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# Sustainability of the Energy Sector in Mexico from 2000 to 2020

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## Abstract

Mexican government has sought a balance, through various public policies, regarding economic growth and social welfare and having a minimum impact on the environment. The objective of this article is to evaluate whether the energy supply in Mexico has become more sustainable between 2000 and 2020, a fundamental premise for any energy system. The analysis is based on a methodological combination of those approaches adopted by the Latin American Energy Organization and those by the World Energy Council, which are international institutions of great prestige in the Energy field. Even though results obtained by several authors show advances and setbacks, the overall result has been a notorious setback in terms of sustainability. These results were compared with those published by the World Energy Council and some notable differences were observed. Analyzed authors conclude that more accurate, effective and sustained public policies are required in the long term to make the energy supply increasingly sustainable in Mexico.

## Keywords

Energy Sustainability, Energy Security, Energy Affordability, Energy Transition

## 1. Introduction

For more than two hundred years, humanity's progress has been based on the use of fossil fuels. Coal, oil and natural gas have been used to produce goods and services to improve the living conditions of the population. The advantages associated with these non-renewable resources surpassed their disadvantages until the negative consequences could no longer be overlooked. Its excessive use has damaged ecosystems and endangered the entire planet. Waste from fossil energy from both ends: production and consumption has become the main cause of global warming and climate change (IPCC, 2018).

Increase in environmental risks, concerns about planetary degradation and aspiration for a balanced development have led the international community to initiate an energy transition with three main pillars: first, the accelerated use of clean energy; second, the replacement of oil and coal by natural gas; and third, a shift towards more rational and efficient energy consumption (García, 2019). It is a collective effort where each country chooses the extent and speed of the transition according to its available resources, capital and technology, but also depending on other priorities set by its national development agenda and international commitments.

In 2015, the General Assembly of the United Nations Organization (Naciones Unidas, 2015) adopted the 2030 Agenda for Sustainable Development, which includes 17 goals, one of which is to guarantee affordable, secure, sustainable and modern energy for all. It is an enormous challenge, not only because of resources and capacities that need to be mobilized, but also because of arbitrations required to solve conflicts between competing desired objectives for energy supply.

For the World Energy Council (WEC), an energy transition will depend on the coherence and effectiveness of public policies aimed at obtaining sustainable energy (World Energy Council, 2018). The challenge is to balance and improve the performance of these policies in three fundamental dimensions: energy security, energy equity and environmental care in a context of economic growth. This Council has developed a methodology to assess national energy systems' performances and rank them based on their achievements. The most recent report (Word Energy Council, 2022) retrospectively analyzes 127 countries with help from 31 indicators grouped into eleven categories and four dimensions, all of them synthesized in an index called the "Energy Trilemma".

The "Energy Trilemma" is an annual assessment that evaluates each country's success in solving the triple challenge of finding solutions for a secure, affordable, and environment-friendly energy. This allows, through an energy sustainability index, to have a global and comprehensive classification for each country's energy policies and it also shows whether success has been achieved or improvement is needed for each case. Based on the above, a list is prepared that concentrates on evolution in such a trilemma and shows the comparative position for each country with a balance that is condensed into three letters (AAD, for example). Such an index indicates how each country is doing, being the letter A in the best position, while D represents the lowest grade. Thus, the better balanced a country is, the greater the area covered by a triangle conformed by the three dimensions of energy: sustainable energy security, energy equity and environmental sustainability each of the three represented by a letter.

Although this methodology makes it possible to compare different performances for different countries, it does not consider individual situations for each one. For example, territorial extension, number of inhabitants, energy resources available for each one and economic resources that can accelerate or delay energy transition, among other factors are not considered.

The methodology proposed by the World Energy Council allows comparison among countries and provides information on challenges and opportunities for each country in the context of the global energy transition. However, this methodology is not without drawbacks. Taking a closer look at the performance of ten countries using principal component analysis (Asbahi et al., 2019), concluding the results are different from those obtained by the WEC. This result is not surprising because using the same rule to measure nations differently in size, geography, natural resources, wealth and history dilutes inherent details in each case. From the moment that specific information for each country is excluded, results may show supposed improvements that are far from the local reality, as it is the case for Mexico, which is discussed in this article.

The WEC concludes that Mexico has had a continuous improvement in energy security between 2011 and 2020, an assessment that is contrary to the perception of numerous analysts (Vargas, 2014; Oswald, 2017; Rodríguez, 2018; Sánchez, 2019) and even to the Mexican government itself, SENER (2020) who highlights a growing deterioration due to the rapid and unstoppable decline of both reserves and production of hydrocarbons, as well as unrestricted importation of natural gas and oil products that have transformed Mexico into a net importer of energy since 2014. On the energy equity side, the WEC reports stability in recent decades, without notable advances or setbacks, which does not reflect the elimination of subsidies and a substantial increase in the domestic price of fuels since 2008 and its impact on the household's economy. It also concludes that environmental sustainability tends to grow, which goes against a continuous increase in Mexican emissions of greenhouse gases. This gap between the results of the WEC and reality is explained because a number and variety of selected indicators have omitted or faded local phenomena of particular importance.

Mexico is a country with multiple economic and social problems, so it is important to find a way, in the short or medium term, to satisfy the basic needs of its population without compromising those of future generations. That is, to have a sustainable energy system with a balance between the environmental, social and economic dimensions.

The case of Mexico is interesting since, due to its geographical position and the hydrological, meteorological and topographic conditions of its territory, it has one of the largest renewable energy potentials worldwide. However, in contrast, it has a notable social inequality in addition to a very marked dependence on fossil fuels. This makes it urgent to achieve an energy transition that allows achieving an environmentally sustainable, low-carbon and socially inclusive energy system.

