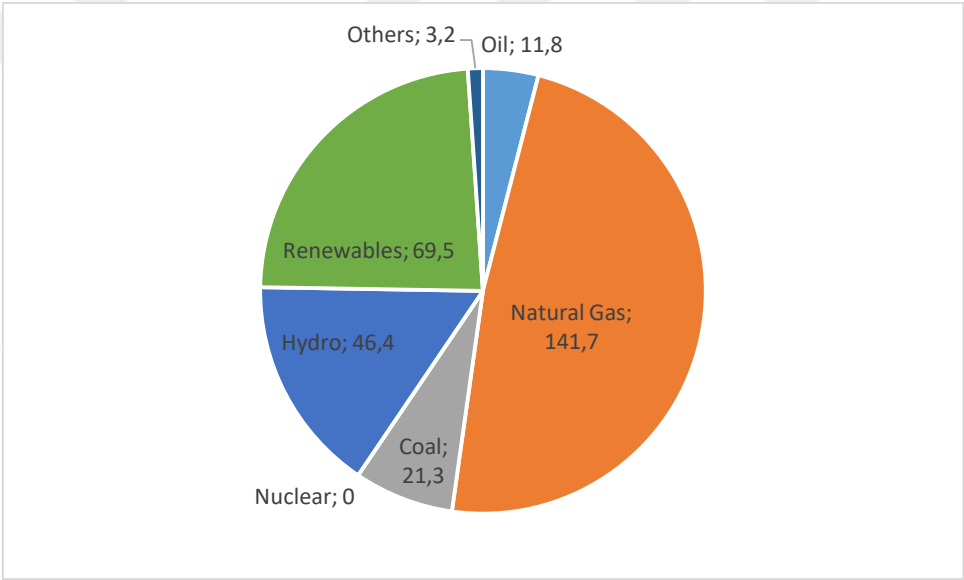


Figure A.1. Energy Mix Values in Italy in 2019 (BP Statistical Review of World Energy, 2021)

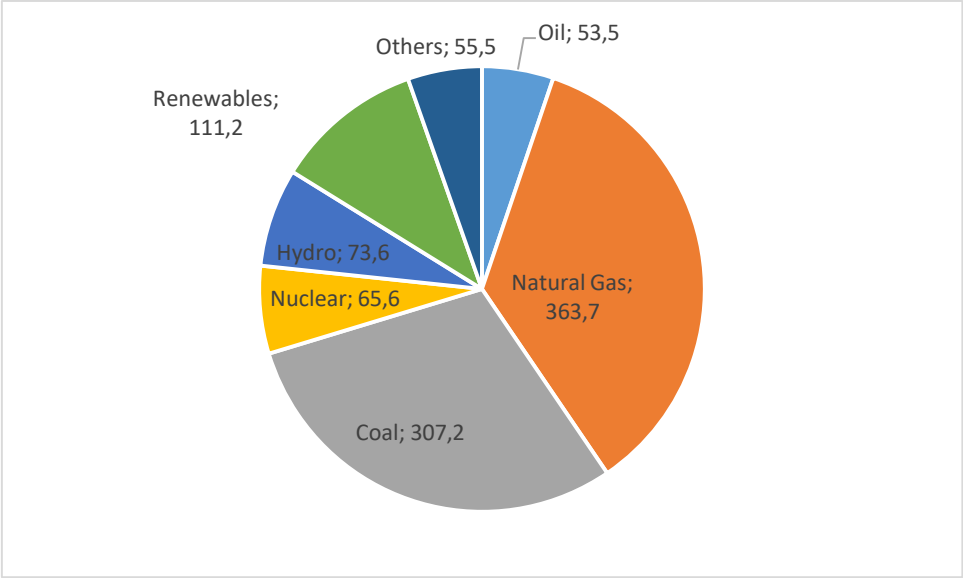


Figure A.2. Energy Mix Values in Japan in 2019 (BP Statistical Review of World Energy, 2021)

