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Measuring energy poverty: evidence from Mexico

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Abstract:

“Energy poverty constitutes one of the main issues of our times. The way in which people have access to energy can strongly affect their living standards and the world’s economy. This work is aimed at quantifying those impacts by analyzing the distribution of energy across a population from an economic point of view. The territory considered in the analysis is Mexico, a fast-growing economy characterized by strong inequalities. This thesis firstly introduces the theme of energy poverty and its definition, followed by a discussion of how energy poverty can be measured. Secondly, selected energy poverty indicators are used to examine the issue of energy poverty in Mexico by using household expenditure data obtained from the Mexican national statistical office. I conclude with the analysis of the results, along with a set of considerations relevant both in terms of economic theory and policy.”

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1. Energy poverty: definition

1.1 The main features of the energy poverty phenomenon

There are many different visions and conceptions of energy poverty. A general definition affirms that energy poverty occurs when a household is unable to secure a level and quality of domestic energy services (space cooling and heating, cooking, appliances, information technology) sufficient for its social and material needs [Bouzarovski, 2018].

Energy poverty affects millions of people worldwide, even if the causes and consequences vary depending on context [ibidem].

The concept can be further detailed, looking at some specific characteristics attributable to this kind of poverty [González-Eguino, 2015]:

- energy poverty is supposed to happen in absence of choice for the household. This means that the energy poor household is deprived of access to energy, or its access to energy is not sufficient to provide basic services such as cooking, washing and home heating and cooling, affecting so the access to other fundamental services such as information, education, health and participation in the society

- the condition of energy poverty does not allow to meet some essential services (in addition to the ones mentioned above, lighting, transportation, work and access to information and communication technologies are some examples). In fact, it is important to remind that energy is a vector to furnish energy services. So, the lack of these services, more than the lack of energy itself, is the main feature of energy poverty

- once the household has access to energy, to not being considered energy poor it is necessary that the energy source is available, so it is “reliable”, for instance not being subject to continual breaks in service, and affordable, meaning that it is at the reach of the household’s economic condition.

  It is generally referred to an energy as being “modern” or “adequate” when its usage is safe, so not liable to endanger health, and environmental benign, thus not compromising environmental damages

The concept of energy poverty can be related to many other important notions. Energy poverty has been explained using the “energy ladder” metaphor. According to this path, the people most affected by energy poverty are the ones with a low income or expenditure level, so those who are located at the bottom of the “social ladder”. On the contrary, as much as the income or expenditure availability increase (and thus the person advances to the top of the ladder), the subject is considered to be marginally affected by energy poverty.

This metaphor is likely to indicate a discriminating conception as it deals with the person condition considering only its income or expenditure level. Some examples that invalidate the “energy ladder” assumption are the contexts in which energy is not accessible, ad so even if people with a higher income or expenditure could afford it, they do not dispose of the energy source. In addition, the people’s energy needs can be differentiated notwithstanding the income or expenditure condition; for instance the differences could depend on the composition and the physical conditions of the people forming the household (as the presence in the household of disable people or of persons having specific energy requirements, which can increase the household energy spending).

For this reason, the slightly different option of “energy stacking” model has been used to describe energy poverty.

In this case, it is assumed that people can be used to dispose of more than one fuel or energy source to fil their energy necessities. The energy poor are the ones that at the time to select an energy source among different alternatives have to adopt a low quality energy source (meaning less performing energy sources which can also have harmful consequences on health and environment). The non-energy poor are those who, between the different energy sources, have the possibility to choose the modern and clean ones. The interesting fact of this approach is that in addition to economic dimension, it stresses on the infrastructural one and it gives more attention of the people possibility of choice between distinct energy sources. But, at the same time, it assumes that low quality energy sources are the cheapest ones, while modern and clean energy sources are at the exclusive reach of the wealthier people.

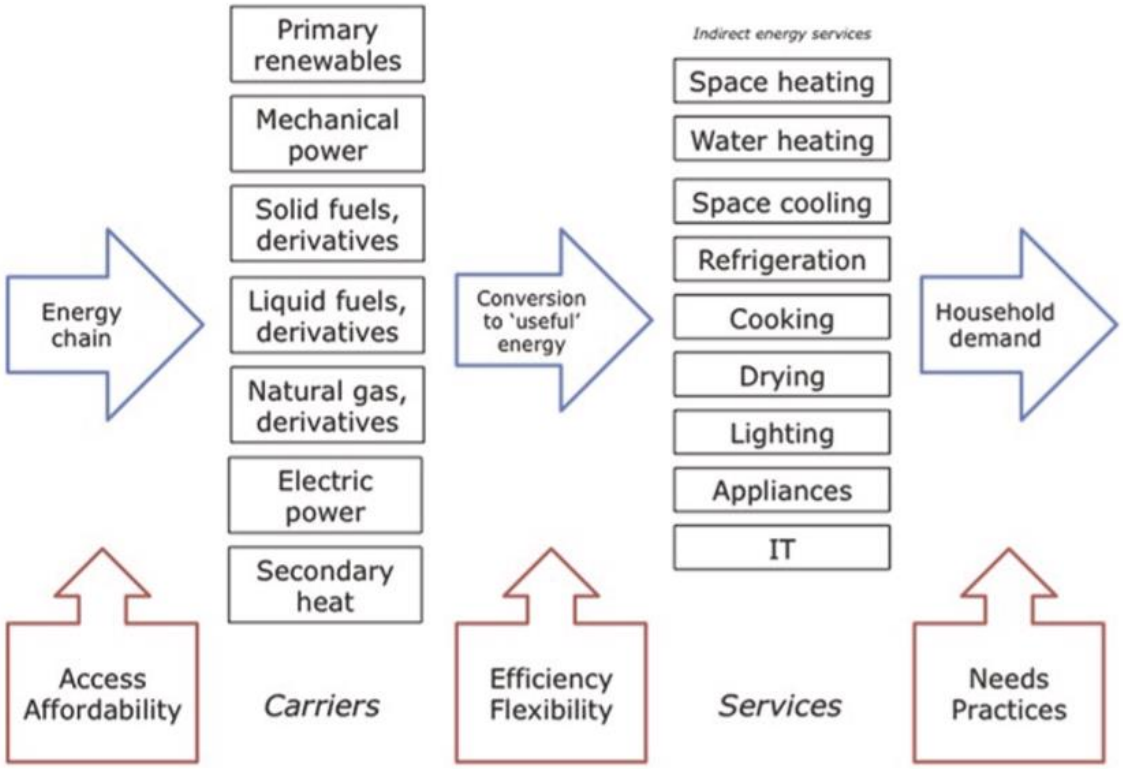
This is situation cannot always be verified and it has to be considered that in the choice among alternative energy sources, also other dimensions intervene such as education and information.

To this extent, Bouzarovski and Petrova elaborated a more comprehensive approach to describe energy poverty which takes into account both the “energy ladder” metaphor and the “energy stacking” model [Bouzarovski, 2018; Simcock et al., 2018].

They so elaborate the “energy vulnerability” system as displayed in Figure 1. This system allows to study the energy flow from its starting point, the energy chain, so the characteristics of the energy supply, to the final point, the household energy demand to accomplish the needed services. The left side of the system mainly relates to the infrastructural aspect of the energy provision, while in the right side are examined the socioeconomic practices that define the household.

The energy vulnerability consists in the presence of one or more lacks or inadequacies in the energy flow, and the existence of energy vulnerability is defined as the condition for energy poverty to happen.

Figure 1 The “Energy vulnerability” system



Source: Bouzarovski (2018)

This “energy vulnerability” approach to define energy poverty is useful to understand the variegate drivers of energy poverty and to capture the dynamic and changing nature of this phenomenon, identifying the possible points of action to control it.

1.2 Measurements of energy poverty

While Chapter 3: Measuring energy poverty will provide a more detailed description of energy poverty indicators, here I describe the general framework to define and measure process energy poverty.

Research on energy poverty has been conducted both in developed and developing countries. While in developed countries the focus has traditionally been on energy affordability issues, in developing countries the attention has centred on energy accessibility and availability, so for example emphasizing on supply side the need to expand electricity grids.

Measuring energy poverty can be a very important and needed process when it comes the time to evaluate this phenomenon. In the meanwhile, to find the right method to measure energy poverty can result in a complex and challenging task. This possibly due to the multi-faceted nature of energy poverty (meaning that it affects many disparate areas of the households' life) and to the various temporal, spatial and sociocultural context in which energy poverty takes place.

To this respect, some different thresholds are identified in order to assess the energy condition of the population and to recognize which people are energy poor and which are not. The energy poverty thresholds can be classified depending on their typology:

-a "physical threshold" approach generally considers some necessities and computes the energy consumption level associated with the fulfilment of these necessities. That minimum level of energy consumption becomes the energy poverty threshold. Who has an energy consumption level below the threshold is considered energy poor while who equals or overcome the threshold is not

-an "economic threshold" approach relates energy poverty to the expenditure or income condition of the household. The definition of the threshold can be made either for the energy expenditure variable or the total expenditure or income variables.

In the first case, it is defined a threshold of minimum energy expenditure that has to be met by the household in order to not being considered as energy poor.

In the second case this minimum energy expenditure is subtracted to the overall income or to the overall expenditure, obtaining a residual income or residual expenditure, which is compared to a previously defined poverty threshold

-a “technological threshold” approach describes the energy poverty condition depending on having access to an adequate energy source. The energy poor are the ones who do not dispose of an adequate energy source to fulfil essential needs, while those who have access to it are defined as not energy poor

Focusing more specifically on the “economic threshold” approach, it is possible to highlight at least three main modalities used to set the energy poverty threshold.
These three modalities actually originate from the measuring process of poverty and can be usefully adapted to measure energy poverty.
The first modality, the *normative approach*, consists in estimating the cost of a set of essential energy goods and services, and thus define the energy poverty threshold as the amount of energy expenditure necessary to get these energy goods and services or alternatively to subtract the so defined energy poverty threshold to the total income or expenditure of the household and relate the result to a poverty threshold, which should also be defined using a *normative approach*.
The second modality, the *positive approach*, estimates the energy poverty threshold to be the amount of energy expenditure of the poor people as so defined by existing absolute or relative poverty lines, in which the poverty threshold is also supposed to be computed using a *positive approach*.
The third modality, the *standard approach*, uses as energy threshold a standard value which has generally already been defined according to historical trends of the considered phenomenon.
The *normative approach* has not been widely used because of the technical difficulties to compute its energy poverty threshold, as well as the value judgement that the adoption of the approach involves and the difficulties in the comparability between the energy poverty thresholds defined by this approach. The *positive approach* is possibly more value neutral and the energy poverty thresholds defined by this criteria are assumed to have a wider degree of comparability one within each other, because they are constructed using

quite similar criteria (for example computing the necessary energy expenditure by deriving it from the one of the poor people who meets the minimum standard of calories consumption). The *standard approach* is probably deemed to be the most comparable one because it is computed using always the same energy poverty threshold; it is nevertheless arguable how this energy poverty threshold could be always representative of the different territorial contexts on which it is applied.

The three distinct approaches, the *normative*, *positive* and *standard* one, described until now for the computation of an "economic threshold" of energy poverty, mainly relates to quantitative methodologies (which are based on the usage of a numerical language). It has to be remarked that even if all these approaches are quantitative ones, they can be integrated with qualitative methodologies (consisting in assessment expressed through a verbal language), which are supposed to capture important and specific features of the energy poverty phenomenon.

1.3 The implications of energy poverty

Measuring energy poverty reveals to be an important task as it can provide a better comprehension of implications of energy poverty.

This phenomenon can have various effects on a society, and at least three relevant affected sectors are identified: health and education, economy and environment.

1.3.1 Implications of energy poverty on health and education

The core definition of energy poverty relates to a household condition in her/his housing (or indoor environment), which is considered as the conjunction of the dwelling (the physical building of the house), the home (the social characterization of the dwelling), the immediate environment (the physical surrounding) and the community (the social relations across the neighbourhood).

Climate-environmental research has put into evidence how health status of human organisms as well as of all living forms (animals, plants, microbiotas) varies in respect to different environmental conditions [de Freitas and Grigorieva, 2017].

These environmental effects strongly interrelate to housing conditions (or indoor environment), because outdoor conditions affect housing and viceversa.

For example, looking from an epidemiological perspective, a humid climate can favour the formation of dampness and mold in the indoor environment, which are factors that negatively impact on the household health. At the same time, proper buildings insulation can prevent these health-risk factors and reduce the humidity in the environment [Condemi and Gestro, 2019].

Efficient and adequate energy-using assets can have an important role to hamper the arise of illnesses' morbidity and mortality. Inadequate lighting, spatial and ventilation conditions in housing have been discovered to damage physical and mental health of the household. Noise exposure and sleep disturbances provoke behavioural problems and neurological and mental illness. The exposition to cold and warm environment also strongly impacts the thermo-hygrometric balance with consequent various dramatic body disfunctions, including cardiovascular and respiratory diseases. All these factors also impact the educational and working results, possibly leading to a decline in the household performance and reducing its possibilities to meet opportunities.

The energy poverty condition, and thus the lack of efficient and adequate energy sources to accomplish essential needs as cooking, lighting, heating, cooling, washing and sleeping does not allow to contrast the increase of certain health-risk factors which can negatively impact the people well-being.

1.3.2 Implications of energy poverty on the economy

Moving from a housing-based conception of energy poverty to a more extensive unit of analysis, as for instance a country, it clearly emerges how also relevant the implications of energy poverty can be for economic growth and development.

Energy is a fundamental source for the majority of the economic sectors: production, transportation, information and communication technologies. Improvements in access and consumption of energy may have a substantial impact on the production path and on the innovation generation in an economy. Given the interrelation between economic sectors, it is predictable that an energy change in one sector will lead further changes in some other sectors [González-Eguino, 2015].

However, it is a matter of fact that access to energy is not uniform worldwide and the costs and the benefits of its usage are not equally distributed within world's and countries' economy. To this extent, it is possible to describe the energy poverty condition

within a territory and its respective economy, using the concept of "energy justice" [Samarakoon, 2019; Bouzarovski, 2018].

This approach examines the level of fairness within the energy system and it is articulated according to at least three dimensions of justice:

-the *distributive justice* considers the fairness among the distribution of energy resources

-the *procedural justice* analyses the fairness in the decision-making processes related to energy sources

-the *recognition justice* relates to the equality of treatment between different sociocultural identity groups

In this case, energy poverty can be considered as the result of an injustice in energy distribution management. Its implications arise not only across socio-demographic or socio-economic groups of the country's economy, but also along the geographical space in which the economy takes place.