Mexican current administration has been carrying out actions in the energy sector that diverge from those of previous governments. This government is promoting an energy system based on a nationalist approach, strengthening public companies but setting aside the participation of private companies. However, regardless of the way to achieve it regarding public or private involvement, the real focus should be to move in the shortest possible time toward a more sustainable energy model.

The main objective of this article is to assess whether the energy supply in Mexico is really becoming more sustainable as indicated by the WEC analysis. With this intention, the essay is divided into four parts: the first discusses what is meant by energy sustainability; in the second, a set of indicators are selected, quantified and synthesized which, in our opinion, better reflect the Mexican reality in the period from 2000 to 2020; in the third part, results obtained are discussed, and in the fourth and last part, an analysis is made regarding what has happened in recent years.

## 2. Literature Review

### 2.1. What Is Meant by Energy Sustainability?

Numerous definitions have been proposed in the literature to characterize what is known as sustainable development (Brundtland, 1987; Bossel, 1999; Karlen, 2008; Iddrisu & Bhattacharyya, 2015). Such quantity and variety of statements are typical of a diffuse concept in essence and scope. Then, it is not surprising that the estimation of progress of countries in this direction is the source of conflicting and debatable opinions (Salgado & Altomonte, 2002; Ibarrarán et al., 2009; Molina et al., 2009; Tsai, 2010).

Starting with the general problem of sustainable development, literature has focused its attention on the meaning of the concept according to different branches of the economy. For Fotourehchi (2017), the sustainability of development depends on the direct and indirect feedback effects between economic growth, social welfare and environmental degradation. For their part, O'Callaghan and Bryant (2012) consider it necessary to adopt the green economy approach to achieve this development. For Kemmler and Spreng (2007), an economic development that leaves aside the environmental and social aspects, it is far from being sustainable, hence the importance of giving equal weight to the economic, social and environmental aspects in order to arrive at a pragmatic notion of sustainability. For the Latin American Energy Organization[1] (OLADE, 2017), sustainable development implies an improvement in the quality of life in an economically, socially and environmentally sustained manner over time on the basis of a solid institutional structure.

Development refers to human progress. It is a process that expands the range of options and opportunities for food and health, education and culture, income and employment, encompassing the full spectrum of human needs, from a healthy physical environment to economic and political freedoms. To facilitate study and analysis, the literature regularly groups human needs and aspirations into three dimensions: economic, social, and environmental. However, as there is no sus-

[1]Organization of cooperation, coordination and technical advice with the fundamental objective of promoting the integration, conservation, rational use, commercialization and defense of the energy resources of Latin America.

tained progress over time without solid institutional foundations, it has been unavoidable, in more recent studies, to add a fourth dimension that includes these aspects (INEGI, 2000; Bell & Morse, 2008; Song et al., 2017; Bell & Morse, 2018).

For Iddrisu and Bhattacharyya (2015), it is not enough to add a fourth category, hence his proposal is to consider an additional, called "technical", which is associated with the ability to have a system of energy sources to meet the present and future needs of society in a reliable, efficient and clean way. More specifically (Ibarrarán et al., 2009), define energy sustainability as energy supply at an affordable cost for the population, ensuring service and respecting the environment. For their part, Vera and Langlois (2007) consider that a sustainable energy system is one that provides adequate energy services at affordable costs in a safe and environmentally friendly manner, taking into account social and economic needs. Tsai (2010) points out that the energy system achieves sustainability when it reaches a balance between a low-carbon economy and economic development, considering environmental protection and energy security under the principles of high efficiency, added value, reduced emissions and low energy dependence, especially on fossil fuels.

For Streimikiene and Šivickas (2008), a sustainable energy system promotes energy efficiency and a use of renewable energies through the mitigation of greenhouse gases and atmospheric pollution, also achieving a positive impact on energy security. Another way to analyze the sustainable development of an energy sector is to consider four aspects: strengths, weaknesses, opportunities and threats (Markovska et al., 2009).

The World Energy Council (2020) defines energy sustainability based on a balance between three fundamental aspects: energy security, energy equity and environmental sustainability. For the World Bank (World Bank Group, 2016), a sustainable energy system is one that guarantees access to energy, energy efficiency and use of renewable energies. For their part, Salgado and Altomonte (2002) consider that a sustainable energy system is one that takes into account four aspects: risks, vulnerabilities and restrictions for socio-economic development, inequitable biases in energy supply, inconsistencies in the use of resources and external effects on the environment. The Secretary of Energy in Mexico, points out that the energy sector is sustainable when it manages to promote economic development and improve the social and economic conditions of the population, through the rational use of the country's energy resources (SENER, 2016).

The abundance of definitions results in a wide variety of proposals to quantitatively estimate energy sustainability. Some authors use dozens of indicators (IAEA, 2005; OIEA, 2008; World Bank Group, 2016); others retain a few: only those that, in their opinion, synthesize the essence of sustainability (OLADE, 1997; Armin Razmjoo et al., 2019, 2020). For their part, Rinne et al. (2013) point out that international enthusiasm for sustainable development has led to multiple classification criteria, although this does not prevent an overlap in the aspects analyzed.

Usually studies select indicators based on the three basic areas: economy, society and environment (Salgado & Altomonte, 2002; Ibarrarán et al., 2009; Sheinbaum-Pardo et al., 2012; Muniz et al., 2020). In contrast, the World Bank (World Bank Group, 2016) prefers a classification based on access to energy, energy efficiency and the use of renewable energies. In turn, the World Energy Council (2016) highlights, as already mentioned, energy security, energy equity and environmental sustainability. On the other hand, Phillis et al. (2020) underline as main areas the environment, the human system and the energy system.