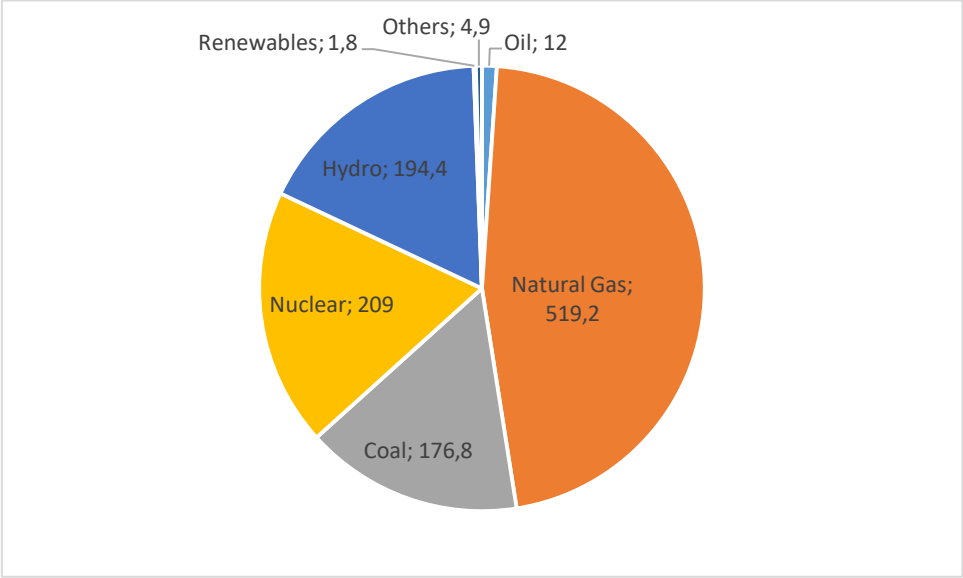


Figure A.3. Energy Mix Values in Russia in 2019 (BP Statistical Review of World Energy, 2021)

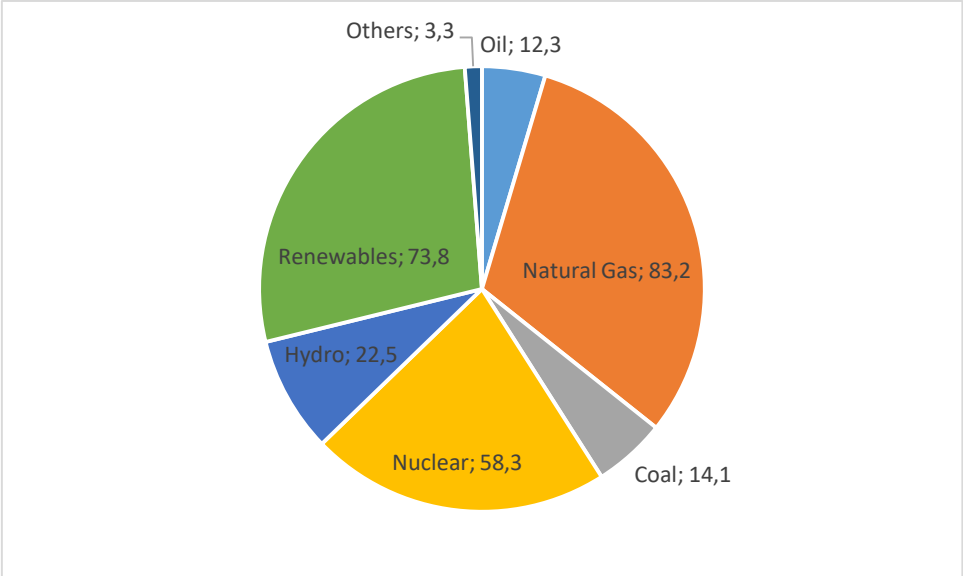


Figure A.4. Energy Mix Values in Spain in 2019 (BP Statistical Review of World Energy, 2021)

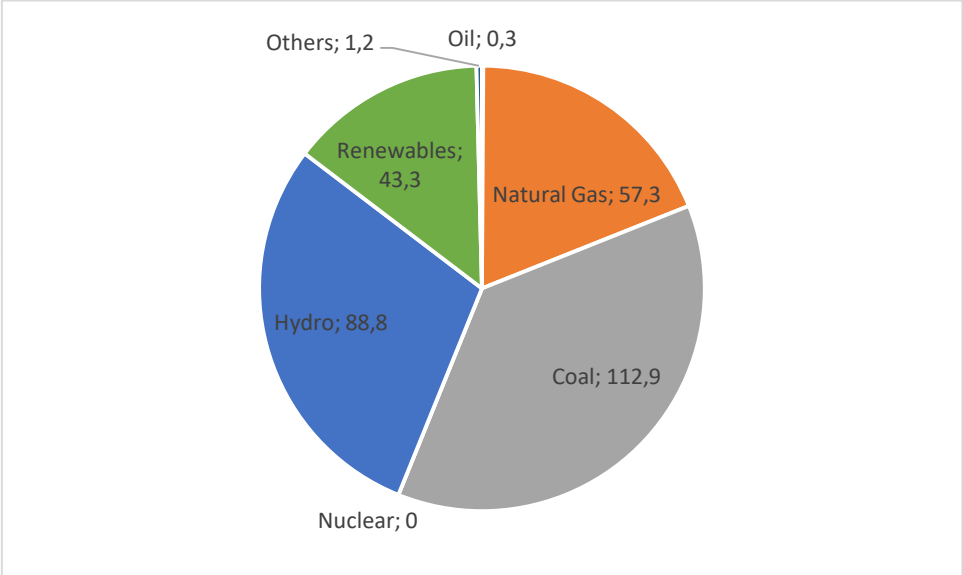


Figure A.5. Energy Mix Values in Turkey in 2019 (BP Statistical Review of World Energy, 2021)

