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APRIL 28 – MAY 1, 2019 | DALLAS, TX

Forecasting CO2 Emission of Electrical Generation By Using SAS® Software

Kaito Kobayashi

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- Discussion
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Abstract

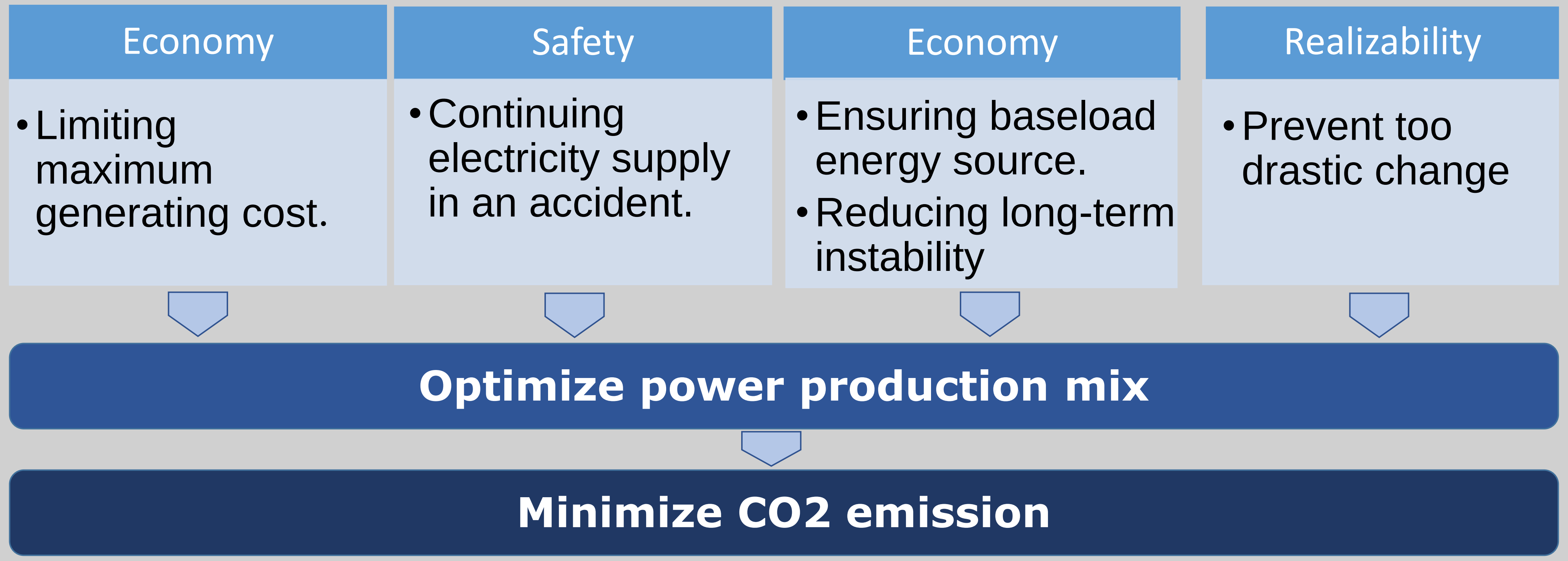
Currently, global warming is one of the most severe problems in the world. Electric generation have stimulated the problem by emitting a great deal of CO2. The power production mix must be reorganized with adopting renewable energy.

This poster aims to propose a model which provides the most environmentally friendly power production mix with fulfilling requirements. We introduced some restrictions which represented following criteria; cost, safety, stability, and we made two environmentally friendly electricity generating scenarios; ideal and realizable. In addition, we forecasted the electricity demand in 2030 so that we could estimate the amount of CO2 emission based on each scenario.

This model will help to determine power production mix under political requirements and contribute to reduce CO2 emissions.

Introduction

Global warming is one of the most severe problems in the world, and a great deal of researches has shown that CO2 is the main cause. However, plenty of CO2 have continued to be emitted in electrical generating every year, which has deteriorated the environment. Under such situation, renewable energies are drawing attention as environmentally friendly generating methods, although their instabilities are pointed out. In generating electricity, four important aspects must be considered; Environment friendliness, Economy, Energy Security and Safety, and an eco-friendly power generation mix should be established under those restrictions. Some studies offered forecasted mixes in the future, nevertheless few researches attempted to optimize power generation mix in terms of minimizing CO2 emission.
This study aims to propose the most environmentally friendly power generation mix with fulfilling other requirements. In addition, we forecasted the electricity demand in 2030 so that we could estimate the amount of CO2 emission based on each scenario. To achieve that, reasonable model was constructed with some parameters, and optimized to minimize CO2 emission under restrictions shown as follows.



Economy
- Limiting maximum generating cost.

Safety
- Continuing electricity supply in an accident.

Economy
- Ensuring baseload energy source.
- Reducing long-term instability

Realizability
- Prevent too drastic change

Optimize power production mix

Minimize CO2 emission

Figure 1. Flow chart of minimizing CO2 emission.

Data/Methods

➢ Optimizing Energy mix:

Here we define variable x_i as the ratio of the energy source i among an energy mix. Suppose e_i to be the amount of CO2 emitted to generate 1kWh electricity. The CO2 emission is proportional to $\sum_i e_i x_i$. Therefore, the objective of this study is to optimize each x_i that minimize $\sum_i e_i x_i$.

- **Economy** : The production cost should not exceed the upper limit.

$$\sum_i c_i x_i \le d \sum_i c_i x_{i,0}$$

c: the electrical generating cost ($/kWh)
d: parameter
0(subscript): current value

- **Safety**: Even in an accident, electricity have to be supplied continuously by operating other plants to the capacity limit.

$$(1-t_i) \times x_i + \sum_k \frac{x_k}{L_k} + \sum_n x_n \ge 1$$

n (subscript): natural energy
k (subscript): the others
t: the ratio of plants which will halt operation after accident situation.
L: load factor

- **Energy Security:**

・The baseload energy needs to be ensured for stable electricity supply through a whole year.

$$\sum_b x_b \ge B$$

b(subscript): baseload energy
B: parameter

・The instability of electricity generation which stems from fuel production and natural condition has to be limited.

$$S \le S_0$$

S: security index (a criterion which represents the instability)

- **Realizability:** Too drastic change from status quo is unrealizable.

$$x_i \le x_{i,0} + r_i$$

r: parameter

Under the restrictions, the power generation mix (x_i) was optimized by SAS® Optimization (on SAS® Viya®) to achieve minimum CO2 emission. The parameter values used in this study is as follows.

Parameter	Base Load (B)	Cost (d)	Safety (t_i)		Realizability (r_i)	
			Nuclear	Other	Natural Source	Others
Value	0.5	1	0	0.5	0.15	0.2

Table 1: Values of each parameter in this poster

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Data/Method

➢ Forecasting Electricity demand:

Using SAS® Visual Analytics, linear regression was conducted with following explanatory variables; GDP, Population, population growth rate. Electricity demand was calculated by applying the forecasting data of explanatory variables, which are published by other authorities, to the equation gained.

➢ Data

Country	Brazil, Canada, China, France, Germany, India, Japan, Korea, Russia, UK, USA
Energy Source	Coal, Petroleum, Natural Gas, Nuclear, Hydro, Solar, Geothermal, Wind, Tide
Data Source	OECD Data, IEA, UN Data, EIA, ITC, IMF

Table 2. The countries and energy sources subject to the study and its data source.

	Coal	Petroleum	Natural Gas	Nuclear	Hydro	Solar	Geothermal	Wind	Tide
Baseload Energy	○	×	×	○	○	×	○	×	×
Natural Energy	×	×	×	×	○	○	○	○	○

Table 3. The kinds of each energy source.

Result

➢ Forecasting electricity demand

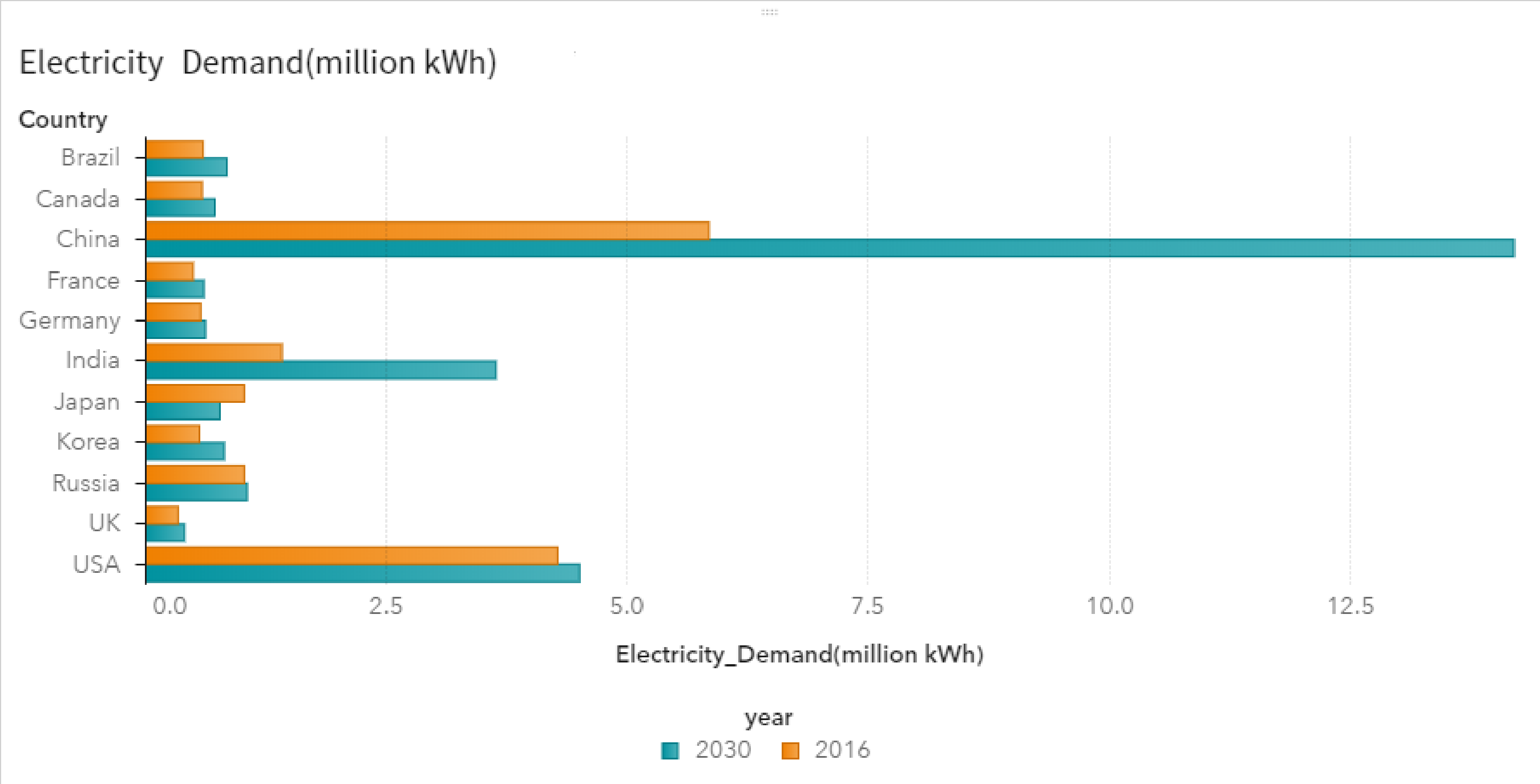

Figure 2: Electricity demand in 2016 and 2030 (forecasting)