It is important to emphasize that regardless of the definition adopted, most authors agree that the concept of sustainable development should be oriented towards considering the human being as the central point. In the same way, there is an agreement regarding the improvement of their quality of life being carried out with productive efficiency and considering at all times the preservation of available natural resources (INEGI, 2000). Furthermore, regardless of the preferred classification, it is undeniable that there is a consensus on the need to strike a balance between the different spheres of development.

The groups of indicators also have a practical purpose: to facilitate information's handling and interpretation. For example, the World Bank consolidates 27 indicators into 3 cores (World Bank Group, 2016), the World Energy Council integrates 35 indicators into just 3 principalcores (World Energy Council, 2020), and the International Atomic Energy Agency consolidates 30 indicators into 7 cores (OIEA, 2008) (see **Table 1**). We can also mention the case of Li and Li (2019) who use 20 indicators but, unlike the cases mentioned above, do not seek to compare several countries or regions, their objective is to evaluate the progress in sustainability of a single nation in a period of 15 years. Iddrisu and Bhattacharyya (2015) choose to integrate all variables into a single general sustainability index, a criterion that is also followed by Schipper et al. (2000), Ibarrarán et al. (2009), Molina et al. (2009), Sheinbaum-Pardo et al. (2012), Bell and Morse (2018), Cîrstea et al. (2018), Armin Razmjoo et al. (2019) among others.

## 2.2. The Mexican Case

What set of indicators are the most appropriate to faithfully reflect the case of the Mexican energy system? From the outset, it is essential to provide a structure, a process and a criterion to build an adequate set. Although there is no single definition of sustainable development (Golusin & Ivanović, 2009), certain aspects can be measured to make the concept operable, so we can say that the indicators facilitate the orientation to follow. Horta (2019) defines an indicator as a quantitative measurement of certain variables or conditions, through which it is possible to understand or explain a particular reality or phenomenon and its evolution over time.

Indicators are useful tools to generate information to support decision making; they allow monitoring available resources, managing processes and their

**Table 1.** Sustainable indicators for different institutions.

| | |
|---|---|
| World Bank | |
| Energy Access | Existence and monitoring of officiallly approved electrification plan |
| | Scope of officially approved electrification plan |
| | Framework for grid electrification |
| | Framework for minigrids |
| | Framework for stand-alone systems |
| | Consumer affordability of electricity |
| | Utility transparency and monitoring |
| | Utility creditworthiness |
| Energy Efficiency | National energy efficiency planning |
| | Energy efficienciy entities |
| | Information provided to electricity consumers |
| | Incentives from electricity rate structures |
| | Mandates & incentives: large consumers |
| | Mandates & incentives: public sector |
| | Mandates & incentives: utilities |
| | Financing mechanisms for energy efficiency |
| | Minimum energy performance standards |
| | Energy labeling systems |
| | Builindng energy codes |
| | Carbon princing and monitoring |
| Renewable Energy | Legal framework for renewable energy |
| | Planning for renewable energy expansion |
| | Incentives & regulatory support for renewable energy |
| | Attributes of financial and regulatory incentives |
| | Network connection and access |
| | Counterparty risk |
| | Carbon princing and monitoring |
| World Energy Council | |
| Energy Security (30%) | Diversity of primary energy supply |
| | Energy consumption in relation to GDP growth |
| | Import dependence |
| | Diversity of electricity generation |
| | Energy storage |
| | Preparedness (human factor) |

**Continued**

| | |
|---|---|
| Energy Equity (30%) | Access to electricity<br>Access to clean cooking<br>Quality of electricity supply<br>Quality of supply in urban vs. rural areas<br>Electricity prices<br>Gasoline and diesel prices<br>Natural gas prices |
| Environmentalsustainability (30%) | Final energy intensity<br>Efficiency of power generation and T&D<br>GHG emmision trend<br>Change in forest area<br>$CO_2$ intensity<br>$CO_2$ emission per capita<br>$CO_2$ from electricity generation |
| Country Context (10%) | Macroeconomic environment<br>Effectiveness of government<br>Pölitical stability<br>Perception of corruption<br>Transparency of policy making<br>Rule of law<br>Regulatory quality<br>Intellectual property protection<br>FDI & tecnhology transfer<br>Capacity for innovation<br>Number of patentes issued by residents<br>Foregein direct investment net inflows<br>Ease of doing business<br>Wastewater treatment<br>Air pollution |
| International Atomic Energy | |
| Equity | Share of households without electricity or commercial energy<br>Share of household income spent on fuel and electricity<br>Household energy use for each income group and corresponding fuel mix |
| Health | Accident fataliities per energy produced by fuel chain |

**Continued**

| | |
|---|---|
| Use and Productionpatterns | Energy use per capita |
| | Energy use per unit of GDP |
| | Efficiency of energy conversion and distribution |
| | Reserves-to-production ratio |
| | Resources-to-production ratio |
| | Industrial energy intensities |
| | Agricultural energy intensities |
| | Service/commercial energy intensities |
| | Household energy intensities |
| | Transport energy intensities |
| | Fuel shares in energy and electricity |
| | Non-carbon energy share in energy and electricity |
| | Renewable energy share in energy and electricity |
| | End-use energy prices by fuel and by sector |
| Security | Net energy import dependency |
| | Sotcks of critical fuels per corresponding fuel consumption |
| Atmosphere | GHG emissions from energy production and use per capita and per unit of GDP |
| | Ambient concentrations of air pollutants in urban areas |
| | Air pollution emissions form energy systems |
| Water | Contaminant discharges in lliquid effluents from energy systems |
| Land | Soil area where acidification exceeds critical load |
| | Rate of deforestation attributed to energy use |
| | Ratio of solid waste generation to units of energy produced |
| | Ratio of solid waste properly disposed of to total generated solid waste |
| | Ratio of solid radioactive waste to units of energy produced |
| | Ratio of solid radioactive waste awaiting disposal to total generated solid radioactive waste |

Source: self-made.

impacts. Dahl (2012) points out that in order to achieve sustainability, a set of indicators based on values is necessary to measure and promote the implementation of ethical principles so that they serve as a guide on the path of sustainability.