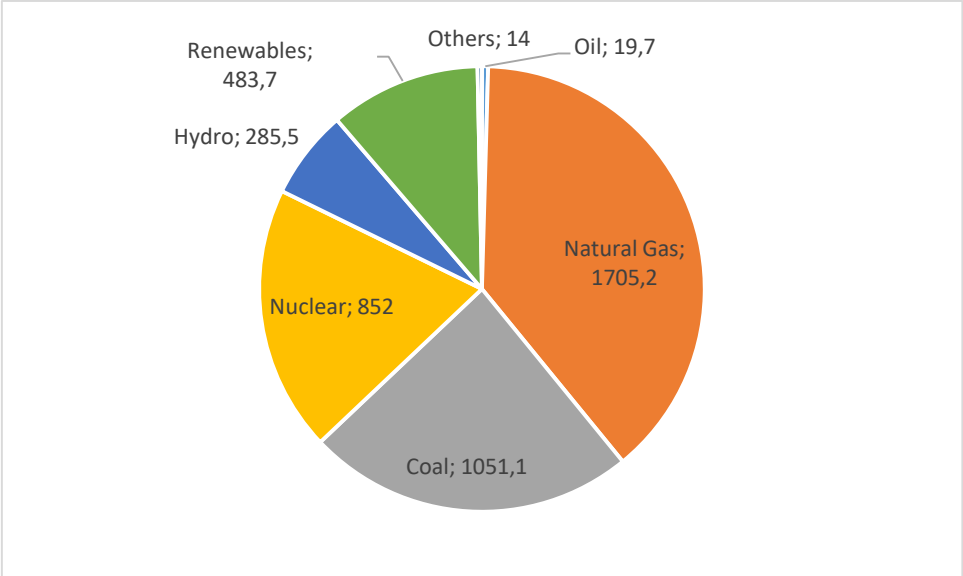


Figure A.6. Energy Mix Values in the US in 2019 (BP Statistical Review of World Energy, 2021)

APPENDIX B

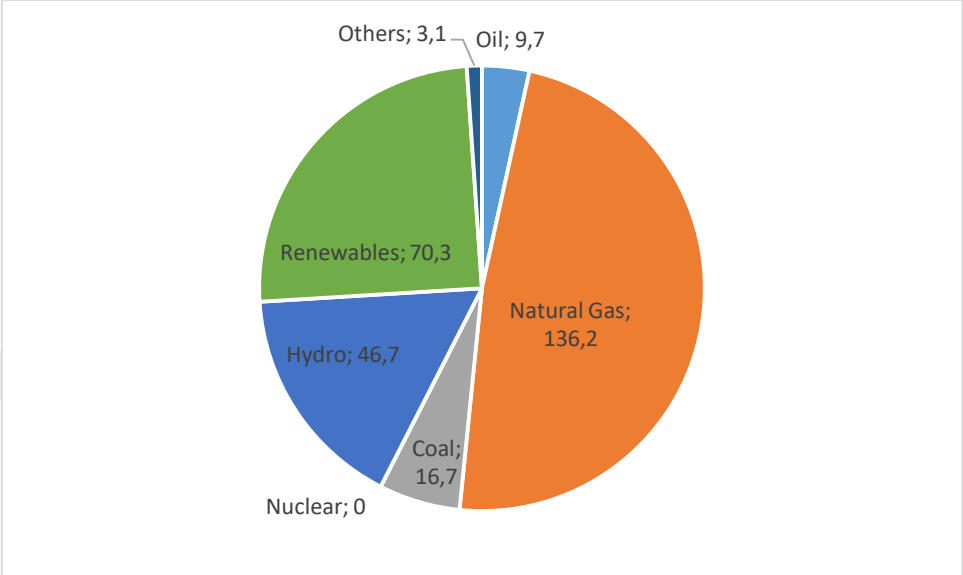


Figure B.1. Energy Mix Values in Italy in 2020 (BP Statistical Review of World Energy, 2021)