➢ Optimizing power production mix

- **United States**

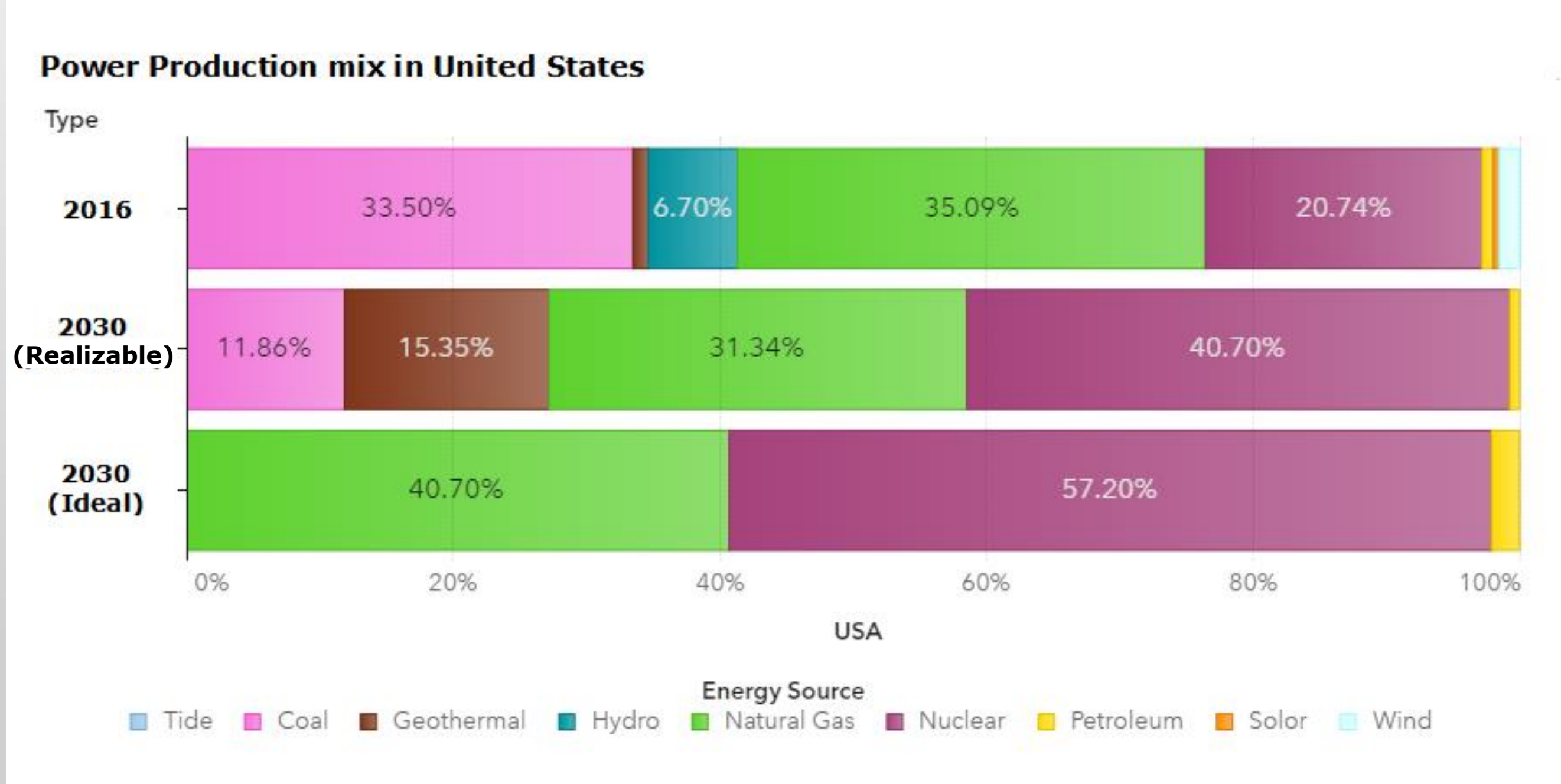

Figure 3.1: Proposed power production mix in USA

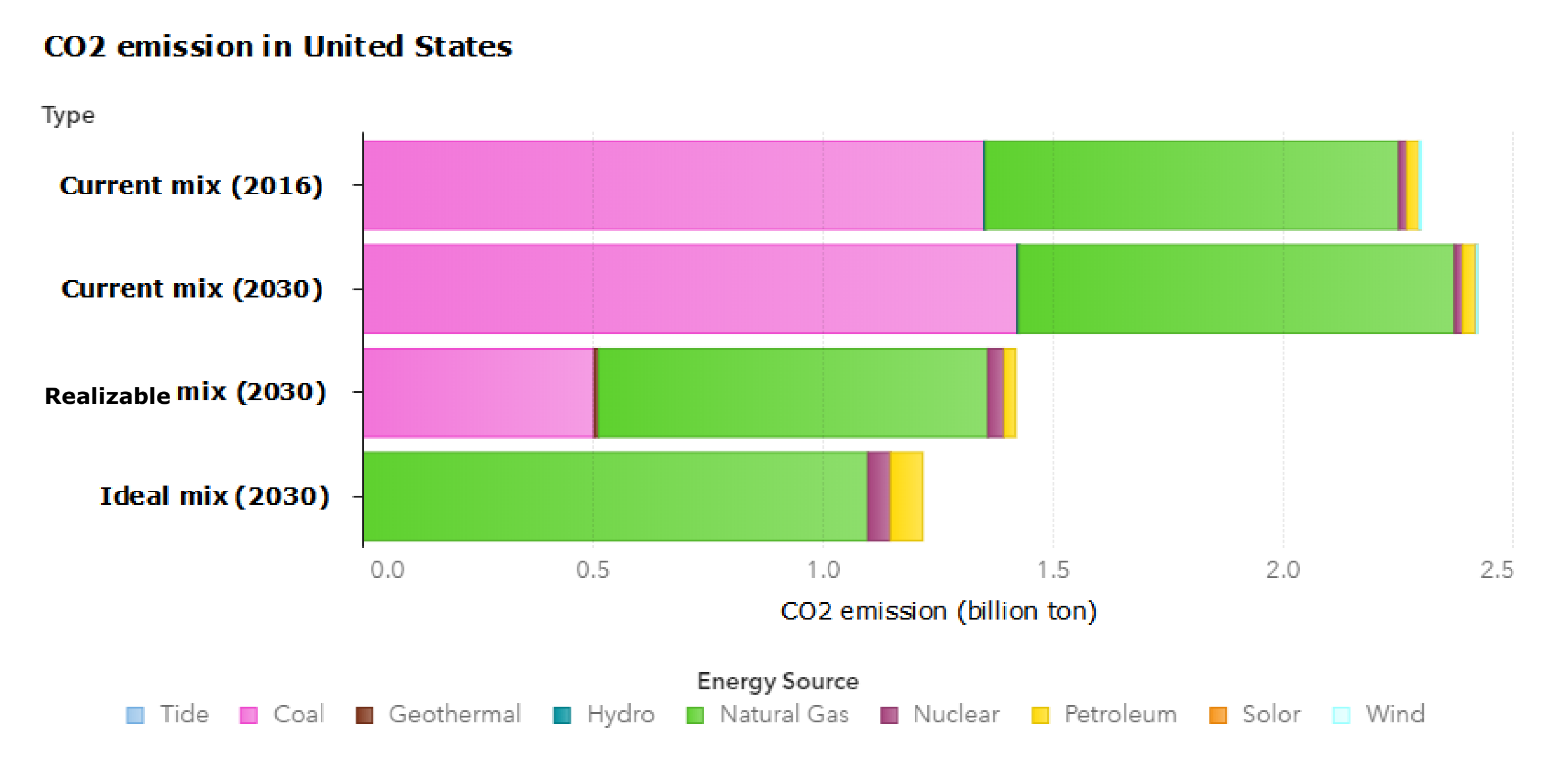

Figure 3.2: Estimated CO2 emission in USA

- **Japan**

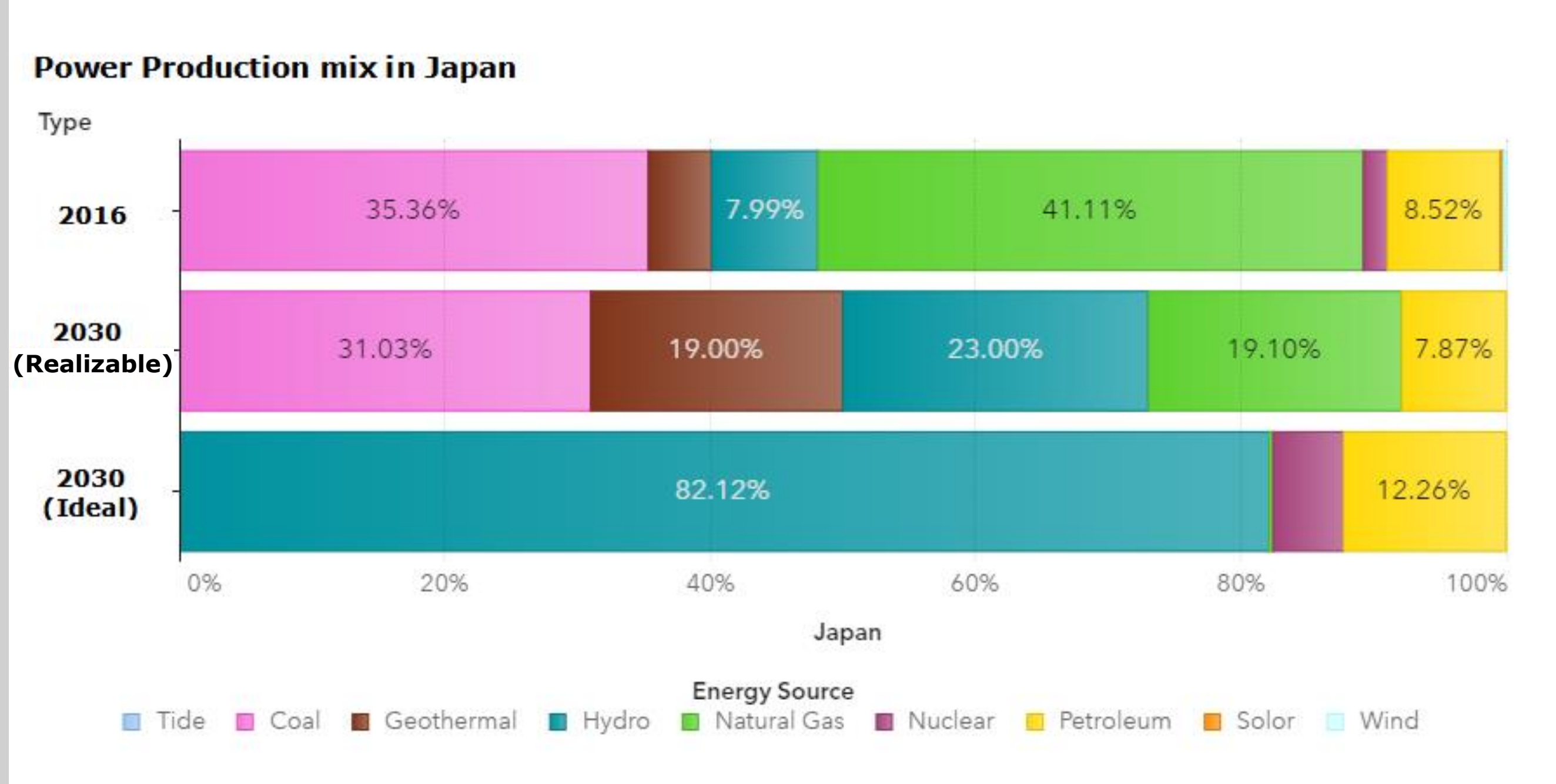

Figure 4.1: Proposed energy mix in Japan

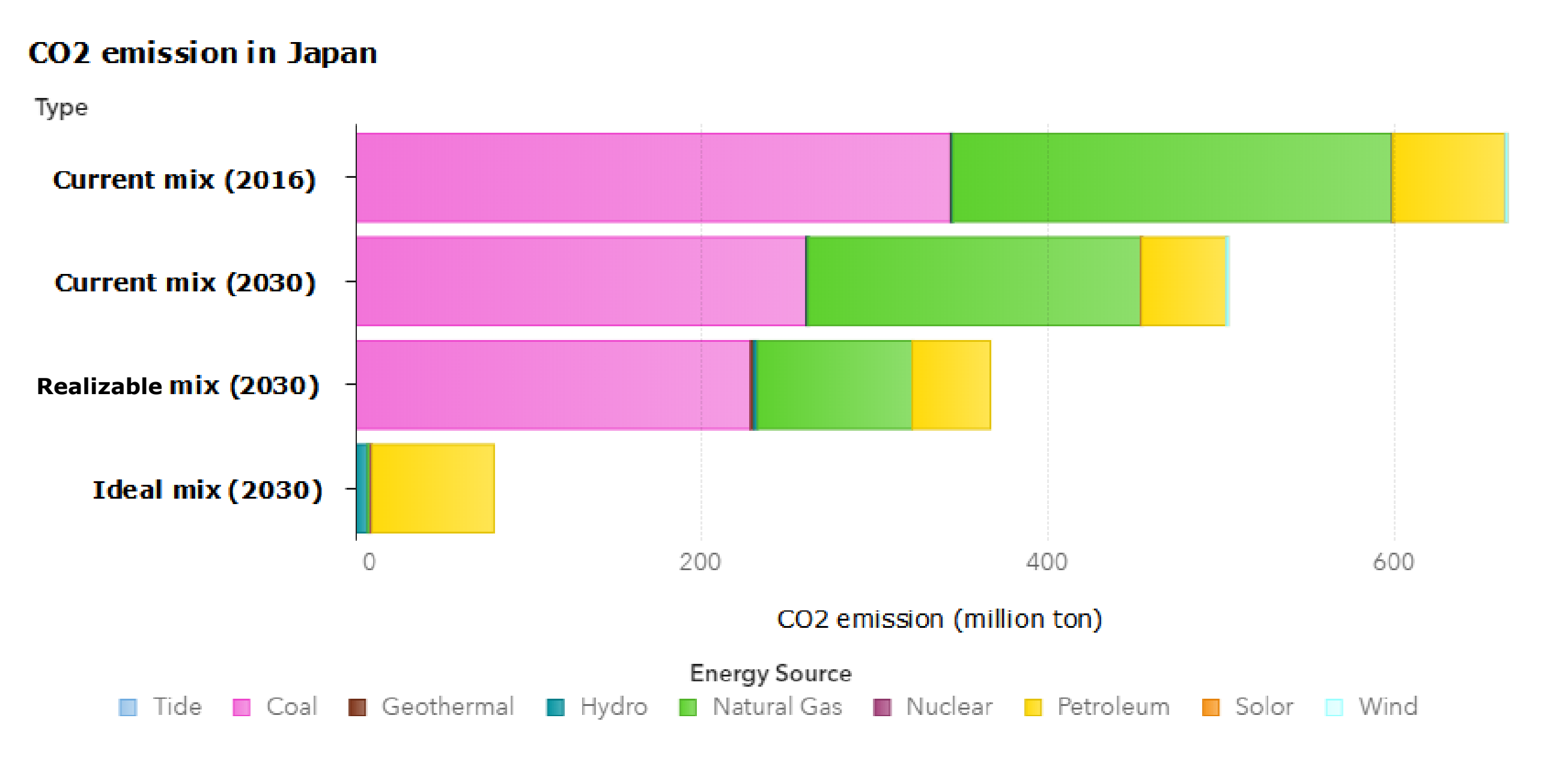

Figure 4.2: Estimated CO2 emission in Japan

Discussion

The goal of this study is to propose a model which provide an eco-friendly power production mix under some restrictions. By optimizing the power production mix ratio, we proved that CO2 emission can be reduced. However, the electricity demand is forecasted to increase, as shown in figure 5. Our research suggests that unless we tackle seriously to alter energy mix, much more CO2 will be emitted, which will stimulate global warming. The proposed models depend on the parameters which represents some restrictions, and to determine them is highly political issue. If there are some regulations which is peculiar to certain country, our model will be improved by adding parameters. Nevertheless, because deciding an energy mix concerns lots of business problems, the proposed energy mixes may be ideal ones. Therefore, feasibility study has to be conducted.

