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# Impacts Analysis of Dual Carbon Target on the Medium- and Long-Term Petroleum Products Demand in China

**Li Shang [1,2], Qun Shen [1], Xuehang Song [1], Weisheng Yu [1], Nannan Sun [1,2,*] and Wei Wei [1,2,*]**

[1] CAS Key Laboratory of Low-Carbon Conversion Science & Engineering, Shanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai 201210, China; shangli@sari.ac.cn (L.S.)
[2] University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: sunnn@sari.ac.cn (N.S.); weiwei@sari.ac.cn (W.W.)

**Abstract:** Petroleum has become a strategic resource to the national economy, and forecasting its demand is a critical step to supporting energy planning and policy-making for carbon reduction. We first conducted a characteristic analysis of end consumption for petroleum products, and the key affecting factors are identified through an extended logarithmic mean Divisia index (LMDI) method. Afterwards, the long-range energy alternatives planning system (LEAP) was adopted to predict the petroleum products demand by considering the potential impacts of different policies on the identified key factors. Through comparative analysis of three scenarios including five sub-scenarios, the findings show that the dual carbon constraints are crucial to petroleum demand control. Under the enforcement of existing carbon peaking policies, the petroleum products demand will peak around 2043 at 731.5 million tons, and the impact of energy intensity-related policies is more significant than that of activity level. However, even if the existing policy efforts are continued, supporting the carbon-neutral target will not be easy. By further strengthening the constraints, the demand will peak around 2027 at 680 million tons, and the abatement contribution will come mainly from industry (manufacturing), construction, and transportation. Additional abatement technologies are necessary for the petroleum industry to achieve carbon neutrality.

**Keywords:** carbon-neutral; demand forecast; LEAP; LMDI; petroleum products

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## 1. Introduction

COP26 reaffirmed the Paris Agreement goal of keeping global average temperature well below 2 °C above pre-industrial levels and pursuing efforts to keep it below 1.5 °C. To support the achievement of the Paris Agreement, China announced, in September 2020, that it would achieve carbon neutrality by 2060. Petroleum is an important energy carrier for the modern economy. In 2020, China's petroleum consumption accounted for 18.9% of the entire energy nexus [1], and contributed ca. 20% of the national carbon emissions [2]. Decarbonization of the petroleum industry will play an important role in achieving carbon neutrality in China. Meanwhile, the oil demand shocks are highly sensitive to the inefficiency degree of the carbon market based on the EU carbon market experience [3], and the oil market emerged as a significant factor causing substantial changes in emission prices, which has a strong correlation with the rebound of the decarbonization effect in the carbon emission trading scheme [4,5]. Unlike coal or natural gas, oil mainly extends its emissions to the end products, therefore, the forecast of petroleum products demand based on end product consumption can effectively support energy planning and policy-making for carbon reduction.

For the low-carbon transition of the petroleum industry, the relevant state departments and industries are taking active actions. On 26 October 2021, the state council issued "the Action Plan for Carbon Peaking by 2030" (referred to as the Action Plan) [6]. It put forward main objectives including increasing the proportion of non-fossil energy consumption, improving energy utilization efficiency, and reducing carbon dioxide emissions. For example, by 2025, the proportion of non-fossil energy consumption will reach about 20%, energy consumption, and $CO_2$ emissions per unit of GDP will drop by 13.5% and 18% compared to 2020, respectively. These will form a solid foundation for achieving the emission peaking. In terms of the petroleum industry, the Action Plan states that “oil consumption should be controlled in a reasonable range” and “promotes the petrochemical and chemical industry to achieve carbon peaking”. The Ministry of Ecology and Environment, the Ministry of Industry and Information Technology, and the National Development and Reform Commission have successively issued the “Emission Standards for Pollutants in Petroleum Refining Industry” [7], the “Emission Standards for Pollutants in Petrochemical Industry” [8], and other requirements to actively explore the pathways of carbon peaking. Additionally, the Chinese Petroleum and Chemical Industry Federation, together with 17 major enterprises, launched the “Declaration on Carbon Peaking and Carbon Neutrality in China’s Petroleum and Chemical Industry” [9], which advocated promoting a clean and low-carbon energy structure, improving energy efficiency, enhancing the supply of high-end petrochemical products, accelerating the deployment of carbon dioxide capture and utilization, increasing scientific and technological research and development, and significantly increasing the intensity of green and low-carbon investment. Under the dual carbon target, the accelerated “de-oiling” represented by the automobile industry and the rapid development of low-carbon transportation will drive the entire transportation energy supply chain to change, and the traditional oil supply will face huge challenges [10]. The withdrawal of conventional internal combustion engine vehicles (ICEVs) is no longer a theoretical discussion but has entered the stage of substantive action. Table 1 shows the timetable for banning the sale of ICEVs in various countries/regions, and most of the major car companies have also taken the initiative to announce their schedule for discontinuing the production of ICEVs.

**Table 1.** Time Schedule for Prohibiting the Sale of ICEVs in Different Regions/Time Schedule for Stopping the Sale of ICEVs by Different Vehicle Enterprises.

<table>
<tr><th>Time</th><th>Regions</th><th>Time</th><th>Schedule of Vehicle Enterprises</th></tr>
<tr><td>2024</td><td>Rome, Italy</td><td rowspan="4">2025</td><td>Honda plans to increase the proportion of new energy vehicles in the European market to two-thirds by 2025</td></tr>
<tr><td>2025</td><td>Norway, Mexico, Greece Athens, Spain Madrid, France Paris</td><td rowspan="2">BAIC Group proposed that by 2025, its own brands will completely stop selling conventional ICEVs in China</td></tr>
<tr><td>2029</td><td>California, USA</td></tr>
<tr><td>2030</td><td>China Hainan, Netherlands, Britain, India, Israel, Japan Tokyo</td><td>Chang’an Automobile proposes to stop selling conventional ICEVs in 2025</td></tr>
<tr><td>2035</td><td>Canada, Japan, European Union</td><td rowspan="2">2030</td><td rowspan="2">Volkswagen plans to electrify all cars by 2030, and the sales of conventional ICEVs will be completely stopped</td></tr>
<tr><td>2040</td><td>Spain</td></tr>
</table>

As a basic energy carrier, petroleum is an important strategic material related to national economic security. There are several established methods for petroleum related demand forecasting, such as system dynamics, gray system theory, BP neural network, long range energy alternatives planning system (LEAP), multi-objective optimization model, computable general equilibrium (CGE), etc. Sun et al. (2006) used the oil supply and demand dynamics model to forecast oil demand for the period 2005–2020 and proposed solutions to the contradiction between oil supply and demand in China [11]. Xu et al. (2009) developed a grey VAR combination forecasting model and obtained more accurate forecasting results [12]. Shi et al. (2011) developed a time-series-nervous network model to forecast China’s oil demand from 2010 to 2012 by using historical data from 1965 to 2009 [13]. Based on the LEAP model, Chi (2014) predicted the future energy demand and pollutant emissions of passenger transportation in Beijing, which took considerations on the effects of economic growth, energy structure, and industrial structure [14]. Chang (2015) constructed a LEAP-Shanghai model to simulate the energy consumption and carbon emissions trends by designing three comprehensive scenarios, which include industrial structure optimization, terminal energy efficiency improvement, and so on [15]. Jiao (2015) established an oil demand optimization model with $CO_2$ intensity reduction as the main constraint, the model also integrated factors including economic growth, energy structure, industrial structure, etc. [16]. In 2018, the Research Institute of Economics and Technology of China Petroleum & Chemical Corporation conducted a research project on China's oil consumption cap plan and policy research, CGE model was used to provide an outlook on medium- and long-term domestic primary energy demand [17]. Poudyala et al. outlined a long-term outlook on the energy situation by using LEAP model, aiming to show how to exploit the tremendous renewable energy resources in Nepal [18]. Nevertheless, predictions with enhanced accuracy are still needed, and purpose-directed models are thus drawing wide attentions.

