**Mexico, towards the energy transition? The chances of success of Mexico's current energy policy**

## Introduction

The need to mitigate the impacts of climate change calls for energy alternatives based on clean energies that facilitate the energy transition. In Mexico, the new government shares this vision and considers it urgent to achieve the national energy transition within the framework of the Energy and Climate Change Program, one of the Strategic National Programs that are part of the government's developmental strategy[1].

To achieve this objective, it is necessary to consider that on the one hand, the national energy demand has increased significantly during the decade of the 2000s and is mainly satisfied with hydrocarbons, generating a dependence on fossil fuels that is significantly higher than that of the world, with 85% and 55% respectively (BP, 2022: 9); and on the other hand, that the Mexican State historically controls and exploits a sector of a clear strategic nature that is key to national macroeconomic stability in terms of exchange rate and public budget, which represents a long-term opportunity to promote the change towards a national energy transition (IEA, 2020).

Therefore, this paper presents a preview of the analysis of the current national energy policy with the objective of understanding and assessing the possibilities of achieving this energy transition process and its impact on the energy sector and the national economy. This exercise is carried out with a multifactor input-output methodology, which will allow us to build scenarios and to systematically understand with precision and depth the impact of these policies, and to identify opportunities for improvement and success of the implemented policies.

## 2. Changes in the new national energy policy (2018-Present)

Historically, the type and characteristics of energy policy were designed according to the State-market dichotomy within the framework of national development strategies of economies on a global scale. Thus, during the 1940s, the State played a leading role with a strong control of the energy sector and the creation of public companies among other mechanisms of action, while in the 1970s it was the market that acquired a greater role in the sector, prioritizing the opening and liberalization of the energy sector in these economies. For example, in the Latin American context, refining monopolies were abolished, the oil products market was deregulated and public oil companies were restructured and privatized in countries such as Argentina, Bolivia, and Peru (Goldthau, 2012; De la Vega, 1999).

[1] The government approved ten Strategic National Programs (PRONACES) aimed at solving major national problems through the solution of proposals. The selected themes were: health, water, education, human security, toxic agents and polluting processes, food sovereignty, energy and climate change, socio-ecological systems, housing, and culture.

Once again, during the 2000s, a stage characterized by a renewed protagonism and control of hydrocarbon resources by the State emerges within the framework of the resurgence of nationalist tendencies in economies such as Russia, Venezuela, Bolivia or Kazakhstan due to, among other reasons, the volatility of hydrocarbon prices or the insufficient results of the neoliberal policies applied in countries such as Argentina, Venezuela, and Bolivia during the 1980s (Guzmán et al., 2006:27).

This return of the State to the sector was followed from 2013 onwards and probably as a consequence of the fall in crude oil prices, a stage of return of the market expressed in the announcement of the opening of the sector and of some public companies to private investment in countries such as Nigeria, Iran, Russia or Egypt (EY, 2017:5-6).

Precisely Mexico opened its energy sector with the approval of the energy reform formally in 2013, but as of 2018, there was a change of government with a substantially different proposal to the one that had been applied for almost forty years in the country. Indeed, while decades ago the energy policy was characterized by the progressive opening of the energy sector to private capital in different phases; the dependence on hydrocarbons, and the export orientation of the sector, with the entry into the government of Andrés Manuel López Obrador (2018-act.) the national energy policy was oriented towards self-sufficiency and national energy security through the rescue of the public sector composed of two large companies of the sector Petróleos Mexicanos (Pemex) and the Federal Electricity Commission (CFE).

The government's commitment to rescue the energy sector has been endorsed through different publications or government declarations where the need to guarantee the development of the national energy sector in terms of hydrocarbon production and reserves and to increase the degree of industrialization of the resource in terms of gasoline production and petrochemical products has been made clear. For example, of the Commitments[2] made by the government when it came to power, those related to energy proclaimed the need to urgently produce oil, gas, and electric energy and the promotion and development of alternative renewable energy sources, such as wind, solar, geothermal and tidal energy.

## 3. Methodology

This paper aims to analyze the current national energy policy with the objective of understanding and assessing the possibilities of achieving this energy transition process and its impact on the energy sector and the national economy. Specifically, we analyze the impact that the local content policy; domestic production to satisfy domestic demand; and the evolution of final energy demand would have on the national economy.