1.3.3 Implications of energy poverty on the environment

When considering the energy poverty implications in relation to health and education, it is stressed how the energy poverty condition affects the health and the education, as the phenomenon leaves the household in a more vulnerable condition. As regards the economic implications, it comes into evidence that energy poverty undermines the potential of growth and development of a country, but at the same time it can be considered as a condition determined by unproper economic and political decisions. In relation to the environment, it becomes more evident how actually are environmental conditions to influence energy poverty [González-Eguino, 2015]. If it is true that energy poor households can be more used to rely on polluting energy sources (as less efficient energy implants or non-technological use of biomass) which damage the environment, it is also true that climatic and environmental effects as global warming affects more the energy poor households, who don't have the necessary energy equipment to face the situation.

1.4 The compliance with the sustainable development goals (SDGs)

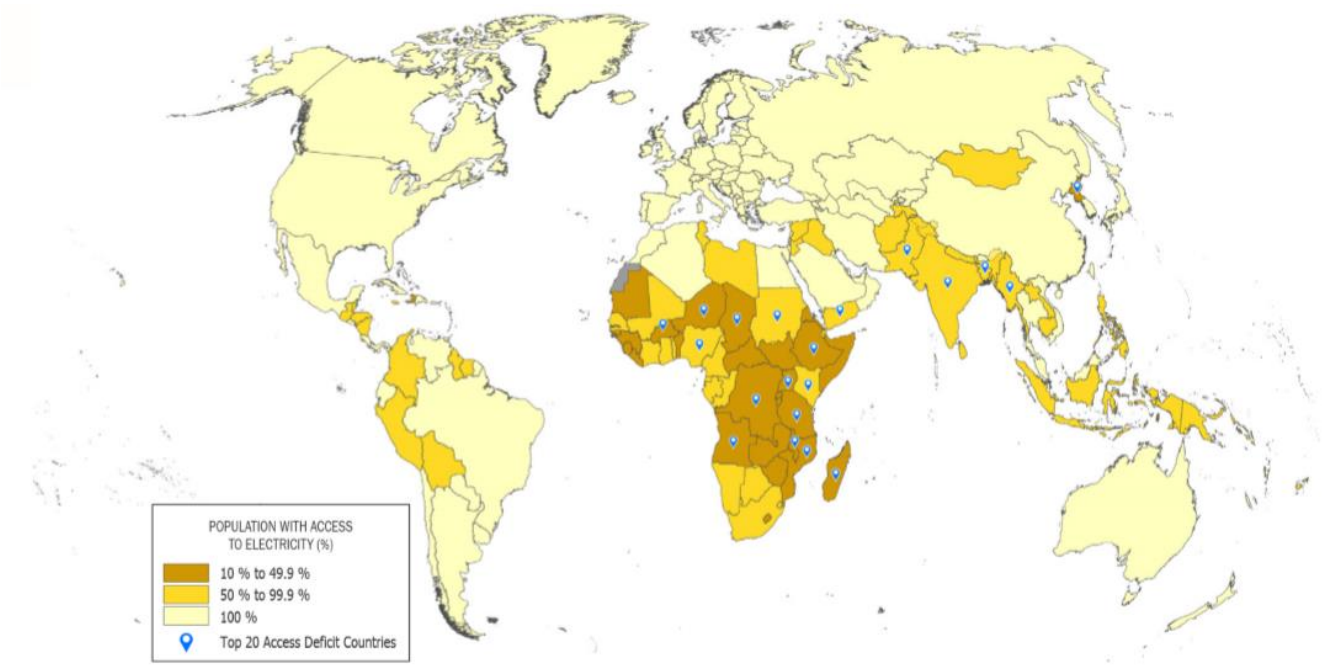
The attention to energy poverty issues has been growing in the last years both in academic research and in policymaking. The United Nations organization addressed energy poverty in the formulation of Sustainable Development Goals (SDGs) in 2015. Specifically, the Sustainable Development Goal 7 aims to "ensure access to affordable, reliable, sustainable and modern energy for all" [United Nations, 2019]. This goal is articulated in three main targets: provide universal access to electricity and access to clean cooking solutions, increase the share of renewable energy on global energy, improve energy efficiency and promote access to technology and investments in clean energy [World Bank and International Energy Agency 2015; International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank and World Health Organization, 2019]. The "Tracking SDG 7: The Energy Progress Report 2020" provided by the IEA, IRENA, UNSD, WB, WHO international organizations, presents the results that follow in relation to the process of achievement of the sustainable development goal 7 and thus to the possible consequent reduction of energy poverty.

1.1.1 Access to electricity and to clean cooking solutions

The share of the global population with access to electricity was estimated in the 90% of the total global population, with 789 million people resulting excluded from the access. This is an advance in respect to the share of 83 % in 2010. Anyhow, this advance has not equally proceeded among world's countries.

Countries in Central and South America, Central, South and East Asia increased their shares of electricity and some of them approached universal access. The most affected area by deficit in electricity access remained the sub-Saharan Africa, where the population access rate is 47%. In addition, the 78% of the global population without access to electricity results to be located in 20 countries, the ones with the largest access deficits including among the main three Nigeria, Democratic Republic of Congo and India. Disparities have been denoted also among world's rural and urban areas. In 2018, in rural areas the electricity access rate was 80%, while urban areas were close to electricity universal access, with a population access rate of 97%.

Figure 2 Share of population with access to electricity, 2018



Source: Tracking SDG 7: The Energy Progress Report 2020, IEA, IRENA, UNSD, WB, WHO

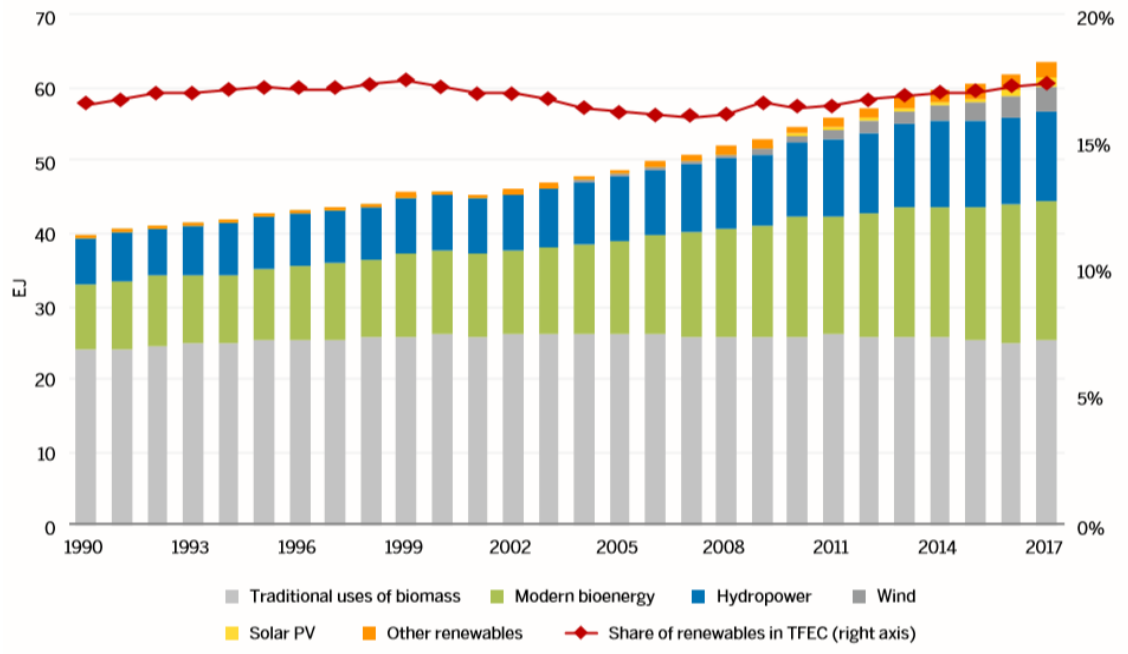
As for the access to clean fuels and technologies for cooking, the share of global population who disposed of it in 2018 was approximately 63%, leaving 2.8 billion people without access. The value of this share in 2010 was estimated in 56%. The slower increase in this kind of access is attributable to the simultaneous growth trend in the population. While in Central, South and East Asia resulted important improvements, in sub-Saharan Africa the increase rate of access (8.5% between 2014-2018) was too reduced in respect of population growth rate (26.7% in the same period). From 2014 to 2018, the 82% of the global population without access to clean fuels and technologies for cooking was located in the 20 countries with the largest rates of lacking access population.

In 2018, a strong disparity in this access was evidenced between rural areas (the access share was 37%) and urban areas (the access was 83%).

1.1.2 Renewable energy

The share of renewable energy consumption over total final energy consumption (TFEC) in 2017 was 17.2%, showing an increasing trend with regard from the previous years. Renewable energy is classified in modern renewable energy and renewable energy based on traditional uses of biomass, which can be associated to adverse health and environmental effects. The growth of renewables has been primarily driven by increased consumption of modern renewables, which commanded a 10.5% share of TFEC in 2017. For the same year, the largest increase in the use of renewables came in the power sector, where their share of global electricity consumption reached 24.7 %. This latter share presented a growing trend in the last years, which was mainly driven by solar photovoltaics (PV) and wind energy increase.

Figure 3 Share of renewable energy over total final energy consumption, by technology, 1990-2017



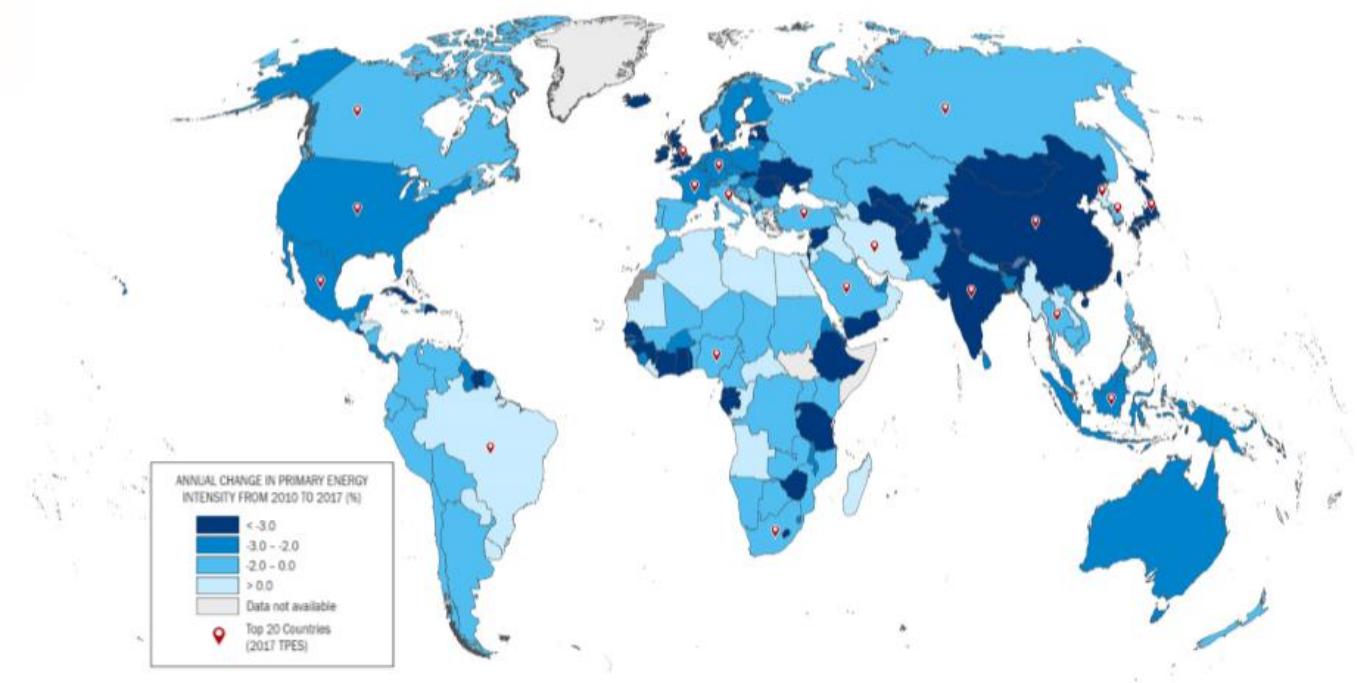
Source: Tracking SDG 7: The Energy Progress Report 2020, IEA, IRENA, UNSD, WB, WHO

The highest share of renewable energy in TFEC for 2017 was in sub-Saharan Africa. However, it has to be considered that reliance on traditional uses of biomass in the region accounted for almost 85 % of its renewable energy consumption, leaving a reduced space for modern renewables.

1.1.3 Energy efficiency

The proxy used to represent global energy efficiency is the decrease of global primary energy intensity, which is the ratio of global total primary energy supply per unit of gross domestic product (GDP). From 2010 to 2017 the decrease of global primary energy intensity, and thus the rate of improvement of global energy efficiency, followed a positive trend, with an annual average decrease of -2.2%.

Figure 4 Annual decrease of global primary energy intensity (the proxy of the annual rate of improvement of global energy efficiency), 2010-2017



TPES = Total primary energy supply.

Source: Tracking SDG 7: The Energy Progress Report 2020, IEA, IRENA, UNSD, WB, WHO

This is attributed to numerous examples around the world of successfully implemented policies, ranging from minimum energy-efficiency standards, financial incentives, market-based mechanisms, capacity-building initiatives, and regulatory instruments. Nevertheless, in 2017 the decrease of global primary energy intensity (-1.7% from 2016) and so the corresponding rate of improvement of global energy efficiency (1.7%) were the lowest from 2010.

Between 2010-2017, the decrease of energy intensity was higher in the transport sector (indicating an improvement in its energy efficiency), while it was more reduced in services, agricultural and industrial sector (stating for a lower energy improvements efficiency in those sectors).

For the same period, the lowest decreases of energy intensity, so the lowest rates of improvement of energy efficiency, were found in Latin America and the Caribbean (0.5%), Northern Africa (0.4 %) and the Middle East (0.3 %). Asia is where robust and continuous rates of improvement of energy efficiency have been noticed, more than in any other world region.

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2. Energy poverty: literature review

Energy is considered to be an important driver of economic growth and development [Pachauri and Spreng, 2004; Sagar 2005; Phoumin and Kimura 2019; Sadath and Acharya 2017]. Deprivations in clean energy have a negative consequence on a multiplicity of aspects, such as livelihood, health, climate and economy [Pachauri and Narasimha, 2013; Yadav et al., 2019].

Policy making plays an essential role into addressing a country's resources and promoting their fair usage, assuming as its own priority the well-being of the population. A number of energy-related policies and interventions, both at the international and national level, started to take place. The Paris Agreement (2015), the carbon tax, the cap-and-trade systems, as well as fiscal incentive policies to encourage modern renewable energies, are some examples.

Addressing energy poverty today means doing that in a sustainable way. This means that, if on one side it is remarkable that more poor people are gaining access to electricity, on the other side a bigger effort is required by governments to invest in and guarantee renewable and efficient energy systems [World Bank and International Energy Agency 2015; International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, World Bank and World Health Organization, 2019].

Indeed, the United Nations organization included the topic among the Sustainable Development Goals (SDGs) and in goal 7 it is specifically stated the need to achieve "affordable and clean energy" for all.