Petroleum products are important for energy security and emission reduction, and the motivation for the research is to accurately predict future demand to support energy planning and emission control. Generally, the forecasting of energy demand is carried out by historical data and vital influencing factors, the largest difference among the previous works lay on the used model and the corresponding targets. The LEAP system is a scenario-based integrated energy–economic–environmental modeling platform developed by the Stockholm Environment Institute (SEI). It is a bottom-up tool for accounting energy demand and production, which is extensively used for national-level medium- and long-term energy planning and forecasting [19–22]. During the LEAP modeling process, identification of influencing factors is an endogenous requirement for scenario analysis. To this end, the Logarithmic Mean Divisia Index (LMDI) [23] method provided a mature and target-directed means, which has been widely used to analyze the drivers of energy consumption and carbon emissions [24–27]. Therefore, the combination of LMDI and LEAP offers a promising way for more reliable forecasting of petroleum demand by rational recognition of influencing factors.

Encouraged by the above idea, identifying the pivotal influencing factors and conducting quantitative prediction of future hypothetical scenarios are critical issues for the study. An extended LMDI method was first developed according to the practical feature of the petroleum industry—that is, for the traditional LMDI decomposition procedure, primary energy intensity is generally used, but for the petroleum industry, only the data at the consumption end is observable. The extended LMDI decomposition not only retains the advantages of the traditional model, but also can incorporate the terminal energy consumption structure. Together with the holistic picture of petroleum product characteristics and end consumption sectors in China, key factors could be obtained. Afterwards, the LEAP-Petroleum Products of China model (hereafter referred to as LEAP-PPC) was constructed, and three types of scenarios including five sub-scenarios are designed by considering potential impacts of different policies on these important factors. By comparing and analyzing the future development of end-consumption sectors under different policy constraints, the demand for petroleum products in China was predicted, and several policy recommendations on carbon neural strategies, emission reduction in consumption sectors, and the layout of emission reduction technologies have been proposed. This paper may provide theoretical support for the capacity planning and emission reduction of the petroleum industry in China. In addition, it should be noted that the methodology applies to the situation at the normal level of economic development, while the extreme conditions have not yet been considered.

The rest of this paper Is structured as follows: Section 2 presents the current status of petroleum production and consumption in China; Section 3 describes the used methodology including LEAP-PPC modeling and scenarios setting. The obtained results and related discussion are included in Section 4, and Section 5 concludes the work with the obtained policy implications.

## 2. Characteristics of Petroleum Products in China

According to the China energy statistical yearbook 2021, energy flow of petroleum related products was systematically described in Figure 1. The production of petroleum products is dominated by refining, and the crude oil imported are 2.8 times greater than domestic production. By the end of 2020, China's refining capacity reached 890 million tons/year, which is projected to be controlled within 1 billion tons/year by 2025 according to the Action Plan (Figure 1, left). In 2020, the end consumption of petroleum products in China is 620.85 million tons, the descending order of different petroleum products follows: (1) gasoline, diesel, kerosene, and other transportation fuels; (2) olefin aromatics and other petrochemical raw materials; (3) lube oil, solvent oil, and other waste fuel oil products; and (4) paraffin wax and asphalt and other solid products (Figure 1, middle). In terms of the end consumption sectors (Figure 1, right), transportation and industry dominated for a long time, accounting for about 75% of the overall petroleum products consumption (Figure 2).

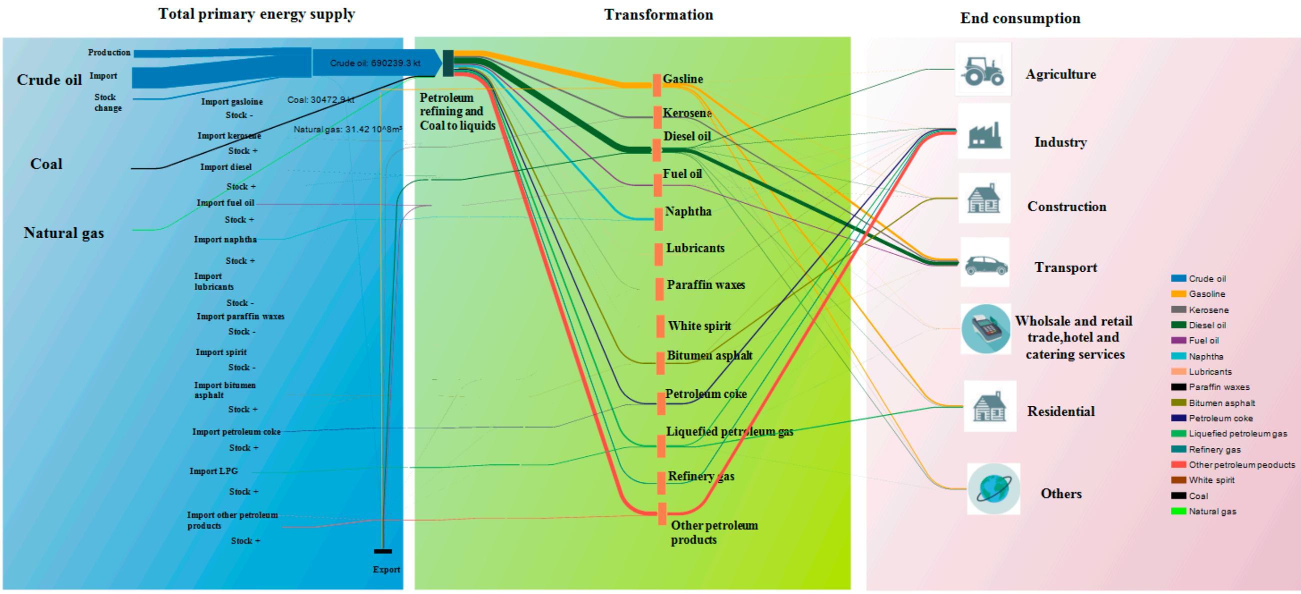


**Figure 1.** Panorama of petroleum production and consumption in 2020. Note: the line thickness represents the amount of quantity.

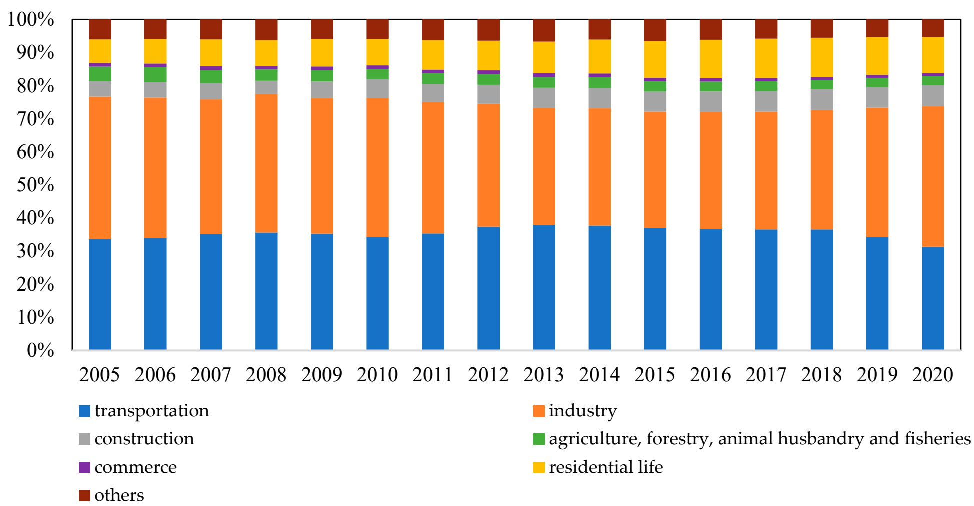


**Figure 2.** End consumption shares of different sectors.

## 3. Modeling Methodology of LEAP-PPC

The LEAP model, a bottom-up energy-modeling tool based on scenario analysis [28], can be used as a database to the comprehensive investigation of the energy system, as a forecasting tool to predict energy supply and demand over the medium to long term, and as a policy analysis tool to integrate the impacts of population, economic development, traffic turnover, technology, prices, and other factors on energy-environment development. In the study, the demand module of LEAP was employed to forecast and analyze the demand for petroleum products in China. Figure 3 shows the components and implementation steps of this work. First, based on the characteristics of historical data, seven core-end consumption sectors of the petroleum industry were identified for sector decomposition of the demand module in LEAP (step ①–②). Then, the factors affecting end consumption are identified through the extended LMDI, based on which different scenarios are set assuming different policy effects on these important factors (step ③–④). Finally, the input data required for the LEAP-demand forecasting model is analyzed and collected, with the relevant data mainly coming from sectoral research reports and national planning documents (step ⑤).