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Appendix 1

- **France**

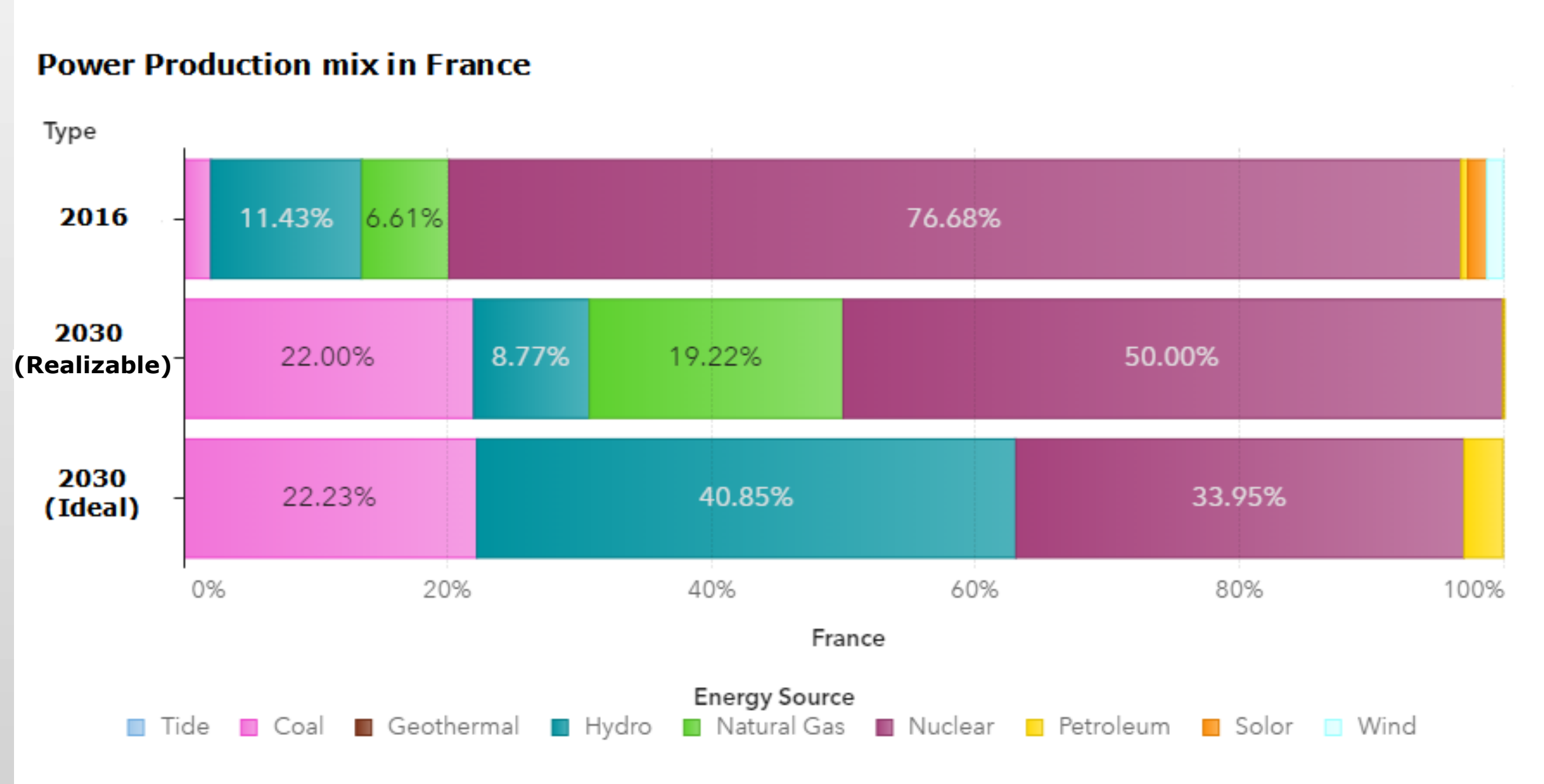

Figure 5.1: Proposed energy mix in France

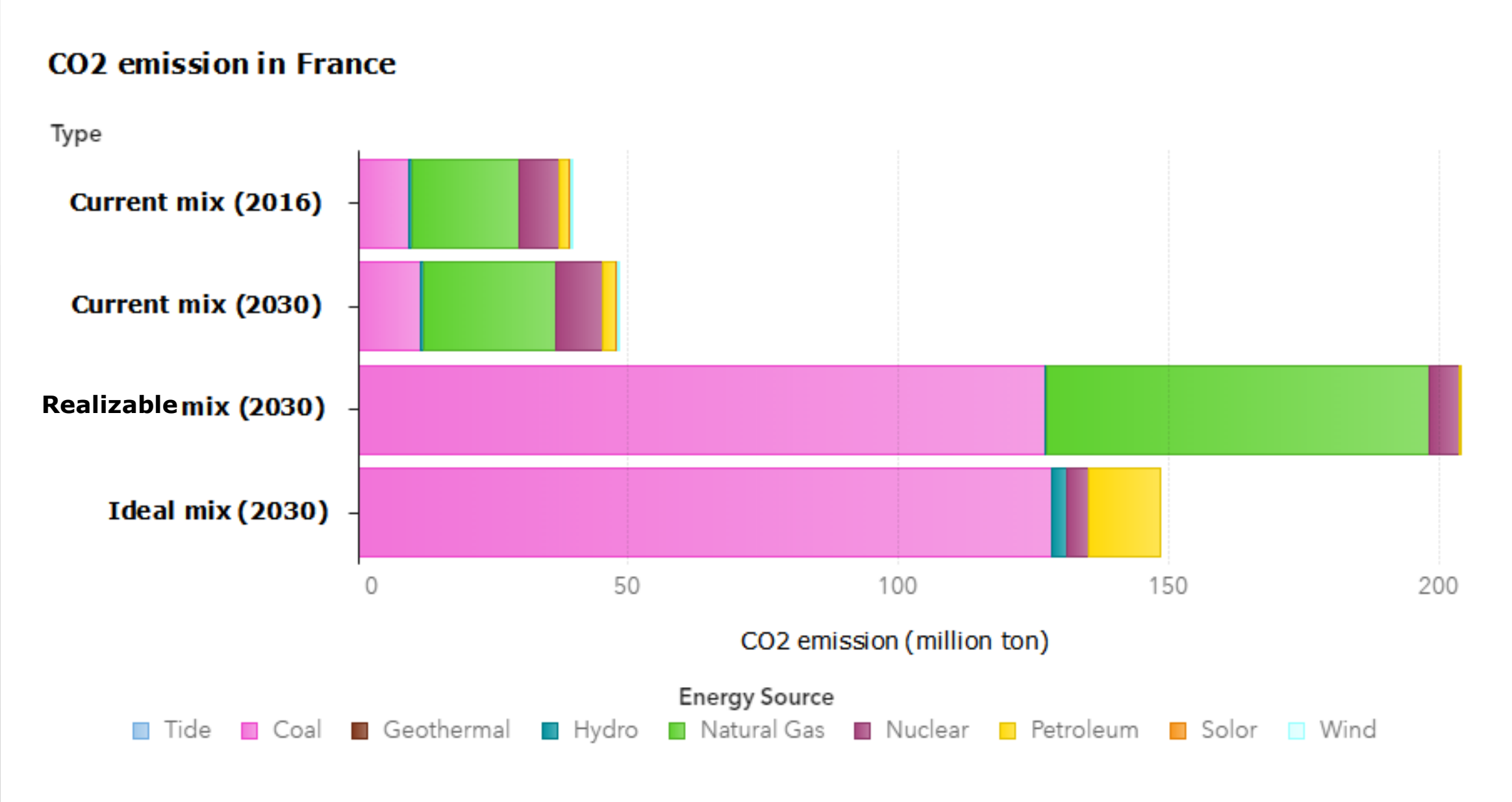

Figure 5.2: Estimated CO2 emission in France

- **Korea**

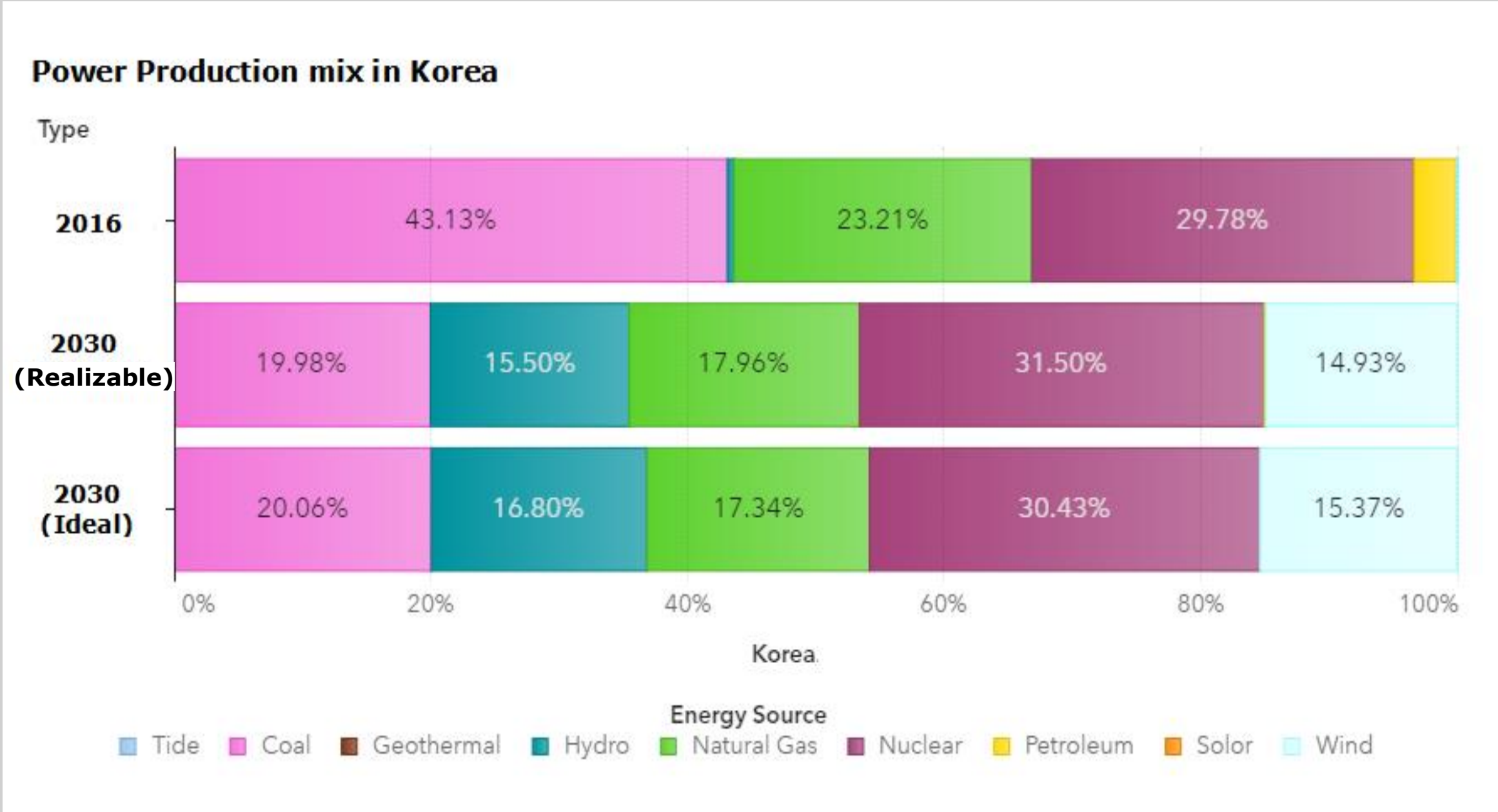

Figure 6.1: Proposed energy mix in Korea

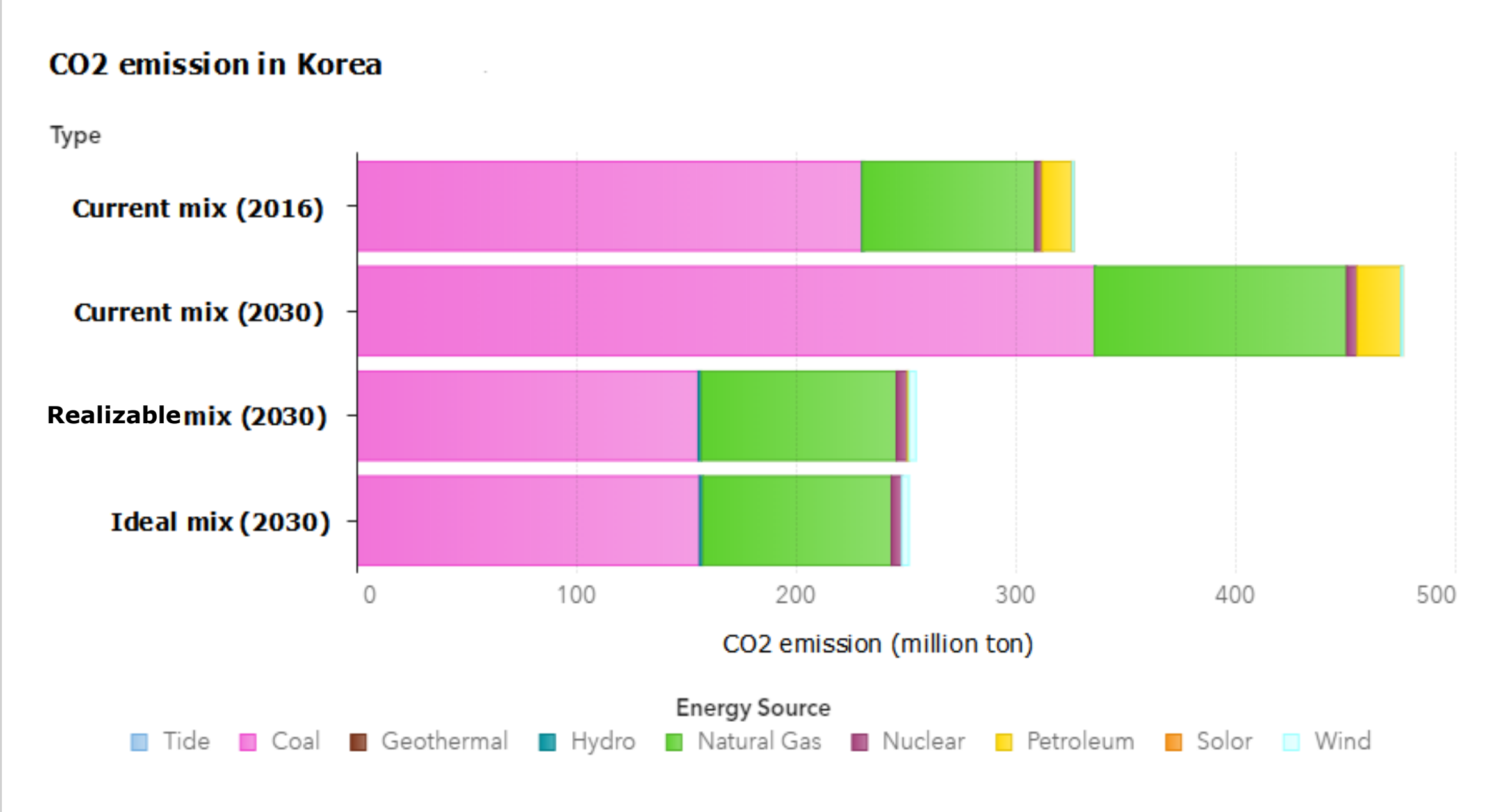

Figure 6.2: Estimated CO2 emission in Korea

- **India**

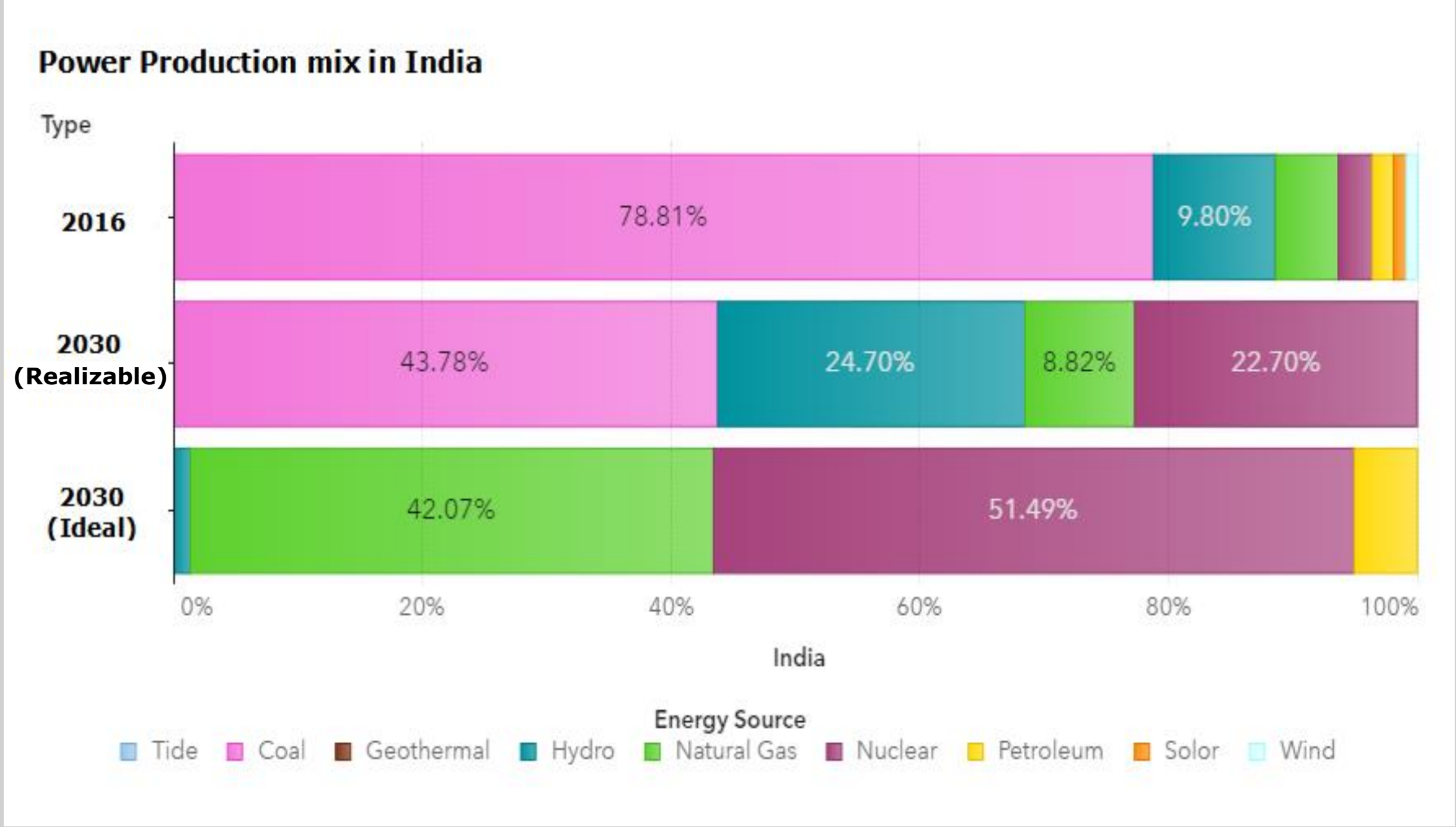

Figure 7.1: Proposed energy mix in India

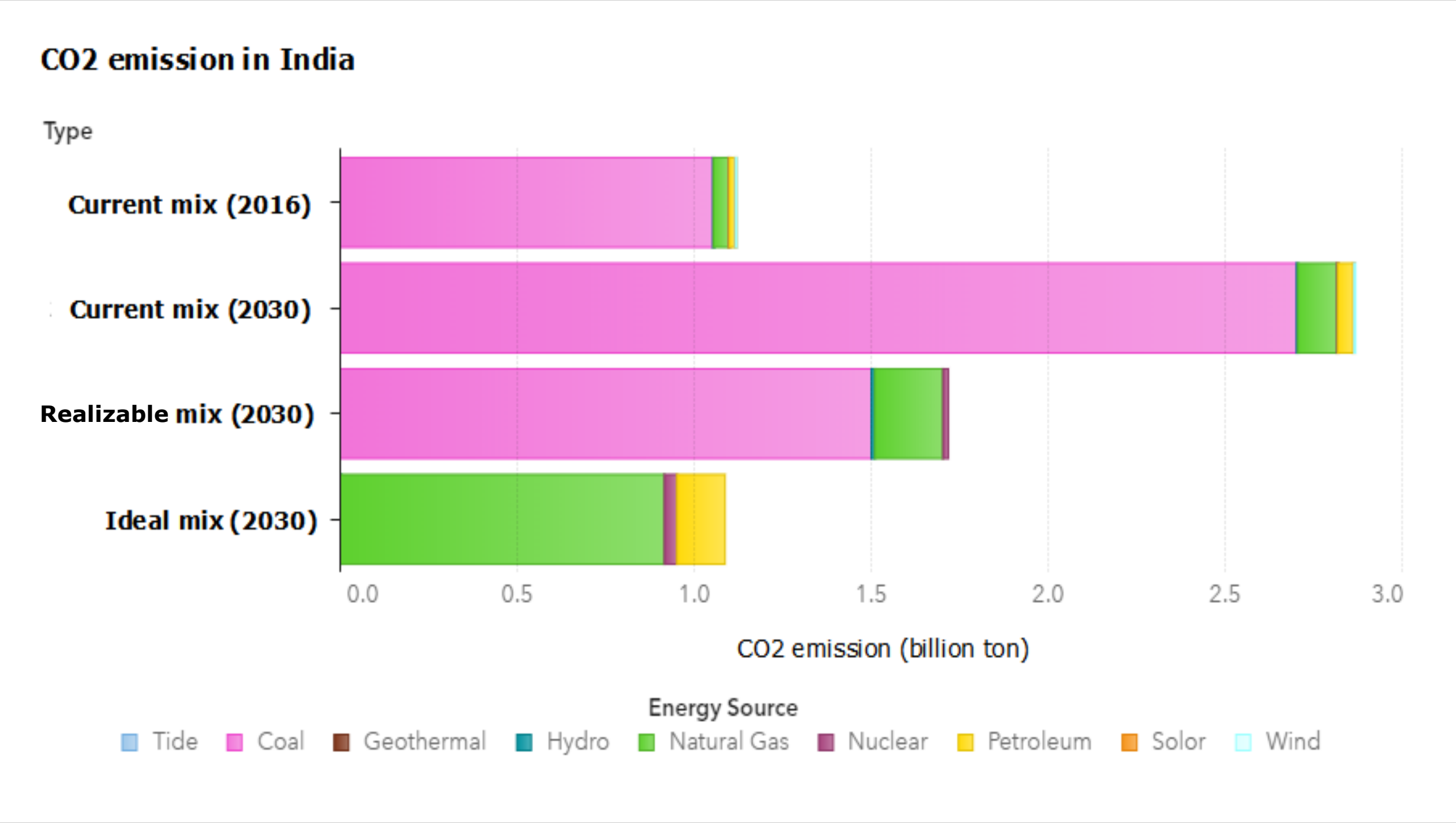

Figure 7.2: Estimated CO2 emission in India

- **Brazil**

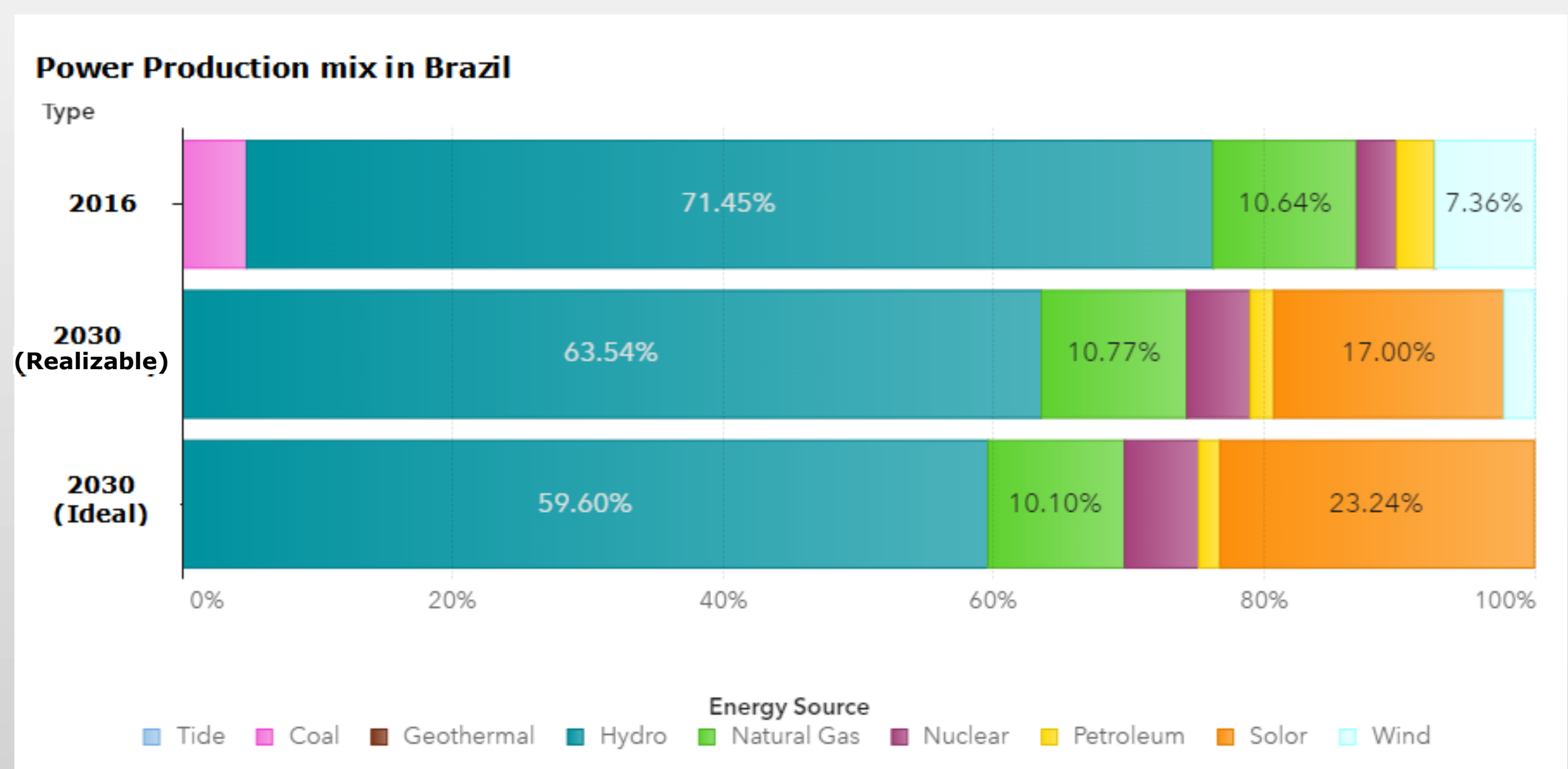

Figure 8.1: Proposed energy mix in Brazil

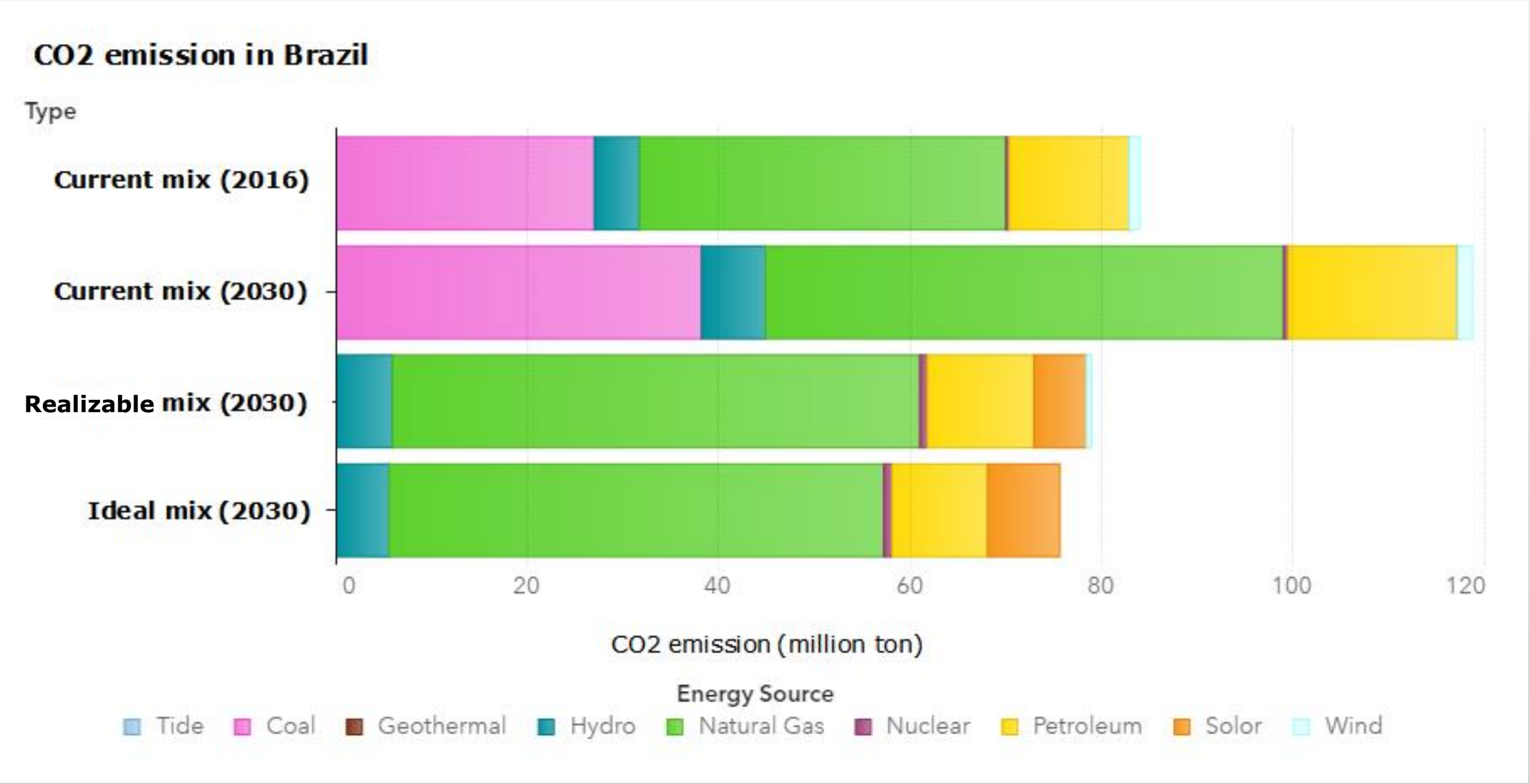

Figure 8.2: Estimated CO2 emission in Brazil

- **China**

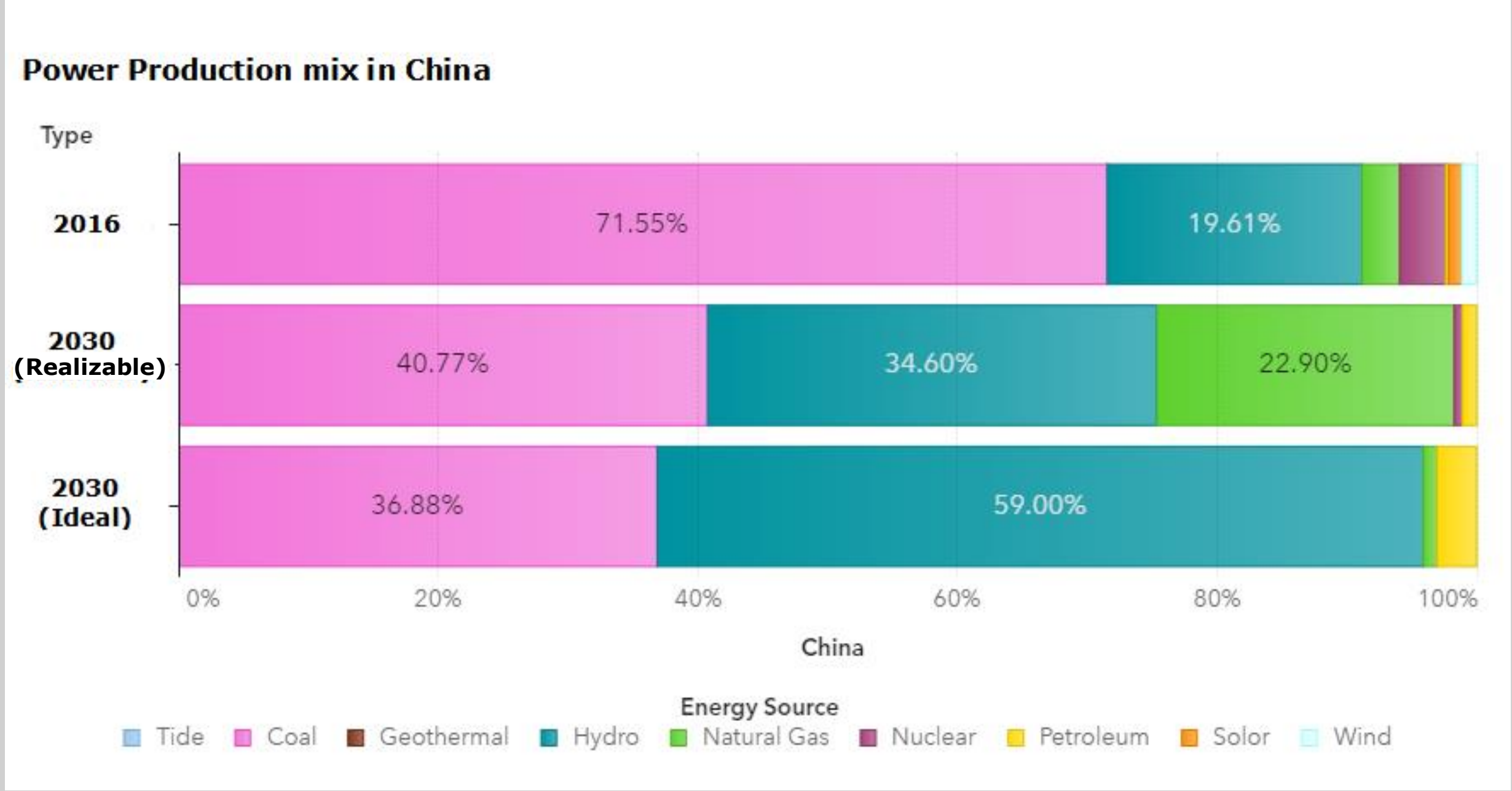

Figure 9.1: Proposed energy mix in China

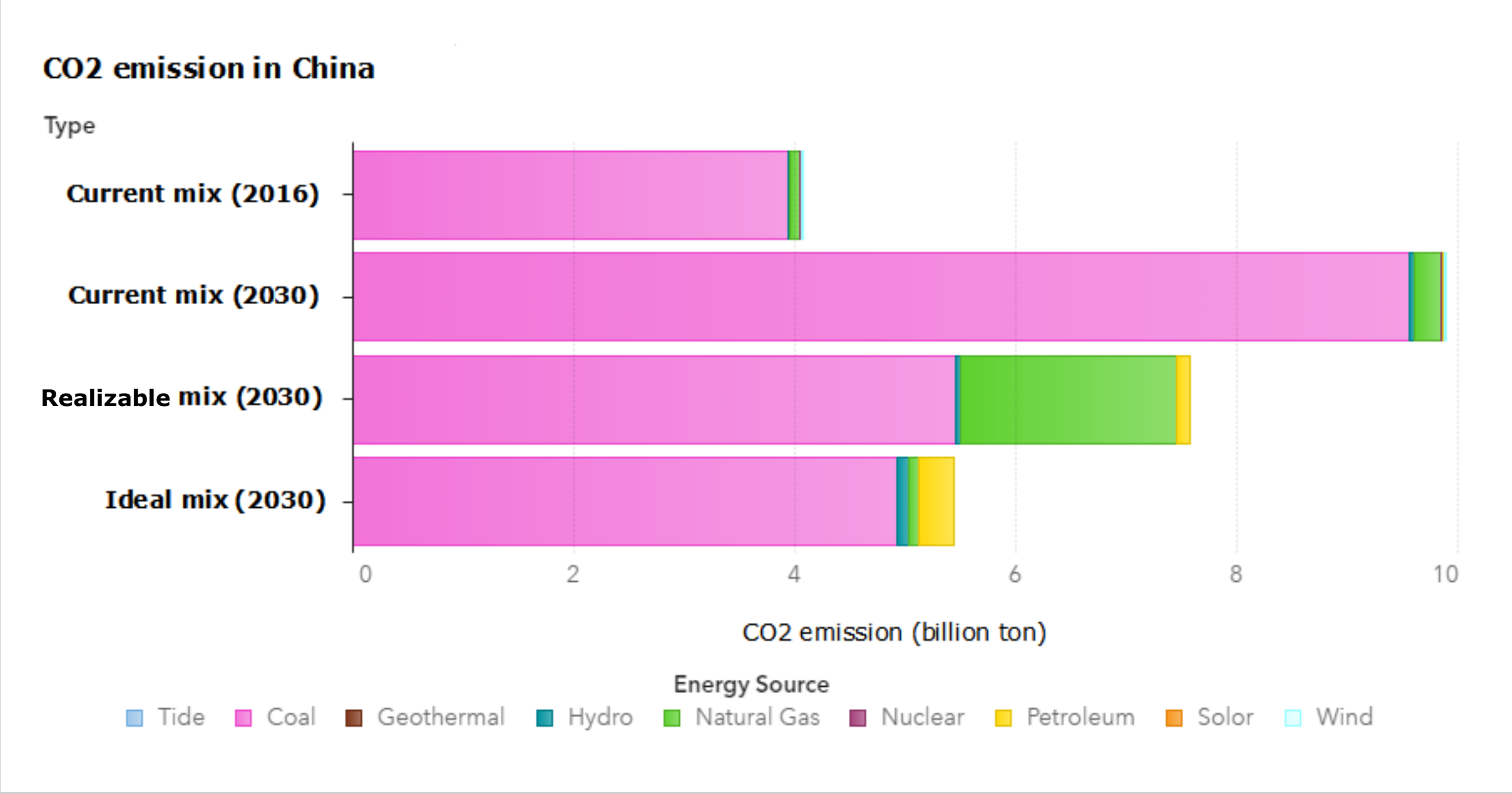

Figure 9.2: Estimated CO2 emission in China

- **Canada**

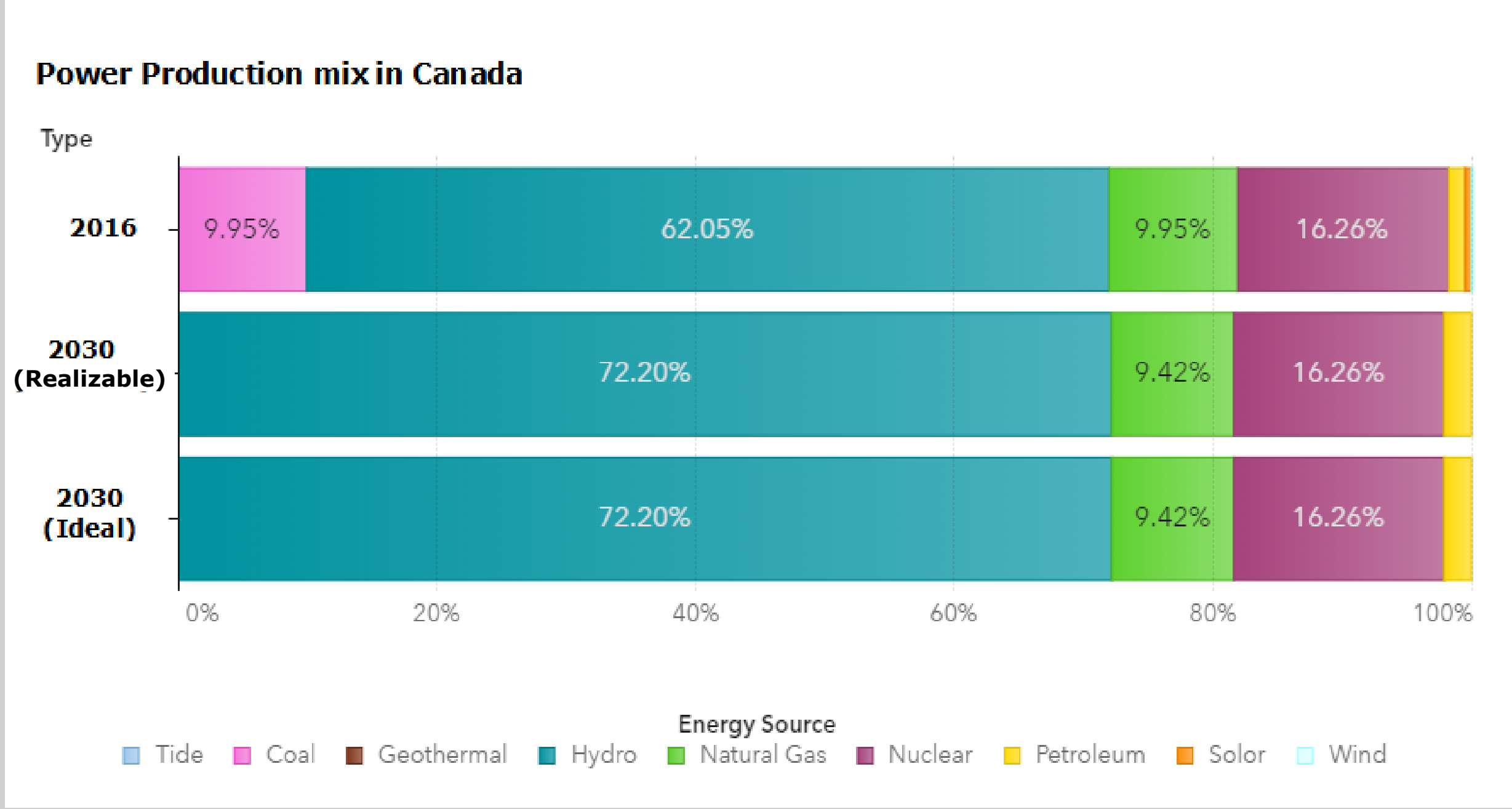

Figure 10.1: Proposed energy mix in Canada

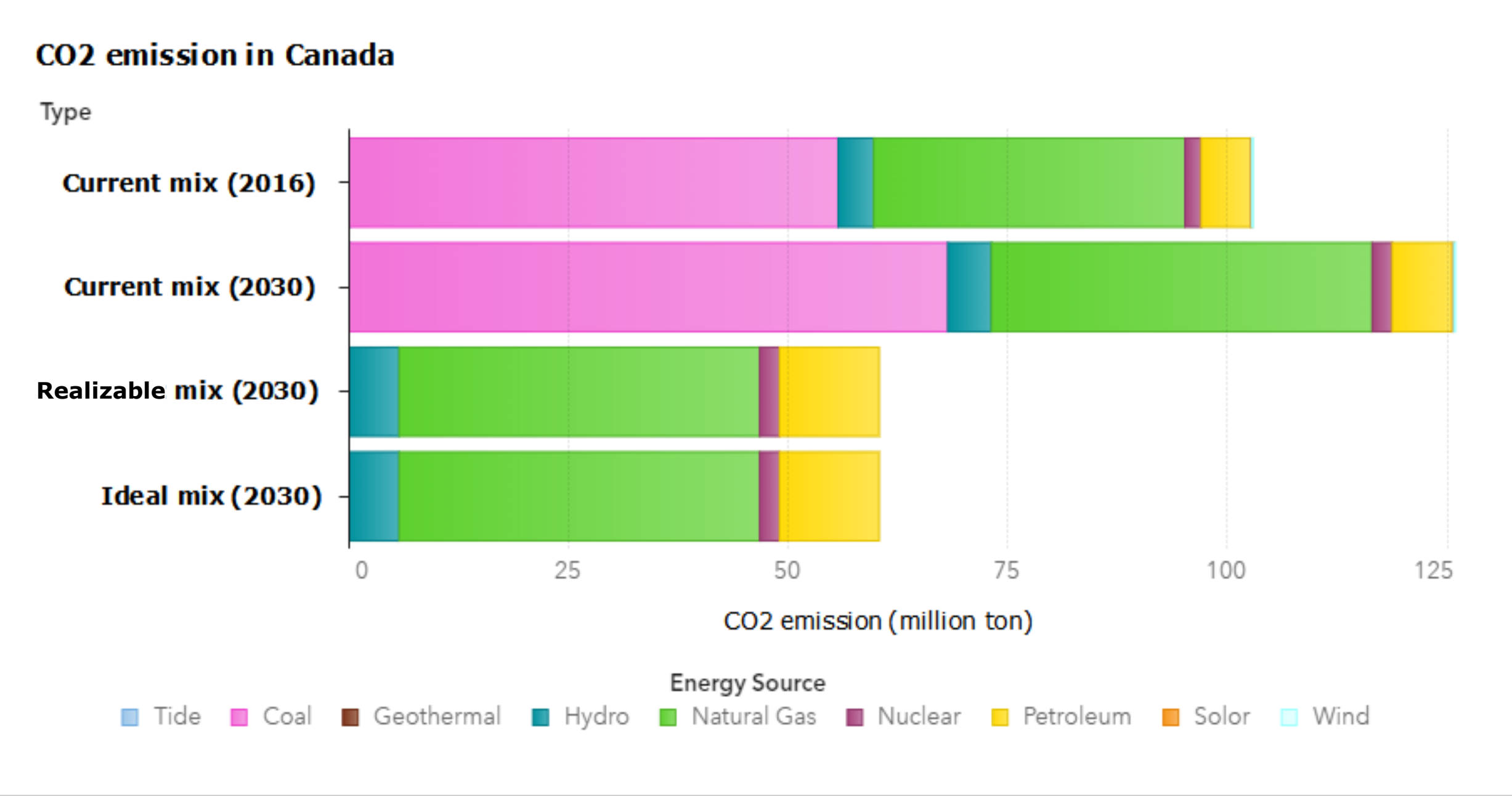

Figure 10.2: Estimated CO2 emission in Canada

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- **Russia**

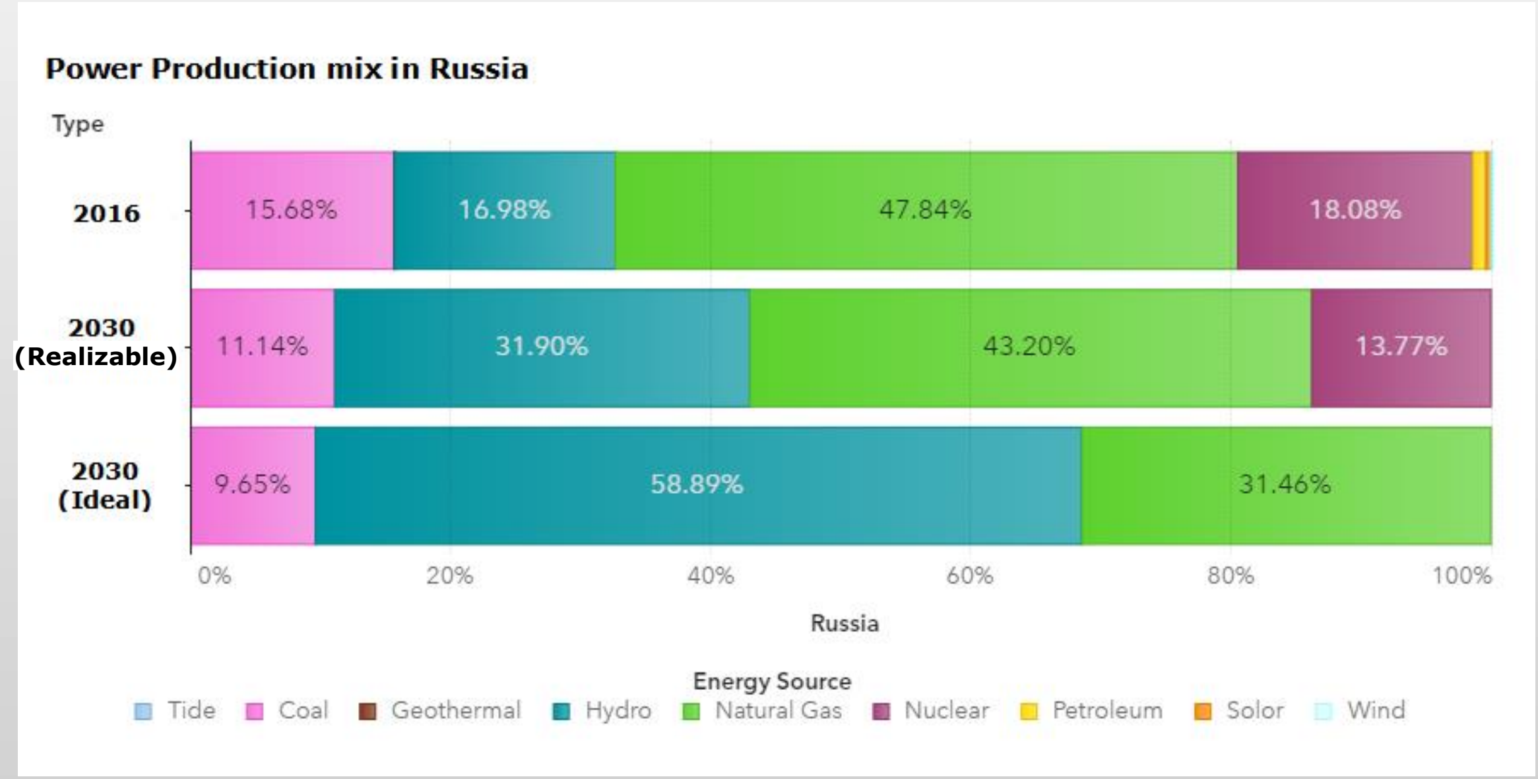

Figure 11.1: Proposed energy mix in Russia

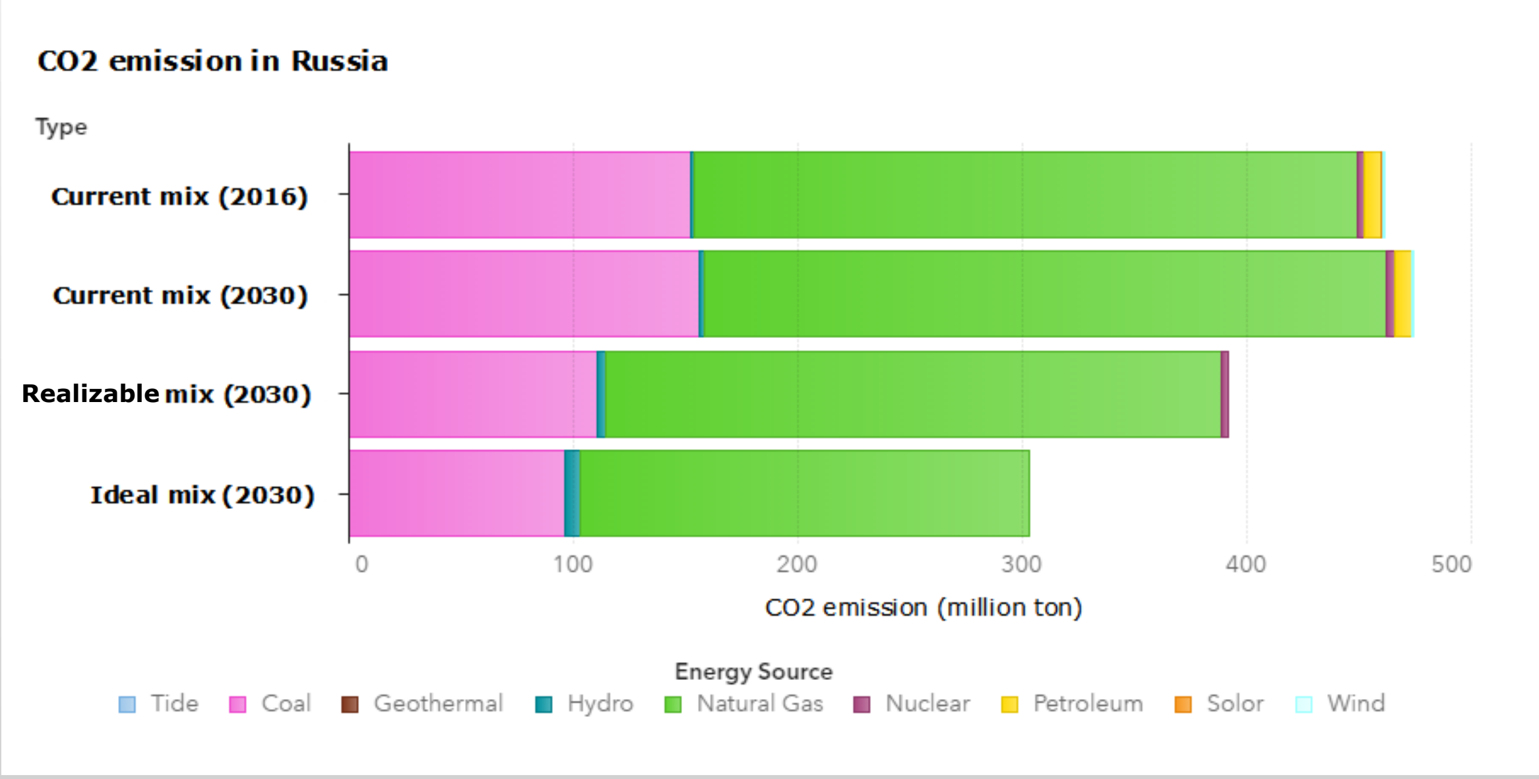

Figure 11.2: Estimated CO2 emission in Russia

- **United Kingdom**

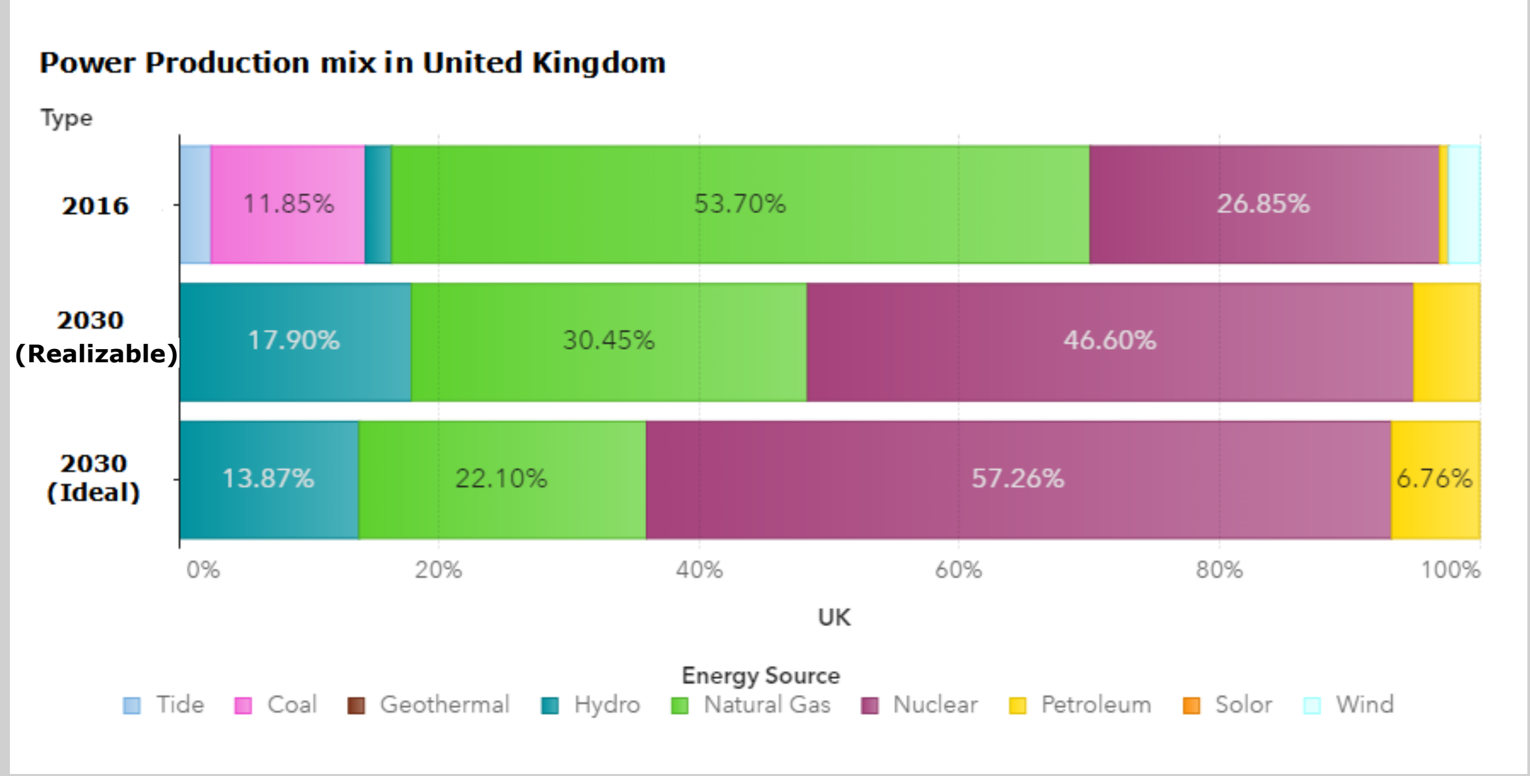

Figure 12.1: Proposed energy mix in United Kingdom

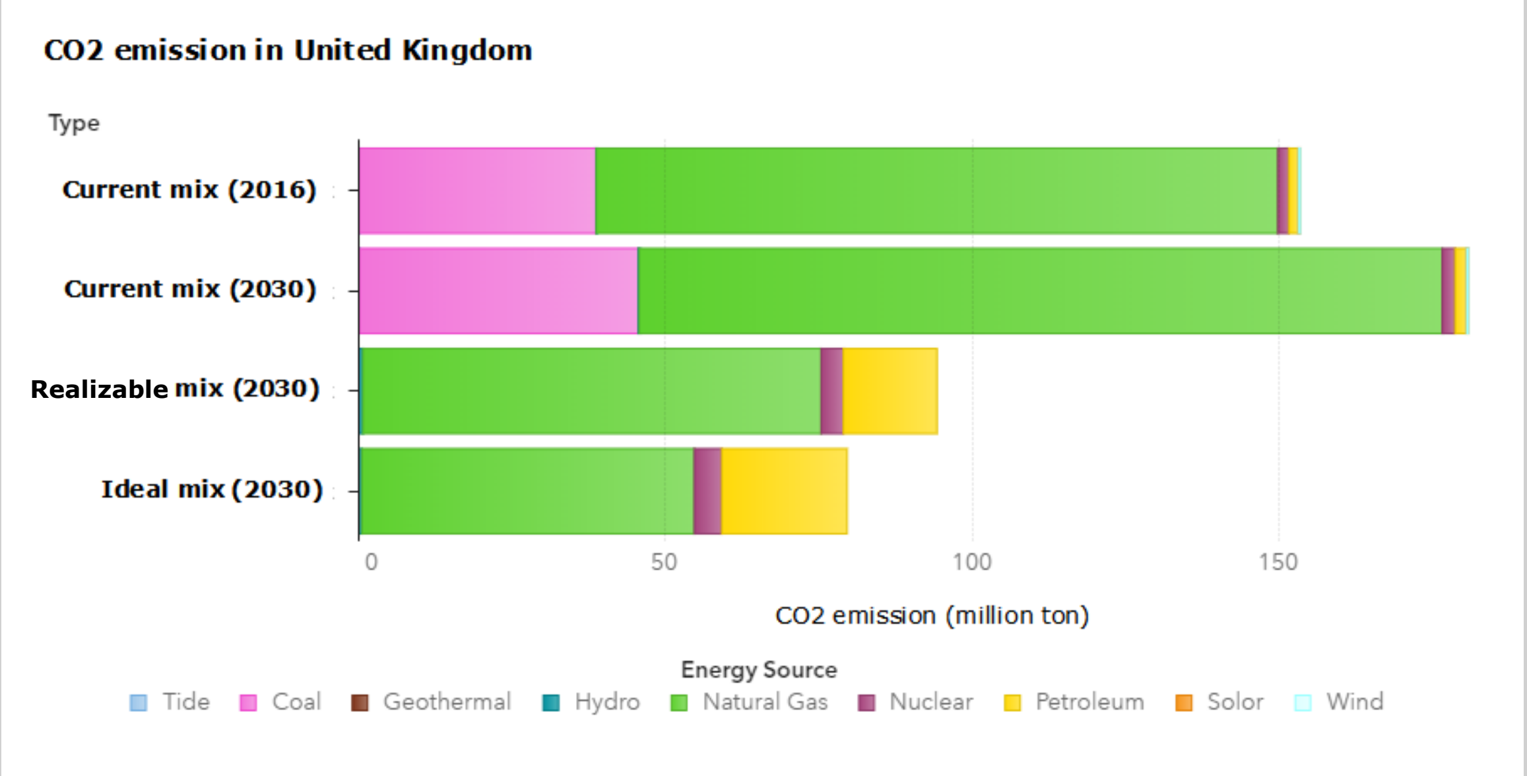

Figure 12.2: Estimated CO2 emission in United Kingdom

- **Germany**

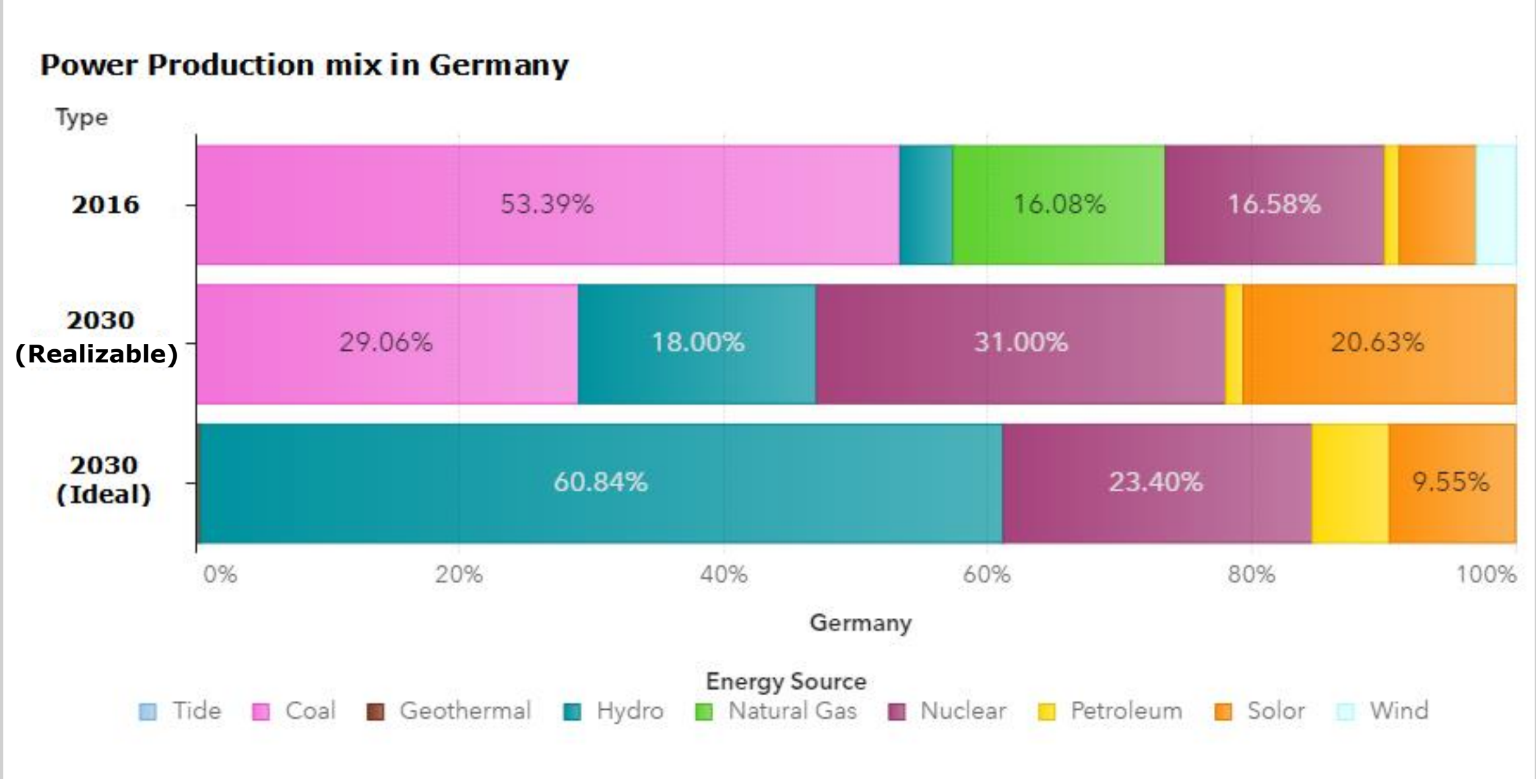

Figure 13.1: Proposed energy mix in Germany

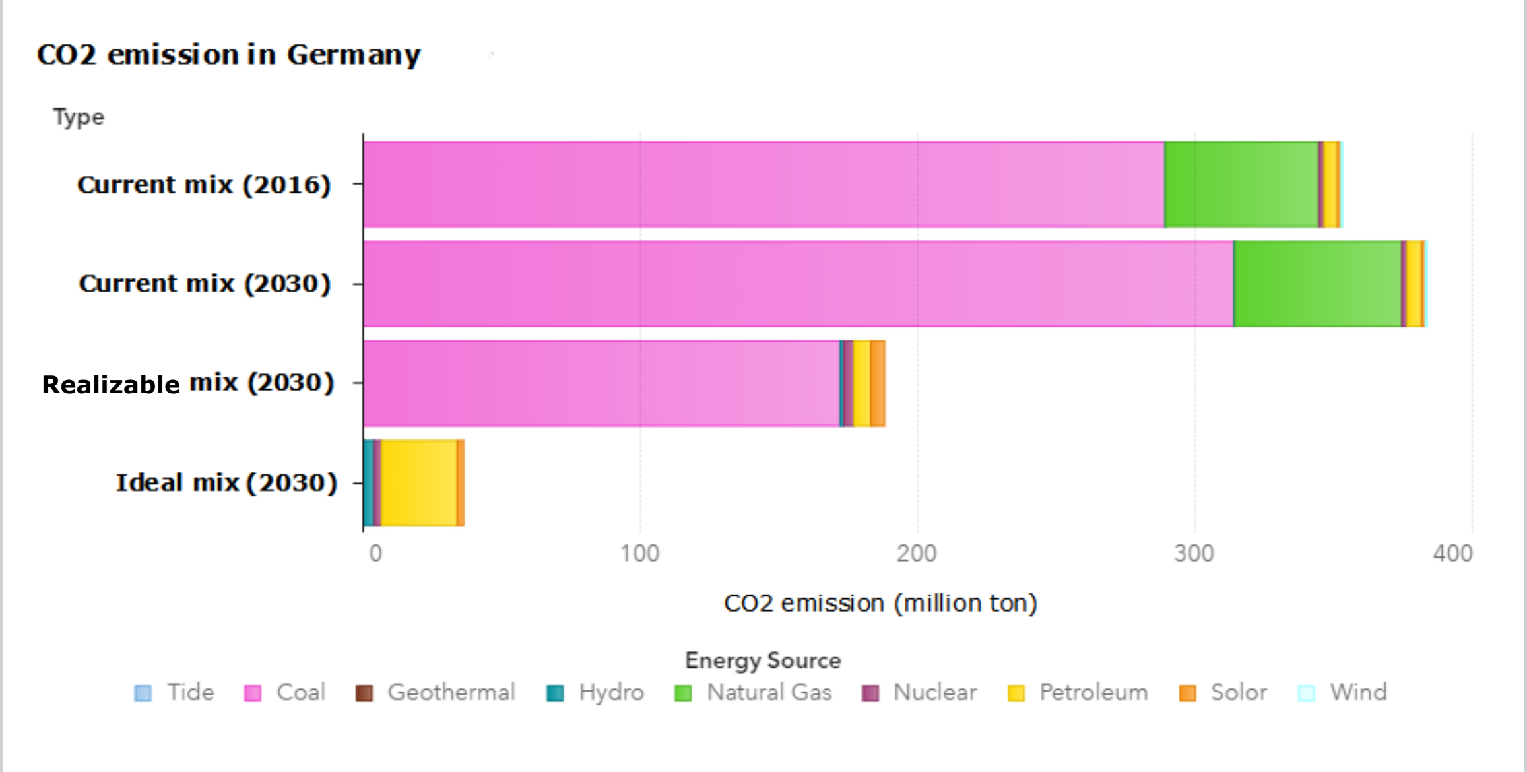

Figure 13.2: Estimated CO2 emission in Germany

➢ Calculation of Security Index

Here we show how to calculate *Security score* s_i and *Security index* S. As mentioned above, Security score s_i denotes the stability of the energy source, and security index S is defined as $\sum_i x_i s_i$. First, we divide cases according to the energy type.

Case1: Energy from fossil fuels

The production of fossil fuel holds the risk of fluctuation year by year. The variation in one country affects to the all counties which import the source from the country. Here we define *production rate* as a criterion to assess the instability of production. Suppose p_{ik} is the amount of production in a certain country in year k. *Production rate* of the country in the year is defined as follows.