The number of indicators should be as small as possible but not fewer than necessary and they should be understandable and compact as well as cover all relevant aspects in the required field of study. The selection process must be participatory to ensure that each indicator contemplates the visions and values of the community or region under analysis.

Bell and Morse (2008) ensure that a good indicator must be simple to facilitate its management, in addition to having sufficient scope to cover environmental, social and economic aspects without overlapping with other indicators. It is also important that it is measurable and sensitive to indicate time lines, trends and changes. For indicators to be useful they must be relevant, based on a methodology, measurable, easy to communicate and access, but also limited in number and structured with a logical consequence (Taylor et al., 2017).

For their part, Armin Razmjoo et al. (2019) ensure that the set of indicators associated with energy sustainability must contain at least 7 in order to identify gaps and weaknesses in public policies that seek to achieve this objective. For Patlitzianas et al. (2008), the indicators must be appropriate for a realistic description, transparent and simple, complete, which means technical and scientific suitability, as well as having international acceptance and being flexible, easy to calculate and being relatable to other models. For (Gunnarsdottir et al., 2020), the indicators have important limitations, among them the ambiguity in the definition of sustainable energy development, the difficulty to reflect national or regional circumstances and the inconsistency of results because they vary according to the methodology used. Regardless of their limitations, the indicators must necessarily meet two essential characteristics: be complete and robust.

On some occasions, when there are no direct indicators or there is a lack of sufficient information, it is feasible to use substitute indicators (Karlen, 2008; Kettner-Marx et al., 2018); for example, greenhouse gas emissions being used to reflect the effects of climate change is a typical case in this area. Kettner-Marx et al. (2018) point out that an important additional difficulty is insufficient information, especially in the social field where there is a great lack of information even in developed countries. For his part, Bossel (1999) explains that indicators are essential to guide policies and decisions at any governmental, social and territorial level. Such indicators should consider the possible implications and should not focus on a single segment of the problem, but on the whole.

Based on the proposals suggested in the reviewed literature, the relevance of the "Energy Trilemma" proposed by the WEC (Gunnarsdottir et al., 2020) and on the specificities of the Mexican energy system, we have selected 12 indicators to analyze Mexico's progress in terms of energy sustainability during the last 20 years (see **Table 2**). The scarcity or inconsistency of the available information prevented the construction of complete data series for some important indicators and we were forced to replace them with others.

## 3. Methodology

The period of analysis goes from 2000 to 2020, during this time, the Mexican

Table 2. Energy sustainability indicators selected for Mexico.

| | |
|---|---|
| Energy Security | Autarky |
| | Robustness |
| | Diversity of internal energy supply |
| | Diversity of sources in electricity generation |
| | Duration of fossil resources |
| Energy Equity | Electrical coverage |
| | Access to clean technologies and fuels at home |
| | Consumption of electrical energy per capita |
| Environmental Sustainability | Use of renewable energy sources |
| | Electricity production with renewable energy resources |
| | Energy productivity |
| | Emission of greenhouse gases |

Source: self-made.

energy sector experienced profound transformations in both supply and demand, had a context of market reforms, wide variations in the price of oil and Mexico's commitments to international community regarding climate change. Based on a combination of the methodology from the Latin American Energy Organization and that of the World Energy Council, both prestigious institutions in the field of energy, each indicator was given the same importance since what is sought is to achieve a balance between the 3 dimensions shown in Table 2. Additionally, in order to be able to compare these indicators with each other and assess sustainability, they were normalized in a scale of 0 to 1, so that, the higher the value, the greater progress in terms of sustainability and vice versa. This methodology allows, based on this normalized indicators, to elaborate a polygonal graph in which the greater the sustainability, the greater the area and vice versa.

The indicators selected for the analysis for the Mexican case was the following (see Table 2):

1) Autarky. This indicator is obtained by dividing imports by energy consumption. It allows to determine a country's situation, whether independence, self-sufficiency or dependence with respect to external energy supply. In general terms, it is desirable that demand is covered with local energy so as not to be at the expense of the volatility of international markets and geopolitical risks. The normalization criterion consists of setting the maximum value when there are no net imports and the minimum when all the energy comes from the international market.

2) Robustness. It is related to the economic strength of the energy system. Conceptually, it has to do with the energy trade balance, oil export revenues, oil's share of tax revenue, investment leverage, and other economic issues. While in the past abundant oil exports were considered an element of strength of the Mex-

ican economy, in terms of sustainability of the energy sector, they are a negative element due to generated imbalances. The selected indicator is the weight of energy exports in Gross Domestic Product (GDP): a low value denotes greater robustness and vice versa.

3) Diversity of the internal energy supply. A diversified energy basket is the best way to ensure continuous and sufficient supply at an affordable price. Having multiple options at hand makes it easier to resolve imbalances between supply and demand. Diversification makes it easier to reduce dependence on fossil fuels and to increase the share of clean energy.

The option selected to estimate diversification is the Herfindahl index (Molina et al., 2009). A high value is associated with a highly concentrated supply and vice versa.

4) Diversity of sources in electricity generation. Electric power is an essential good for the development of productive activities, as well as for the well-being of a society, so it is important to ensure a sufficient and reliable electricity supply that allows growth and economic development of a country. The multiplicity of options available becomes more relevant in the generation of electricity since it cannot be stored in large quantities and must be generated at the time it is needed, hence, the importance of having a wide range of options to meet demand at all times. As in the previous case, the option selected to estimate the degree of diversification was the Herfindahl index.