While the number of people without access to affordable and clean energy has been declining, energy poverty still remains a relevant issue.

According to the latest available data, the "Tracking SDG 7: The Energy Progress Report 2020" provided by the IEA, IRENA, UNSD, WB, WHO international organizations, estimates in 789 million the number of people in the world living without access to electricity in 2018. For the same year, the number of people without access to clean fuels and technologies for cooking was approximated to 2.8 billion people. In 2017, the world share of renewable energies over total final energy consumption resulted to be 17.3 %.

However, it has to be considered that within the renewable energy set are included traditional uses of biomass, whose impacts are associated to adverse effects on health and environment. Although great progress has been made with respect to the

improvement of access to electricity and clean fuels for cooking, energy poverty can be defined more broadly as a condition of deprivation of adequate energy services for heating, cooling, and lighting, at home [EU Energy Poverty Observatory, 2020].

Energy poverty has become a relevant theme of interest for academic studies and many authors have analyzed the nature and the impact of this phenomenon. In the energy poverty literature, the idea of insecurity has been defined as the status deriving from an inadequate and insufficient energy consumption that prevents households from meeting basic energy needs [Phoumin and Kimura, 2019].

Developing countries constitute an important context of analysis, as they form a consistent part of the world economy. In developing countries, the issue of energy poverty is mostly related to the need of providing modern energy services for the households, reducing so their dependence on unhealthy and polluting forms of energy and improving energy efficiency [Sagar, 2005].

The remainder of this Chapter reviews the existing literature on energy poverty. The first seminal paper introducing the concept of fuel poverty was published in 1991 by Brenda Boardman with the title "Fuel poverty: from cold homes to affordable warmth". The paper detected the inability to obtain sufficient energy to keep warm in the home in United Kingdom and started to profile the fuel poor and the socioeconomic dimension of fuel poverty.

Since then, the analysis of energy deprivation saw a huge expansion. The impacts of energy poverty were studied in many other countries in the world and implications of this phenomenon on related issues such as health, environment and well-being were discovered [Bouzarovski and Petrova, 2015; Darby and McKenna, 2012; Liddell, 2012].

Next section discusses why, according to the literature, energy poverty can affect growth, population and wellbeing. Next, I focus on the literature addressing energy poverty in developing countries. Section 2.3 reviews how the literature has measured energy poverty. Section 2.4. looks at the literature exploring the connections between energy poverty, climate change and energy policy, and climate change impacts. In the later paragraphs, I discuss the impacts of energy policies in developing countries, with a specific focus on the experience of Mexico.

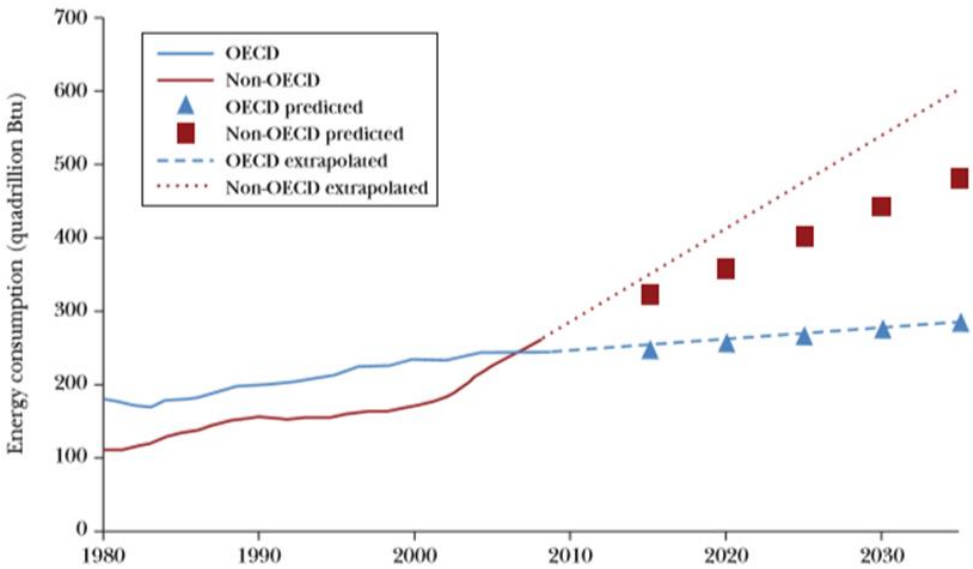
2.1 The relevance of energy poverty

Various academic studies affirm the importance to tackle energy poverty and highlight the negative implications of the energy poverty phenomenon on growth and development opportunities [Teschner et al. 2020; Zhang et al., 2019; Alem and Demeke, 2020]. Persisting lacks of energy access and inequalities in the distribution of energy among a population and a country, undermines low income people's capability to gain adequate living conditions and thus generate long-term growth and development in the country's economy [Oum, 2019; Mastropietro 2019].

Energy-related topics are assuming a growing attention in the economic literature nowadays. Among the other factors, this is also motivated by the fact that the demand of energy is supposed to grow substantially in the next years. Energy can be described as a label under which a number of goods is included such as gas, fossil fuels, electricity, nuclear and natural elements. These elements are used to provide the majority of the existing services like transportation, cooking, manufacturing, heating and many more. Indeed, while the literature commonly talks about energy demand or energy consumption, households actually demand the services that are provided by energy, in combination with durable goods and appliances.

The increase of the demand in energy will be mainly driven by the developing world [Wolfram, Shelef and Gertler 2012 and Davis and Gertler 2015].

Figure 5 Long term projection of energy consumption in OECD and non-OECD countries

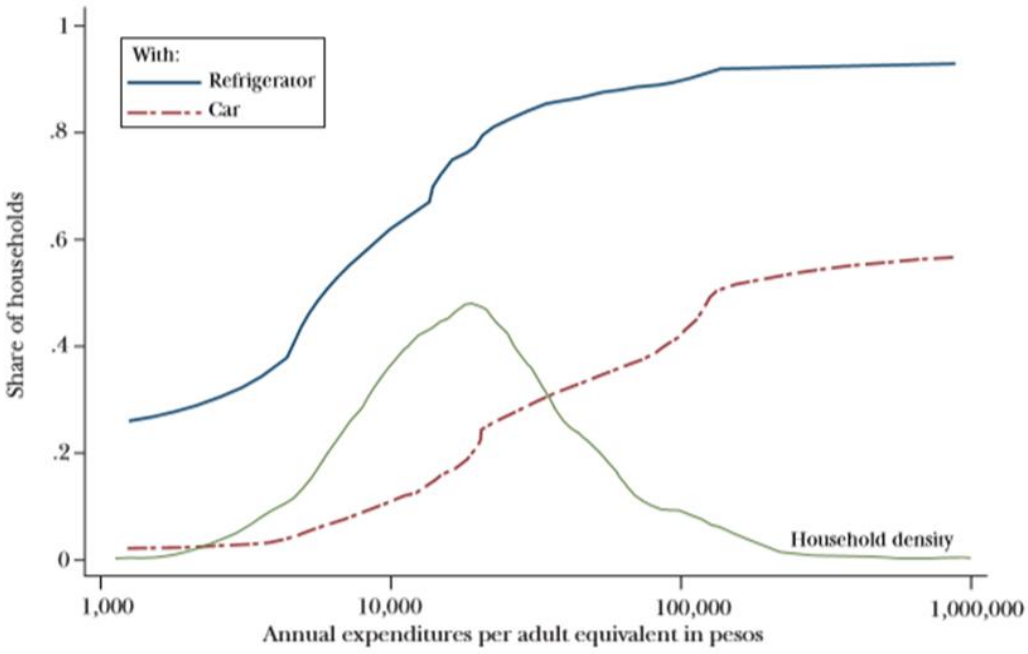


Source: Wolfram et al. (2012)

The economic growth in the developing countries' economies, as well as the demographic increase that characterizes them, can represent some relevant reasons of the augment in energy consumption. Two essential energy vectors that have been considered by the literature include electricity, for the fundamental services it provides, such as refrigeration, clean cooking, light, air conditioning and vehicles.

An example is given considering the situation is Mexico in 2000, according to the data of its national statistical office. The households are classified by adult equivalent (a conversion scale that considers in this case an adult as 1 unit and a household member under 12 as 0.5 unit) and are ordered according to their annual expenditure. The annual expenditure has been prioritized as criteria respectful to the annual income, which can represent a more difficult variable to estimate as it is supposed to be more subject to transitory shocks [Hassett et al.,2007]. The energy consumption level has been plotted along with the ownership rates of refrigerators and cars, as it is displayed in Figure 6.

Figure 6 Refrigerators and cars ownership by expenditure in Mexico, 2000



Source: Wolfram et al. (2012)

The curves of the two assets indicates an S-shaped distribution in relationship to the growth in the expenditure. This condition states for: a low acquisition of the assets in case of low expenditure, a growing acquisition of the assets in an increasing expenditure situation and a stable acquisition of assets after a certain threshold of high expenditure.
Considered this S-shaped pattern for such energy-using assets, the energy growth along the extensive margin, assuming the low-income households increasing expenditure capability and their consequent acquisition of such energy-using assets, is described as an important driver of the demand for energy in the near future.

2.2 Energy poverty in developing and emerging countries

In academic literature, the attention to energy poverty themes is growing. This can be possibly explained by the fact the energy poverty is a phenomenon that, in some measure, affects many territories of the planet.
Studies on this topic cover an increasing number of countries across the five continents: in America (United States, Mexico, Chile, Argentina, Brazil and central American countries), Europe (United Kingdom, France, Spain, Italy, Greece, Portugal ad well as the whole European Union), Africa (mainly sub-Saharian countries like Ghana, Zambia, Nigeria, Republic Democratic of Congo and South Africa), Asia (India and the south-east Asian countries) and Oceania (Australia and other Pacific island states).
Energy poverty affects the developing world, but also the so considered developed countries presents social and geographic areas in which energy poverty is strongly existent, for example because even if energy is available ad accessible it is not affordable for the households [Phoumin and Kimura, 2019].
The reason because of many articles focus on developing countries and precisely on Global South is probably that within this macro-region it is more evident the transitioning process from traditional energy systems to modern ones [Samarakoon 2019]. Furthermore, included in the region, there are countries like India with a supposed relevant impact in energy production and consumption and a consistent potential in determining future energy patters [Sokołowski, 2019].

Considered the recommendations of international institutions such as the World Bank, the United Nations, the International Energy Agency, the International Renewable Energy Agency and of the national governments , it is still not clear which resources should be prioritized in pursuing a sustainable development energy model.

For instance, in some countries the usage of Liquefied Petroleum Gas (LPG), a fossil fuel, is prioritized as a more modern and clean energy to traditional systems based on biomass, which is considered a source of renewable energy [Crentsil et al., 2019; Bhide and Monroy 2011].

In addition, when structuring an energy model in a territory it is essential to understand and evaluate the existing energy patterns within its population. In fact, a number of studies in the literature have identified the power of these patterns to determine the outcomes of policy implementation [Kumar, 2020; Yadava et Sinha, 2019; Mohan and Topp, 2018; Yadav et al., 2018; Yadav et al.,2019].

Once the complexity in regard to energy poverty among and inside countries is assumed, the operational approach in the economic literature is to measure the phenomenon and to provide possible solutions to it. While a general trend to energy poverty reduction has been estimated in developing world [Pachauri et al., 2004], a wide set of actions is proposed in order to contrast this kind of poverty and promote a more sustainable development across the world.

A first suggestion is mainly based on ameliorating the electrification process [Khanna et al. 2019]. Especially in the Global South, various authors identify huge shares of population still lacking electricity and so impeded to adequately benefit of essential services for their life and well-being. This lack can result amplified in rural and remote areas and in low income or wealth populations, such to have negative impacts on health, gender and environmental conditions of those regions and to hamper their development in the future. Investments to deliver electricity and to supply clean energies should be actuated in order to allow people to accomplish services they need in a more socially and environmentally sustainable way [Samarakoon, 2019; Khanna et al. 2019].

Secondly, in the present context of increasing global warming, it is encouraged the pursuing of policy strategies to improve efficiency of energy-using assets like air conditioner, to implement passive solutions such as buildings and city designs aimed at

minimizing environmental damages and incentivize innovative technologies for the improvement of the sustainable development goals (SDGs) [Mastrucci et al.,2019].
It is also displayed that this energy transition process, to eradicate poverty and to improve people's living conditions, to the extent of being effective needs to be associated to educational empowerment in schooling as well as to educational and promotional campaigns with the scope to raise awareness on energy usage, energy dependency, energy economic costs and the implications of energy patterns on health and environment [Crentsil et al., 2019].

2.3 Approaches to measure energy poverty

Given the previous assumptions, in order to promote a better management of energy and to implement specific policies targeted at reducing energy poverty, the quantification of the phenomenon is a fundamental aspect.
A part of the literature has developed decision-making frameworks consisting of three main approaches to measure energy poverty [Pachauri et al., 2004; Pachauri et Spreng, 2004]. The first approach consists in deriving an "energy poverty line", with the purpose to compute the number of energy poor people among a population. To this extent, some options can be:
-calculating the energy needs, usually expressed in an income ore expenditure amount, associated to the poor people defined by a general poverty line and assume that the new calculated value represents an energy poverty threshold that shapes the "energy poverty line"
-establishing an energy poverty threshold, and the consequent "energy poverty line", by looking at energy aggregate information along with other development indexes at the country level (such as the Human Development Index HDI)

The second approach stands on a more engineering insight and it measures energy poverty through the identification of a minimum level of energy consumption, under which the person is considered energy poor. This energy threshold can be more specifically and adequately computed, for instance according to different energy levels (primary, end-use, householder, energy service) and to the nature of their flows (direct and indirect).

The third approach is a sort of combination between the previous two. Once the group of poor people is identified, the categories of energy values associated to it are combined in a matrix together with the values linked to the various kinds of energy sources, which has also to be previously identified and computed. This allows to visualize for each category of energy usage the relative nature of its energy components. It provides a widen perspective on the phenomenon but, as for the other approaches, it has to be considered that a number of value assumptions intervene in the stages of the measuring process and those assumptions should be well-known and displayed when examining the results [Pachauri et Spreng, 2004].

Looking at energy poverty in a broader sense, the literature on the theme has taken into consideration which dimensions of energy poverty are analyzed in the economic studies [Samarakoon, 2019].

A first group of studies is referred to treat energy poverty as only related to consumption, income or expenditure conditions of the household and therefore a more restricted consideration of human behaviour is adopted within these studies, which are so defined unidimensional works. One relevant evidence has been described regarding the differences between the income and the expenditure usage in the analysis [Hassett et al.,2007; del Castillo Negrete, 2015; 2017]. In some cases, current income condition is quite volatile and in a survey context can tend to be underreported, especially by richer households. These factors led some economists to use expenditure as a more useful proxy of the household's economic condition [Granger and Kolstadt, 2009].