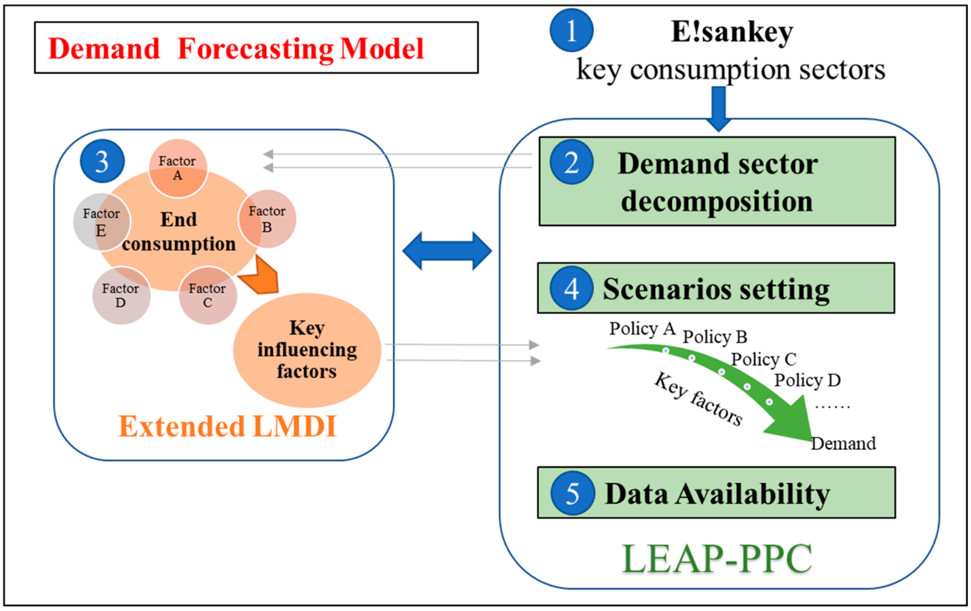


**Figure 3.** Framework of methodology.

### *3.1. Principle of Demand Calculation*

LEAP is an integrated, scenario-based modeling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy, so the calculation structure of LEAP includes the analysis of demand, transformation, and resource. In this paper, the demand forecast modeling for petroleum products is mainly based on the blue bolded in Figure 4. i.e., the demand module of LEAP.

The total terminal petroleum products demand is the sum of each sector, which is obtained by multiplying the sectoral activity level (traffic turnover, industry output, population, etc.) with its corresponding energy intensity as shown in Equation (1):

$$\mathrm{PP} = \sum_{i=1}^{n} \mathrm{PP}_i = \sum_{i=1}^{n} \mathrm{AL}_i \times \mathrm{EI}_i = \sum_{i=1}^{n}\sum_{k=1}^{m} \mathrm{AL}_{ik} \times \mathrm{EI}_{ik} \quad (1)$$

where: $i$—the end-use sector of petroleum products; $n$—total numbers of sectors; PP—petroleum products demand; AL—activity level data; EI—consumption intensity of petroleum; $k$—the petroleum consumption technology of sector $i$ (i.e., different vehicle modes in the transportation sector, urban and rural in residential sector); $m$—total technology numbers of sector $i$.

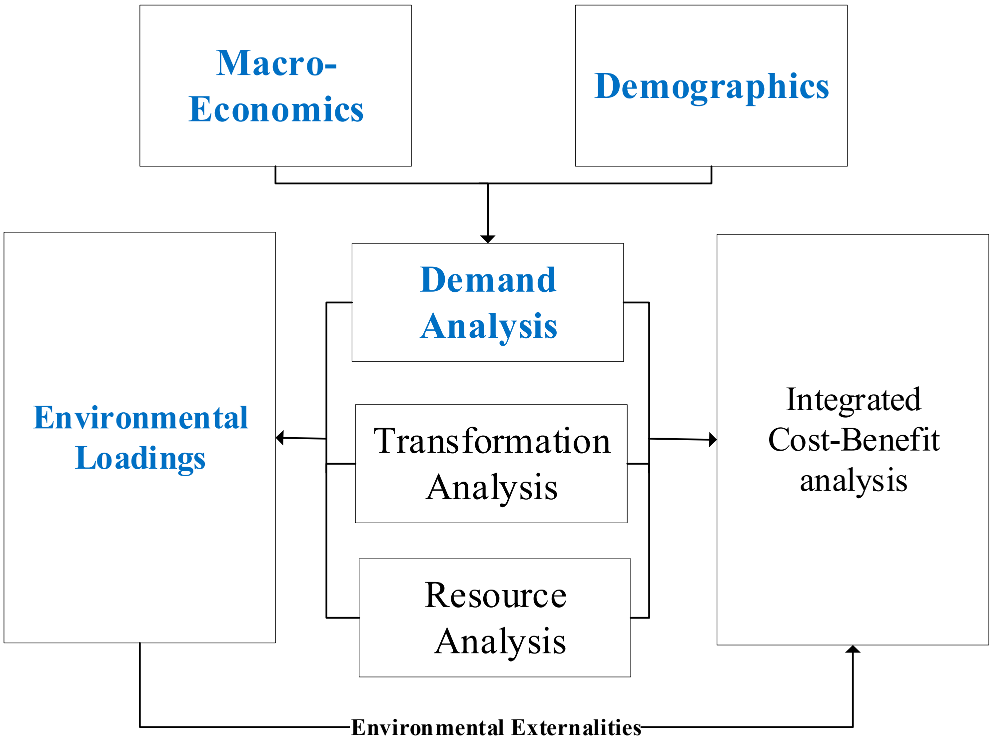


**Figure 4.** The Structure of LEAP's Calculations.

### *3.2. Decomposition of Demand Sectors*

Based on the characteristics of end consumption in Section 2, end-use sectors of petroleum industry were divided into three major categories including transportation, industry, and others (Figure 5). Among them, transportation was further decomposed into passenger transport and freight transport, railway, road, waterways, and aviation were considered for the former, while a pipeline was also involved for the latter. The industry sector was divided into three sectors: mining, manufacturing, and electricity/gas/water supply according to the classification of Energy Statistics Yearbook. Other sectors include residential (urban and rural), construction, agriculture, commerce, and others. Overall, the end-use sector of petroleum products "i" can be broken down into seven sectors: (1) transportation; (2) industry; (3) residential; (4) construction; (5) agriculture; (6) commerce; and (7) others.

According to Equation (1), the calculation of future petroleum products demand is as followed: transportation demand is the product of travel turnover and its corresponding energy intensity, since the travel object is divided into two categories, the oil consumption per passenger-kilometers and per ton-kilometers are calculated separately; except for the residential sector, the total demand of industry and other sectors is the product of the output value and its corresponding energy consumption per GDP; the total petroleum products demand of residential life is the product of the population and the corresponding energy consumption per capita, and urban and rural areas are calculated separately.

### *3.3. Identification of Key Factors by Extended LMDI*

The LMDI decomposition method has unique advantages over other index decomposition models, such as the absence of decomposition residuals, consistency between the summation of subsector effects with the total effect, its ability to decompose and handle data sets containing zero and negative values, etc. [29].