$$Production\ rate = \frac{p_{i,k}}{max(p_{i,k-2}, p_{i,k-1}, p_{i,k}, p_{i,k+1}, p_{i,k+2})}$$

Here we define the standard deviation of production rate as V. Security score s_i is the sum of V of each country with weight based on the import ratio of the country among all. However, since self-independence decrease the risk related to importing, the weight reduced to the half in using domestic energy.

Case2: Renewable energy.

Energy productions from renewable energies also varies by year since it is affected by natural condition. We define *generation rate* just the same as production rate. Suppose $g_{i,k}$ is the amount of electricity generated in year k. generation rate of a certain year is defined as follows:

$$Generation\ rate = \frac{g_{i,k}}{max(g_{i,k-2}, g_{i,k-1}, g_{i,k}, g_{i,k+1}, g_{i,k+2})}$$

Security score s_i is defined as the standard deviation of generation rate. Note that $s_{nuclear}$ is calculated in this way because it does not depend on the importing of uranium.

Finally, from $\sum_i x_i s_i$, we can get security index S.

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FORECASTING CO2 EMISSION OF ELECTRICAL GENERATION BY USING SAS® SOFTWARE

Kaito Kobayashi, The University of Tokyo

ABSTRACT

Currently, global warming is one of the most severe problems in the world. Electric generation have stimulated the problem by emitting a great deal of CO2. The power production mix must be reorganized with adopting renewable energy.

This poster aims to propose a model which provides the most environmentally friendly power production mix with fulfilling requirements. We introduced some restrictions which represented following criteria; cost, safety, stability, and we made two environmentally friendly electricity generating scenarios; ideal and realizable. In addition, we forecasted the electricity demand in 2030 so that we could estimate the amount of CO2 emission based on each scenario.

This model will help to determine power production mix under political requirements and contribute to reduce CO2 emissions.

INTRODUCTION