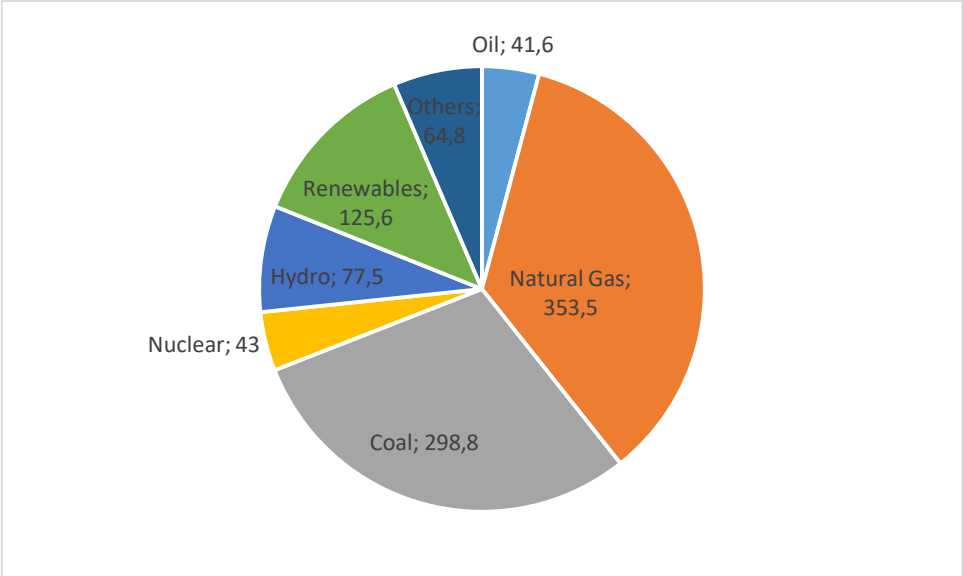


Figure B.2. Energy Mix Values in Japan in 2020 (BP Statistical Review of World Energy, 2021)

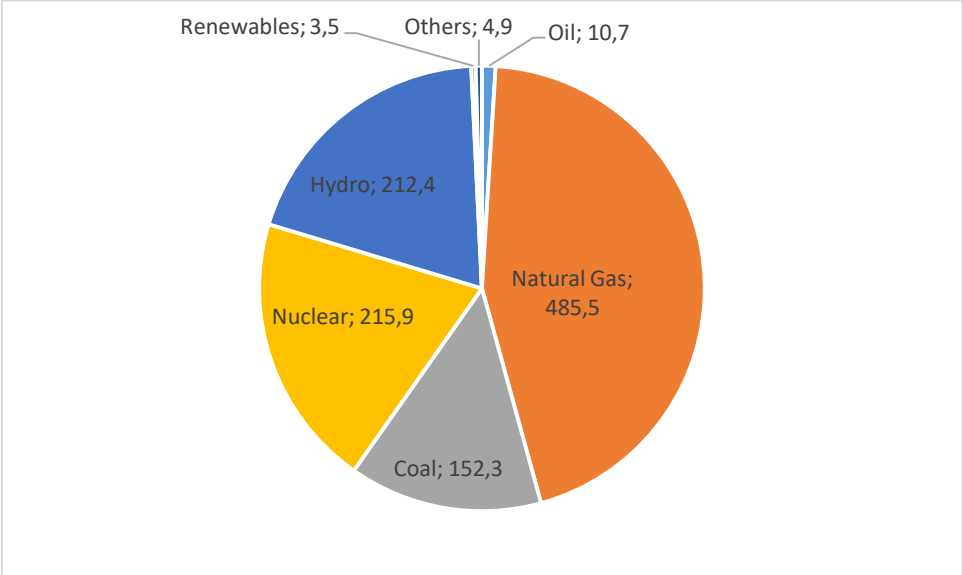
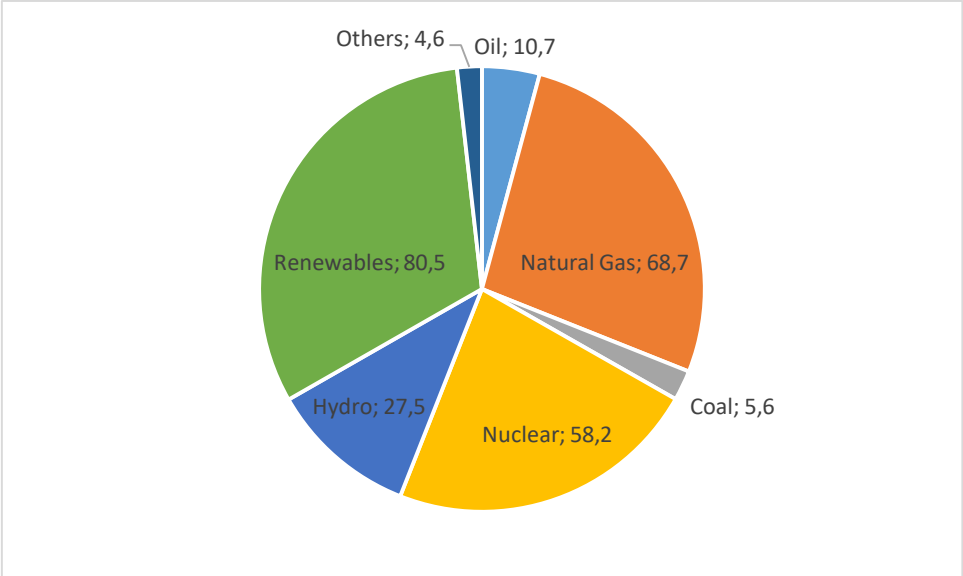


Figure B.3. Energy Mix Values in Russia in 2020 (BP Statistical Review of World Energy, 2021)