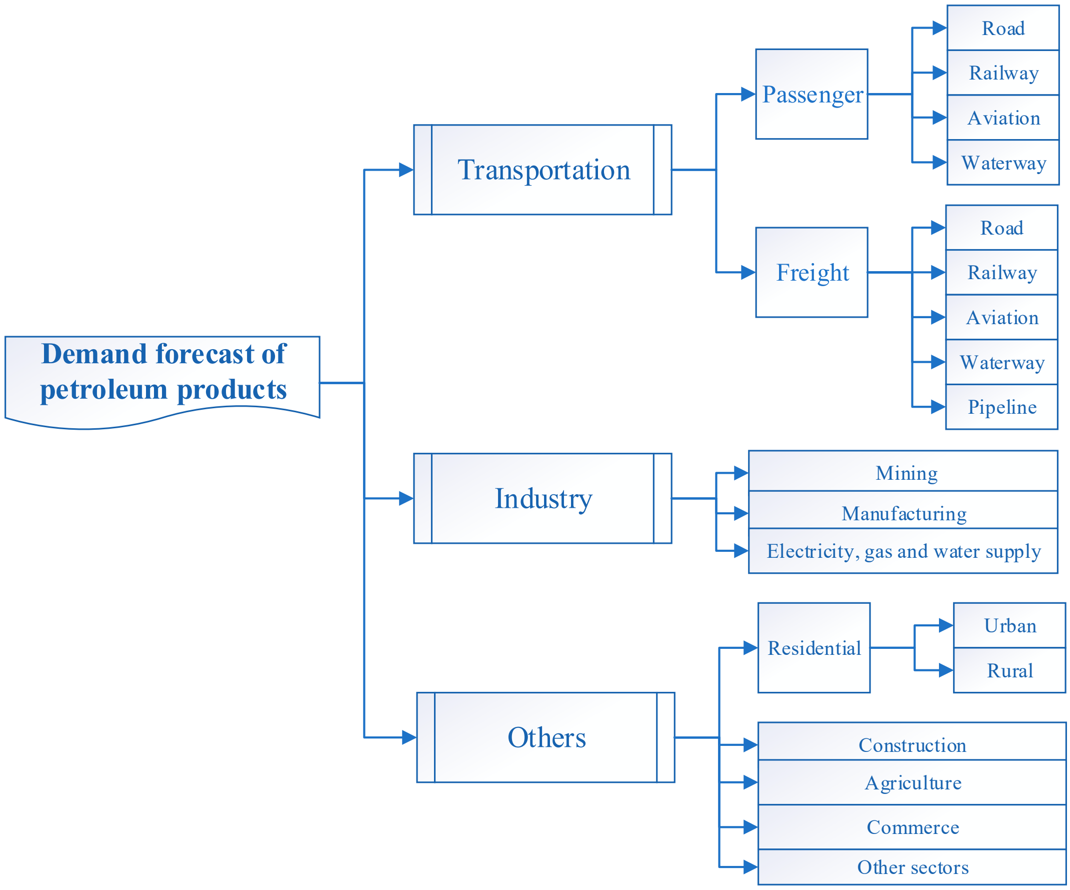


**Figure 5.** The division of sectors for petroleum products demand forecasting.

Traditional LMDI decomposition method to analyze the factors influencing energy consumption can be described by Equation (2) according to reference [23]:

$$E = \sum_i E_i = \sum_i \frac{E_i}{G_i}\frac{G_i}{G}G = \sum_i I_i S_i G. \quad (2)$$

where: $E$ is the total energy consumption, $G$ is the total activity level data of the sector, and Ii ($Ei/Gi$) and $Si$ ($Gi/G$) are the energy intensity and the activity level structure of sector $i$, respectively.

However, the traditional LMDI decomposition is generally applied to the primary energy consumption. For the petroleum products sector, only the end consumption energy is observable in practice. Therefore, this study extends the traditional LMDI decomposition model based on Kaya's constant equation by introducing a total energy conversion efficiency factor to transfer the primary energy structure to terminal consumption [30–33]. To be more specific, the extended LMDI classifies the causes of changes in petroleum end consumption into "economic scale effect—$G$", "industrial structure effect—$S$", "energy intensity effect—$I$", "energy conversion efficiency effect—$e$" and "terminal energy structure effect—$f$". Therefore, the factors influencing end consumption can be analyzed by Equation (3).

$$F_{pp} = \sum_i F_i = \sum_i \frac{F_i}{Qi}\frac{Q_i}{E_i}\frac{E_i}{G_i}\frac{G_i}{G}G = \sum_{\mathrm{i}} f_i \cdot e_i \cdot I_i \cdot S_i \cdot G \quad (3)$$

where "$F$" represents the end demand for petroleum products, "$G$" is the scale effect of economic development expressed by GDP. $S$ is the GDP proportion of different industries. "$I$" is represented by the total primary energy consumed per unit of GDP in China. "$e$" is represented by the ratio of total terminal energy consumption to total primary energy consumption. "$f$" is the ratio of petroleum consumption to the total terminal energy consumption, which can reflect the substitution effect of coal, natural gas, and other new energy sources on oil.

In this study, the LMDI additive decomposition is used and each decomposition follows the series of Equation (4).

$$\begin{aligned}
\Delta F_{tOt} &= F^t - F^0 = \Delta F_G + \Delta + \Delta F_I + \Delta F_e + \Delta F_f \\
\Delta F_G &= \sum_i L(F_i^t, F_i^0) \ln\left(\frac{G_i^T}{G_i^0}\right) \\
\Delta F_S &= \sum_i L(F_i^t, F_i^0) \ln\left(\frac{S_i^T}{S_i^0}\right) \\
\Delta F_I &= \sum_i L(F_i^t, F_i^0) \ln\left(\frac{I_i^T}{I_i^0}\right) \\
\Delta F_e &= \sum_i L(F_i^t, F_i^0) \ln\left(\frac{e_i^T}{e_i^0}\right) \\
\Delta F_f &= \sum_i L(F_i^t, F_i^0) \ln\left(\frac{f_i^T}{f_i^0}\right)
\end{aligned} \quad (4)$$

Based on the petroleum products consumption from 2005–2020, the influencing factors have been identified by the above algorithm and the results are shown in Figure 6. It was found that the economic scale effect-*G* is strongly positively related, while as the energy intensity effect-*I* is strongly negatively related. Other factors, including the industrial structure effect-*S*, the energy conversion efficiency effect *e*, and the terminal energy structure effect-*f*, have relatively small effects.

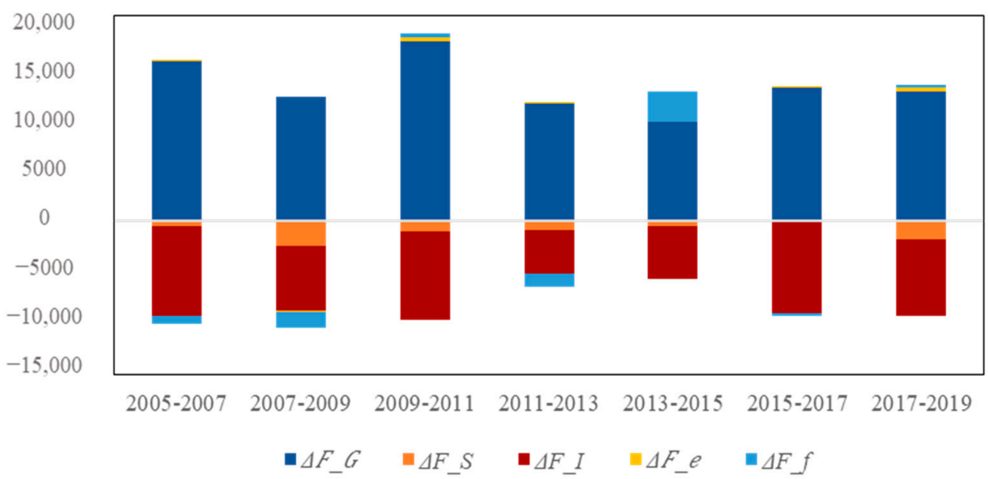


**Figure 6.** The impact of key factors on the consumption of petroleum products.

### 3.4. Scenarios Setting

Based on the identified influencing factors, we further integrate the related policies of existing dual carbon target by reasonably setting the changes of key factors under the influence of different policies and the corresponding future development of the end consumption sectors, three types of policy scenarios have been designed for petroleum products demand forecast in China, namely the baseline scenario, the carbon peaking scenario, and the carbon neutral scenario. In order to distinguish the effects of different policies, three sub-scenarios are included in the carbon peaking scenario: policy of activity level adjustment, policy of energy intensity adjustment, and the integrated policy; the carbon neutral scenario is to further strengthens the constraints based on the integrated policy sub-scenario of carbon peaking. The structure of scenarios and sub-scenarios can be found in Figure 7. See more details in the following of this section and specific parameters of each scenario are listed in Table 2.