Global warming is one of the most severe problems in the world, and a great deal of researches has shown that CO2 is the main cause. However, plenty of CO2 have continued to be emitted in electrical generating every year, which has deteriorated the environment. Under such situation, renewable energies are drawing attention as environmentally friendly generating methods, although their instabilities have been pointed out. In generating electricity, four important aspects must be considered; Environment friendliness, Economy, Energy Security and Safety, and an eco-friendly power generation mix should be established under those restrictions. Some studies offered forecasted mixes in the future, nevertheless few researches attempted to optimize power generation mix in terms of minimizing CO2 emission.

This study aims to propose the most environmentally friendly power generation mix with fulfilling other requirements. In addition, we forecasted the electricity demand in 2030 so that we could estimate the amount of CO2 emission based on each scenario. To achieve that, reasonable model was constructed with some parameters, and optimized to minimize CO2 emission under restrictions shown as follows.

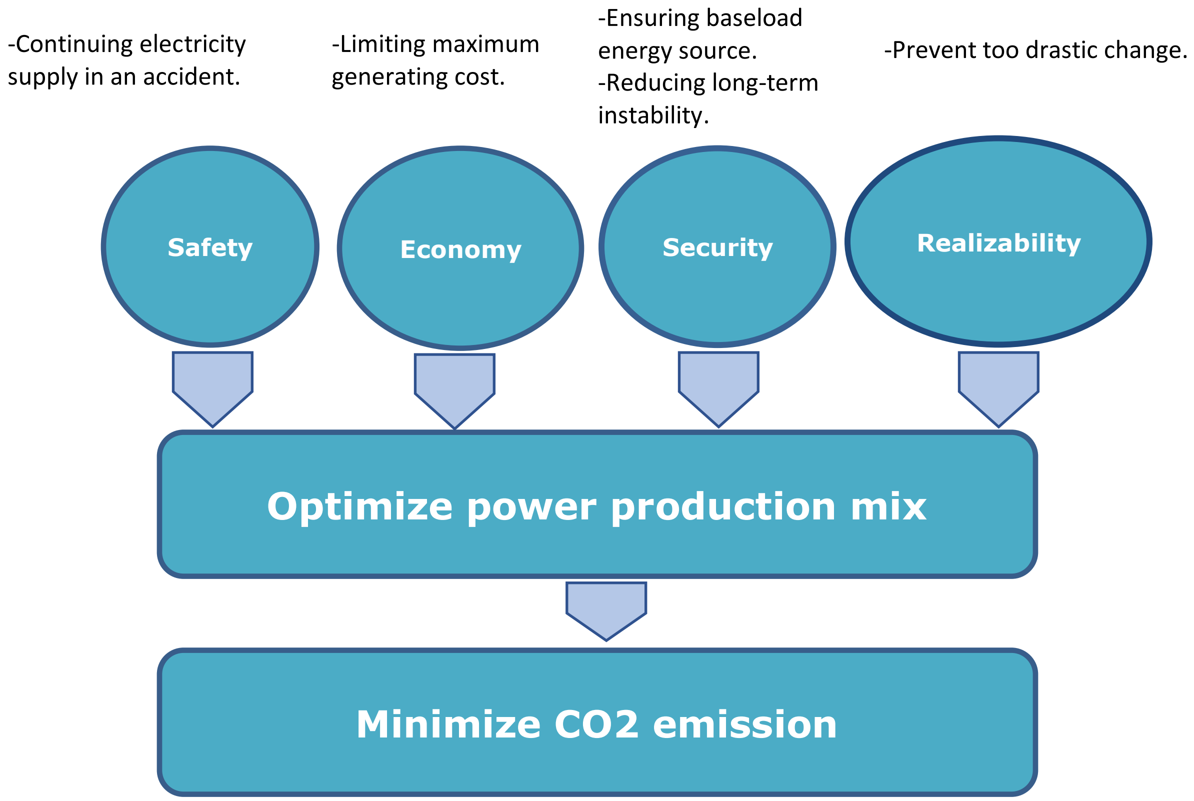

Figure 1. Flow chart of minimizing CO2 emission.

DATA/METHOD

DATA

The countries and energy sources subject to this study and the data sources are followings.

Country	Brazil, Canada, China, France, Germany, India, Japan, Korea, Russia, UK, USA
Energy Source	Coal, Petroleum, Natural Gas, Nuclear, Hydro, Solar, Geothermal, Wind, Tide
Data Source	OECD Data, IEA, UN Data, EIA, ITC, IMF

Table 1. The countries and energy sources subject to the study and its data source.

	Coal	Petroleum	Natural Gas	Nuclear	Hydro	Solar	Geothermal	Wind	Tide
Baseload energy	○	×	×	○	○	×	○	×	×
Natural energy	×	×	×	×	○	○	○	○	○

Table 2. The kinds of each energy source.

FORECASTING ELECTRICITY DEMAND

Using SAS® Visual Analytics, linear regression was conducted with following explanatory variables; GDP, Population, population growth rate. Electricity demand was calculated by applying the forecasting data of explanatory variables, which are published by other authorities, to the equation gained.

OPTIMIZING POWER GENERATION MIX

Here we define variable x_i as the ratio of the energy source *i* among an energy mix. Suppose e_i to be the amount of CO2 emitted to generate 1kWh electricity. The CO2 emission is proportional to $\sum_i e_i x_i$. The objective of this study is to optimize each x_i that minimize $\sum_i e_i x_i$.

- **Economy**

Let c_i be the cost needed to generate 1kWh electricity. Using a parameter *d*, we impose following cost-management requirements.

$$\sum_i c_i x_i \leq d \sum_i c_i x_{i,0}$$

Note that subscript *0* denotes current value.