The second group of studies considered by the literature deals with energy poverty including in the analysis also other dimensions than income or expenditure. This is the case of multidimensional studies, that include in measuring energy poverty also housing, health, education or political participation of the household [Berry, 2018; Papada and Kaliampakos, 2016; Scarpellini et al., 2019].

This sort of studies offers probably a wider perspective on the energy poverty phenomenon, but in some cases they consistently reduce its comparability among different countries. One possible solution is identified in the contextual development of at least two sets of energy poverty indicators: the first one should be highly specific on the country level, with the aim to permit a consistent comprehension and segmentation

of the phenomenon and to provide useful result in the evaluation of the territorial incidence of a policy. The second set of indicators should balance international measurement requirements and uniformize them at a global level, in order to provide a comparable tracking of the energy poverty phenomenon worldwide [Pelz et al., 2018].

2.4 Poverty, Climate, Energy

Poverty and climate constitute some relevant areas of exploration in economic analyses. The interrelation between the two as well as their effect on a society, is present in many economic studies as well as in other fields of research outside the economic one (e.g. engineering and humanities).

As regards the energy poverty literature, it has been evidenced how poverty alleviation and climate change mitigation are inextricably linked [Ürge-Vorsatz and Tirado Herrero, 2012]. These authors firstly introduce the so-called trade-off between climate and energy-poverty. This conception argues that pursuing climate change actions, such as reducing carbon emissions, consists in investing in energy-efficiency which would be traduced in a higher cost of the energy itself, a cost that would weigh more on poor households.

This can be particularly the case in less affluent geographic and social areas where immediate economic priorities override environmental concerns. So, considered that evidence, they are identified synergies to build, in order to pursue simultaneously the short-term policy goal to alleviate poverty and the long-term one of environmental safeguard. A concrete example is in the buildings sector. Creating energy-efficient residential buildings, equipment and infrastructures can allow a substantial reduction of energy-poverty among the households and mitigating the environmental effects of the assets. In addition, co-benefits of these synergic policies would be the positive impacts on health and living standards of the present generations and the higher socioeconomic and environmental opportunities for the future ones. In fact, effects of insecure and vulnerable conditions on people's quality of life have been revealed to be present and strong.

In the energy poverty literature, the idea of insecurity has been defined as the status deriving from an inadequate and insufficient energy consumption that prevents households from meeting basic energy needs [Phoumin and Kimura, 2019]. Not only

availability, but also accessibility and affordability of energy represents essential characteristics for an energy system to avoid the upsurge of disadvantages that could threaten people's daily life. Many authors extensively studied the characteristics of energy poverty within a country's population, quantifying their different and harmful consequences and identifying the potential of policymaking to solve them [Papada and Kaliampakos, 2019; Boemi and Papadopoulos, 2019; Gouveia et al., 2019]. Specifically, a set of both environmental, meaning ecological and infrastructural, conditions (heating degree days HHDs, cooling degree days CDDs, performance of energy systems) and socioeconomic conditions (household electricity consumption, household water consumption, household income, unit price of heating, cooling, electricity and water) have been considered.

It is denoted that persisting lacks or inadequacy of one or more of these conditions are exacerbating factors of health and social inequality [Condemi and Gestro, 2019]. Therefore, it is deduced that welfare and infrastructural (such as building and lighting) improvements as well as local-based policies are decisive solutions to improve the energy efficiency of a country and thus reduce energy poverty within its population [Gouveia et al., 2019; Gupta et al., 2020].

A fundamental point in the process has been also declared to be the transition from fossil fuels energy systems to renewable energy systems. In this case it becomes evident the so-defined energy trilemma [Gunningham, 2013]. This definition intends to describe three main components that comes into action when dealing with an energy-related policy: energy security, climate change mitigation and energy poverty.The trilemma exists according to the difficulties that are generated in a country at the time to formulate an energy policy. They are supposed at least two types of response when managing the "energy trilemma": one type (the weakest version of the dilemma) occurs when all the three priorities are achieved concurrently, as it can happen in electricity generation, energy efficient initiatives or nuclear power; the second type (the strongest version of the dilemma) consists in the impossibility to pursue the three goal simultaneously and only two of them are achieved.

Anyway, a consistent evidence across the literature is that the management of energy is a prominent link between poverty-related issues and climate change actions.

2.4.1 The energy taxes across the income or expenditure distribution

Access to energy and the ability to pay for energy bills is affirmed to primarily depend on the cost of energy [Hallegatte et al.,2014]. One critical element that affects the cost of energy are energy of pollution taxes. These instruments are supposed to reduce harmful emissions from energy production and consumption, in order to control human action on the environment and to guarantee its protection as well as better living standard for the whole world population.

Energy taxes can be considered as a part of a wider environmental policy because they indirectly internalize the external costs associated with the combustion of fossil fuels [Sterner and Coria, 2012]. Historically energy taxes have been implemented with the main goal of discouraging environmental damaging practices and of raising revenue. The government obtains some revenues by sanctioning polluting activities and unfair use of energy, and later it redistributes those revenues across the population with the aim to promote development. It is affirmable that this kind of policy can result in increasing prices of energy and considering the topic from an equity perspective it is important to evaluate on which group of the population the policy burdens more. Previous contributions [Pizer and Sexton, 2019; Grainger and Kolstad, 2009] have analyzed the distributional impact of energy taxes, reaching important conclusions. The first two authors put into evidence that the most common used environmental taxes nowadays (so taxes on energy included) can present slightly different effects on the population. They define vertical impacts as those affecting different income groups, while horizontal equity refers to the distributional impacts of a tax policy on households belonging to a same income group.

The approach used to analyze the impact of energy taxes on a population can be articulated into the following steps:

1) The considered population is segmented into income or expenditure-based percentiles, which are usually deciles ordered from the lowest (the decile of the population with the lowest income or expenditure, the poorest one) to the highest (the decile of the population with the highest income or expenditure, the richest one)
2) For each decile is computed the share of energy, meaning the amount of income or expenditure devoted to energy over the total amount of income or expenditure

Energy taxes and levies that are imposed in a flat constant way across income groups tend to be regressive. The tax base is computed only on energy consumption without considering other factors, like income condition.

A tax is regressive when the burden, measured in terms of increased energy expenditure, is relatively higher within the poorest part of the population.

In the case of energy taxes and levies, this happens because energy goods and services which are subject to taxation can compromise a more consistent part of the low-income people's budget. In fact, the poor people as the other ones need to spend money to get essential energy goods and services for an adequate living standard, but their budget is reduced.

In addition, another factor that can accentuate the regressivity of the tax is that low-income people are more likely to own older energy-consuming goods, which can present an higher level of energy inefficiency in respect of the newer energy implants, that are supposed to be more within high-income people's reach. Energy poverty is likely to increase if the rise in energy prices is not offset by an increase in energy efficiency [Ürge-Vorsatz and Tirado Herrero, 2012].

Thus, regressivity has been defined by the literature as a direct effect of energy taxes on the population, even if with different gradualities. This is an evidence that poses important questions above the implications of energy policies and climate change mitigation. In fact, given that the aim of those instrument is to pursue equity in the population, it should be relevant to consider the distributional effects that their implementation generates.

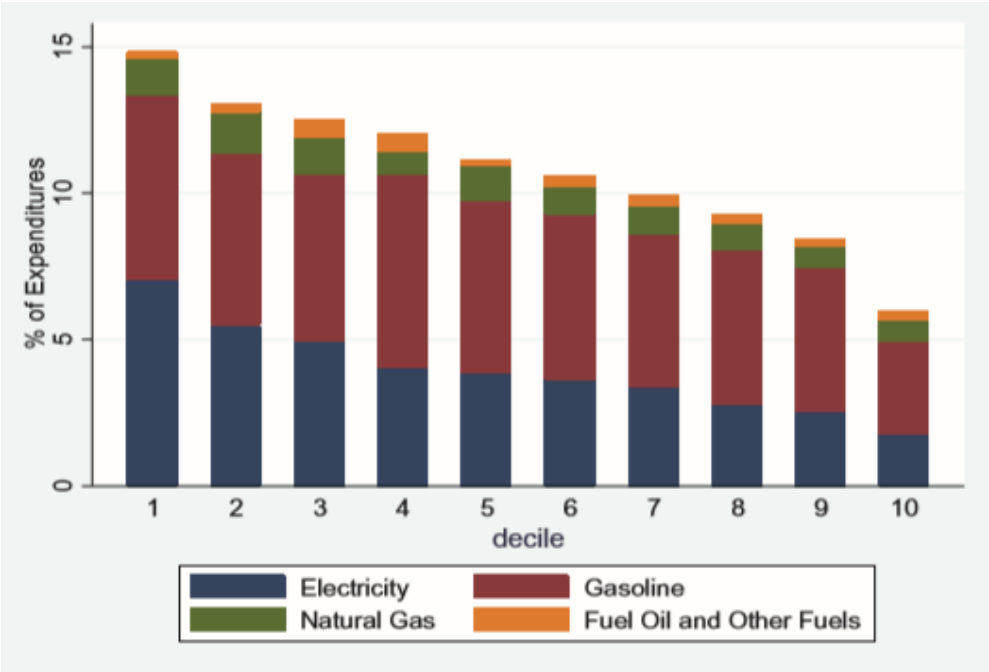
To address these concerns, the contributions on the theme suggest to monitor the variations of the effects of the regulation within the population and promote a goal-oriented usage of the revenues deriving from the taxes.

A possible concrete representation of the matter is provided by the following figures.

In Figure 8 are shown the shares of energy expenditure on the overall expenditure (where energy main components are considered to be electricity, gas, gasoline and other fuels) of each decile of the population in the United States of America as for 2014.

In this case, it is evident that the shares of energy expenditure on the overall expenditure decrease at the increasing of the overall expenditure (which is expressed through growing deciles of the population).

Figure 8 The share of energy expenditure in the USA

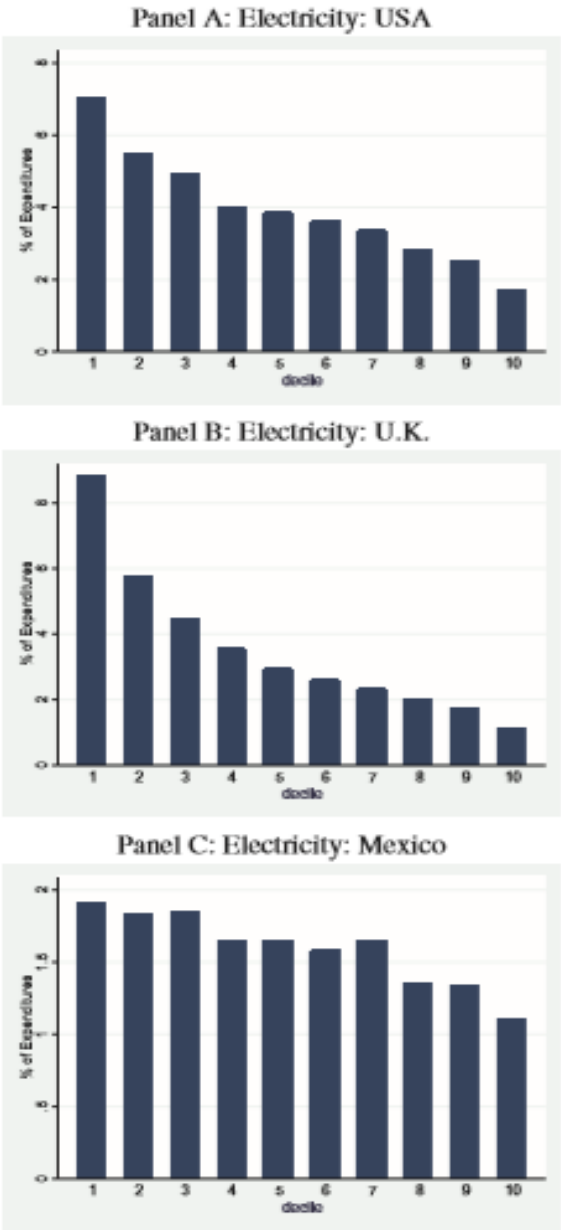


Source: Pizer and Sexton, (2019)

So according to this trend, the energy expenditure represents a much more consistent portion of the poorer household's budget in respect to the richest households whose budget is less affected by the energy expenditure, considered their higher availability of expenditure. This means that direct effects of an energy tax can have a higher impact on poorer groups rather than on the richer ones.

This condition of energy shares disparity has been estimated also for other countries and it is among the principal drivers of the energy taxes regressivity. Electricity is the component in which the difference among the shares of energy expenditure is more present, as it is described by Figure 9. Therefore, it is predictable that the regressivity of an energy tax based on electricity consumption would be quite relevant.

Figure 9 Shares of electricity expenditure by decile in USA, UK and Mexico



Source: Pizer and Sexton (2019)

2.4.2 The energy taxes within income or expenditure groups

As it has been mentioned, one of the main approaches adopted in the literature to measure energy poverty across a population has been to consider the differences of energy spending among income or expenditure groups of the population.

One further option is to evaluate the changes of energy patterns within a specific group of income or expenditure.

The ratio of this approach is to evaluate possibly different impacts of energy taxes on households with similar income or expenditure levels. Those differences can arise because of other characteristics that can distinguish a household, such as its location, its habits, or other environmental and infrastructural factors. When formulating and implementing energy policy, these factors should also be considered given that they can influence and differentiate the households' treatment by the policy. If a number of factors define dissimilarities among households, it is affirmable that heterogeneity within their income or expenditure groups is present too and it will emerge in response to the policy. This heterogeneity is therefore supposed to eventually generate variation in tax burden for the households.

Some authors investigated on the subject [Poterba 1991] identifying evidences of considerable within-decile expenditure variation, especially among low-income groups.