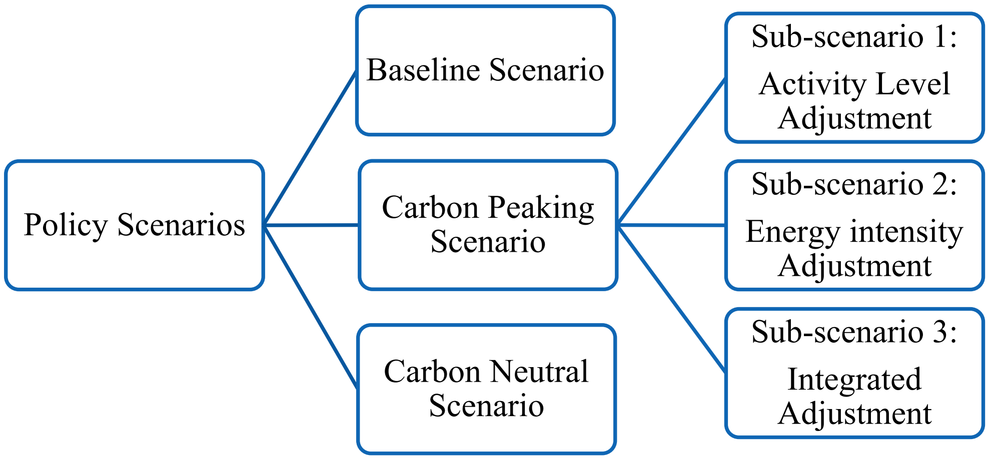


**Figure 7.** The structure of scenarios and sub-scenarios.

#### 3.4.1. Baseline Scenario

The baseline scenario is used as a reference, where the annual GDP growth rate before 2022 follows the actual statistics and stable growth rates of 5.5 and 4.5% were assumed for the periods of 2022–2035 and after 2035, respectively [34–36]. In terms of population, according to the UN medium variant [37], it reaches a peak of 1425.9 million in 2022 and will decrease gradually to 1211 million in 2060. The industrial structure, urbanization rate, traffic structure, and energy consumption intensity are all maintained at the 2020 levels.

#### 3.4.2. The Carbon Peaking Scenario

The carbon peaking scenario, also known as the existing policy scenario, is set according to the "Action Plan", the "Notice on the issuance of the 14th Five-Year Plan comprehensive work for energy saving and emission reduction" [38], as well as the "Implementation Plan for Carbon Peak in Industry" [39]. In order to further analyze the contribution of different policies, three sub-scenarios are set as follows.

Sub-scenario 1: only the activity levels including changes in GDP growth rate, industrial structure, and population structure were adjusted.

Sub-scenario 2: only the energy intensities including changes in energy consumption per unit of output value, energy consumption per unit of mileage, and fuel structure of vehicles were adjusted.

Sub-scenario 3: both the activity level and energy intensity involved in Sub-scenario 1 and 2 were adjusted.

#### 3.4.3. The Carbon Neutral Scenario

Carbon neutral policy scenario is also called a policy enhancement scenario. The dual goals of carbon peak and carbon neutral represent China's short-term and long-term target in tackling climate change, respectively. Currently, the existing policies are mostly oriented towards the goal of carbon peaking, under the carbon-neutral scenario, parameters were considered on a longer time scale, and further strengthen emission reduction through the upgrading of existing policies.

**Table 2.** Connotations of different scenarios.

| Key Factors/Sectors | Baseline Scenario | The Carbon Peaking Policy Scenario (Policy already in Place) | | | The Carbon Neutral Policy Scenario (Policy Enhancement) |
|---|---|---|---|---|---|
| | | **Sub-scenario 1: Activity Level** | **Sub-Scenario 2: Energy Intensity** | **Sub-Scenario 3: Integrated Policy** | |
| | **Petroleum Products-Related Industries all Maintain the Development Level in 2020** | **Policy Effects of GDP and Industrial Structure Optimization** | **Policy Effects of Industrial Energy Intensity Reduction** | **Combined Effects of "Activity Level + Energy Intensity" Policy** | **Further Tightening and Upgrading of Existing Carbon Peaking Policies.** |
| Economy | GDP growth rate is maintained at 2.3% in 2020, 8.4% in 2021, and 3% in 2022. | | | | |
| | Annual growth rate of GDP: 5.5% in 2022–2035 and 4.5% after 2035. The industrial structure is maintained at the 2020 level. | Annual growth rate of GDP: 5% in 2022–2035 and 4% after 2035. Industrial structure optimization: by 2035, the tertiary sector will account for 60%. | Same as the Baseline scenario | Same as the Sub-scenario 1 | Annual growth rate of GDP: 5% in 2025–2035, slowing down to 4% after 2035 Continuous optimization of industrial structure, with the tertiary sector accounting for 60% in 2035 and 75% in 2050. |
| Population | According to the UN medium variant: a peak of 1425.9 million in 2022, 1416.8 million in 2030, and 1211.0 million in 2060. | | | | According to the UN low variant: it reaches a peak of 1425.9 million in 2022 and 1396.2 million in 2030, and 1080.6 million in 2060. |
| | By the end of 2020, the urbanization rate is 63.89% | According to the National New Urbanization Plan (2014–2020), it is expected to reach 66% in 2030, enter a period of stable urbanization development after 2040, and have an urbanization rate of 75% in 2050 | | | |
| Transportation sector | The transport demand continues to grow. In 2060, passenger turnover will be 8,503,924 million passenger-kilometers; the freight turnover will be 514,902 billion-ton kilometers. | | | | |
| | Traffic structure and energy intensity are maintained at the 2020 level. The passenger turnover is 1925.15 billion passenger-kilometers at the end of 2020, of which railways, roads, waterways, and aviation account for 42.94%, 24.11%, 0.17%, and 32.78%, respectively. The freight turnover is 20,221.1 billion ton-kilometers at the end of 2020, of which railways, roads, waterways, aviation, and pipeline account for 15.09%, 29.76%, 52.34%, 0.12%, and 2.7%, respectively. | Comprehensively promote green and low-carbon transformation, and deeply promote the restructuring of transportation. Gradually build a medium- and long-distance freight transport system, and the proportion of railways and waterways will increase significantly. Energy intensity is maintained at 2020 level. | Optimize the energy structure of vehicles. Railways: full electrification in 2035. Roads: vigorously promote the transformation of motor vehicle fuels from oil to electricity, with the new energy vehicle ratio to be 40% in 2030. Waterways: increase the application of new energy-saving technologies and optimize the energy efficiency of ships. Aviation: biofuels will account for 2% in 2025 and 63% in 2050. The traffic structure is maintained at the 2020 level. | Optimize the traffic structure and energy structure of vehicles. The specific parameters are the same as in Sub-scenario 1 and Sub-scenario 2. | Further deep optimization of traffic structure and non-fossil fuel substitution of vehicles. Especially after 2030, the policy is further strengthened and the intensity of energy consumption improvement in transportation is higher than that in other sectors. The energy consumption intensity will decrease by 15% in 2025, 30% in 2030, and further increase in 2040 when the sale of fossil fuel cars is completely banned. |