[2] The government enunciated in 2018, 100 Commitments to be fulfilled in its legislature. https://www.gob.mx/cms/uploads/attachment/file/580709/100_compromisos_1_de_septiembre_2020.pdf

This exercise is carried out with an input-output methodology, which is useful for understanding past and present interactions between the economy and the environment. Thus, this method has a simple representation of the economic structure and therefore provides a framework for modeling the relationships between energy use and economic activities.

Our input-output model will have a multifactorial character. Thus, based on Guevara and Domingos (2017) we consider it necessary to apply a new multifactor energy input-output model (MF-EIO model), which is obtained from the partitioning of a hybrid unit input-output system of the economy. This model improves the current models by describing energy flows according to energy conversion processes and energy use levels in the economy. Among the main advantages of this model we can highlight:

- Energy (in physical units) and non-energy (in monetary units) production processes in the economy are accounted for separately. In addition, energy flows are organized according to the processes of energy use and conversion.

- The primary and secondary levels of energy use are represented, which improves the understanding of the mechanisms of energy use in the economy. In this sense, the model complies with the principle of conservation of embodied energy, which is not always true for the DIC-EIO model.

- The model is able to isolate two energy efficiency indicators and account for them separately. The $\boldsymbol{L}E$ and $\boldsymbol{T}E$ factors give a primary-to-secondary idea of conversion efficiencies and direct energy use efficiency, respectively.

- The model allows the evaluation of energy use, energy decoupling and efficiency trends in the economy in combination with structural decomposition analysis (Guevara and Rodrigues, 2016).

- The approximate MF-EIO model, allows the use of the available monetary input-output data ($\boldsymbol{L}\psi$ and $\boldsymbol{L}\pi$) without the need to build a hybrid unit input-output system; and The level of detail in the energy sector can be further improved in the approximate MF-EIO model by coupling a more detailed input-output model of the energy sector, under the product by industry approach, to the sub-model of the rest of the economy in the as done by Guevara and Rodrigues (2016). It is possible to do the same for the exact H-EIO and MF-EIO models, albeit with more complexity in data processing (e.g., estimation of non-energy monetary inputs for each energy technology that are not accounted for in the economic input-output data).

- However, the model cannot address the following problems, also present in conventional EIO models: as in the basic input-output model - see Leontief (1955), Miller and Blair (2009). EIO models assume: constant returns to scale; fixed technical coefficients; no substitutability between inputs to production processes; resources supply is infinite and perfectly elastic; and resources are used efficiently;

Under that modeling framework we build scenarios to understand the possible structural changes in the Mexican economy and in the oil and gas sector caused by the national energy policy. These scenarios are constructed by simulating changes in inter-industry transactions introduced directly and will allow us to relate environmental performance to the Mexican economy (gross value added, employment and energy-related CO2 emissions), and to compare the effectiveness of policies and identify the most economically, socially and environmentally successful ones.

Economic data were collected from official national and international sources. Specifically, SAM tables (Social Accounting Matrices) were taken from the Mexican National Institute of Statistics and Geography (INEGI) and the Organization for Economic Cooperation and Development (OECD); and national energy from the National Energy Balances.

Next, we present the mathematical foundations of the multifactor input-output model based on Guevara and Domingos (2017) and Guevara et al (2022). The model will allow us among other aspects to identify the energy needs and energy-related CO2 emissions of the economy.

The approximate MFEIO model is built by coupling two input-output sub-models:

a) an energy submodel in physical units
b) a non-energy submodel in monetary units.

The energy submodel starts from the basic input-output relationship of energy flows, i.e., $\boldsymbol{g} = \boldsymbol{B}\boldsymbol{i} + \boldsymbol{h}$, in terms partitioned as:

$$\boldsymbol{g} = [\boldsymbol{B}_\theta \quad \boldsymbol{B}_\tau]\boldsymbol{i} + \boldsymbol{h}$$

where g is the vector (length m_T) of total energy use, B¬_θ of size m_E×m_E and B-_τ of size m_E×m_I are the submatrices of energy flows from m_I energy industries to direct energy demand by m_I non-energy industries in physical units, and the vector h of length m_E represents energy deliveries to final demand.

where $\boldsymbol{g}$ is the vector (length $m_T$) of total energy use, $\boldsymbol{B}_\theta$ of size $m_E \times m_E$ and $\boldsymbol{B}_\tau$ of size $m_E \times m_I$ re the submatrices of energy flows from $m_I$ i energy industries to direct energy demand by $m_I$ non-energy industries in physical units, and the vector, and the vector $\boldsymbol{h}$ of length $m_E$ represents energy deliveries to final demand.