In relation to this approach, the different positions of the authors in the literature can be grouped in the two main categories that follow:

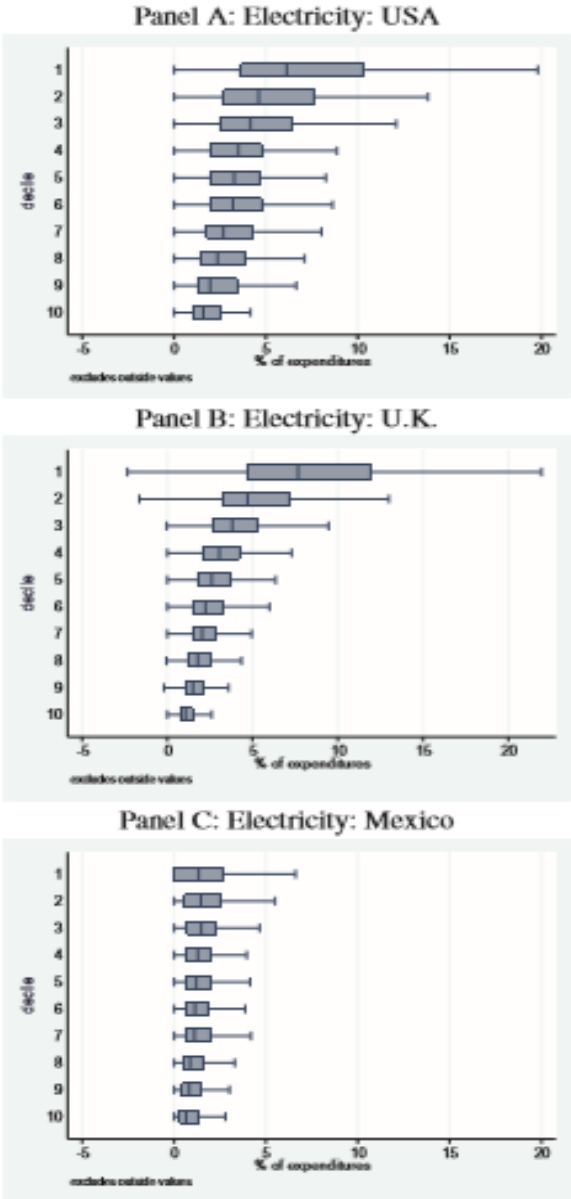
1) Considered the possible difference among households, because of their geographical area, environmental and infrastructural conditions and behaviours, these differences exist before income. Income distributions reflect the households' willingness to pay and therefore the income dimension should be prioritized as criteria to define the tax-payment base
2) Those differences are present notwithstanding the income condition and can largely affect the households. The existing distinctions in other dimensions should be addressed to policy making in order to pursue more effectively the equity goal, introducing compensation mechanisms such as transfers of specific targeting in policy

The different effects of energy taxes within income or expenditure groups of population are displayed in Figure 10.

In this case, for the three countries, it is expressed for each decile the range of values of the shares of electricity expenditure (the lines) and their interquartile range, so the values of the shares located between the 25% and the 75% of the normalized population (the boxes, the vertical line within them indicates the mean of the shares).

The variation within each decile of expenditure is consistent, stating for a relevant difference within each group in bearing the tax burden.

Figure 10 Shares of electricity expenditure within deciles in USA, UK and Mexico



Source: Pizer and Sexton (2019)

The potential growth in energy demand has been also studied in relation to other energy-using assets, like the air conditioners [Davis and Gertler 2015]. In this case as well, it has been identified a growing trend of energy consumption which is supposed to characterize the sector in the close future. Starting from data archived by the US National Climatic Data Center, it has been studied the relationship between temperature, income and air conditioning in the country.

The following regression has been formulated:

$$ln(e_{it}) = \sum_{j=1}^{n} \alpha_j TEMP_{itj} + \beta RAIN_{it} + \gamma_i + \omega_t + \varepsilon_{it}$$

where

$ln(e_{it})$= logarithm of the electricity consumption of the household i in the period t

α= coefficient of change in the temperature

$TEMP_{itj}$= number of days for the household i in the period t at a certain temperature grouped in bin j

β= coefficient of change in the precipitation

$RAIN_{it}$= total precipitation for the household i in the period t

γ_i= fixed effects associated to the household i

ω_t= fixed effects associated to the period t

ε_{it}= error term for the household i in the period t

The study denotes that at the increase of the number of days with a high temperature, the electricity consumption of the household is also incremented.

This increment can be motivated by the usage of energy-using assets, such air conditioners, on behalf of the household.

This aspect has been called in the analysis the “intensive” margin, that is how electricity increases with temperature given today’s equipment stock.

The “extensive margin”, on the other hand, is aimed to indicate how income and climate drive air conditioning adoption decision.

To this extent, basing on the data of the Mexican national statistical office (the ENIGH Survey of 2010), the households have been classified according to their cooling degree days per person CDDs.

The cooling degree days CDDs are used to describe energy consumption of a household according to the need to cool its building. They are computed by subtracting, for each day exceeding the 65°F (18° Celsius) degrees, the mean temperature of the day to the 65°F (18° Celsius) degrees value.

Later on, the households have been divided in two sets according to their average CDDs:

-the below-average CDDs set of households

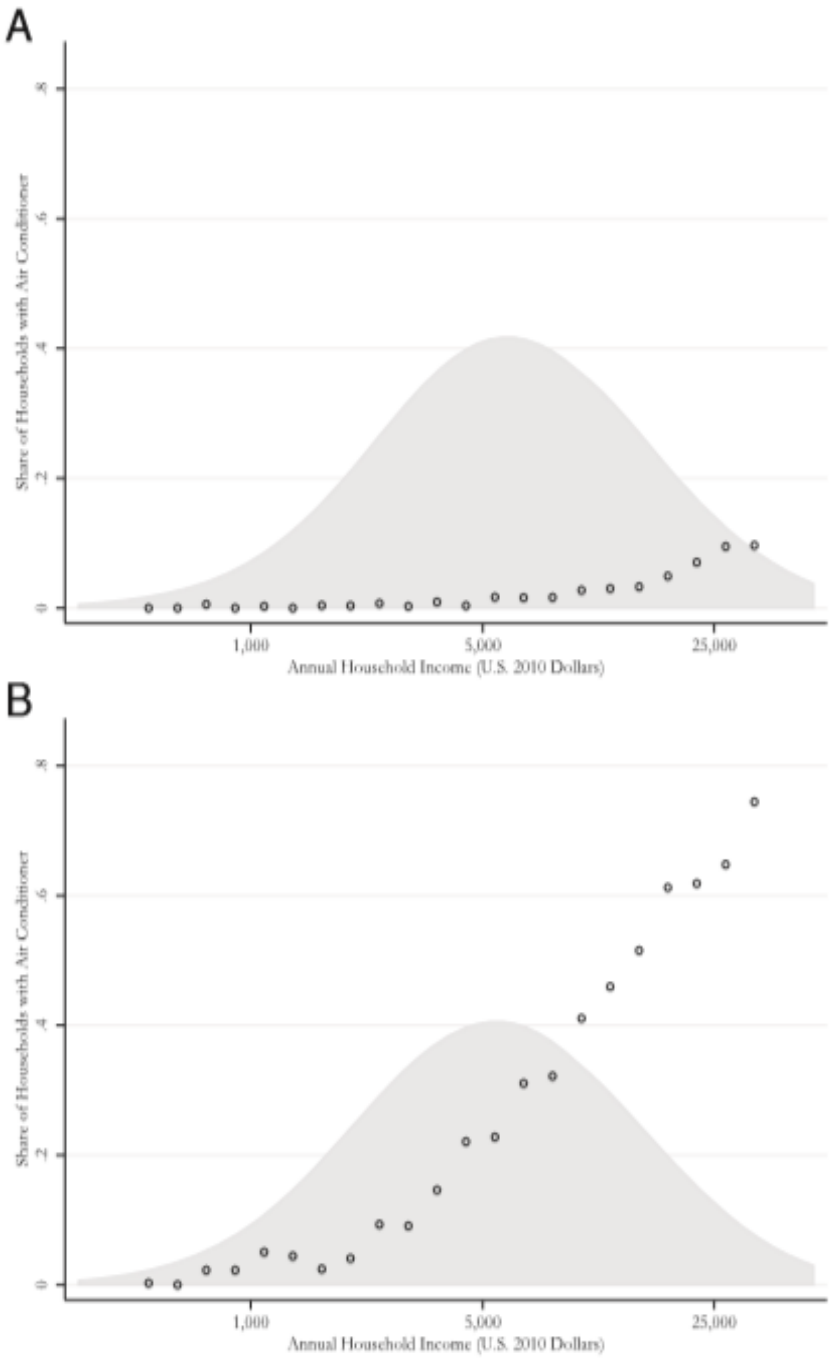
-the above-average CDDs set of households

For each set it has been computed the annual income level of the households and the corresponding share of households with air conditioner. A graphical representation of the topic is provided by Figure 11. It can be put into evidence that both in the below-average CDDs households set and in the above-average CDDs households set, the share of households with air conditioner grows at the increase of the income level of the household.

This means that owning energy-using assets like air conditioner is related to the income availability of the household. It is supposable that a certain level of income is required to install the asset and to afford the additional cost of energy consumption that it entails.

Secondly, it is denotable that the increasing trend of the shares of households with air conditioning is much more consistent in the above-average CDDs households set (B) in respect to the below-average CDDs households set (A).

Figure 11 Share of households with air conditioner by household income, in below-average CDDs municipalities (A) and in above-average CDDs municipalities (B) in Mexico, 2010



Source: Davis and Gertler (2015)

It is so deducible that, along with the income condition, the temperature plays an important role in the acquisition of air conditioning: where the temperature is higher more energy is needed to cool a building, so there are more CDDs per household as in picture B and in this case the households are more oriented to acquire air conditioning systems.

Looking at the near future, a relevant growth in energy demand is predicted by this study. It is assumed that a future growth in GDP will take place in developing economies and this will represent an increment of the income or expenditure of the households. Considered that this is going to be associated to an increasing trend of the global temperature, which is supposed to rise in the very next years, the effects would be the following:

-given the rise of the global temperature, the cooling degree days per person CDDs will augment

-considering the growing income or expenditure level of the households, those ones will be more likely to acquire energy-using assets such as air conditioner

-the energy demand will dramatically increase

In relation to these considerations, there are several implications for policy making. Specifically, it is recommended to promote poverty reduction in order to guarantee an increase in the household welfare together with the implementation of energy efficient technologies headed to mitigate climate change.

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3. Measuring Energy Poverty

Energy poverty is a phenomenon that can be measured by using specific indicators.

An indicator can be considered to be an "*instrument used to measure the condition of something. In economics, it can be computed using data available from statistical offices*".

For example, Gross Domestic Product (GDP) is an indicator that inform us about the level of economic activity.

Indicators, therefore, have a relevant role in shaping our understanding of a phenomenon.

If, on the one hand, an indicator gives us a quantitative and measurable information about something, on the other hand, the selection of a specific indicator affects the measure. Therefore, choosing which indicator to use requires deep understanding of the phenomenon and the indicator themselves. The implication is that, when looking at the results of any analysis that is based on indicators, the conclusion can be sensitive to the indicators that have been selected.

For this reason, it is important to examine to what extent results are sensitive to the choice of the indicator.

This thesis examines the extent of energy poverty by using a number of alternative indicators that have been defined by the literature. The selection of specific indicators reflects the point of view on the theme and it constitutes the way in which the issue of energy poverty is measured and evaluated.

This Chapter reviews the main energy poverty indicators that have been developed and used by the literature [Faiella and Lavecchia 2019]. They are classified into categories based on the following indicators' characteristics:

- Nature: subjective or objective
- Components: budget (expenditure/income) dimension or multiple dimensions
- Degree of analysis: headcount indicators or intensity indicators

3.1 Subjective and objective indicators

The nature of an indicator depends on the type of data used to define it and measure it. Subjective indicators are mostly based on qualitative data, such as factual information expressed by a verbal language and collected through surveys asking specific questions. Objective indicators instead are based on quantitative data, in which the evidence is formulated in a numerical or statistical language [Corbetta, 2015; Cardano et al. 2013].

A deeper view would argue that also the way in which these data are recollected could be connected to the subjectivity or objectivity of the indicators.

Independently from the nature of the data and on whether the information acquired would be processed using narrative techniques or mathematical techniques, it is important to consider:

- the modality through which the information is acquired and how its respective documentation is later constructed. This aspect is able to tell us something in regards to the reliability of our final data, meaning that for example a self-reported information would present a further level of subjectivity, and so a lower reliability, in relation to an officially-tracked information, which could show a wider degree of objectivity and thus an higher reliability [Corbetta et al. 2015]

- the amplitude of the study population, hence on which portion of our unit of analysis (the population) the information is obtained. This aspect affects the generalizability of the analysis. Acquiring information on the entire unit of analysis would provide the maximum amplitude of the study population, so a wider level of objectivity and hence a higher generalizability. Nevertheless, the most common acquisition of information is over part of the unit, a sample. Its realization is ought to obtain a more faithful as possible representation of the whole unit of analysis, but more subjectivity is supposed to be present leading so to a narrower generalizability.

Many works on energy poverty rely on survey-based analyses and not on census, meaning that they refer to a sample population and not to its totality. Surveys based on a sample of the population, however, can be designed to be representative. Population weights are generally used to extend the analysis based on the sample to the entire population. Usually in works both self-reported and officially tracked data are included [Peri 2015]. Notwithstanding these nuances, here the simplistic definition of subjective indicators being defined in terms of qualitative data is adopted, while objective indicators are based on quantitative data.

Objective indicators can be further distinguished into relative indicators and absolute indicators. Objective-relative indicators are defined on the basis of a specific threshold for energy expenditure. Objective-absolute indicators are defined in terms of a minimum basket of services.

3.1.1 Subjective indicators

Subjective indicators are based on questions regarding the subjective perception of a situation or of a phenomenon that is being investigated, and are mainly expressed in words. Some examples of the questions used to build subjective indicators include the followings[1]:

- *Can your household afford to keep its home adequately warm?*

- *In the past twelve months, has the household been in arrears, i.e. has been unable to pay the utility bills (heating, electricity, gas, water, etc.) of the main dwelling on time due to financial difficulties?*

- *Do you have any of the following problems with your dwelling/accommodation?*
  A leaking roof
  Damp walls/floors/foundation
  Rot in window frames or floor

[1] The questions are taken from the European Union Survey on Income and Living conditions (EU-SILC). Available at Eurostat, 19th December 2018, "List of variables", *Income and living conditions-Methodology*, https://ec.europa.eu/eurostat/web/income-and-living-conditions/methodology. The ones that are displayed are respectively questions HH20, HS021, HH040.

3.1.2 Objective-relative indicators

This group of indicators refer to the ones that rely on quantitative data and whose value is defined in comparison to a specific threshold.

A commonly used indicator computes energy poverty in relation to an economic threshold (for this definition, see Chapter 1, paragraph 1.2 Measurements of energy poverty), consisting in the share of energy expenditure over an aggregate measure of household's economic resources. This means that within an objective-relative indicator we first compute the expenditure on energy for household *i*, and we relate that to the total value of its economic resources;

$$Share_i = \frac{energypurchases_i}{economicresources_i}$$

The total value of economic resources, the denominator, can be expressed in either expenditure or income terms. This share, which can be computed for each household, can then be related to a specific threshold, σ.

The threshold σ is a quantity usually computed in the same manner as the share of energy expenditure over total expenditure or income, but it is fixed in time and across households and can be determined through different approaches:

- the *normative* approach: in order to set the σ, it is established a subsistence level of energy expenditure later divided by the overall spending

- the *positive* approach: the share of energy expenditure is determined statistically on the basis of the observed distribution of the historical data of a particular group, for example the poor households

- the *standard* approach: the share of energy expenditure is set equal to a percentage value, generally 10% for gas and 5% for electricity. These are percentages that have been used in specific countries, such as in the United Kingdom, and are also based on observed pattern of historical data

A condition of energy poverty (EP), for the household *i* exists if the ratio between energy expenditure and total expenditure/income is greater than the selected threshold:

$$EP_i = \frac{energypurchases_i}{economicresources_i} > \sigma$$

By counting the total number of households that are in energy poverty conditions, we can define the total number of energy poor.