**Table 2.** *Cont.*

| Key Factors/Sectors | Baseline Scenario | The Carbon Peaking Policy Scenario (Policy already in Place) | | | The Carbon Neutral Policy Scenario (Policy Enhancement) |
|---|---|---|---|---|---|
| | | Sub-scenario 1: Activity Level | Sub-Scenario 2: Energy Intensity | Sub-Scenario 3: Integrated Policy | |
| | **Petroleum Products-Related Industries all Maintain the Development Level in 2020** | **Policy Effects of GDP and Industrial Structure Optimization** | **Policy Effects of Industrial Energy Intensity Reduction** | **Combined Effects of "Activity Level + Energy Intensity" Policy** | **Further Tightening and Upgrading of Existing Carbon Peaking Policies.** |
| Industrial Sector | The industrial structure (30.8% of GDP) and energy intensity are maintained at 2020 levels. | Continuous optimization of industrial structure, with the goal of basic modernization in 2035, and the tertiary sector will reach the benchmark level of developed countries, i.e., 60%. Energy consumption intensity is maintained at the 2020 level. | The efficiency of energy and resource utilization will be significantly improved, by 2025, the energy consumption per GDP of industry above the scale will drop by 13.5% compared to 2020. During the "15th Five-Year Plan" period, the carbon-neutral capacity will be strengthened on the basis of achieving the carbon peak in the industrial sectors. The industrial structure is maintained at the 2020 level. | Continuous optimization of industrial structure. Energy intensity decreases by 13.5% by 2025, and maintains the decline rate after 2025. The specific parameters are the same as in Sub-scenario 1 and Sub-scenario 2. | Further optimization of the industrial structure, with the share of tertiary sector reaching the average level of developed countries, i.e., 75%, by 2050. The energy intensity of the industrial sector further decreases on the basis of the carbon peaking policy. In particular, the manufacturing has a higher reduction in energy intensity than other industries. |
| Other sectors (residential, construction, agricultural, commercial, and other consumer sectors) | Population/industry structure and energy intensity are maintained at 2020 levels | Optimize industrial structure. Energy intensity is maintained at the 2020 level | With a 13.5% reduction in energy intensity by 2025, and maintain the decline rate after 2025. | Optimize industrial structure and energy intensity. The specific parameters are the same as in Sub-scenario 1 and Sub-scenario 2. | With the gradual improvement of the new power system and the continuous progress of technology, the energy consumption intensity of other sectors will be optimized, of which construction will decrease more strongly than other sectors. |

### 3.5. Data Availability

In this study, the petroleum demand and fuel structure of each sector in 2020 are obtained from the energy statistical yearbook 2021 [2], the socioeconomic and population data are obtained from China statistical yearbook 2021 [40]. Industrial structure and urbanization rate are obtained from sectoral research reports and relevant development plans.

For demand forecast: activity level data—"GDP": due to the impact of the epidemic, the annual GDP growth rate is set to 2.3%, 8.4%, and 3.0% for 2020, 2021, and 2022 according to literatures [1,41,42]. China's economy has entered the "new normal" stage, and the future economic development will be stabilized with an appropriate slowdown in growth rate. Through emphasizing the deepening reform and structural adjustment, we can finally achieve progress with stability in economic development. Activity level data—"Population": the UN population projections data was directly adopted. Activity level data—"Industrial structure": the 19th National Congress report has made clear strategic arrangements for the long-term development [43]. This strategic plan is the basic guidance for studying the long-term trend of China's industrial structure. In general, the 13th Five-Year Plan period is the initial period for China's industrial restructuring and upgrading, the 2020–2035 period may be the accelerated period, and the 2035–2050 period will be the relatively stable period. According to "the Outline of the 14th Five-Year Plan for National Economic and Social Development and the Vision 2035" [44], China will basically realize modernization in 2035, and the industrial structure will continue to be optimized, and the tertiary industry will account for 60% of GDP. Activity level data—"Urbanization rate": at the end of 2020, the urbanization rate is 63.89%, which is still in the rapid development range of urbanization (30%–70%), and according to the National New Urbanization Plan (2014–2020) [45], it is expected to reach 66% in 2030, and enter a stable development period of urbanization after 2040, the urbanization rate will be 75% in 2050. Activity level data—"Traffic turnover": according to the development of traffic turnover in 2005–2020, the turnover of each transportation sub-sector has been estimated by using the trend extrapolation method. In 2060, China's passenger turnover will be 850,324 million person-kilometers and the freight turnover will be 514,902 million ton-kilometers. See Figure 8 for details.

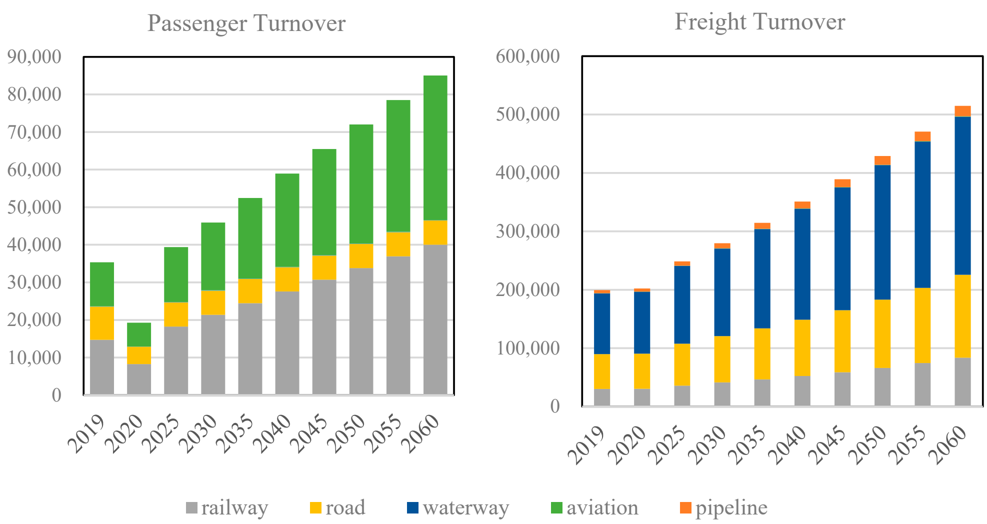


**Figure 8.** Forecast of passenger and freight turnover.

Energy intensity of petroleum products: the sectoral energy intensity data for 2020 is calculated based on the actual petroleum consumption data in Energy Statistics Yearbook, as well as the traffic turnover, production value, and population of each sector in the Statistical Yearbook. The change rate of influencing factors is set according to the "14th Five-Year Plan", the "Implementation Plan for Carbon Peaking in the Industrial Sector", and other related policies.

Based on the content above, Table 2 systematically describes the specific content and parameter settings of each scenario.

## 4. Results and Discussions

### 4.1. Baseline Scenario

Without the constraints of the dual carbon policy, the demand for petroleum products will keep rising in the future. As shown in Figure 9, the total petroleum products demand will reach 3212 million tons in 2060, which is about five times as much as that in 2020. The main driving sectors are industry and transportation, with aviation fuel, diesel, and naphtha as the major petroleum products.

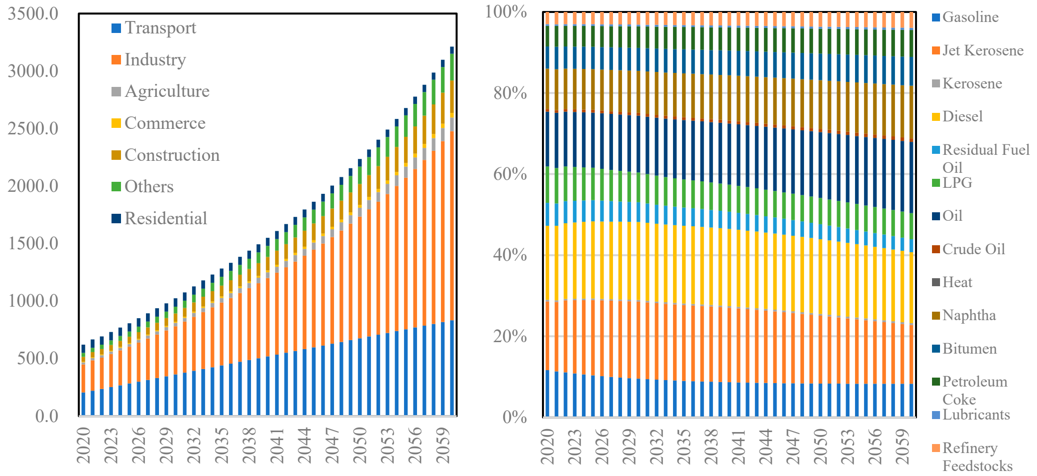


**Figure 9.** Petroleum products demand by sector (**left**) and fuel type (**right**) in the baseline scenario.

### 4.2. Policy Impacts of Activity Level Adjustment on Petroleum Products Demand

China's economy is projected to develop in a high-quality manner, and the growth rate is no longer considered the first priority. As a result, the optimization of industrial structure will become the focus in the future. Through the implementation of the activity level adjustment policy, mainly including policies affecting GDP, industrial structure, and population structure. Figure 10 shows a decline in overall petroleum product ddemands relative to the baseline scenario. In 2060, the petroleum products demand will be approximately 2197 million tons, a 31.6% decline from the baseline scenario. In other words, policies for economic stabilization and industrial structure optimization can substantially control future demand on petroleum products.