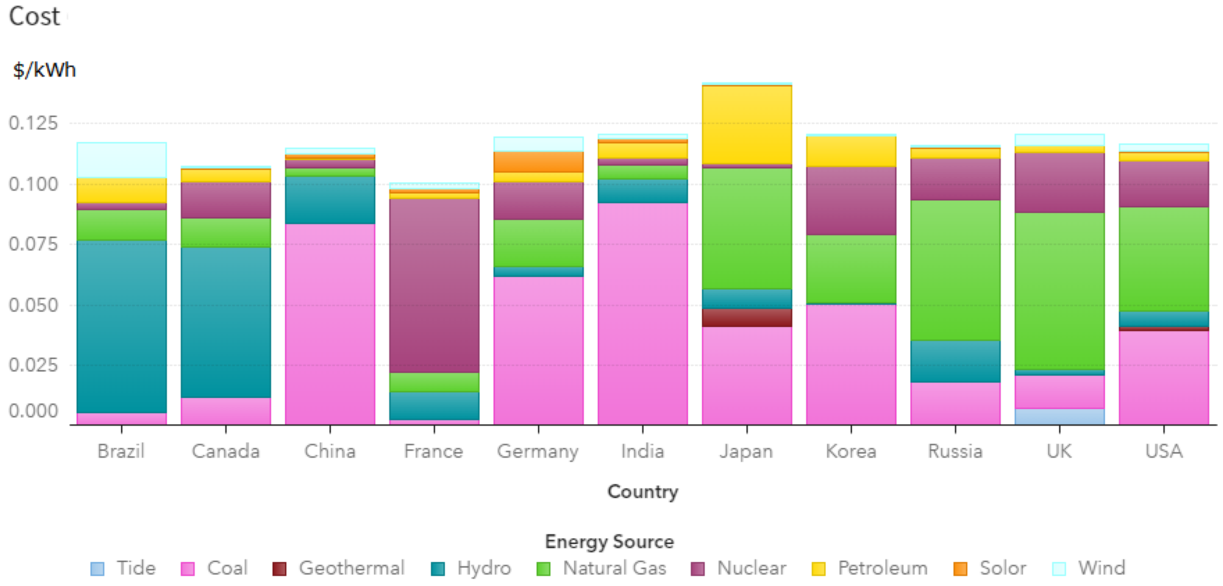

Figure 2. The costs needed to generate 1kWh electricity in 2016.

- **Safety**

Even if some accidents happen in power plants, electricity have to be supplied continuously by operating other plants to the capacity limit. If the cause of the accident is structural defects, plants which share the same structure have to stop running in order to avert another accident. Here I define parameter t_i as the ratio of plants which will halt operation after accident situation. Then $x_i t_i$ has to be compensated. Besides, Load Factor L_i denotes the average load divided by the peak load in a specified time period. In emergency we can generate electricity to $\frac{x_i}{L_i}$ by operating plants to the capacity limits. However, we assume it is impossible to manipulate the production by renewable energies because they completely depend on natural condition. Considering these points, the following inequality have to be fulfilled.

$$(1-t_i) \times x_i + \sum_k \frac{x_k}{L_k} + \sum_n x_n \geq 1$$

Here subscription *n* denotes energy sources related to natural power and *k* denotes the others.

- **Energy Security**

1. **Base Load power plants** (Short term energy security)

Base Load power plants usually provides a continuous supply with minimum electricity requirement, and they contribute to the stable electricity supply through a whole year. We define parameter *B*, and minimum requirement was imposed.

$$\sum_b x_b \geq B$$

Here subscription b indicates base load energy source.

2. **Security index** (Long term energy security)

In order to access energy security in long term, here we introduce following criteria, "*Security score* s_i" and "*Security index S".* Security score s_i denotes the instability of energy source, and security index *S* is defined as $\sum_i x_i s_i$. First, we divide cases according to the energy type.

Case1: **Energy from fossil fuels**

The production of fossil fuel holds the risk of fluctuation year by year. The variation in one country affects to the all counties which import the source from the country. Here we define *production rate* as a criterion to assess the instability of production. Suppose p_{ik} is the amount of production in a certain country in year k. *Production rate* of the country in the year is defined as follows.

$$Production\ rate = \frac{p_{i,k}}{max(p_{i,k-2}, p_{i,k-1}, p_{i,k}, p_{i,k+1}, p_{i,k+2})}$$

Here we define the standard deviation of production rate as *V*. Security score s_i is the sum of *V* of each country with weight based on the import ratio of the country among all. However, since self-independence decrease the risk related to importing, the weight reduced to the half in using domestic energy.

Case2: **Renewable energy.**

Energy productions from renewable energies also varies by year since it is affected by natural condition. We define *generation rate* just the same as production rate. Suppose $g_{i,k}$ is the amount of electricity generated in year k. generation rate of a certain year is defined as follows:

$$Generation\ rate = \frac{g_{i,k}}{max(g_{i,k-2}, g_{i,k-1}, g_{i,k}, g_{i,k+1}, g_{i,k+2})}$$

Security score s_i is defined as the standard deviation of generation rate. Note that $s_{nuclear}$ is calculated in this way because it does not depend on the importing of uranium. Finally, from $\sum_i x_i s_i$, we can get security index *S*. To achieve energy security in long term, *S* must not exceed the current value S_0. Therefore, the inequality should be fulfilled;

$$S \leq S_0$$

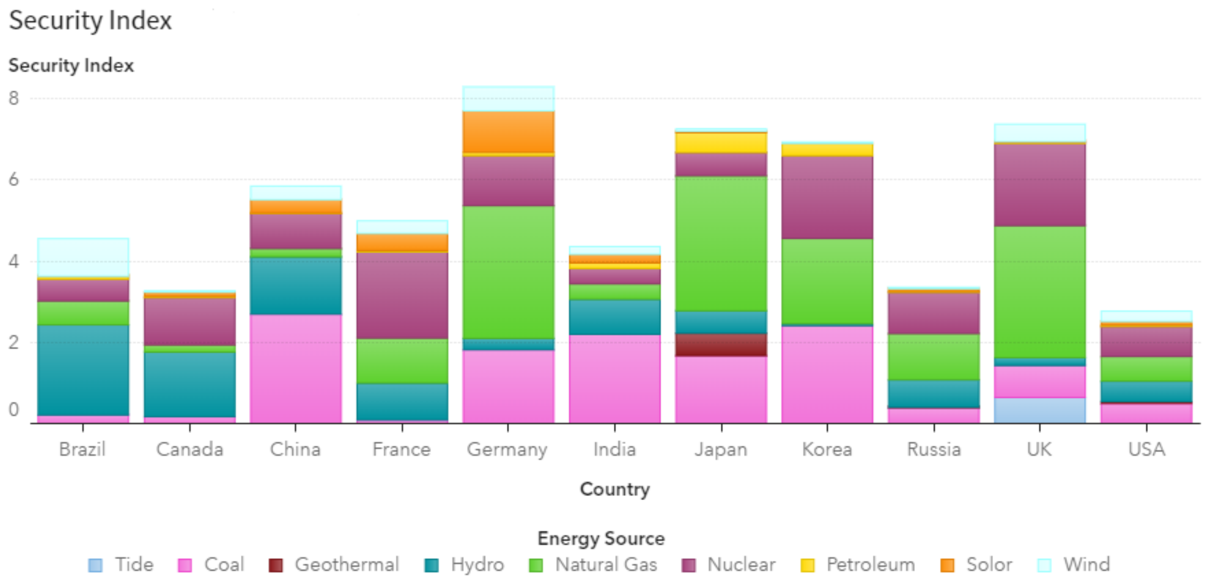

Figure 3. The values of security index in 2016.

● Realizability

Too drastic change from status quo is unrealistic. Therefore, we introduced a parameter r_i, and imposed following restriction.

$$x_i \leq x_{i,0} + r_i$$

In this study, we made two scenarios. The one considers realizability (Realistic), the other doesn't (Ideal).

Under the restrictions above, the power generation mix (x_i) was optimized by SAS® Optimization (on SAS® Viya®) to achieve minimum CO2 emission. The parameter values used in this study is as follows

Parameter	Base Load (*B*)	Cost (*d*)	Safety (t_i)		Realizability (r_i)	
			Nuclear	Other	Natural Source	Others
Value	0.5	1	0	0.5	0.15	0.2

Table 3. The value of each parameter

RESULTS

● Forecasting Electricity Demand

Linear regression was conducted to forecast electricity demand in the future. For the analysis, GDP, Population and Population growth was treated as explanatory variables. Table 4 shows the R-square of the linear regression of all countries, and judging from this, the regression models were reasonable. Besides, every variable was significant. Since we focused on the CO2 emission in 2030, by applying the concrete forecasted data to the explanatory variables, electricity demand in 2030 was forecasted as shown in Figure 4. The electricity demands were estimated to increase in most countries.

country	Brazil	Canada	China	France	Germany	India	Japan	Korea	Russia	UK	USA
R^2	0.996	0.908	0.995	0.873	0.809	0.992	0.895	0.989	0.887	0.87	0.926

Table 4. The R-square of the linear regressions.

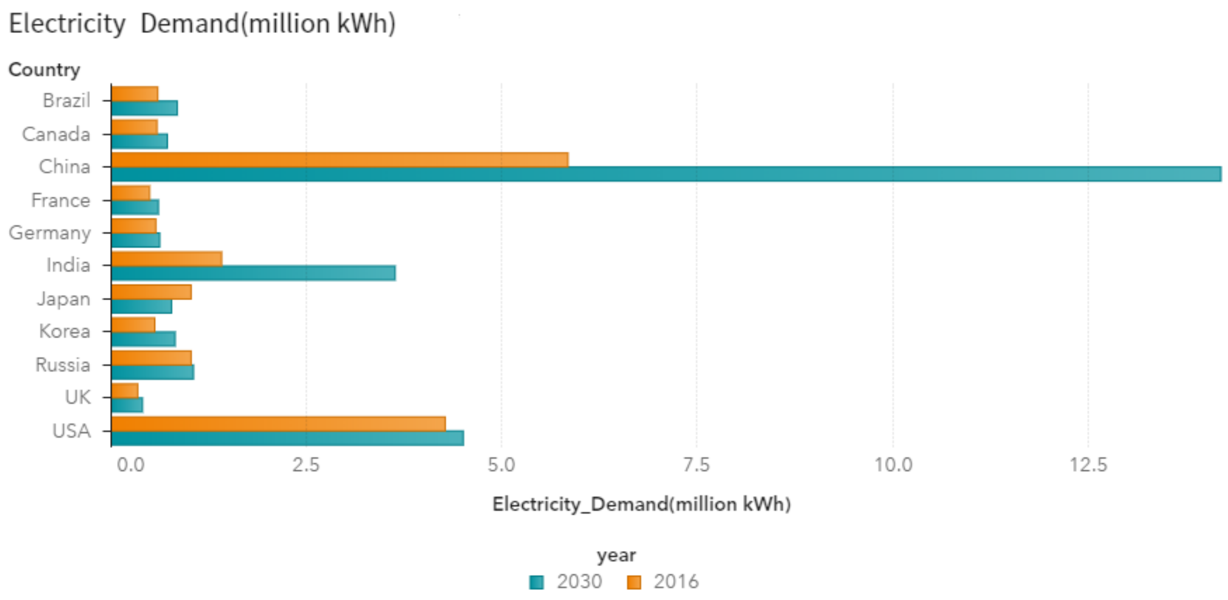

Figure 4. Electricity Demand in 2016 and 2030 (forecasting).

● Optimizing Power generation mix

The optimization of power generation mix was conducted which purpose was to minimize CO2 emission. Two scenarios were made, which were Realistic and Ideal. Figure 5 to 26 shows the power production mix in each scenarios and estimated CO2 emissions in each country. Tendency of shifting from fossil fuels to nuclear energy or hydro power was recognized. By applying forecasted electricity demand to these mixes, the CO2 emission in 2030 was estimated. Table 5 shows the CO2 emission in each production mix scenario when we define current emissions as 1. The CO2 emissions were forecasted to increase if current power production mix remains, however, after optimizing, it will be reduced drastically in all countries except for France. The parameters didn’t fit to French case which largely depends on nuclear energy.

	Brazil	Canada	China	France	Germany	India	Japan	Korea	Russia	UK	USA
Current mix (2016)	1	1	1	1	1	1	1	1	1	1	1
Current mix (2030)	1.41	1.22	2.43	1.22	1.09	2.56	0.76	1.46	1.03	1.18	1.05
Realistic mix (2030)	0.94	0.59	1.86	5.17	0.53	1.54	0.55	0.78	0.85	0.61	0.62
Ideal mix (2030)	0.90	0.59	1.33	3.76	0.10	0.97	0.12	0.77	0.66	0.52	0.53

Table 5. Comparison of estimated CO2 emissions between 2016 and 2030.

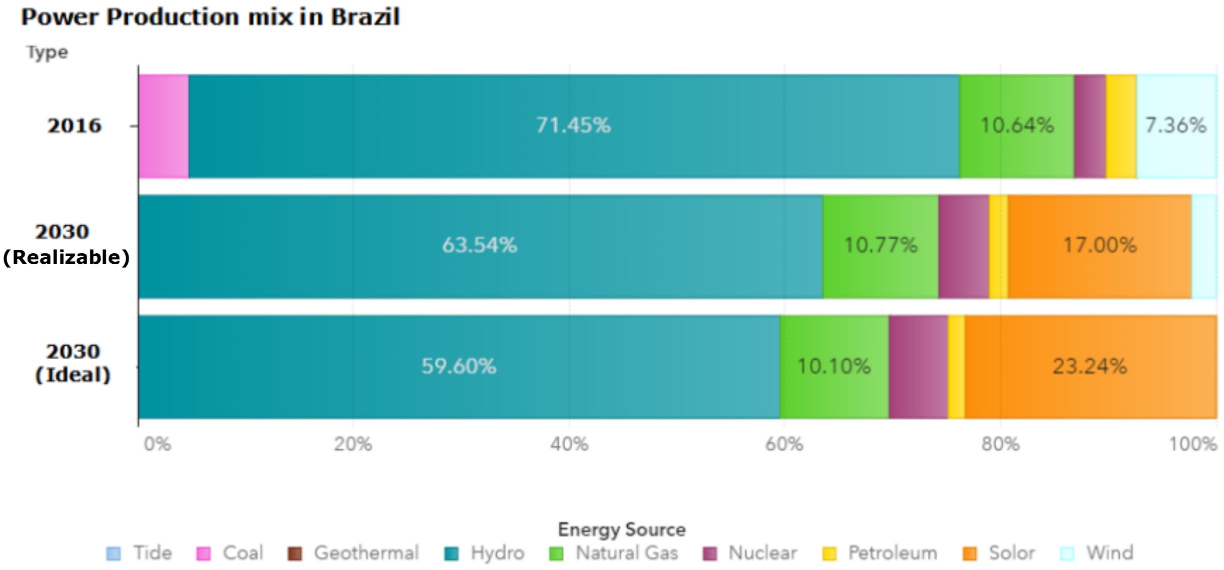

Figure 5. Proposed power production mix in Brazil.

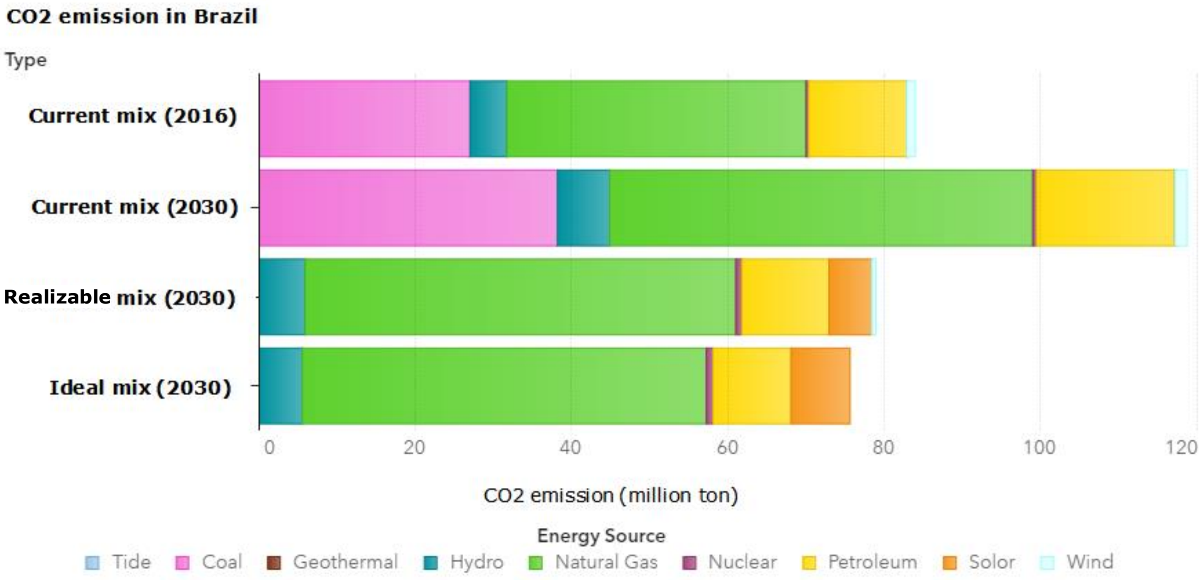

Figure 6. Estimated CO2 emission by power production mix in Brazil.

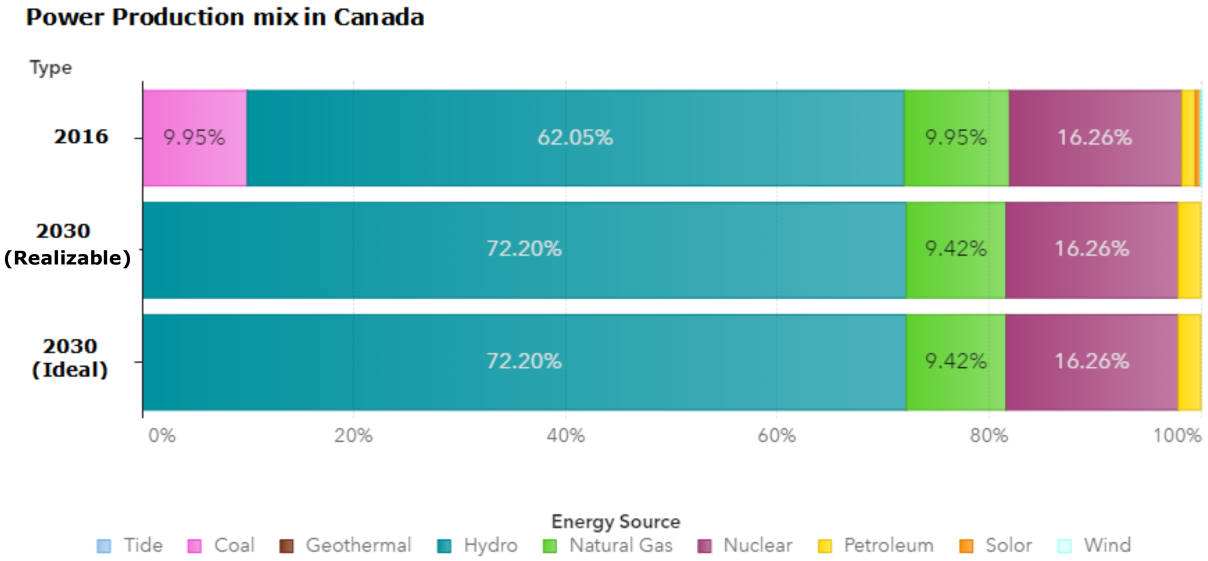

Figure 7. Proposed power production mix in Canada.

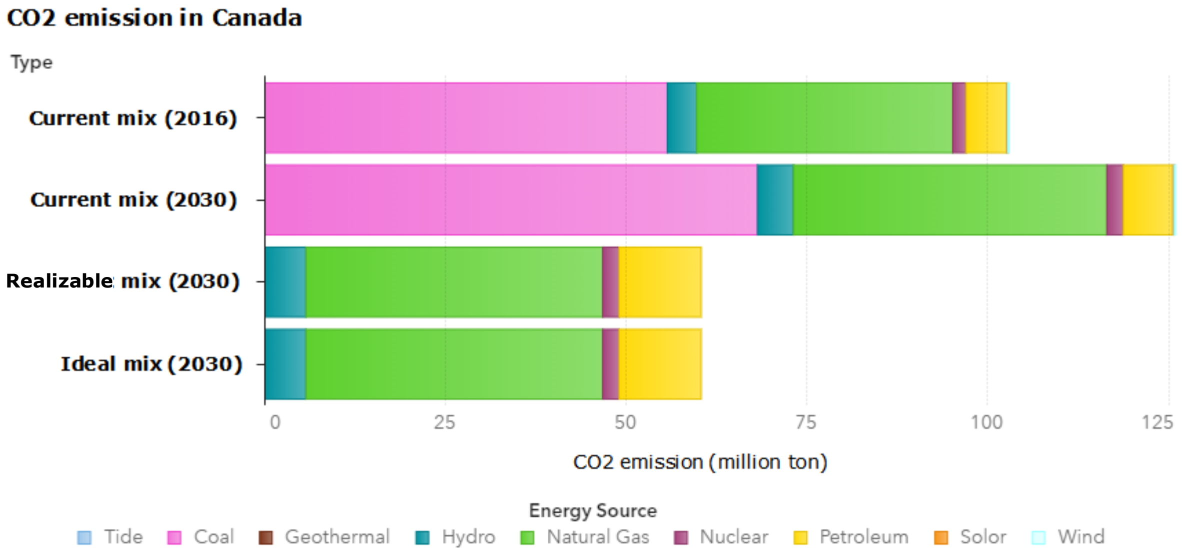

Figure 8. Estimated CO2 emission by power production mix in Canada.