Some examples of aggregate measures of energy poor based on objective-relative indicators include the following three indicators:

- $\gamma_1 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{\gamma_i} \geq 0.1\right)$

where

γ_1= the energy poverty indicator

n= the total number of households

i= the household

w_i= the weight of the i-th household on the total households

I= the indicator function counting all households for which the condition in parenthesis is satisfied

s_{ie}= the energy expenditure of the i-th household

γ_i= the income of the i-th household

0.1= the settled threshold for electricity expenditure; for gas expenditure it is generally used the 0.05 value

- $\gamma_2 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{S_i} \geq 0.1\right)$

in which the terms are the same of the previous indicator, with the exception of the income of the i-th household γ_i which it has been substituted with its overall expenditure S_i

Both γ_1 and γ_2 provide a primary framework to classify the total number of households that suffer energy poverty.

Yet, neither γ_1 nor γ_2 inform about the socioeconomic conditions of the *i*-th household. For example, there could be rich households that spend a large fraction of their resources on energy, because they are rich and own many energy-using appliances, and fall within the energy poor despite being rich.

To address this drawback the so-called Low-Income High Costs (LIHC) approach, promoted by the British Government in 2011, has been introduced. This indicator can be represented as follows:

- $\gamma_3 = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50_t(s_{ie})] * I[(y_i - s_{ie}) < \gamma_J^*]\}$

in which

γ_3= the energy poverty indicator

n= the total number of households

i= the household

w_i=the weight of the i-th household on the total households

I= the indicator function counting all households for which the condition in parenthesis is satisfied

s_{ie} = the energy expenditure of the i-th household

$P50_t$= the population median at the t time

γ_i = the equivalized income of the i-th household

γ_J^*=the at-poverty risk threshold; the European Union institute of statistic (Eurostat) defines it as the 60% of the national median equivalized disposable income after social transfers

In this case, we can underline that the indicator considers at the same time the socioeconomic condition of the i-th household and its energy expenditure.

By using the γ_3 indicator instead of γ_1 and γ_2 we are able to:

- Avoid incorporating in the energy poors those households whose high share of energy expenditure does not derive from low income but is caused for example by wasting energy habits:

-Distinguish between the energy poor households those whose energy poverty originates from a high share of energy consumption possibly due to the usage of dissipating energy facilities (which is the Low Income High Costs LIHC case)

These differences between the objective-relative indicators can be so displayed:

for the i-th household

in γ_3

s_{ie} / γ_i	Reasons for high energy expenditure	
	Wasting energy habits	Dissipating energy facilities
High income	*Non energy poor*	*Non energy poor**
Low income	*Energy poor**	*Energy poor*

in γ_1 and γ_2

s_{ie} / γ_i	Reasons for high energy expenditure	
	Wasting energy habits	Dissipating energy facilities
High income	*Energy poor*	*Energy poor**
Low income	*Energy poor**	*Energy poor*

*these two conditions are supposed to assume a lower relevance, given that the high-income household is presumed to afford more energy-saving facilities while the low-income household is ought to have saving energy habits as it disposes of a lower expenditure capacity

3.1.3 Objective-absolute indicators

Differently from the above-exposed indicators, the set of the objective-absolute indicators still includes quantitative data based measurements, but those ones instead of being referred to a threshold are related to a considered basket of minimum energy services, usually defined as σ_h for a h-class of households. In this case the energy poverty condition for the i-th household in the h class occurs when:

$$EP_{i,h} = energypurchases_{i,h} < \sigma_h$$

3.2 Headcount and intensity indicators[2]

A further distinction can be made between aggregate indicators of energy poverty [Miniaci et al. 2008]. For example, we can define headcount indicators as the ones that inform us on how many observations forming the unit of analysis are directly impacted by the studied phenomenon; so in our context these indicators would count the number of households who suffer energy poverty.

On the other side, the so-called intensity indicators can capture the depth within the studied phenomenon, such as the distance between an observation to another one. Or, like in our case, how much a household's expenditure or income differ from a critical value of energy poverty.

Taking into account this aspect, we exemplify the difference between the headcount indicators and the intensity indicators presenting an index for each kind of set.

Generally, as for the headcount indicators we can consider the following index:

$$HI = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{s_{ie}}{S_i} \geq \sigma \right)$$

It is evident that the headcount index HI basically recalls what it has been exposed through the γ_2 indicator.

[2] The distinction is here presented focusing on the work of Miniaci, R , Scarpa, C , Valbonesi, P 2008, "Measuring the affordability of public utility services in Italy", *Giornale degli economisti e Annali di Economia*, 67, Jul 2008, pp. 185-230

In this manner we are able to count the number of the so defined energy poor households, such as the ones whose share of energy expenditure on their overall expenditure exceeds a given threshold σ (which is also a share of energy expenditure on the total expenditure and it is considered to be the maximum affordable share for an household).

Regarding the intensity index, which is for instance definable as a poverty gap index PGI, we propose the following equation:

$$PGI = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{s_{ie}}{s_i} \geq \sigma\right) * \left(\frac{s_{ie}}{s_i} - \sigma\right)^{\alpha}$$

where, assuming the other value to be the ones previously defined, we identify in α (which is going to be explained soon) the policy maker's concern for the breach beneath the affordability issues related to energy poverty.

Let us say that with this indicator we do not only consider if the household's share of energy expenditure overcomes a given threshold, but we also define how much this share differs from the threshold.

What we get in the end is a weighted energy poverty. The distance between the household's share of energy expenditure on its overall expenditure and the considered threshold, so $\left(\frac{s_{ie}}{s_i} - \sigma\right)$, depends on the α coefficient.

Usually its value goes from 0 to 2, assuming its increase represents a growing interest of the policy maker to the affordability of energy (basically how much s/he cares about the gap between the household's share of energy and the threshold value):

-with α=0 the policy maker interest on energy poverty is very low; in this case $\left(\frac{s_{ie}}{s_i} - \sigma\right)^0 = 1$ such that the PGI presents the solely first term and it becomes the HI, counting only the number of poor energy households

-with α=1 and onwards the policy maker interest on energy poverty is ought to be higher, as it considers also the gap between the energy poor household and the defined threshold

In addition to these indexes, we might have others more elaborated indicators both for the headcount set and for the intensity set if we opt for a residual income RI-based approach.

It is expressed as follows:

$RI=S_i-s_{ie}$

where

$S_i= p^e * q_i^e + p^o * q_i^o$

$s_{ie}= p^e * q_i^e$

with

p^e=market prices for energy consumption

p^c=market prices for other goods consumption

q_i^e=energy consumption for the i-th household

q_i^o=other goods consumption for the i-th household

To these parameters we add:

q^{em}=minimum quantities of energy considered to provide a decent standard of living

q^{om}= minimum quantities of other goods considered to provide a decent standard of living

Given that, we could identify an Energy Poverty Index EPI, for the i-th household in relation to energy as well as to other goods consumption.

In this way

$$EPI_i^e = 1 * (S_i - p^e * q_i^e < p^o * q^{om})$$

we define the i-th household as energy poor in energy if its remaining expenditure after energy consumption $S_i - p^e * q_i^e$ does not allow her or him to afford the minimal consumption of other goods $p^o * q^{om}$.

That is to say, consumption of other goods $s_{io} = p^o * q_i^o = S_i - p^e * q_i^e$ is above the minimal level $p^o * q^{om}$

$$EPI_i^o = 1 * (S_i - p^o * q_i^o < p^e * q^{em})$$

we define the i-th household as energy poor in other goods if its remaining expenditure after other goods consumption $S_i - p^o * q_i^o$ does not allow her or him to afford the minimal consumption of energy $p^e * q^{em}$.

That is to say, consumption of energy $s_{ie} = p^e * q_i^e = S_i - p^o * q_i^o$ is above the minimal level $p^e * q^{em}$

Conclusively among the residual income-based headcount and intensity indicators we get, there are the followings:

$$HI^{RI} = \frac{1}{n}\sum_{i=1}^{n}(EPI_i^u + EPI_i^c - EPI_i^u * EPI_i^c)$$

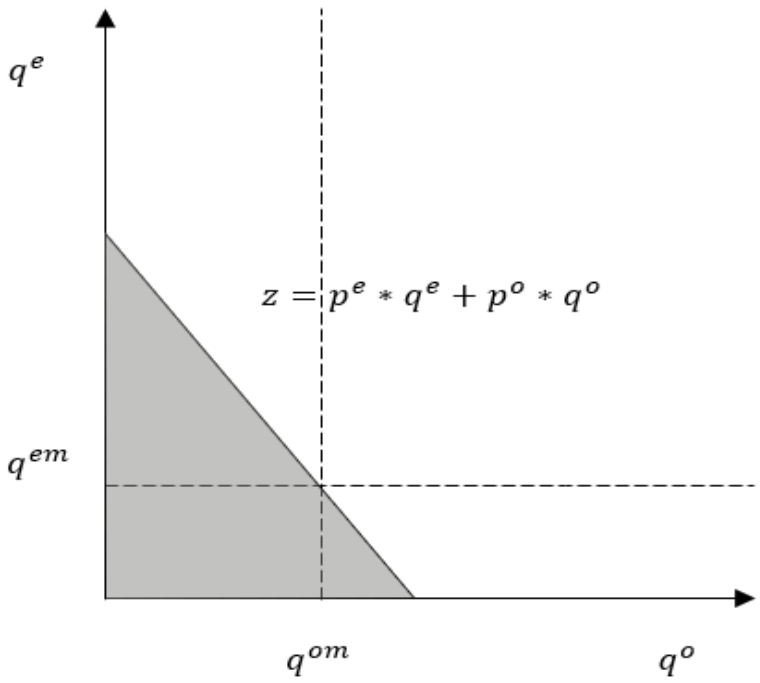
$$PGI^{RI} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{EPI_i^u * (p^c * q^{cm} - p^c * q_i^c)^2 + EPI_i^c * (p^u * q^{um} - p^u * q_i^u)^2}$$

The relevant difference between the headcount and intensity indicators explained at the beginning of this paragraph and the latter residual income-based headcount and intensity indicators can be displayed through the so-called poverty line.

This line is definable as $z = p^e * q^{em} + p^o * q^{om}$ and it indicates a minimal total consumption of goods (here expressed as the sum of energy and other goods) considered to provide an adequate standard of living.

In Figure 12 we see the representation of the absolute poverty line *z*. What is located below the line itself is considered to define the poor households, which are highlighted by the grey area.

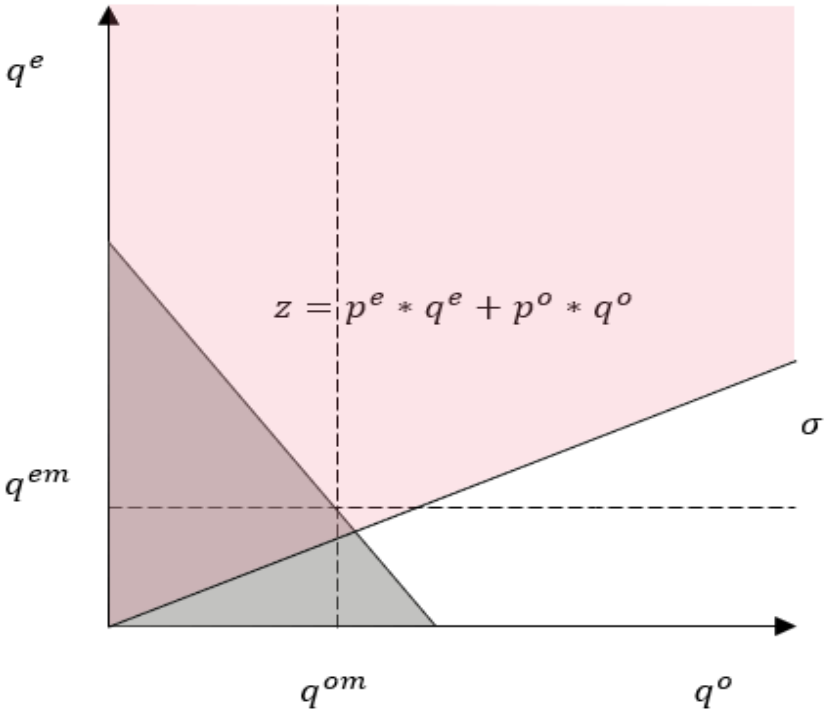
Figure 12 The poor households within the absolute poverty line



Source: Author's elaboration of Figure 5 in Miniaci, R, Scarpa, C , Valbonesi, P 2008, "Measuring the affordability of public utility services in Italy", Giornale degli economisti e Annali di Economia, 67, Jul 2008, pp. 185-230

On this assumption we can now turn to the headcount and intensity indexes and to the residual income-based headcount and intensity indexes, respectively presented through Figure 13 and Figure 14.

Figure 13 The energy poor households as for the HI and PGI



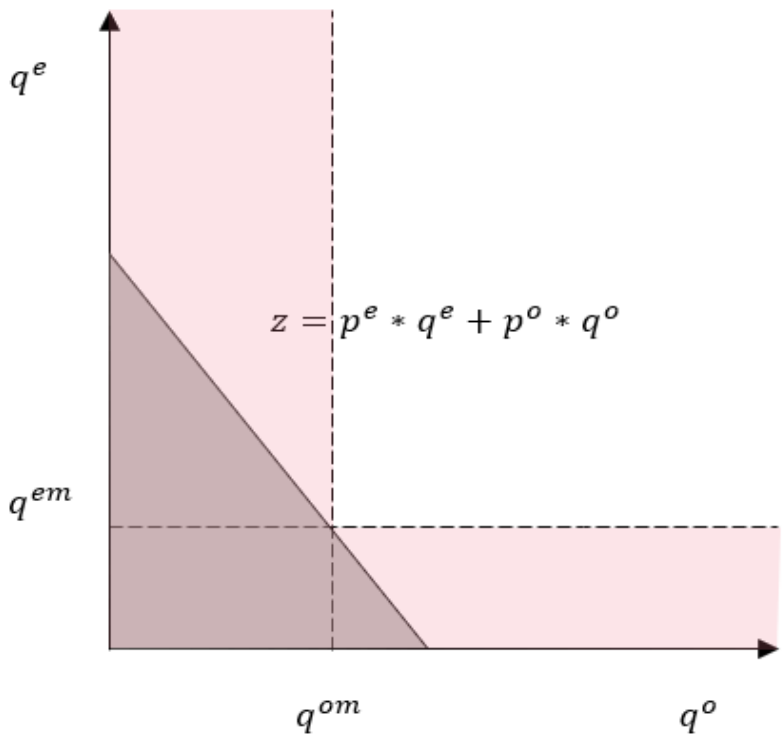
Source: ibidem

In this case $HI = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{s_{ie}}{s_i} \geq \sigma\right)$ and $PGI = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{s_{ie}}{s_i} \geq \sigma\right) * \left(\frac{s_{ie}}{s_i} - \sigma\right)$ defines energy poor household the values that stands above the threshold σ, which is supposed to be the household's maximum share of energy expenditure on the overall expenditure after which the household becomes energy poor.