It is assumed that the amount of energy inputs of an energy industry varies proportionally to its total output, which would imply constant coefficients of a technical matrix $\boldsymbol{A}^E$ that solves $\boldsymbol{B}_\theta = \boldsymbol{A}^E \widehat{\boldsymbol{g}}$.

Including this assumption in Equation g=[■(B_θ&B_τ )]i+h and solving g leads to g=E(h+B_τ i), where the matrix E=(I-A^E )^(-1) of size m_E×m_E is the total energy matrix energy sector needs. Furthermore, B_τ can be decomposed as Cr^S, where C and r^S are the demand composition matrix and the aggregate vector of direct energy demand. Therefore, the energy submodel is represented as:

Including this assumption in Equation $\boldsymbol{g} = [\boldsymbol{B}_\theta \quad \boldsymbol{B}_\tau]\boldsymbol{i} + \boldsymbol{h}$ and solving $\boldsymbol{g}$ leads to $\boldsymbol{g} = \boldsymbol{E}(\boldsymbol{h} + \boldsymbol{B}_\tau \boldsymbol{i})$, where the matrix $\boldsymbol{E} = (\boldsymbol{I} - \boldsymbol{A}^E)^{-1}$ of size $m_E \times m_E$ is the total energy matrix energy sector needs. Furthermore, $\boldsymbol{B}_\tau$ can be decomposed as $\boldsymbol{C}\boldsymbol{r}^S$, where $\boldsymbol{C}$ and $\boldsymbol{r}^S$ are the demand composition matrix and the aggregate vector of direct energy demand. Therefore, the energy submodel is represented as:

$$\boldsymbol{g} = \boldsymbol{E}\,\boldsymbol{h} + \boldsymbol{E}\,\boldsymbol{C}\,\boldsymbol{r}^{S}$$

On the other hand, the non-energy submodel starts from the basic input-output model in monetary units ($\boldsymbol{x} = \boldsymbol{L}\boldsymbol{f}$) in terms partitioned as follows

$$\boldsymbol{x} = \begin{bmatrix} \boldsymbol{x}^e \\ \boldsymbol{x}^n \end{bmatrix} = \underbrace{\begin{bmatrix} \boldsymbol{\theta} & \boldsymbol{\tau} \\ \boldsymbol{\pi} & \boldsymbol{\psi} \end{bmatrix}}_{\boldsymbol{L}} \begin{bmatrix} \boldsymbol{e} \\ \boldsymbol{n} \end{bmatrix}$$

where

$\boldsymbol{x}^e$ y $\boldsymbol{x}^n$ Subvectors of total production of energy industries in monetary units (length $\mathrm{m_E}$) and total production of non-energy industries (length $m_I$).

$\boldsymbol{L}$ Total requirements matrix (size 〈m_E+m_I〉 × 〈m_E+m_I〉 ).

$\boldsymbol{\theta}$, $\boldsymbol{\tau}$, $\boldsymbol{\pi}$ and $\boldsymbol{\psi}$ Submatrices of: total energy requirements of energy industries; total energy needs of non-energy industries; total non-energy needs of energy industries; and total non-energy needs of non-energy industries.

$\boldsymbol{e}$ and $\boldsymbol{n}$ Subvectors of final energy and non-energy demand (lengths $m_E$ and $m_I$)

The submodel of the rest of the economy is obtained by substituting for final energy demand in monetary units ($\boldsymbol{e}$) is replaced by $\widehat{\boldsymbol{b}}\boldsymbol{h}$, where $\boldsymbol{b}$ is the vector of average energy prices (length $m_E$); and isolating total output of non-energy industries ($\boldsymbol{x}^{n)}$) from Equation

$\boldsymbol{x} = \begin{bmatrix} \boldsymbol{x}^e \\ \boldsymbol{x}^n \end{bmatrix} = \underbrace{\begin{bmatrix} \boldsymbol{\theta} & \boldsymbol{\tau} \\ \boldsymbol{\pi} & \boldsymbol{\psi} \end{bmatrix}}_{\boldsymbol{L}} \begin{bmatrix} \boldsymbol{e} \\ \boldsymbol{n} \end{bmatrix}$ Then,

$$\boldsymbol{x}_n = \boldsymbol{\pi}\,\widehat{\boldsymbol{b}}\,\boldsymbol{h} + \boldsymbol{\psi}\,\boldsymbol{n}$$