5) Duration of fossil resources. Producing and holding oil reserves has long been considered the strength of the energy system due to the importance of oil in the economy, especially in transportation. The indicator par excellence for estimating the scope of resources of this type is the reserves/production ratio, which estimates the reserves in years of production, assuming that the rate of extraction remains constant. Due to the characteristics of our country, the criterion Salgado and Altomonte (2002) use was considered adequate. In such, the most desirable is to have a reserve/production ratio of at least 45 years, which would correspond to a value of 1 in normalization.

6) Electrical coverage. The energy equity dimension is characterized by three indicators. The first is electricity coverage, which refers to the number of people who have electricity compared to the total population. The increase in coverage is considered an element of sustainability since the availability of this type of energy substantially improves quality of life. Normalization is direct: the maximum value is reached when the entire population has access to the service.

7) Access to clean technologies and fuels at home. More than half of the population in Mexico lives in poverty. The distance from urban centers and their low economic power prevent this group from accessing clean technologies and fuels for use at home, which is another attribute of a sustainable energy system. This requirement is associated not only with energy equity but also with social justice and solidarity. The use of firewood, charcoal, manure and coal for cooking, heating water and air conditioning spaces leads to premature deaths from pulmonary emphysema and asphyxia, as well as poisoning and other diseases

associated with the inhalation of combustion gases in enclosed places. In this area, the most affected are women and infants; such problem has a gender dimension. The indicator that reflects this situation is the relationship, which allows direct normalization: the maximum is reached when the entire population has access to technology and clean fuels at home.

8) Consumption of electrical energy per capita. Access to electricity is essential for development; it is one of the sustainable development objectives of the 2030 Agenda. Electric power is necessary to meet basic needs for lighting, education, health, drinking water supply, communication and information, among a wide range of services. There is a very marked correlation between residential electricity consumption and social well-being. This indicator is defined as the ratio of electricity consumption in the residential sector divided by the number of inhabitants. What is desirable is that the entire population has an acceptable standard of living thanks to availability and use of electricity in their homes. To normalize this indicator, the level reached by the European Union was taken as a reference, given that it is a group of countries with high economic development and social welfare.

9) Use of renewable energy sources. Reducing the carbon footprint requires a greater share of renewable sources in energy consumption. It is one of the objectives of the 2030 Agenda. It is highly desirable that the replacement of fossil fuels is accelerated, but in practice it will depend on the characteristics of the local energy system, the available means, the resistance and the restrictions of any public policy. In this case, the normalization considers, on the one hand, the level reached by renewable sources in the energy basket in 1990 and, on the other, Mexico's commitment to reach a penetration rate of 35% in 2030 (SEGOB, 2015).

10) Electricity production with renewable energy sources. The greatest potential for diversification is located in the generation of electricity due to the high consumption of energy and the diversity of technology used. This is where wind and solar, geothermal and hydroelectric power have found a niche to expand. The participation of renewable sources in the production of electrical energy is an extremely important indicator. In the Paris Agreement, Mexico committed to generate 35% of its electricity with clean energy in 2024 (SEGOB, 2015). The normalization of this indicator takes into account this goal and the progress achieved in 1990, the year from which there is consistent statistical information.

11) Energy productivity. Energy intensity is a classic indicator in the world of energy that is calculated as the ratio between national energy consumption and GDP. It indicates the amount of energy that a country needs to generate a unit of GDP. Energy intensity is declining as the economy leaves behind heavy industrialization and infrastructure creation while it increasingly relies on low-energy activities. The higher the productivity, the lower the energy intensity and the lower the need for energy to sustain the development process. The indicator is normalized considering the aspirational goal of doubling energy productivity with respect to that achieved in 1990, the base year of the study prepared by the Latin

American Energy Organization (OLADE, 1997), which may allow a historical comparison with the perspective of this international organization.

12) Emission of greenhouse gases. There is a broad consensus among the scientific community in pointing the emission of greenhouse gases of anthropogenic origin as responsible for climate change and global warming. Within emitting industries, the energy sector is the most relevant. The relationship between carbon dioxide ($CO_2$) emissions and primary energy consumption is used as an indicator in this study and is normalized based on Mexico's commitment at the Paris Summit to reduce greenhouse gas emissions by 22% by 2030 (SEGOB, 2015).

## 4. Analysis and Discussion of Results

**Table 3** shows the normalized quantification of the indicators at the beginning and at the end of the analysis period. The global energy sustainability index has gone from 0.70 in 2000 to 0.61 in 2020, which indicates a clear decrease in the sustainability of this sector by 13% as well as a marked deviation from the sustainability path.

In general terms, the energy supply has lost sustainability (**Figure 1**). Advances in robustness, diversity of internal energy supply, electricity coverage, access to clean technologies and fuels at home, electricity consumption per capita, as well as increased energy productivity, do not compensate for setbacks in terms of self-sufficiency, diversity of sources in the generation of electricity,

**Table 3.** Normalized values of sustainability indicators for the Mexican energy sector between 2000 and 2020.

| | | 2000 | 2020 |
|---|---|---|---|
| Energy Security | Autarky | 0.87 | 0.54 |
| | Robustness | 0.65 | 0.82 |
| | Diversity of internal energy supply | 0.53 | 0.68 |
| | Diversity of sources in electricity generation | 0.67 | 0.48 |
| | Duration of fossil resources | 0.84 | 0.48 |
| Energy Equity | Electrical coverage | 0.98 | 0.99 |
| | Access to clean technologies and fuels at home | 0.82 | 0.85 |
| | Consumption of electrical energy per capita | 0.31 | 0.38 |
| Environmental Sustainability | Use of renewable energy sources | 0.62 | 0.32 |
| | Electricity production with renewable energy resources | 0.71 | 0.46 |
| | Energy productivity | 0.59 | 0.79 |
| | Emission of greenhouse gases | 0.70 | 0.49 |
| | Global Sustainability Index | 0.69 | 0.61 |

Source: self-made.