It is possible to denote that these poor households (indicated by the rose area in Graph 2) exclude a consistent part of poor households (in the grey area), including at the same time an extensive portion of households (on the right side of the rose area) beyond the minimum consumption lines q^{om} and q^{em}, which is supposed to afford an energy consumption and an other-goods consumption that exceeds the responding minimum settled levels.

The indicators γ_2 and γ_3 defined in the previous paragraph (3.1.2) constitute an example respectively of HI and PGI.

Figure 14 The energy poor households as for the HI^{RI} and the PGI^{HI}



Source: Author's elaboration of Figure 6 in ibidem

The other options $HI^{RI} = \frac{1}{n}\sum_{i=1}^{n}(EPI_i^e + EPI_i^o - EPI_i^e * EPI_i^o)$ and $PGI^{RI} = \frac{1}{n}\sum_{i=1}^{n}\sqrt{EPI_i^e * (p^o * q^{om} - p^o * q_i^o)^2 + EPI_i^o * (p^e * q^{em} - p^e * q_i^e)^2}$ identify the energy poor households (settled in the rose area) as the ones who are not able to afford the minimum level of energy consumption q^{em} or those who do not afford the minimum level of other goods consumption q^{om} as still as the households who cannot afford neither of the two.

3.3 Budgetary indicators and multidimensional indicators

As we have already said, we can suppose that the role of the indicators is essential in detecting the nature of a phenomenon.

For several years, the economic approach to energy poverty has mostly relied on budgetary indicators [Berry, 2018]. A budgetary indicator defines energy poverty according to the position occupied by energy expenditure within the budget of a person/group/household. In this case, an energy poor is the one whose budget is relevantly affected by energy expenses.

Budgetary indicators, however, neglect other important dimensions that come into play when defining energy poverty. This limitation is being addressed by multidimensional indicators, which include in their structure two or more different dimensions at the time to make an analysis.

This kind of approach highlights energy poverty as a multidimensional condition. In this context, energy poverty is connected not only to monetary economic resources but also to conditions pertaining health, living conditions and quality of life.

For this reason, it assumes multidimensional indicators to become necessary in order to study the phenomenon.

Here are some examples of multidimensional indicators of energy poverty.

The EPVI indicator, defined as the energy poverty vulnerability index, provides a value located in a range that goes from a minimum to a maximum. The index is supposed to detect the energy poverty condition, meaning that a growing EPVI value states for a higher energy poverty. The EPVI is computed as the arithmetic mean of the EPG sub index and the gap within the AIAM sub index.

- $EPVI = \frac{EPG+(maximum\ AIAM\ value-AIAM)}{2}$

in which

EPG= the energy performance gap is the sub-index that analyses the structure of each building and it is realized taking the difference between the building's final energy demand and the building's final energy consumption, weighted for the building's dimensions

AIAM= the ability to implement alleviation measures is a sub-index composed by some socioeconomic variables (such as unemployment, dwelling ownership, education level, monthly income, age of the population, building's state of conservation) which is aimed to evaluate the characteristics of a given area's population in order to determine its level of ability to mitigate potential energy poverty conditions. It is expressed as a range with the minimum value corresponding to the lowest ability and the maximum value showing the highest ability

Another indicator is the $CEPI_x$, defined as the composite energy poverty index for the x country. It is a comprehensive indicator whose main intent is to consider simultaneously accessibility, availability and affordability of energy when assessing the energy poverty within a country.

It is computed as the difference between the maximum value of energy poverty (100) and the WAEPI index. The resulting number is the value of the x country in the so defined energy poverty scale.

- $CEPI_x = 100 - WAEPI$

The weighted average of the energy poverty indicators, *WAEPI*, can be expressed as follows:

$$WAEPI_{x,year} = \sum_{1=w_i}^{4} (w_1 * access\ to\ electricity + w_2 * access\ to\ modern\ fuels + w_3 * TFES\ pc + w_4 * TPEC\ pc)$$

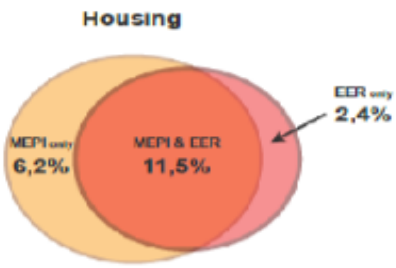
All the indicators are supposed to be normalised. They respectively represent and are related to

w_1= total population with access to electricity (%)	*energy accessibility*
w2= access to clean fuels and technologies for cooking (% of population)	
w_3= total final energy supply per capita ($TFES_{pc}$)	*energy availability*
w_4= total final energy consumption per capita ($TFEC_{pc}$)	*energy affordability*

We can consequently denote that multidimensional indicators are ideally able to provide a wider view on a topic. Meaning that they could cover more of its characteristics. Therefore we affirm that these indicators can capture an higher number of observations within the unit of analysis, basically because the latter is examined in its several facets. But when using multidimensional indicators, it becomes even more important to avoid multicollinearity: meaning that the robustness of our results could derive not from a real expectation but from counting multiple times the same facet of a phenomenon. Furthermore, it is essential to remember that these kinds of indicators, in order to be measured, require a consistent availability of different categories of data, which are not always easily obtainable.

In Figure 15 it is possible to visualize an exemplification of the tie between budgetary and multidimensional indicators, looking at the different portion of sample they cover.

Figure 15 Budgetary and multidimensional indicators



Source: Part of Figure 6 in Berry, A 2018, "Measuring energy poverty: uncovering the multiple dimensions of energy poverty", CIRED International Conference on Electricity Distribution Working Papers, 69, March 2018

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4. Energy poverty in emerging economies: the case of Mexico

4.1 The context of Mexico: a general overview

This analysis focus on measuring energy poverty across emerging market economies. Specifically, a time-series approach is adopted as it considers data regarding different periods of time within the same unit of analysis, the state of Mexico.

The concept of emerging economies is multipolar and mutable, meaning that it is expressed starting from socioeconomical, political and cultural assumptions which have been characterized in different ways over time.

It was originally attributed to World Bank's International Financial Corporation (IFC)'s Investment officer Antoine van Agtmael, which use the term to describe "progress, uplift and dynamism" within developing countries' economies.

On that note, it is possible to restate this classification designing the emerging (market) economies such as:

> *"those countries whose economy is facing a rapid growth and industrialization processes, which can also involve changes in cultural and social structures"*

In the last decades the definition has been adjusted on many diverse countries. Firstly, the BRICs acronym was coined to include in the emerging economies Brasil, Russia, India and China. Secondly, the MINT indicated the presence of Mexico, India, Nigeria and Turkey.

The more general classification of NICs has been also used to describe the so-called Newly Industrializing Countries, thus the states with growth and development rates transitioning from a developing country level to a developed country one.

This abbreviation mainly embraced Singapore, Hong Kong, South Korea and Taiwan to which were subsequently added Indonesia, Vietnam, Malaysia, Thailand and Philippines.

These kinds of classifications are constantly under review however they can provide us a first perspective on the global assets.

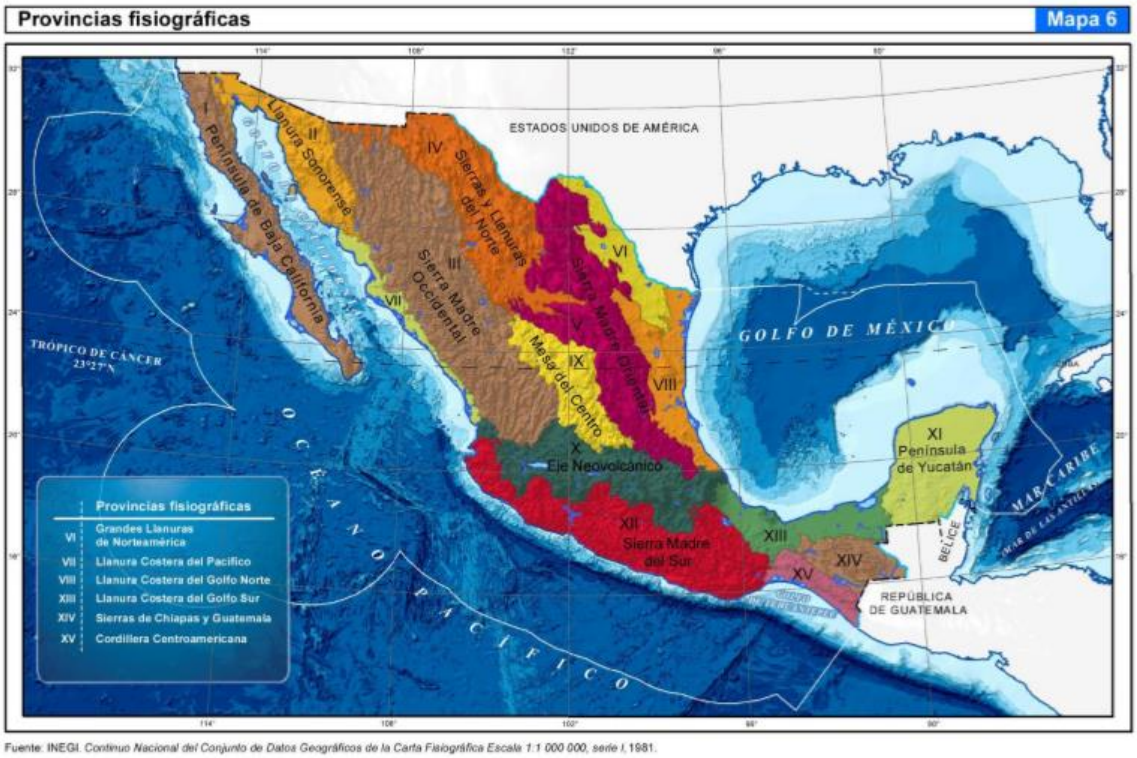
In fact, what they do is to underpin some common features among different countries' market economies with the aim to identify similar path of growth. The country of Mexico, with its peculiarities, which are going to be explained, can be a representative case of the transitions within the set of the emerging economies.

4.1.1 Territory

Mexico, officially named the United Mexican States, has a land surface area of 1 964 375 km^2. According to this parameter it is one of the smallest countries of North America and the sixth largest country of the American continent.

From a physiographic point of view, its territory can be divided into fifteen provinces (as displayed in Map 1).

Map 1 Physiographical provinces in Mexico



Fuente: INEGI. *Continuo Nacional del Conjunto de Datos Geográficos de la Carta Fisiográfica Escala 1:1 000 000, serie I*, 1981.

Source: INEGI Anuario estadístico y geográfico de los Estados Unidos Mexicanos 2019

In the country we can identify four main different kind of climate conditions: the dry clime occupies nearly the half of the state and it is mainly based in the north, another quarter of the territory presents a mild clime that develops from the centre, the remaining quarter shows a warm clime and is principally located in the south while an extremely little part of the country, basically composed by some of inner mountain heights, constitutes a cold clime.

The country is a federal republic composed of thirty-two federal entities and it has a presidential form of government. The president has a term in office of six years with no possibility of re-election.

The division between the executive, legislative and judicial power is present both at the federal level and at the state level. On the federal level, the three ones are relatively represented by the President, which is the head of Government and head of the State as well as Commander in Chief of the Armed Forces, the Federal Congress, a bicameral institution formed by the Senate (upper Chamber) and the Chamber of Deputies (lower Chamber), and the Supreme Court of Justice.

On the state level, there are the Governor of the State, a unicameral Congress and the Supreme Court of the state.

Map 2 The United Mexican States

Source: Maps of the World-Large detailed political and administrative map of Mexico with roads and cities on http://www.vidiani.com/maps-of-mexico/

4.1.2 Population

At the half of 2019, Mexican population was estimated in 126 577 691 people. Among them, female population counted on 64 600 059 members while male population was 61 977 632.

The most consistent part of the individuals was in a range of age of 15-64 years (84 066 399 people), other 33 098 834 were between 0-14 years and the remaining 9 412 458 were among the over 65.

One further relevant distinction that can be considered, is the difference between indigenous speaking and non-indigenous speaking population. In 2015 their percentages on total population were respectively 6.5 % and 93.1 % (a 0.4% was not specified).

In addition to that, at the half of 2018 the crude birth rate (consisting in the number of live births per 1 000 people of the considered population at mid-year) was 1.75 % and the crude death rate 0.6 %. The average annual population growth rate was 1%, with a life expectancy of 75 years.

For the same period, divorce rate on total marriages was 31.2 %.

4.1.2.1 Health

Both the private and the public sector participate in the Mexican healthcare system.

The public sector operates with different healthcare bodies: the IMSS (Instituto Mexicano del Seguro Social), the ISSSTE (Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado), the PEMEX (Petroléos Mexicanos), the SEDENA (Secretaría de la Defensa Nacional), the SEMAR (Secretaría de Marina), the IMSS-Bienestar and some other programmes, the SSA (Secretaría de Salud) and the SESA (Servicios Estatales de Salud). As it is possible to deduce one peculiarity of this healthcare system is that it is centred on the employee position and not on the person itself.

Various national authorities and international organizations recommend the need to develop a unique public health system, which would also necessitate of improvements in accessibility and quality terms. This intention is supposed to be currently pursued through the INSABI (Instituto de Salud para el Bienestar).

4.1.2.2 Education

Among the Organization of Economic Cooperation and Development (OECD) countries, Mexico presents an over-average percentage of public expenditure for education. In 2015 an estimation of the alphabetisation level within the population with 15 years or more indicated a rate of alphabetized people of 93.6 %. The non-alphabetized ones were the 5.5 % and a 0.9 % remained unspecified.

Across the years many Mexican institutions have promoted the realization of a free public education system. Anyway, the situation still remains critic. It is also important to underline that the ethnic and cultural context of the federal republic is widely variegated. If we consider the school enrolment rate in the country, among the population of the 17 years old in 2015, the 65.1 % was supposed to be enrolled in a school institution while the portion of non-enrolled was 34.6 % (a 0.3 % was non-specified).

4.1.2.3 Work

At the half of 2019 the economically active population in Mexico was estimated in 56 951 200 people (34 670 200 males and 22 281 000 females) over a total of 94 622 900 individuals aged 15 or more years (44 983 800 males and 49 639 100 females).

In the group of the 56 951 200 people, the employed were 54 936 700 and the remaining 2 014 500 were unemployed. The prevalent sector of employment was the tertiary with 34 014 100 people, followed by the secondary (13 881 600 people) and the primary (6 731 600 people).

The national minimum salary in 2019 was settled in 3 080.4 pesos per month. This amount corresponds to 160 USD, using Purchasing Parity Power (PPP) Exchange rate. Considering the monthly household total income in 2018, its average value was 16 536.66 pesos. In the lowest household income decile, the average value was 3 037.66 pesos while in the highest one it was 55 583.33 pesos. This is a first measure that detects an existing context of inequality in the country.