These submodels are coupled through the direct energy intensity of non-energy industries. ($\boldsymbol{T}^S$), which is defined as the direct energy consumption per unit of economic output ($\boldsymbol{T}^S = \widehat{\boldsymbol{r}^S}\widehat{x_n}^{-1}$), leading to:

$$\boldsymbol{g} = \left(\boldsymbol{E} + \boldsymbol{E}\ \boldsymbol{C}\ \boldsymbol{T}\ \boldsymbol{\pi}\ \widehat{\boldsymbol{b}}\right)\boldsymbol{h} + \boldsymbol{E}\ \boldsymbol{C}\ \boldsymbol{T}\ \boldsymbol{\psi}\ \boldsymbol{n}$$

Where

$\boldsymbol{E} = (\boldsymbol{I} - \boldsymbol{B}_\theta\ \widehat{\boldsymbol{g}}^{-1})^{-1}$ *Structure and efficiency of energy conversion industries (size* $m_E \times m_E$*)*

$\boldsymbol{C} = \boldsymbol{B}_\tau\left\{\widehat{colsum}(\boldsymbol{B}_\tau)\right\}^{-1}$ *Composition of energy demand by non-energy industries (size* $m_E \times m_I$*)*

$\boldsymbol{T} = \widehat{colsum}(\boldsymbol{B}_\tau)\widehat{x_n}^{-1}$ *Direct energy intensity of non-energy industries* ($m_I \times m_I$)

$\boldsymbol{\psi}$ *Structure of the rest of the economy (size* $m_I \times m_I$*)*

$\boldsymbol{\pi}$ *Structure non-energy inputs for energy sectors* ($m_I \times m_E$)

$\boldsymbol{b} = \boldsymbol{e}\widehat{\boldsymbol{h}}^{-\boldsymbol{1}}$ *Average energy prices (length* $m_E$*)*

$\boldsymbol{h}$ *Final energy demand (length* $m_E$*)*

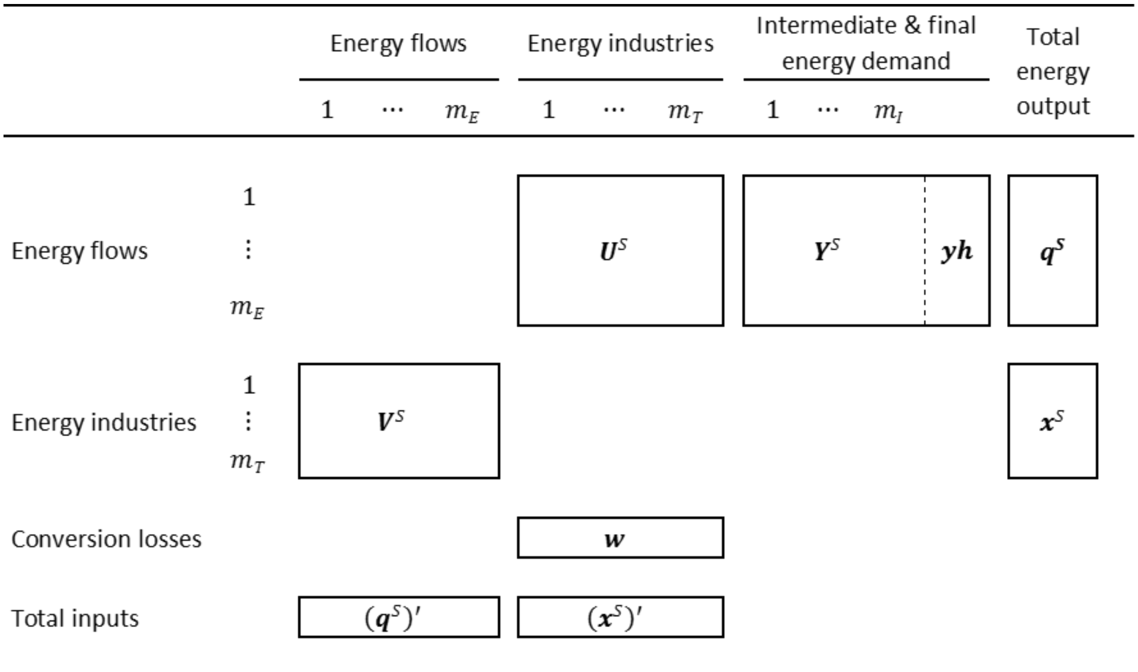
$\boldsymbol{n}$ *Non-energy final demand (length* $m_I$*)*