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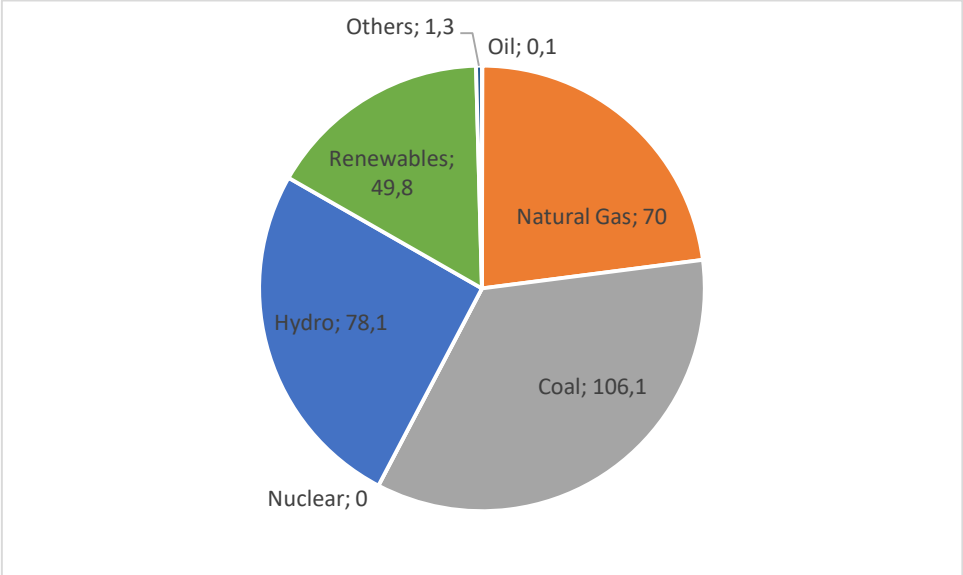


Figure B.5. Energy Mix Values in Turkey in 2020 (BP Statistical Review of World Energy, 2021)

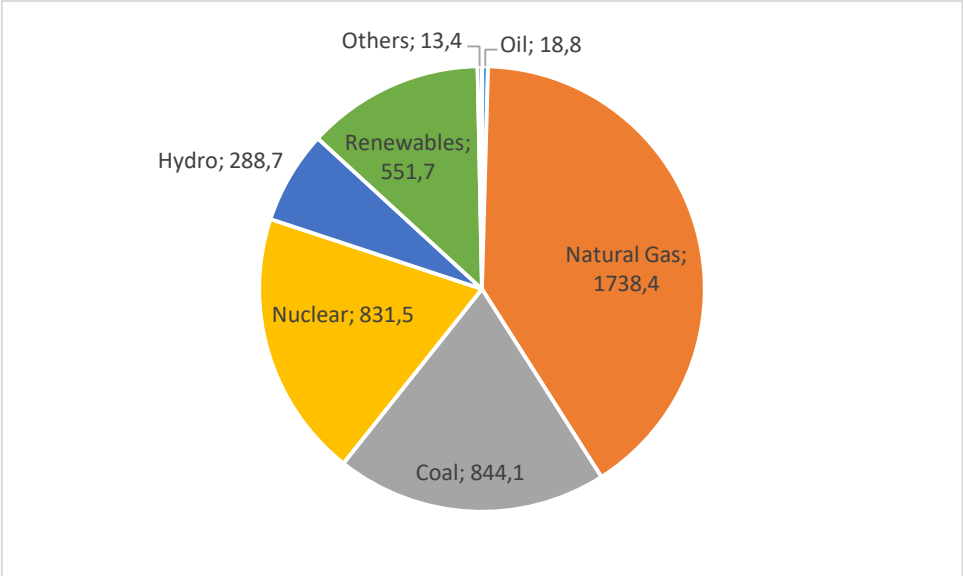


Figure B.6. Energy Mix Values in the US in 2020 (BP Statistical Review of World Energy, 2021)