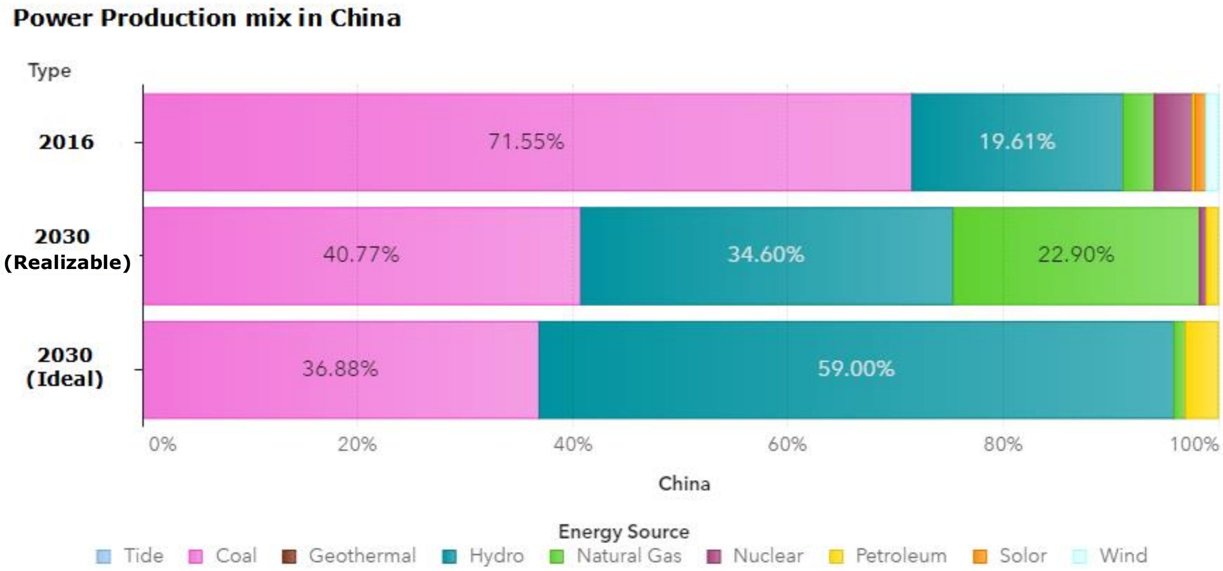

Figure 9. Proposed power production mix in China.

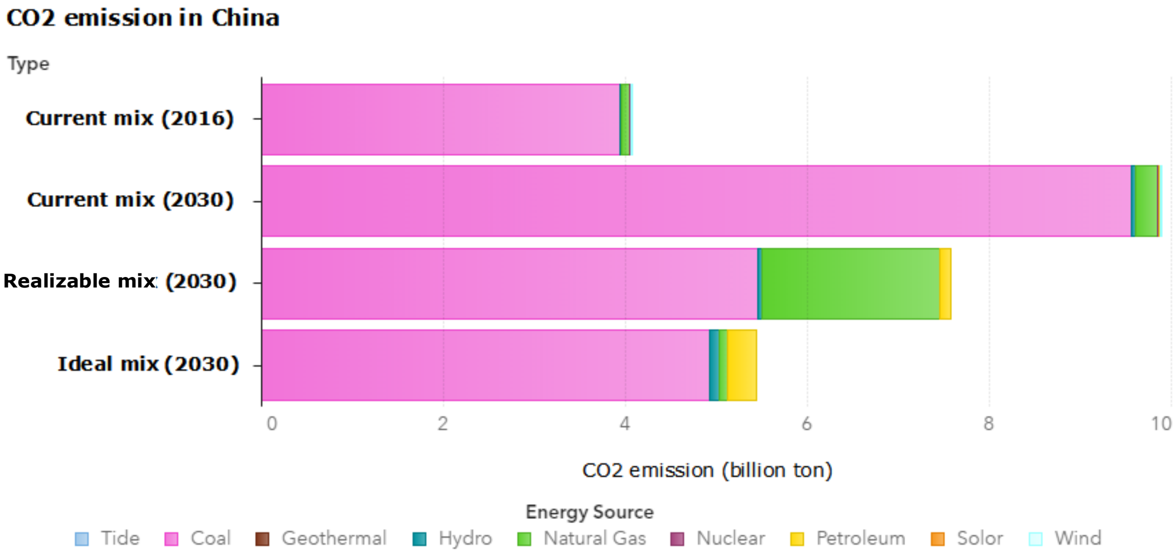

Figure 10. Estimated CO2 emission by power production mix in China.

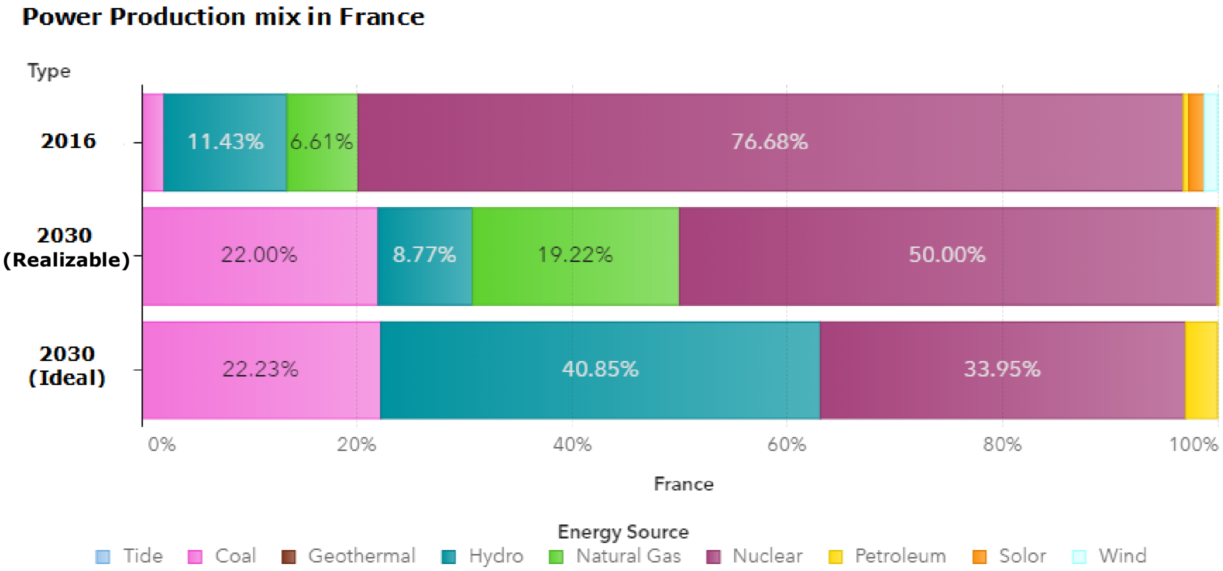

Figure 11. Proposed power production mix in France.

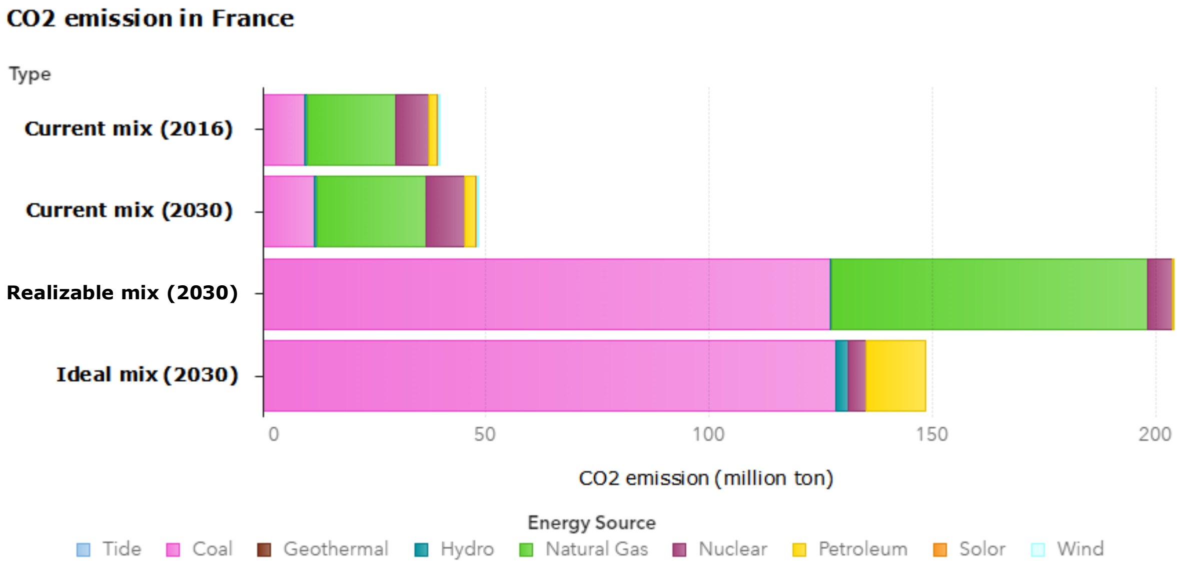

Figure 12. Estimated CO2 emission by power production mix in France.

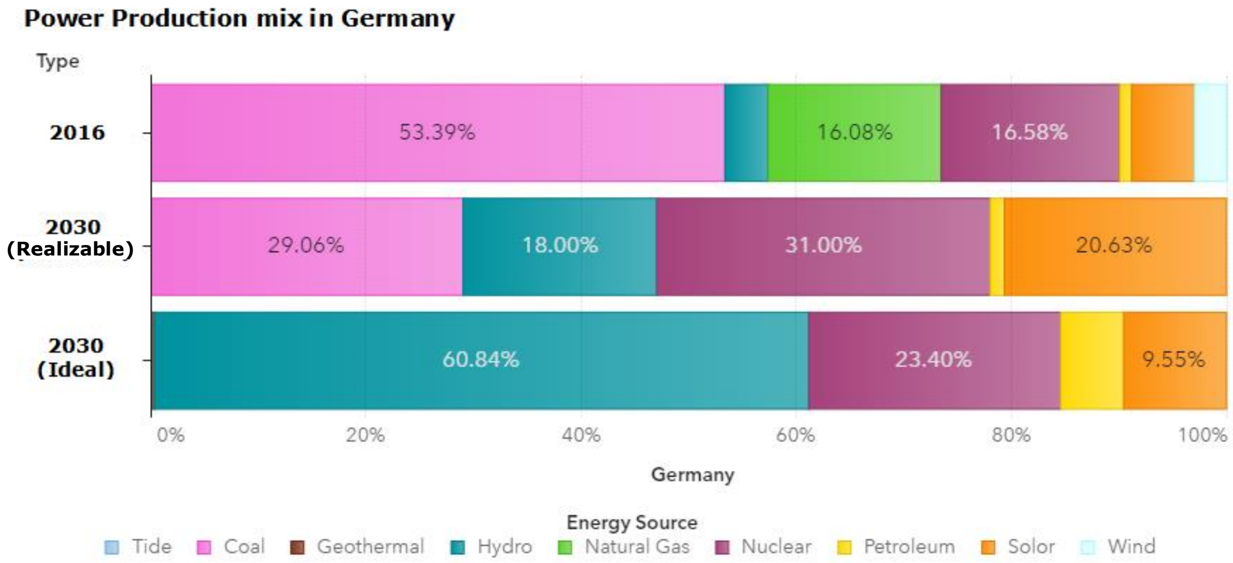

Figure 13. Proposed power production mix in Germany.

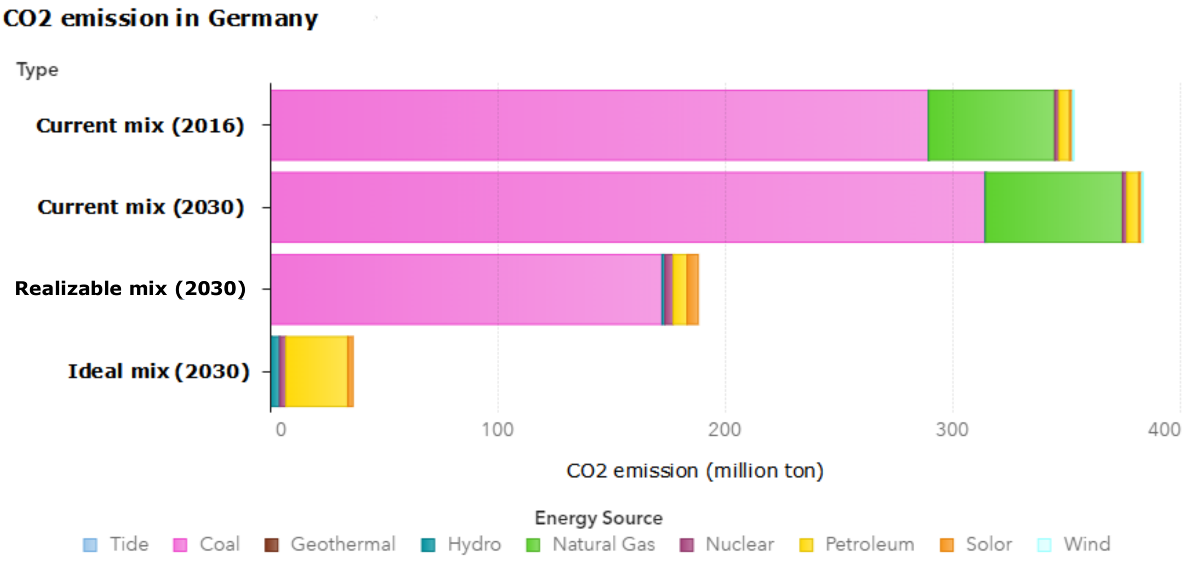

Figure 14. Estimated CO2 emission by power production mix in Germany.

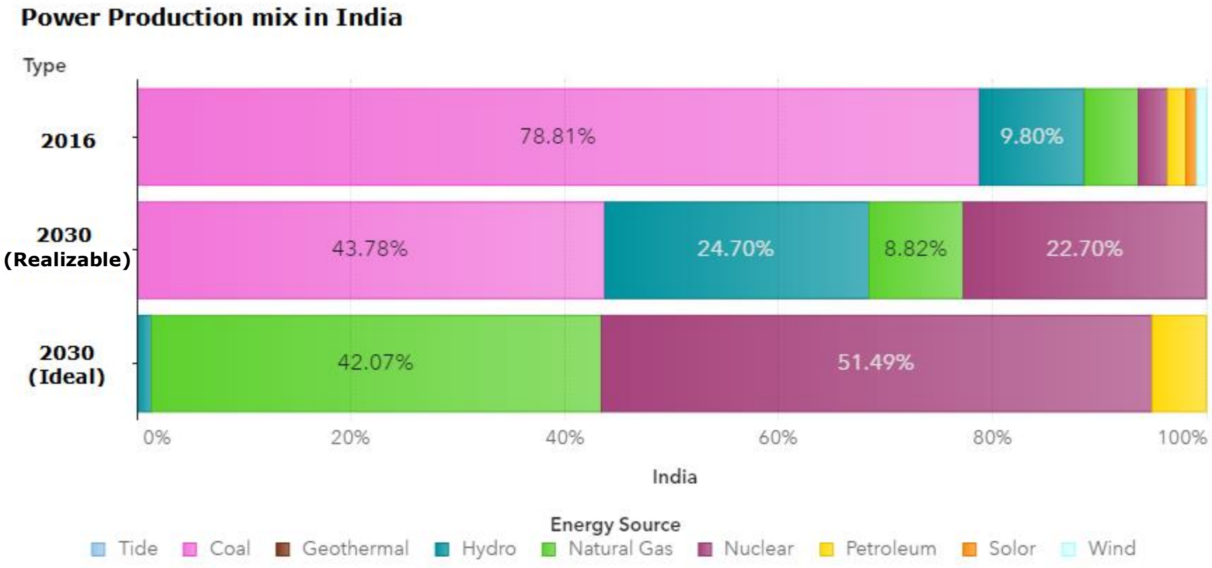

Figure 15. Proposed power production mix in India.

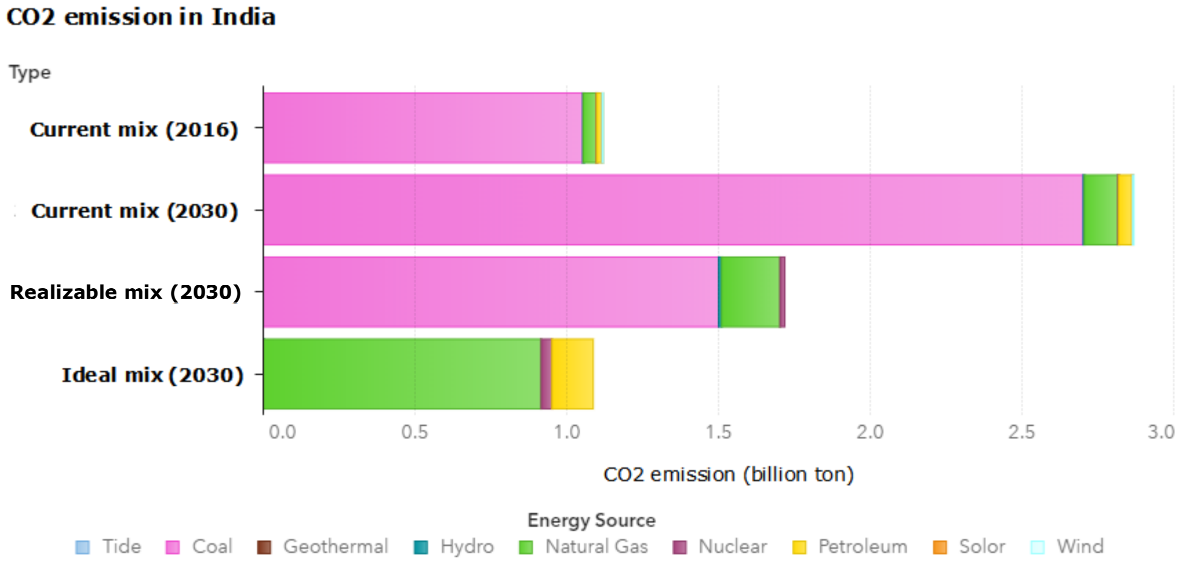

Figure 16. Estimated CO2 emission by power production mix in India.

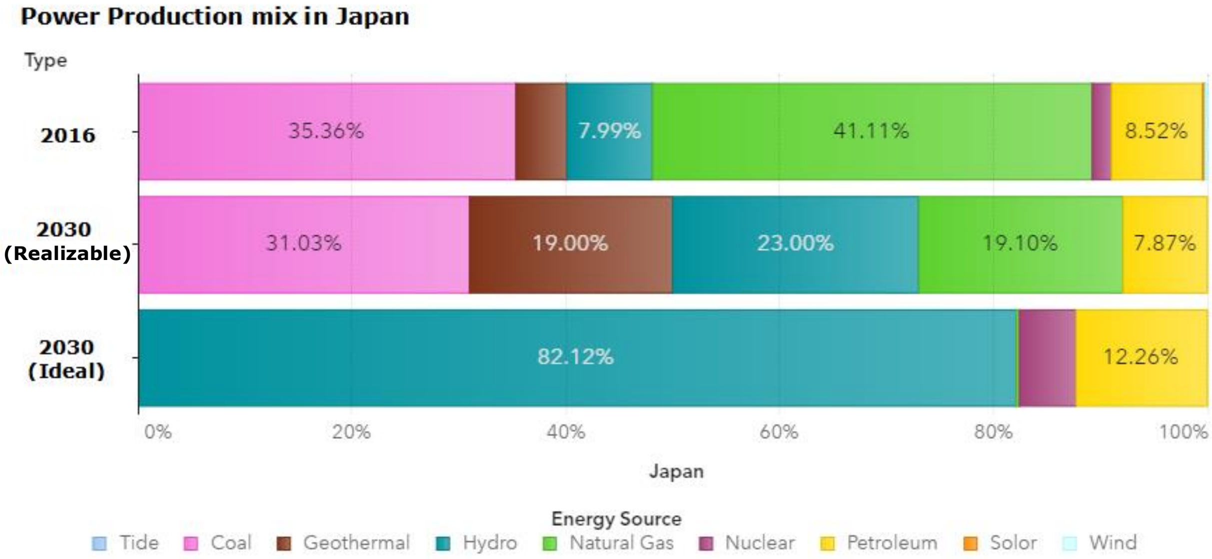

Figure 17. Proposed power production mix in Japan.