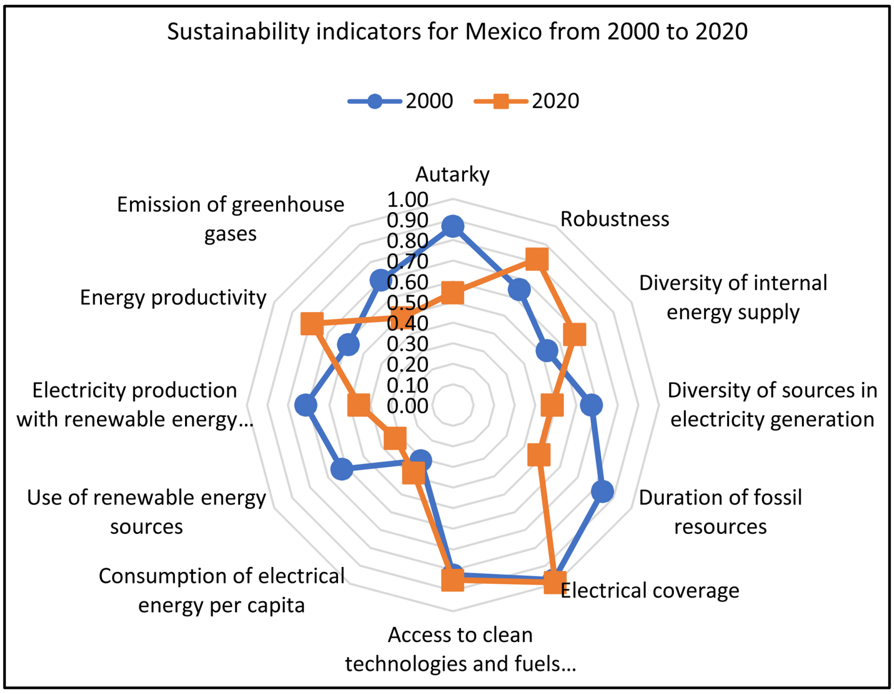


**Figure 1.** Sustainability indicators for Mexico from 2000 to 2020. Source: self-made.

outreach of fossil resources, use of renewable energy sources, production of electricity with renewable energy sources, as well as emission of greenhouse gases. The net result is declining sustainability (**Figure 2**).

We can observe that the factors that played against sustainability were the following (see **Table 4**).

Energy autonomy was lost. The relative weight of imports in primary energy consumption multiplied by 3.5, going from 13% to 46% between 2000 and 2020. The production of oil products and natural gas was insufficient to cover the increase in demand, hence the import growth. The domestic production of hydrocarbons began to suffer from the maturity of the geological heritage. Investments in exploration and development were insufficient to reverse the decline, and although solely oil production may have been insufficient to produce the oil products that were needed, refining capacity remained stagnant additionally.

- The energy basket for the production of electrical energy became even more concentrated instead of being diversified. The country accentuated its dependence on fossil fuels. The greater use of nuclear, geothermal, solar, wind and other alternative energies was not enough to achieve a better balance between the available options.
- Oil reserves were reduced to almost a third. In 2000, reserves reached 41.495 million barrels of crude oil equivalent, 20 years later they barely reached 13.518 million barrels (PEMEX, 2019). In temporary terms, the scope of the reserves was reduced from 38 to 22 years.
- The share of renewable sources in energy supply has regressed instead of progressed. Its relative weight in primary energy consumption went from 12.2%