APPENDIX C

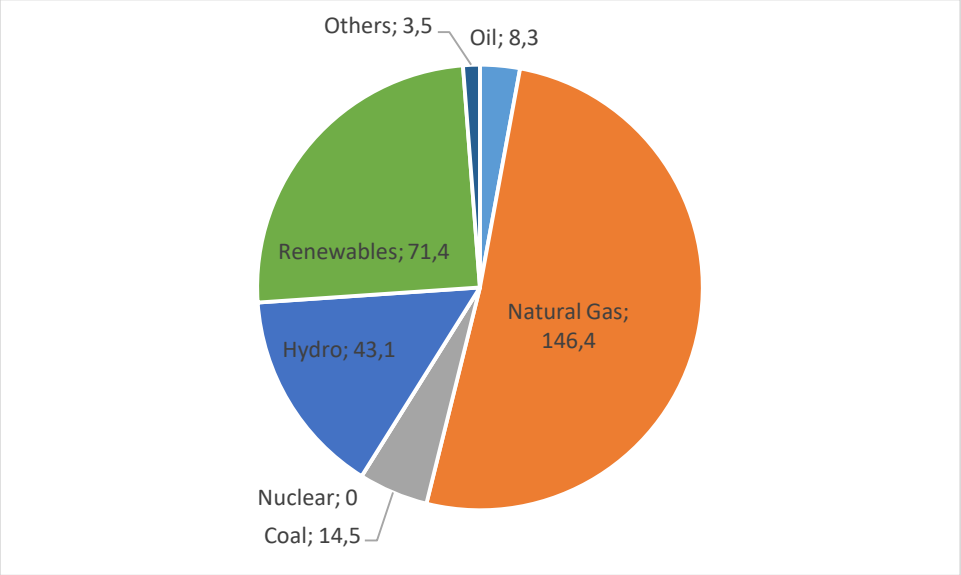


Figure C.1. Energy Mix Values in Italy in 2021 (BP Statistical Review of World Energy, 2022)

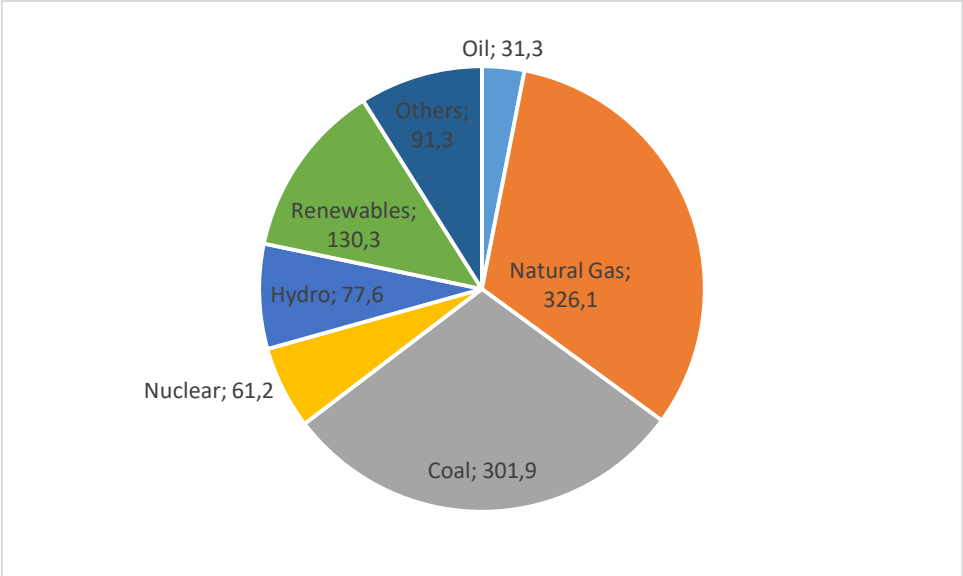
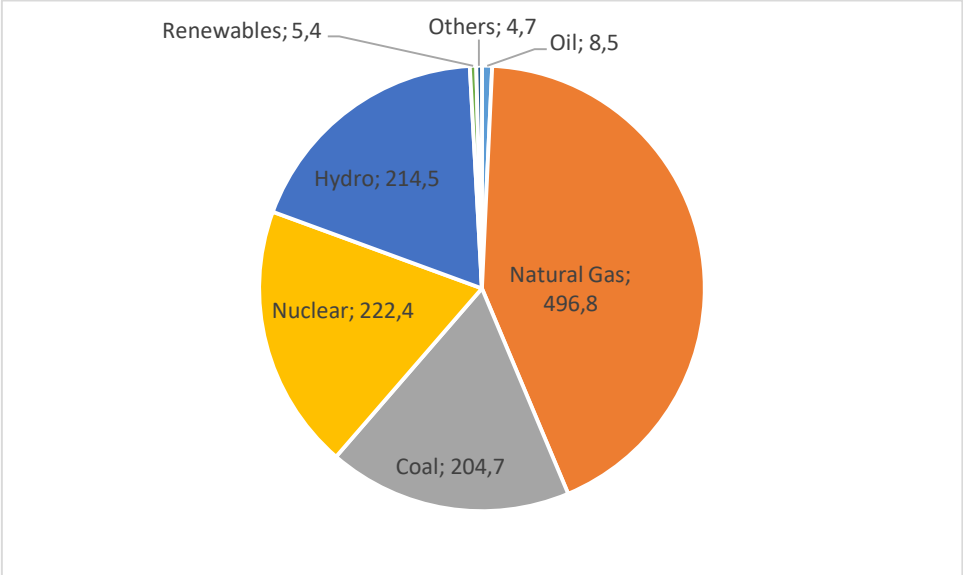


Figure C.2. Energy Mix Values in Japan in 2021 (BP Statistical Review of World Energy, 2022)