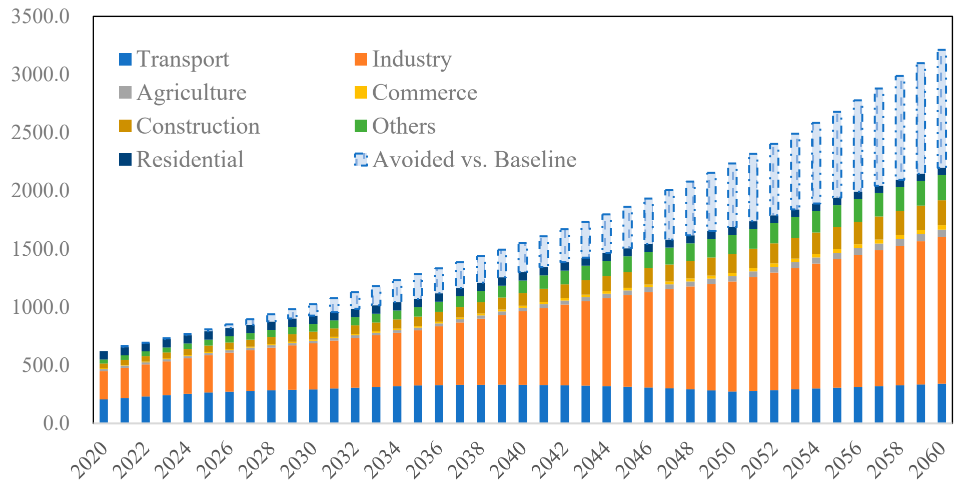


**Figure 10.** Petroleum products demand under sub-scenario 1 and the changes relative to baseline.

### 4.3. Policy Impact of Energy Intensity Adjustment on Petroleum Products Demand

Another crucial factor affecting petroleum products consumption is energy intensity. According to the "Implementation Plan for Carbon Peak in Industry", positive progress will be made to optimize energy structure, and the energy utilization efficiency will be significantly improved during the "14th Five-Year Plan" period. By 2025, energy consumption per unit of GDP will drop by 13.5% compared to 2020, and the foundation of carbon peaking in industry will be firmly established. Affected by this policy, Figure 11 shows that petroleum products demand in 2060 is 1007 million tons, which is about 1.6 times that of 2020 but 69 and 54% lower than the baseline scenario and sub-scenario 1, respectively. Clearly, the energy intensity adjustment contributes more significantly to the decline in future demand than the activity level adjustment in sub-scenario 1.

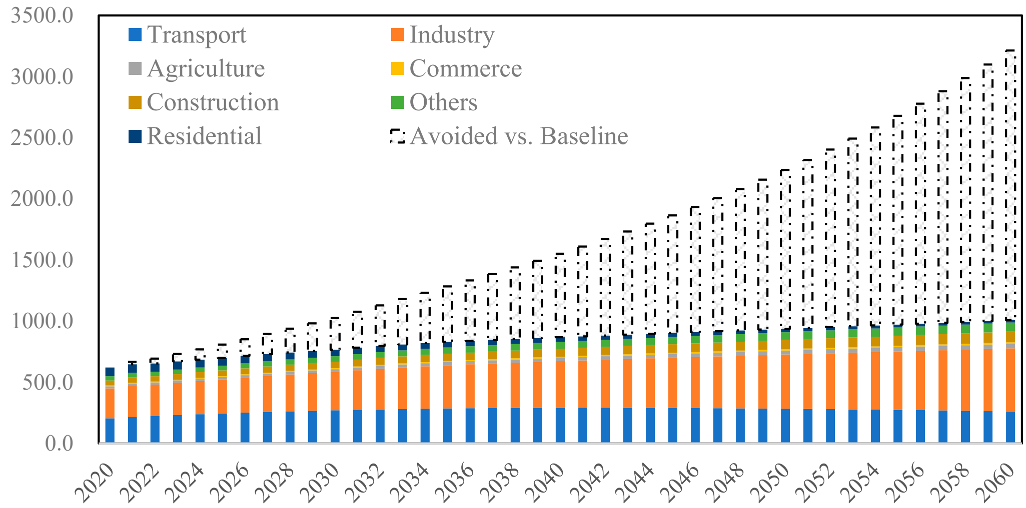


**Figure 11.** Petroleum products demand under sub-scenario 2 and the changes relative to baseline.

### 4.4. Impacts of the Carbon Peaking Policy on Petroleum Products Demand

With all of the existing policies in place, both the activity level and energy intensity can be lowered, and the overall petroleum products demand will experience a slow growth to peak and slowly decline afterwards (Figure 12). The future demand will peak around 2043 at 731.5 million tons, and the demand in 2060 is 688.8 million tons, which is very close to the demand in 2020. Compared to the baseline scenario, the petroleum products will decline by 78.6%, of which, change in the activity level and energy intensity will contribute 40.2 and 59.8%, respectively. Therefore, through the implementation of the carbon peak policy, the petroleum products demand in the future will be avoided significantly compared to the baseline scenario. However, under the existing policy constraints, the amount of petroleum consumed in 2060 will still emit about 2 billion tons of $CO_2$ according to the IPCC emission factor database. According to the Annual Report of China Carbon Dioxide Capture, Utilization and Storage (CCUS) (2021) by Chinese Academy of Environmental Planning, in terms of the carbon neutrality target, the amount of emission reduction that needs to be achieved by CCUS technology in 2060 is 1 to 1.8 billion tons of $CO_2$ based on the current technology development projection. That is to say, if the existing policy efforts are continued, the corresponding emission amount is huge which will pose a huge challenge to achieving the goal of carbon neutrality.

### 4.5. Impacts of Carbon Neutral Policy on Petroleum Products Demand

The carbon neutral scenario further strengthens the existing constraints, and it is found that future petroleum products demand will peak around 2027, which is 16 years earlier than that in the carbon peaking scenario. Meanwhile, the peak will be limited to 680 million tons, and petroleum products demand in 2060 will be 300.9 million tons, which is 56% lower than the existing carbon peaking policy scenario. Besides, the overall trend in petroleum products demand forecasts is consistent with the IEA's results [46]. An integrated comparison of petroleum demand for the five scenarios is shown in Figure 13.