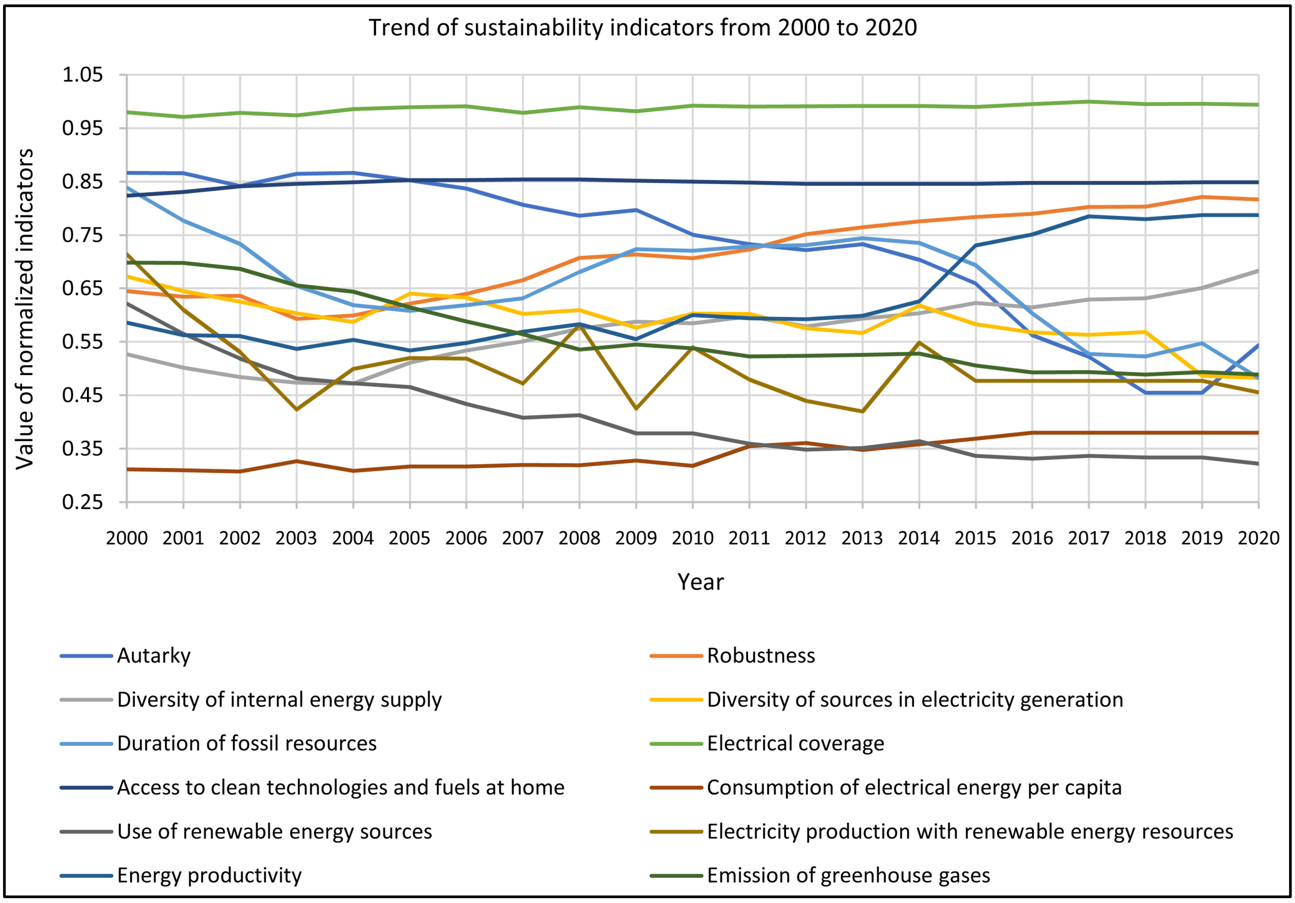


**Figure 2.** Trend of sustainability indicators for Mexico from 2000 to 2020. Source: self-made.

in 2000 to 9.6% in 2020, which means a decline of 21%. This clear departure from sustainability will make it more difficult for Mexico to reach the goal of 35% use of renewable sources in 2030, an international commitment it has signed.

- Electricity generation accentuated its dependence on fossil fuels. The percentage of generation from renewable energies fell from 19.8% in 2000 to 15.4% in 2020. As electrical energy is a fundamental factor to achieve sustainable development, a growing participation of low-carbon energy was necessary. Petroleum derivatives were replaced by natural gas, another fossil fuel.
- Environmental pollution has increased substantially. Greenhouse gas emissions went from 532 to 680 Mt of $CO_2$ equivalents during the analyzed period, which means an increase of 28%.

In contrast to the above, the factors that played in favor of sustainability were the following (see Table 4):

- Robustness of the energy system improved. Oil exports have assumed a less prominent role and the Mexican economy is no longer putting as much pressure on the energy system to grow as it used to. The relationship between energy exports and GDP was practically divided in half, going from 0.35 to 0.18 barrels of oil equivalent per thousand dollars.

**Table 4.** Evolution of the energy sustainability indicators of the Mexican energy system from 2000 to 2020.

| | | 2000 | 2005 | 2010 | 2015 | 2020 |
|---|---|---|---|---|---|---|
| Energy Security | Autarky: import/consumption | 0.13 | 0.15 | 0.25 | 0.34 | 0.46 |
| | Robustness: exports/GDP (BEP/US$ thousand) | 0.35 | 0.38 | 0.29 | 0.22 | 0.18 |
| | Diversity of internal energy supply. Herfindahl index (H) | 5257 | 5400 | 4734 | 4392 | 3853 |
| | Diversity of sources in electricity generation. Herfindahl index (H) | 4113 | 4397 | 4724 | 4898 | 5775 |
| | Duration of fossil resources: reserves/annual production | 37.74 | 27.38 | 32.42 | 31.21 | 21.72 |
| Energy Equity | Electrical coverage (%) | 98.0 | 98.9 | 99.2 | 99.0 | 99.4 |
| | Access to clean technologies and fuels at home (% of population) | 82.4 | 85.3 | 85.0 | 84.6 | 84.9 |
| | Consumption of electrical energy per capita (kWh/inhabitant) | 1800 | 1996 | 2019 | 2171 | 2184 |
| Environmental Sustainability | Use of renewable energy sources (% of final energy consumption) | 12.2 | 10.3 | 9.4 | 9.2 | 9.6 |
| | Electricity production with renewable energy resources (% of total generation) | 19.8 | 15.2 | 16.6 | 15.4 | 15.4 |
| | Energy intensity wich is the reciprocal of energy productivity (MJ/US$ thousand) | 4.11 | 4.51 | 4.01 | 3.30 | 3.06 |
| | Emission of greenhouse gases (kt de $CO_2$ equiv.) | 531,670 | 586,270 | 650,160 | 670,100 | 679,880 |
| | Global sustainability index | 0.69 | 0.63 | 0.63 | 0.63 | 0.61 |

Source: self-made.

- Electricity coverage went from 98% to 99.4%, which is a notable advance considering that the population without connection to the network is located in remote and mountainous places. At the same time, access to clean technologies and fuels for households increased from 82% to 85%. These were two notable advances in terms of energy equity.
- Per capita consumption of electricity in the residential sector went from 1800 to 2184 kWh per person. This increase reflects a better standard of living for families as they have greater access in their homes to the numerous services that electricity allows for.
- The energy intensity has decreased. The amount of energy needed by the economy to generate a unit of GDP has gone from 4.11 to 3.06 MJ/million dollars. The diversification of the economy towards services or other energy less intensive activities has relaxed the pressure on the energy sector.

## Recent Advances and Setbacks

Although the information available did not allow knowing the value of all the indicators for most recent years, it is possible to have an idea of the trend for sustainability after 2020 to the present. In order to do so, we will broadly analyze the energy policy during that period and its results.