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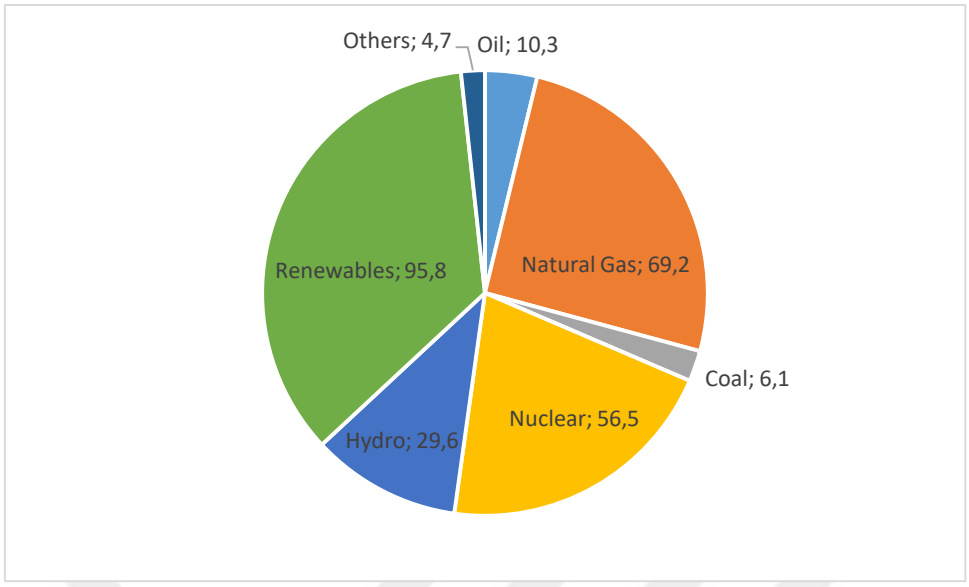

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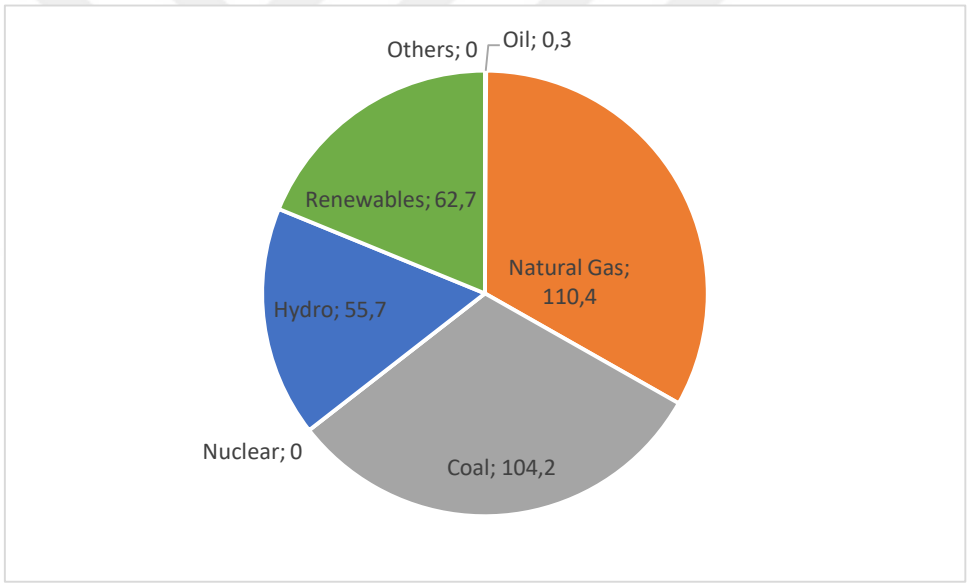

Figure C.5. Energy Mix Values in Turkey in 2021 (BP Statistical Review of World Energy, 2022)