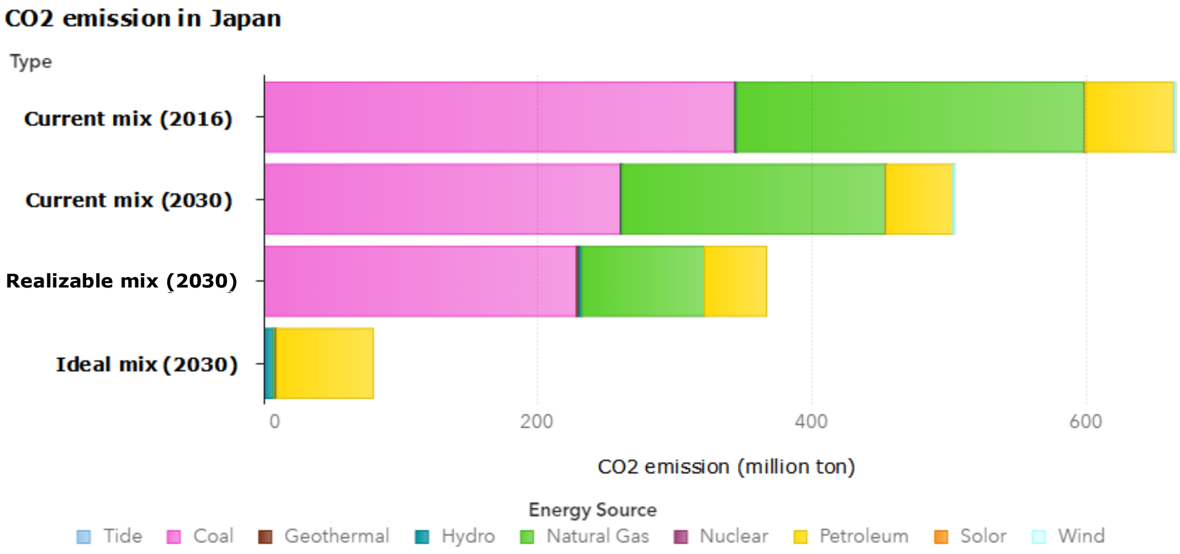

Figure 18. Estimated CO2 emission by power production mix in Japan.

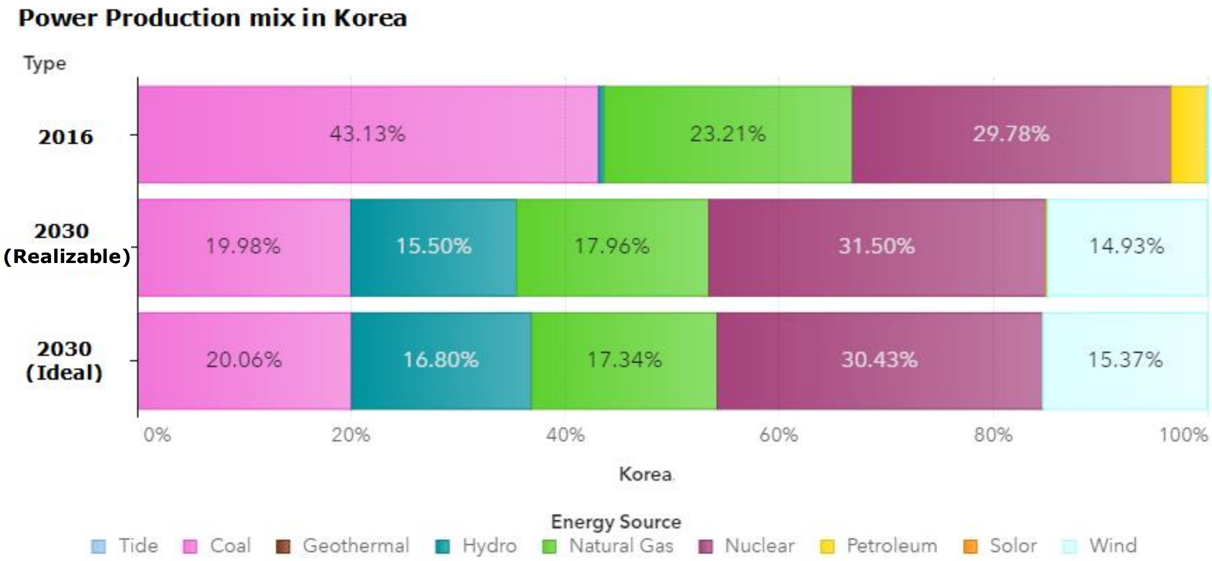

Figure 19. Proposed power production mix in Korea.

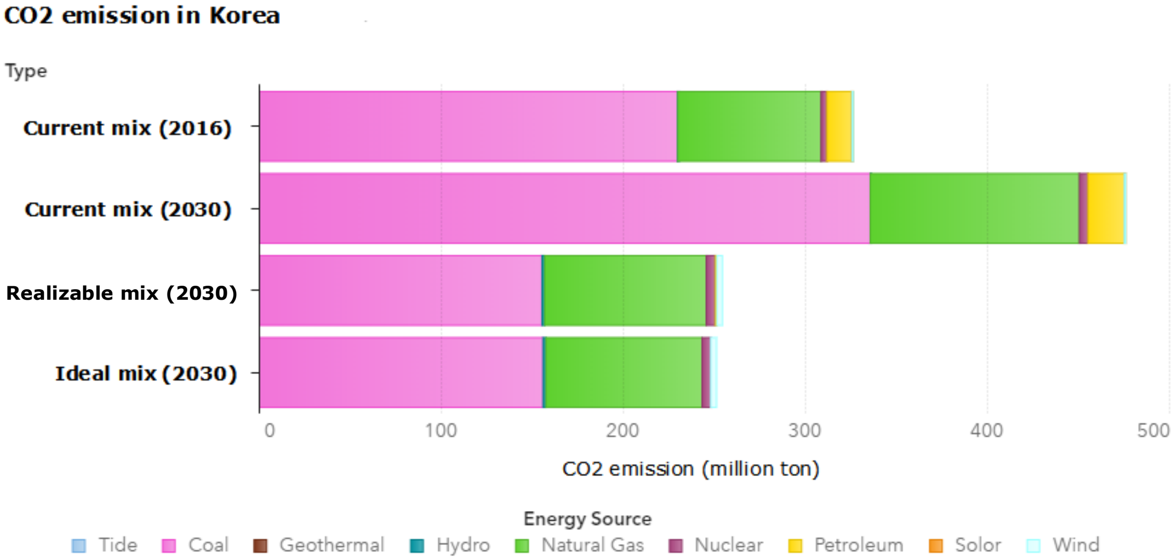

Figure 20. Estimated CO2 emission by power production mix in Korea.

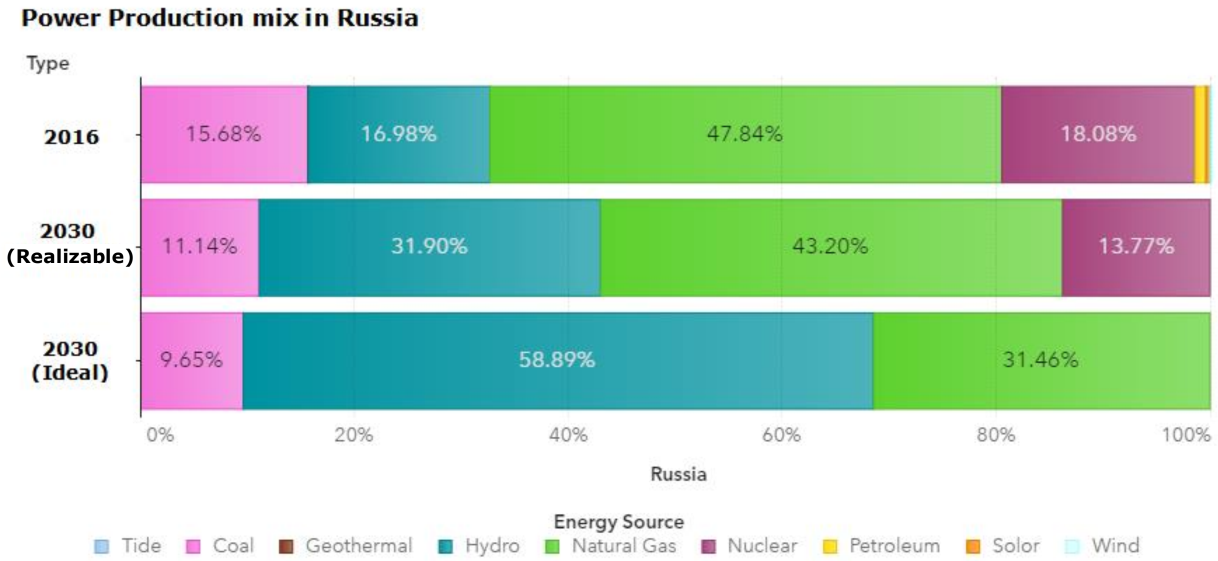

Figure 21. Proposed power production mix in Russia.

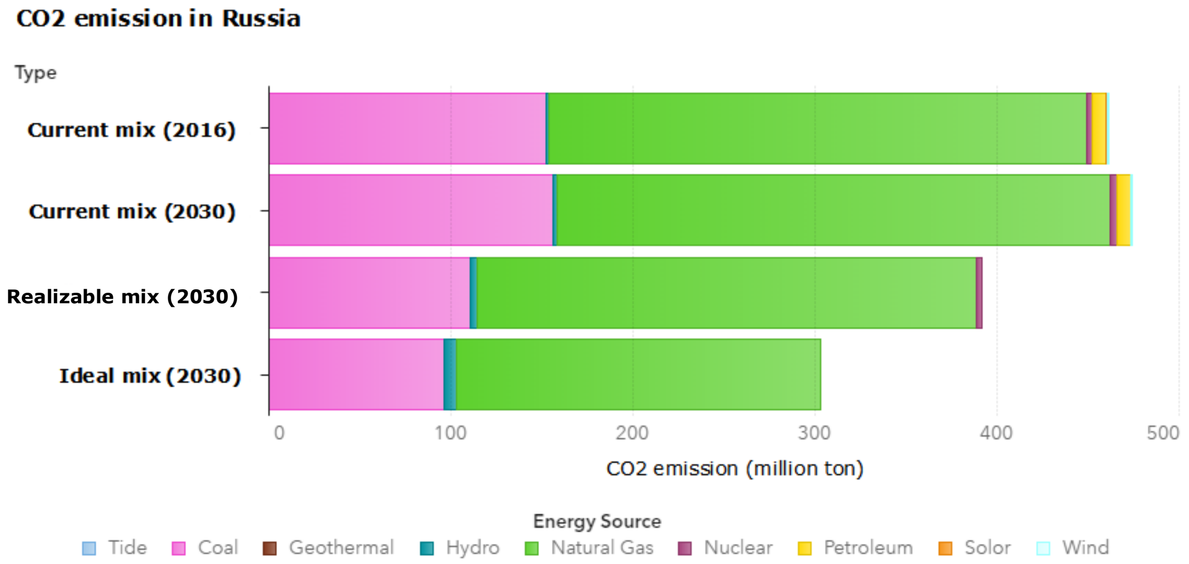

Figure 22. Estimated CO2 emission by power production mix in Russia.

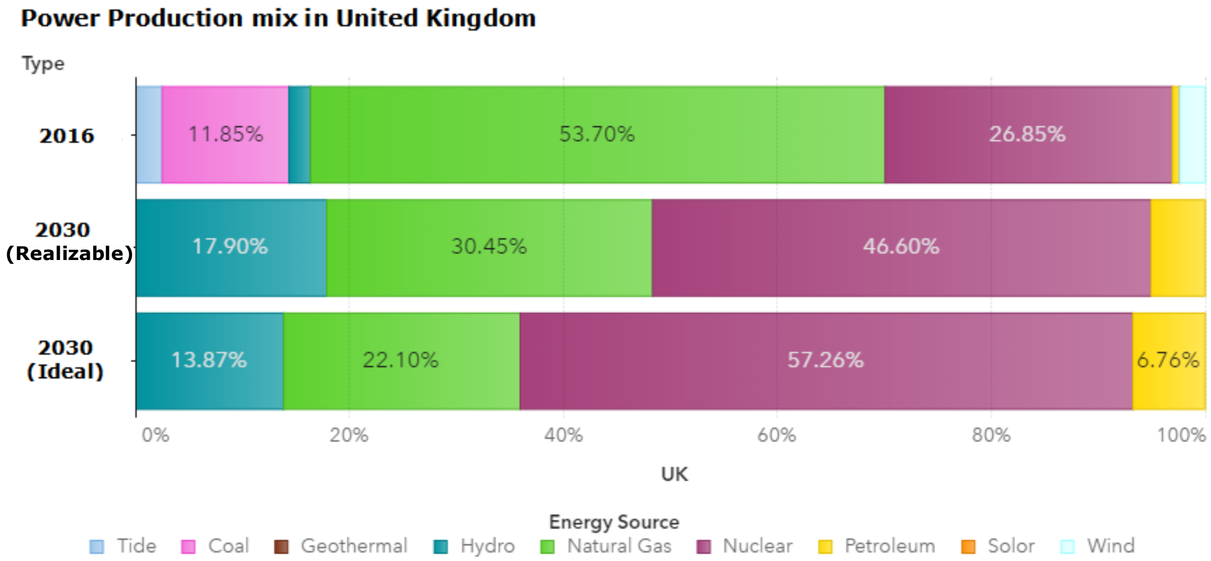

Figure 23. Proposed power production mix in United Kingdom.

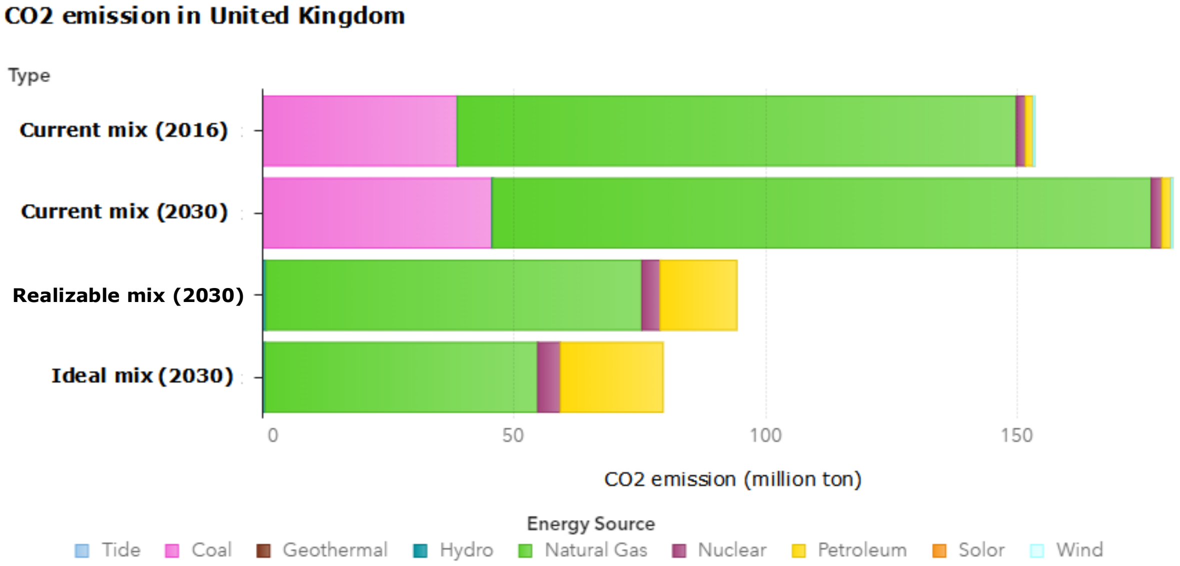

Figure 24. Estimated CO2 emission by power production mix in United Kingdom.

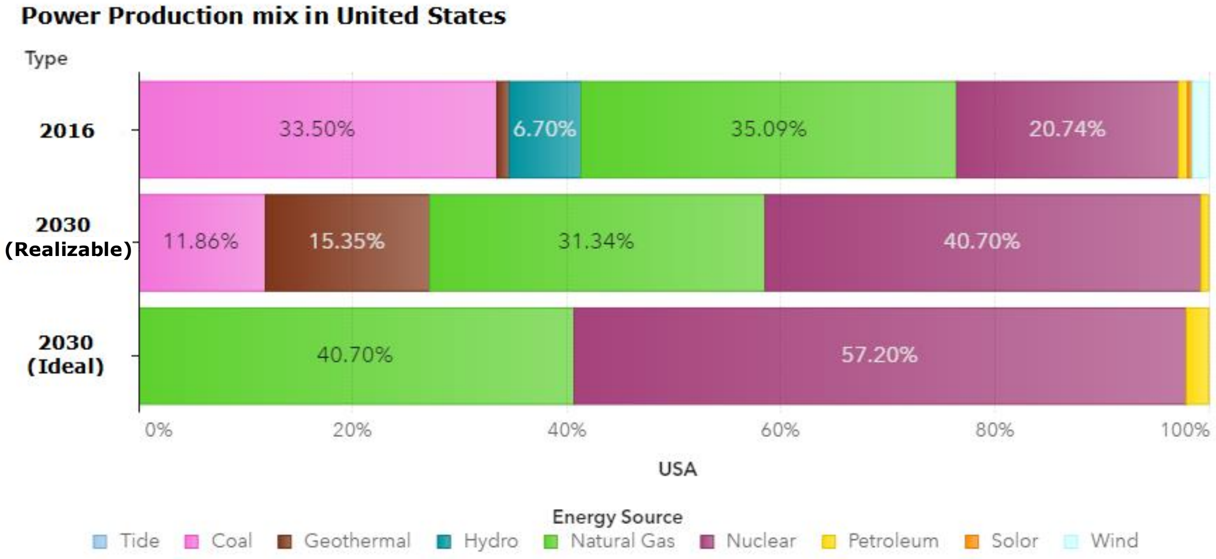

Figure 25. Proposed power production mix in United States.

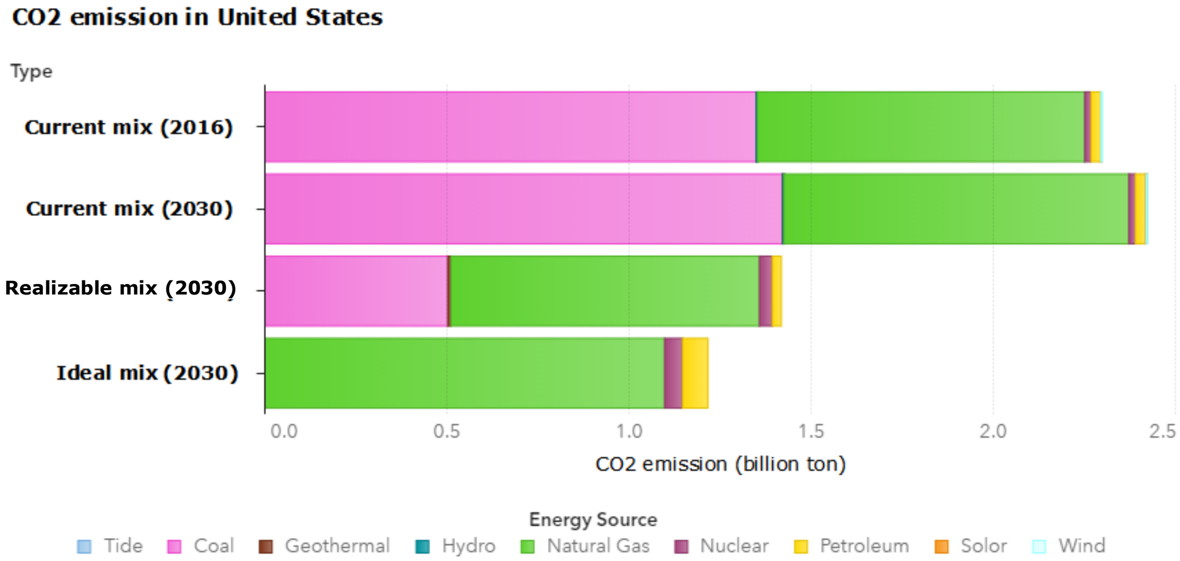

Figure 26. Estimated CO2 emission by power production mix in United States.

DISCUSSION

The goal of this study is to propose a model which provide an eco-friendly power production mix under some restrictions. By optimizing the power production mix ratio, we proved that CO2 emission can be reduced. However, the electricity demand is forecasted to increase, as shown in figure 5. Our research suggests that unless we tackle seriously to alter energy mix, much more CO2 will be emitted, which will stimulate global warming.
The proposed models depend on the parameters which represents some restrictions, and to determine them is highly political issue. If there are some regulations which is peculiar to certain country, our model will be improved by adding parameters. Nevertheless, because deciding an energy mix concerns lots of business problems, the proposed energy mixes may be ideal ones. Therefore, feasibility study has to be conducted.

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