Between 2013 and 2014, a profound market reform was approved designed to meet the growing demand for energy, increase the competitiveness of fuels and electricity, as well as to accelerate the move towards a new model of energy production and consumption (Merchand, 2015). Trade and investment were liberalized and foreign involvement was permitted. By giving greater prominence to the private sector and market mechanisms, it was hoped to attract capital, technology, knowledge and experience, which would come to solve the problems and face related challenges of the energy transition (Montoya et al., 2013).

With the energy reform, bidding rounds for oil areas were opened to reverse the drop in hydrocarbon reserves and production. Subsidized prices were eliminated and imports were encouraged. Petróleos Mexicanos (PEMEX) was subjected to asymmetric regulation to limit its market power and facilitate the emergence of a competitive market. In the same logic, a wholesale electricity market with asymmetric regulation was created to dilute the market power of the Federal Electricity Commission (CFE). Measures were taken to increase fuel storage capacity, in addition to establishing new institutional arrangements and strengthening the body of regulators.

In 2015, the Energy Transition Law was approved, a strategy was established to promote the use of cleaner technologies and fuels, special programs were launched in these areas, and the Paris Agreement was signed. A year later, auctions for the purchase of clean electricity began in connection with a market for green certificates.

Some of these measures were suspended when a new government came into office (2018-2024) that was unsympathetic to the market model and was determined to strengthen public companies, but without returning to the state monopoly. The will to stop the advance of the private sector in oil and electricity, to reverse the decline in oil production and to recover self-sufficiency in gasoline, diesel and other refined products, has introduced a waiting period in terms of energy transition and sustainability.

It is true that some of the decisions of the last five years have been aimed at improving competitiveness, security, equity and environmental sustainability, as well as for the robustness and resilience of the energy supply, that is, to improve its sustainability; however, others have been contrary to that primary objective.

On the one hand, the plan to invigorate oil exploitation by granting a large number of licenses and contracts, with a duration of up to 50 years, has favored the continuity of extractivism and the emergence of interests opposed to the abandonment of a fossil fuel paradigm.

On the other hand, the strategy of encouraging competition through imports has weakened energy security. Mexico was energy self-sufficient in 2014, but now external dependence reaches 70% in the case of gasoline, 72% in diesel, 65% in kerosene and 59% in LP gas.

Similarly, the decision to take advantage of the abundance, proximity and low price of US gas has had the same result because it has discouraged search and extraction of natural gas in Mexico: the most widely used energy source in the country, the one that is most used in the generation of electricity, the one that is imported the most with respect to consumption and the one that is most exposed to geopolitical risks. External dependence on natural gas exceeds 90% because the declining production is consumed almost entirely in the oil industry's own processes. Mexico has managed to raise the competitiveness of Mexican electricity and manufacturing, without having to assume the environmental impact of "fracking" and the production of unconventional gas. However, it has had to assume the geopolitical risks of massive imports, an example of this was the suspension of gas shipments to Mexico decided by the Texas government in February 2021 to address the supply crisis in that state.

Likewise, the decision to hinder the construction and commissioning of private power plants in order to maintain a generation park that is mostly public for reasons of sovereignty and national security, has slowed down the use of wind and solar energy, both necessary to achieve carbon neutrality. The policy of guaranteeing Mexico's energy security within the framework of energy security in North America, a policy in force between 2000 and 2018 has also not favored the transition because said security is based on the dynamics of fossil fuels.

Although Mexico has a rich portfolio of greenhouse gas mitigation options based on renewable energy and energy efficiency (Islas Samperio et al., 2015), the transition to renewable energy sources is not going far enough. The energy policy has favored fossil fuels and substitutions between them, especially the replacement of petroleum products with natural gas, and even in this area the use of gas is far from optimal, judging by the large amount of waste in production fields.

Russia's war against Ukraine has made energy prices much more expensive worldwide, which has undeniably had an impact on the postponement of certain goals for the benefit of sustainability. Even some developing countries are halting the move towards the use of renewable energy sources and marginally returning to the use of fossil fuels. Mexico is not an exception.

## 5. Conclusion and Recommendations

In this work, the objective was to analyze the sustainability of the Mexican energy system due to the discrepancies detected between the results of the World Energy Council studies and the Mexican reality. To this end, a set of indicators was used that, in our opinion, more accurately reflects national specificities. With the analysis carried out, it is possible to affirm that the sustainability of the Mexican energy sector has decreased significantly in the last twenty-five years due to the systematic erosion of energy security and the continuous increase in greenhouse gas emissions.

Despite advances in the robustness of the energy system, electricity coverage, household access to clean technologies and fuels, electricity consumption per inhabitant and energy productivity, there were significant regressions in energy autonomy, the diversity of energy sources used in electricity generation, the extent of fossil resources, the weight of renewable sources in national energy consumption, the emission of greenhouse gases and the emission of $CO_2$ in electricity generation. As progress has been insufficient to offset setbacks, the net result is less sustainability in the energy supply.

It is also important to point out that the main barriers to the transition towards a sustainable energy system are the lack of articulation of energy and environmental policies, as well as the relevant role of oil revenues in public finances that give perenniality to the extraction and consumption of hydrocarbons. The energy policy has focused its attention on the oil sector and has left in the background the use of renewable energy sources, the efficiency of processes and rationality in consumption.

The results obtained lead to the need to establish accurate, effective and sustained energy policy strategies in the long term, regardless of changes in government, in such a way as to make up for lost time and ground. Mexico needs to promote its energy sovereignty, gradually decrease energy dependence on imported gas, and enforce incentives for more efficient use of energy while also maintaining a permanent increase in energy productivity. At the same time, it is important to increase the use of renewable energies, even if this means involving private investment. Finally, it is also necessary to implement strategies for a considerable reduction in greenhouse gas emissions to comply with international agreements combating climate change effects.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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