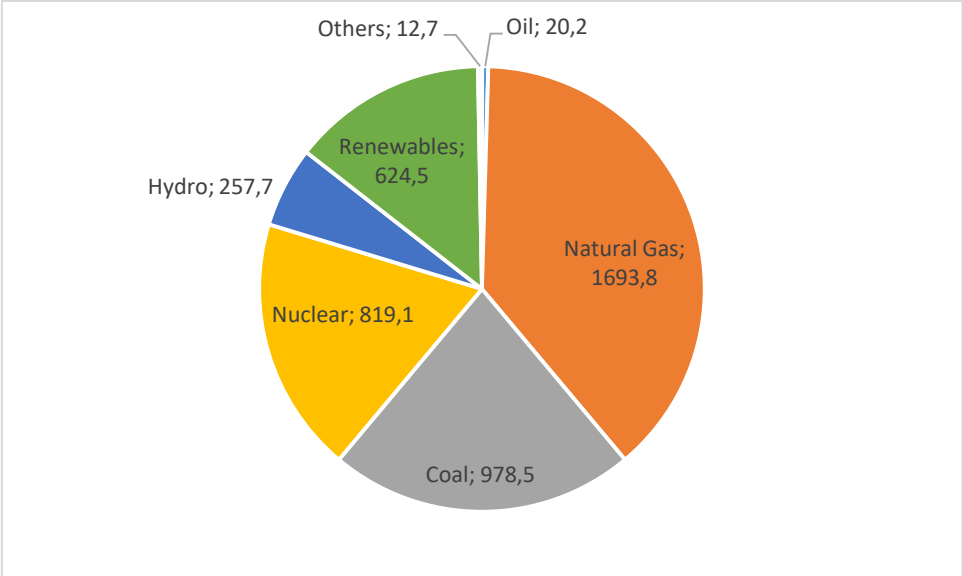

Figure C.6. Energy Mix Values in the US in 2021 (BP Statistical Review of World Energy, 2022)

APPENDIX D

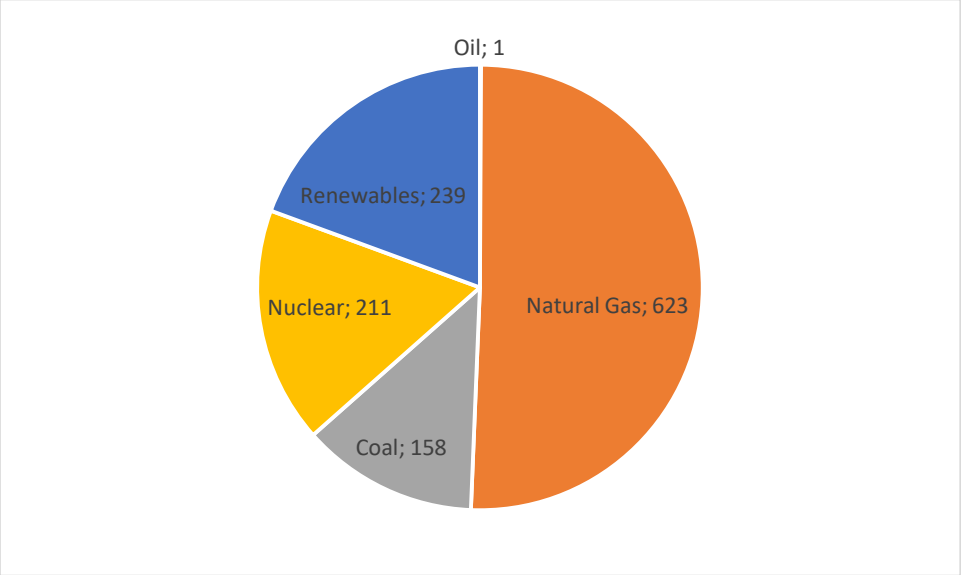

Figure D.1. Energy Mix Values in Russia in 2030 (International Energy Agency, 2019)

APPENDIX E

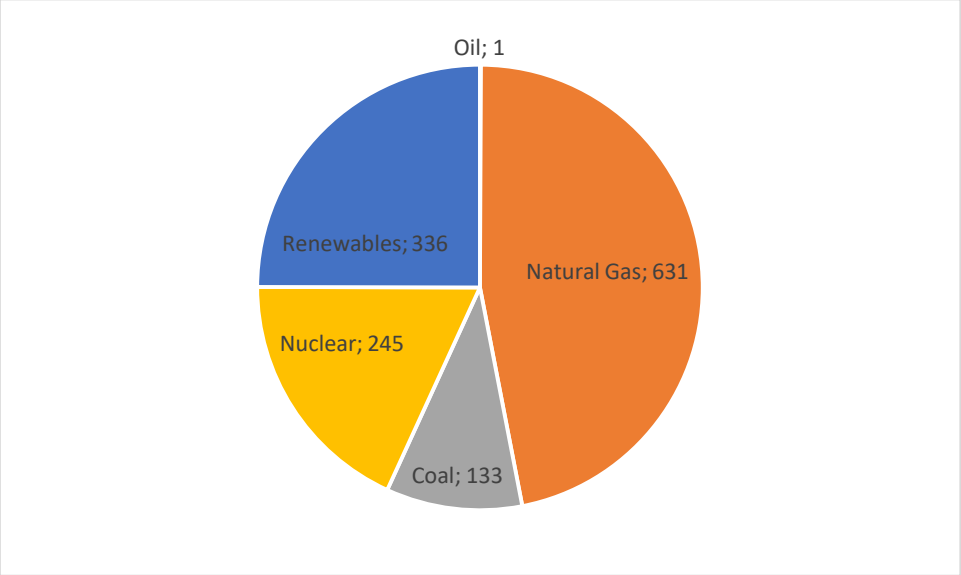

Figure E.1. Energy Mix Values in Russia in 2040 (International Energy Agency, 2019)