<u>*The product-by-industry approach for the energy side of the approximate MF-EIO model.*</u>

In a real economic system, industries can produce more products and not just one as considered in the previous section. To correct this assumption, we present a product-by-industry approach of the MFEIO model, as done by Guevara and Rodrigues (2016).

The energy sector consists of ***m_T*** energy conversion industries (e.g., refineries or wind farms) that produce ***m_E*** energy flows (e.g., crude oil or electricity) for own use and for the energy consumption of ***m_I*** direct energy demand non-energy industries ( e.g., chemical or steel industries) and a final consumer sector. The energy flows in physical units of the energy balances are organized in a supply-use framework (EUROSTAT, 2008), as shown in Figure 1.

**Figura 1. Marco de oferta y uso para datos de productos básicos por industria de un sector energético**




The use matrix ($\boldsymbol{U}^S$) describes the amount of energy flows that are inputs to the production processes of the energy industries. The manufacturing matrix ($\boldsymbol{V}^S$) shows the total supply of energy flows produced by a particular energy industry. $\boldsymbol{Y}^S$is the direct energy demand matrix of the non-energy industries and ***yh*** is the final energy demand. The vector ***w*** represents the energy conversion losses in the energy industries. Finally, $\boldsymbol{q}^S$ and $\boldsymbol{x}^S$ are the total energy use by type of energy flow and by industry, respectively.

The ratio of total energy use by energy flow type to direct and final energy demand is determined under the industrial technology assumption of the product-by-industry approach (Guo et al., 2009; Miller and Blair, 2009) as:

$$\boldsymbol{q}^S = \left(\boldsymbol{I} - \boldsymbol{U}^S(\hat{\boldsymbol{x}}^S)^{-\mathbf{1}}\boldsymbol{V}^S\widehat{\boldsymbol{q}^S}^{-\mathbf{1}}\right)^{-1}(\boldsymbol{Y}^S\boldsymbol{i} + \boldsymbol{yh})$$

Finally, the full MFEIO model by the product-by-industry approach is obtained by substituting the elements $\boldsymbol{L}^E$, $\boldsymbol{C}^S$ y $\boldsymbol{T}^S$ in Equation $= \left(\boldsymbol{E} + \boldsymbol{E}\,\boldsymbol{C}\,\boldsymbol{T}\,\boldsymbol{\pi}\,\widehat{\boldsymbol{b}}\right)\boldsymbol{h} + \boldsymbol{E}\,\boldsymbol{C}\,\boldsymbol{T}\,\boldsymbol{\psi}\,\boldsymbol{n}$ with:

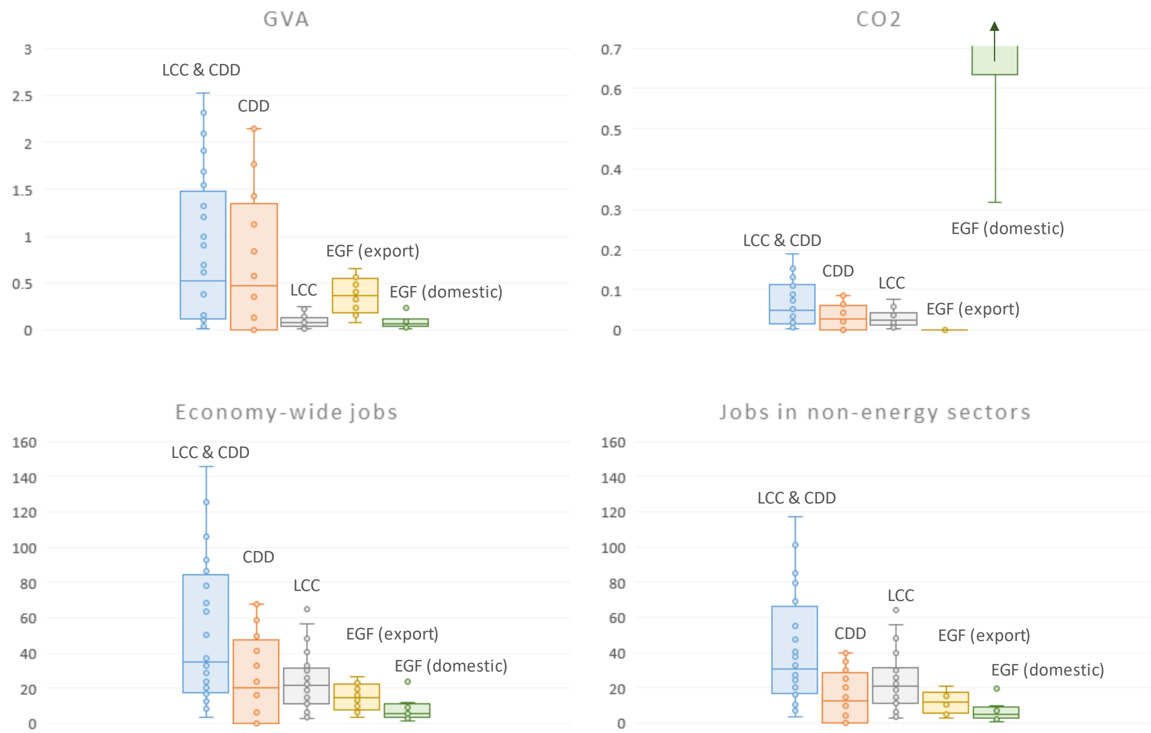
$$\boldsymbol{E} = \left(\boldsymbol{I} - \boldsymbol{U}^S(\widehat{\boldsymbol{x}}^S)^{-1}\boldsymbol{V}^S\widehat{\boldsymbol{q}^S}^{-1}\right)^{-1} \qquad \text{(size } m_E \times m_E\text{)}$$

$$\boldsymbol{C} = \boldsymbol{Y}^S\left\{\widehat{colsum}(\boldsymbol{Y}^S)\right\}^{-1} \qquad \text{(size } m_E \times m_I\text{)}$$

$$\boldsymbol{T} = \widehat{colsum}(\boldsymbol{Y}^S)\widehat{\boldsymbol{x}^n}^{-1} \qquad \text{(size } m_I \times m_I\text{)}$$

$$\boldsymbol{h} = \boldsymbol{yh} \qquad \text{(length } m_I\text{)}$$

## 4. Results




From the economic point of view, the results suggest that the national energy policy can induce important economic and social benefits for the country. Specifically, while local content policy may have the greatest potential for employment generation in both the hydrocarbon sector and the rest of the economy, expanding capacity to meet domestic hydrocarbon demand may have a greater potential for economic growth and a similar potential for job creation in the hydrocarbon sector.

However, the combined application of these two policies can produce the greatest benefits with reasonably small environmental impact.

In addition, growth in final domestic demand for oil and gas has a small impact on job creation and economic growth, but with large $CO_2$ emissions.

## 5. Conclusions

In this research we asked ourselves what are the possibilities of success of the current Mexican energy policy in its objective of moving towards an economy with a greater use of renewable energies in its energy matrix. After applying a multifactor input-output model, we found that the projections of the new national energy policy show important economic and social benefits for the country. In particular, the combination of local content policy and the capacity to cover the national hydrocarbon demand can have a higher potential for economic growth and a similar potential for job creation in the hydrocarbon sector with a reasonably small environmental impact.

In contrast, other policies analyzed in the framework of the national energy policy, in particular the one aimed at the growth of domestic final demand for oil and gas, have a small impact on job creation and economic growth, but would generate large $CO_2$ emissions.

Based on these results, we put forward some energy policy recommendations for government policy makers with the aim of increasing the chances of success of the current energy policy. For example, since the growth of domestic final demand for hydrocarbons has a small impact on job creation and economic growth with a large generation of $CO_2$ emissions, the government should promote programs to reduce domestic final consumption of hydrocarbon products and strengthen industrial energy efficiency policy to limit the total domestic demand for these products. In this way, more of the domestic production of crude oil and derivatives can be used to cover export demand, which has a greater potential for job creation and economic growth with much lower $CO_2$ emissions generation within the borders.

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