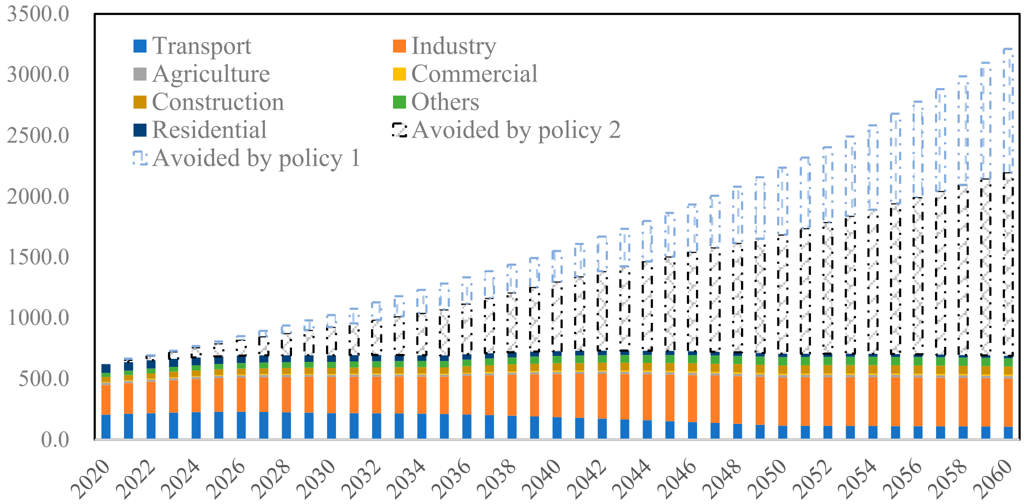


**Figure 12.** Demand under carbon peaking policies and differences relative to sub-scenarios 1 and 2.

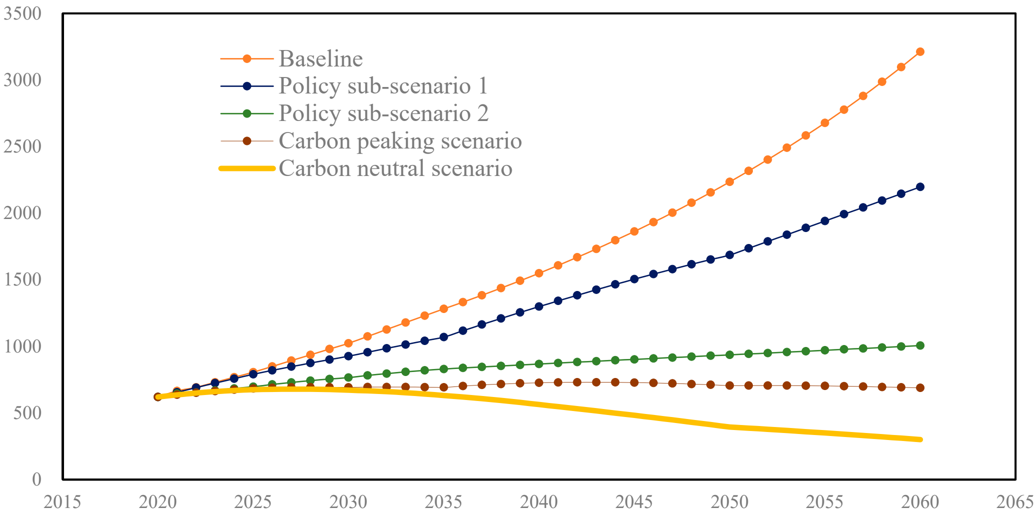


**Figure 13.** Comparison of petroleum products demand under different scenarios.

In order to further clarify the differences between the carbon neutral scenario and the carbon peaking scenarios, a sectoral decomposition of the reduced demand has been carried out, and the results are shown in Figure 14. By quantifying the contribution of each sector, it was found that the contribution of demand reductions before 2035 comes mainly from transportation and industry, and, after 2035, industry (manufacturing), construction, and transportation will become the main contributor.

Under the effects of carbon neutral policy, the corresponding $CO_2$ emissions of petroleum products in 2060 will be 911.8 million tons. Figure 15 shows the share of emissions in each sector. In general, with the upgrading of the carbon peak policy, the proportion of renewable energy and the level of electrification will be further improved in the future, $CO_2$ emission of the petroleum sector will greatly decrease. However, there are still some unavoidable emissions, and additional abatement technologies, such as carbon capture and storage, are indeed necessary for the petroleum industry to achieve carbon neutral.

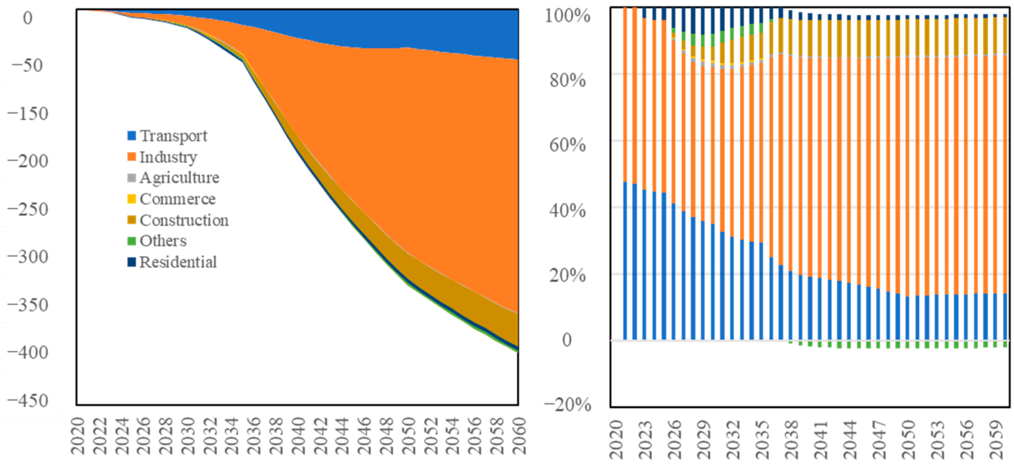


**Figure 14.** Sector contributions of the demand change between carbon neutral and carbon peaking policies.

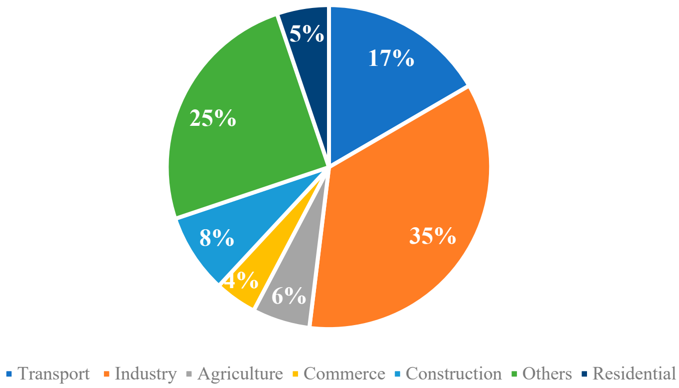


**Figure 15.** Emission share in each sector.

## 5. Conclusions, Policy Recommendations, and Future Work

Based on the characteristic analysis and identification of key factors for the end consumption of petroleum products in China, a LEAP-PPC model is constructed by setting a baseline scenario, an existing carbon peaking scenario, and a carbon neutral scenario with strengthened policy constraints. Through the comparison, it can be concluded that the future petroleum products demand will increase rapidly if no policy constraints on carbon reduction are adopted. By adding policies affecting activity levels and energy intensity, respectively, the future demand for petroleum products will decrease, and the contribution of the latter is more significant compared to the former. If all the existing carbon peaking policies can be implemented, the demand for petroleum products will peak around 2043 with a peak of 731.5 million tons. However, the demand is still very high (688.8 million tons) in 2060, producing ca. 2 billion tons of $CO_2$ emission. By further strengthening the policy constraint (carbon neutral scenario), the demand for petroleum products will peak at 680 million tons around 2027 and drop to 300.9 million tons in 2060, and the related $CO_2$ emission will decrease correspondingly to 911.8 million tons. The emission reduction contribution will come mainly from the transportation and industry sectors until 2035, and from industry (manufacturing), construction, and transportation after 2035.

The following policy recommendations and future work can be obtained: (1) active implementation of the dual carbon policy is necessary to control petroleum products demand, and the impact of energy intensity-related policies is more significant compared to activity level adjustment policies. (2) If the policy efforts of low-carbon transition during the 14th Five-Year Plan are continued (e.g., 13.5% reduction in energy intensity every five years), the amount of petroleum consumed in 2060 will still emit about 2 billion tons of $CO_2$, which will be difficult to support the goal of carbon neutrality in 2060. Thus, the formulation speed and enforcement intensity of carbon-neutral-related policies need to be further increased on the basis of peak policies. (3) Based on the parameter design of the carbon neutral scenario and the comparison of its results with the carbon peaking scenario, the energy intensity controls on the industry and construction sectors need to be more stringent than in other industries, and policy enforcement related to technology improvements (e.g., introduction of low-carbon technologies) and energy efficiency (e.g., development of new power systems) should be prioritized. As to transportation, it is necessary to further increase the adjustment of traffic structure and energy structure, vigorously promote the "oil for electricity", and reduce the proportion of conventional ICEVs. (4) Petroleum is unlikely to be removed from the energy infrastructure completely, therefore technologies such as carbon capture and storage will be needed to offset related $CO_2$ emissions for the petroleum industry to achieve carbon neutral.

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## Abbreviations

| | |
|---|---|
| LMDI | Logarithmic Mean Divisia Index |
| LEAP | A Long-range Energy Alternatives Planning system |
| LEAP-PPC | The LEAP-Petroleum Products of China model |
| ICEVs | Conventional internal combustion engine vehicles |
| PP | Petroleum Products |
| AL | Activity level data |
| EI | Energy consumption intensity |

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