4.1.3 Commerce

The Mexican national statistical office INEGI (Instituto Nacional de Estadística y Geografía) defines an economic unit as an establishment pursuing a permanent activity, characterized by fixed buildings and facilities and attributable to a unique owner or controlling authority that manage those resources with the aim of producing and/or commercializing goods or services either for a commercial or non-commercial purpose Table 1 (each sub-table deepens the condition of the last line of the previous table) displays some numerical information of Mexican economic units in 2018, while Graph 3 shows their distribution in the country:

Table 1 Economic units in Mexico, 2018

ECONOMIC UNITS	INSTITUTES	PERSONNEL
Total number	6 269 309	35 463 625
Activity start date: in 2019	324 451	628 802
Activity start date: before 2019	5 944 858	34 834 823

ECONOMIC UNITS with activity start date: before 2019 according to their location	INSTITUTES	PERSONNEL
Total number	5 944 858	34 834 823
Rural area	864 085	2 377 423
Urban area	5 080 773	32 457 400

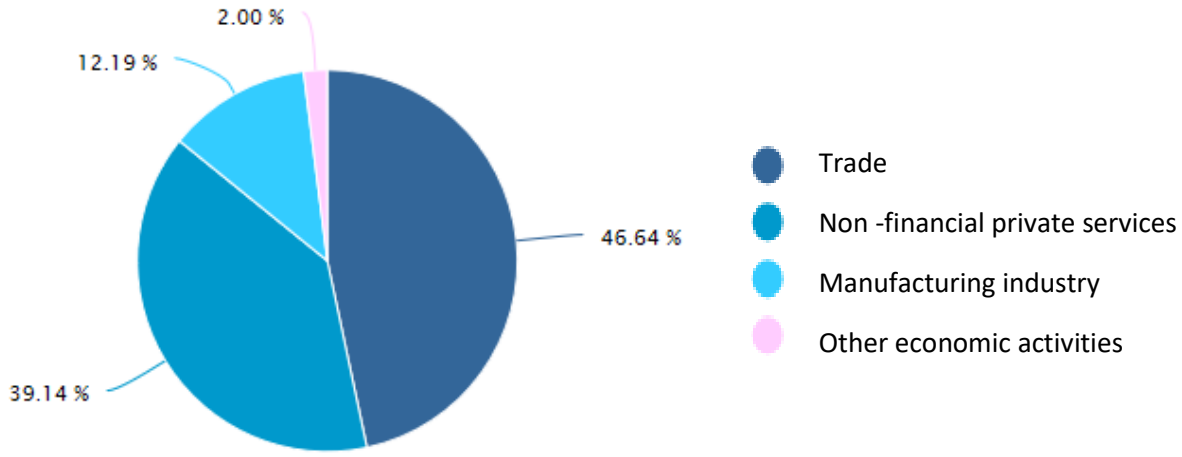
ECONOMIC UNITS with activity start date: before 2019 located in an urban area according to their type of ownership	INSTITUTES	PERSONNEL
Total number	5 080 773	32 457 400
Religious association	85 993	568 462
Public	198 740	5 327 481
Private or para-public	4 796 040	26 561 457

Private or para-public ECONOMIC UNITS with activity start date: before 2019 located in an urban area according by economic sector	INSTITUTES	PERSONNEL	SALARIES (millions of pesos)	COSTS	REVENUES
Total number	4 796 040	26 561 457	1 992 912.2	18 512 156.3	25 675 855.5
Manufacture	582 013	6 555 790	714 467.1	7 971 223.9	11 037 719.7
Trade	2 227 058	7 429 763	300 450	6 493 778.1	8 195 247.9
Non-financial private services	1 868 993	9 542 420	582 726.4	1 775 230.8	3 385 630.5
Others	95 931	3 033 484	395 268.7	2 271 923.5	3 057 257.4

In these terms, within the private or para-public sector the areas with the upmost institutions have been trade (2 227 058 economic units,2 072 796 units in the retail trade and 154 262 in the wholesale), non-financial private services (1 868 993 units), manufacturing industry (582 013 units) and other economic activities (95 931 units). These results are presented in Figure 15.

It is possible to see the geographic distribution of the economic units through Figure 16.

Figure 15 Private or para-public economic units located in an urban area (activity start date: before 2019), by economic activity sector



Source: Re-elaboration of INEGI Censos Económicos. Resultados oportunos available at https://www.inegi.org.mx/programas/ce/2019/

Figure 16 Geographic distribution of the private or para-public economic units in Mexico

Source: INEGI Censos Económicos. Resultados oportunos available at https://www.inegi.org.mx/programas/ce/2019/

4.2 The context of Mexico: the energy sector

Energy demand in Mexico is set to increase significantly in the very next years [International Energy Agency 2020]. This is attributable to potential growth in population and improvements in productivity. The main components of energy in Mexico are oil and gas, as well as a fast-growing electricity sector.

In the last century, Mexico became one of largest oil producers in the world through the State-owned company PEMEX (Petroléos Mexicanos). Despite its status of crude oil exporter, Mexico is an importer of refined petroleum products [Rosas-Flores, 2017].

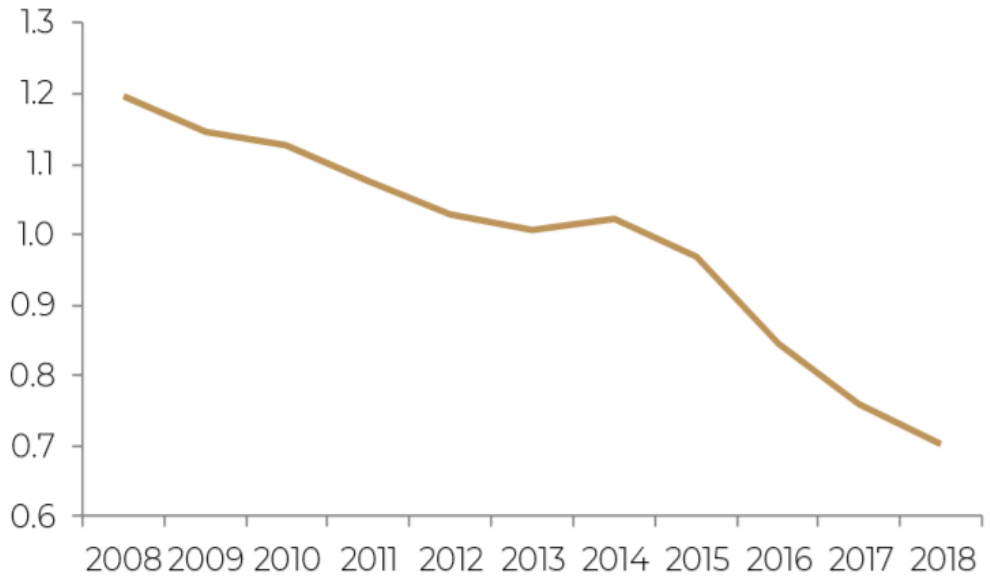
According to the national energy budget report of 2018 (Balance Nacional de Energía 2018), a document periodically issued by the Mexican ministry of energy Secretaría de Energía to track the energy sector, the energy independence index in Mexico for 2018 was 0.7.

The energy independence index is generally computed as the country primary energy production over the country net energy consumption. If the value equals 1 or more, it means that the country has full energy independence, so it is able to produce all the energy it consumes or even more. In this case, Mexico produces the 70% of the energy it consumes, while almost the 30% (precisely 29.8%) of the requested inner energy consumption is not met by the inner energy production and thus is imported.

The Mexican energy independence has decreased in the very recent years, as shown in Figure 17. This is attributable to a context of growing inner energy demand and decreasing inner energy production over years (Figure 18). As for 2018, there was a decrease of 0.1% in national energy consumption, while the decrease in national energy production was 7.7 %.

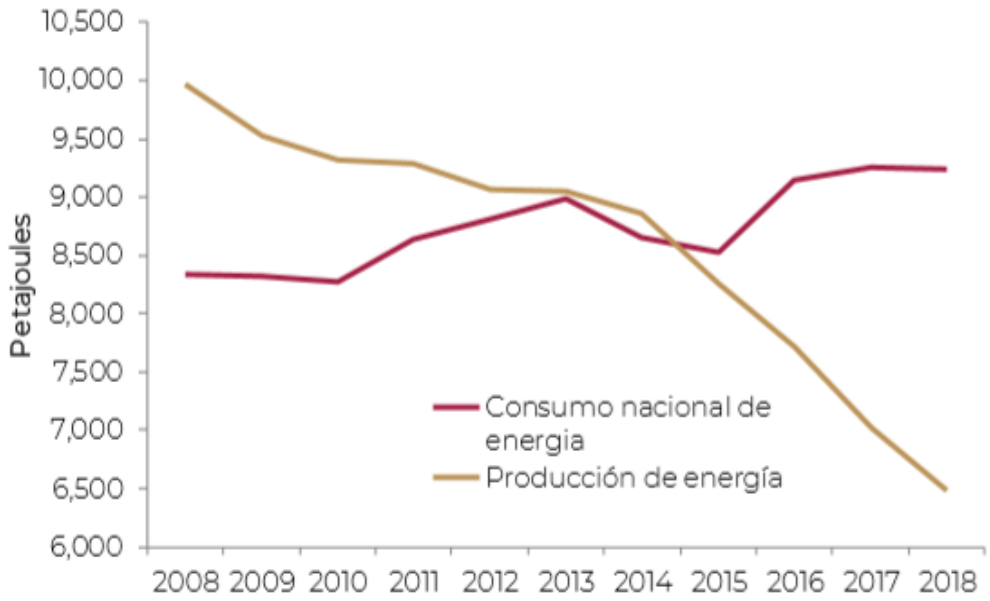
The general growing trend of national energy consumption has also to be weighted to the increase of Mexican population. Between 2017 and 2018 the population growth was 1%. In the meanwhile, from 2008 to 2018 energy consumption per capita decreased on average 1.2% each year. This means that growth in national energy consumption not only derived by an increasing consumption pattern of people, but also by the energy needs of new-born people.

Figure 17 Energy independence index values, in Mexico over time



Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

Figure 18 Energy consumption and energy production, in petajoules (PJ), over time in Mexico



Source: ibidem

4.2.1 Energy production

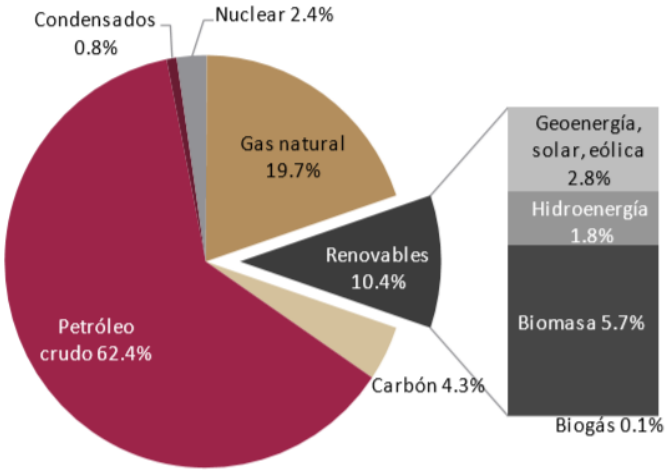
Energy production in Mexico has rapidly decreased in the last years: from 2012 to 2018 there was a diminishing of 33.12%, to which was associated an increase in energy imports.

The main components of Mexican primary energy production are the hydrocarbons (crude oil, condensates and natural gas), which in 2018 accounted for the 82.9 % of the total production (respectively 62.4%, 0.8% and 19.7%).

Coal production constituted the 4.3% of the total, while nuclear energy production compromised the 2.4%.

Renewable energies production formed the 10.4% of total primary energy production. Specifically, geoenergy, solar and wind energy contributed to the 2.8% of the total, hydroenergy represented the 1.8%, biomass stood for the 5.7 % and biogas for the 0.1%.

Figure 19 Primary energy production, in petajoules (PJ), in Mexico, 2018



	2017	2018	Variación porcentual (%) 2018/2017	Estructura porcentual (%) 2018
Total	7,027.22	6,484.84	-7.72	100
Carbón	308.24	279.58	-9.30	4.31
Hidrocarburos	5,940.60	5,374.18	-9.53	82.87
Petróleo crudo	4,354.89	4,045.95	-7.09	62.39
Condensados	67.28	48.90	-27.32	0.75
Gas natural	1,518.43	1,279.33	-15.75	19.73
Nucleoenergía	113.22	156.00	37.79	2.41
Renovables[1]	665.16	675.08	1.49	10.41
Hidroenergía	114.65	116.95	2.00	1.80
Geoenergía	127.43	113.18	-11.18	1.75
Solar	15.16	23.98	58.21	0.37
Energía eólica	38.23	47.12	23.25	0.73
Biogás	2.52	2.84	12.86	0.04
Biomasa	367.18	371.01	1.04	5.72
Bagazo de caña	116.87	121.93	4.33	1.88
Leña	250.31	249.08	-0.49	3.84

Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

Decline in hydrocarbons production has been the main driver of the decrease in energy production: from 2012 to 2018 their production lowered of a 28.4%. In respect to 2017, hydrocarbons production decreased of 9.53% in 2018. In the same year, carbon production diminished of a 9.3%, while renewable energy and nuclear energy increased respectively of 1.5% and 37.8%.It is denotable that, within that period, wind energy, solar energy and biogas productions increased correspondingly of 23.3%, 58.2% and 12.9%.

Primary energy production generally follows two main routes: it goes directly into the market and it is commercialized, or it is transformed in order to generate more useful products.

In the first case, it is put into action the primary energy external commerce. In 2018, the Mexican balance of payments of this commerce had as net balance (exports minus imports) an export surplus of 2404.61 PJ, an increase of 4.2% from the previous year. This value was mainly driven by the increased export of crude oil (mostly to United States of America, Spain, India, South Korea and Japan) and the reduction in coal imports.

Table 3 Primary energy external commerce, in petajoules (PJ), in Mexico, 2008

	2017	2018	Variación Porcentual (%) 2018/2017
Exportaciones totales	2,609.34	2,681.84	2.78
Carbón	0.08	0.14	82.97
Petróleo crudo	2,609.26	2,681.70	2.78
Condensados	0.00	0.00	0.00
Importaciones totales	301.22	277.24	-7.96
Carbón	301.22	268.66	-10.81
Petróleo crudo	0.00	8.57	0.00
Condensados	0.00	0.00	0.00
Saldo neto total	2,308.12	2,404.61	4.18
Carbón	-301.14	-268.52	-10.83
Petróleo crudo	2,609.26	2,673.13	2.45
Condensados	0.00	0.00	0.00

Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

In the second case, which in 2018 concerned the 55% of total primary energy production, a portion of primary energy (3570.66 PJ over a total of 6484.84 PJ of primary energy) is transferred to national processing facilities and generates the secondary energy production.

The processing facilities mainly involved were refineries and machineries (which absorbed the 37.9% of the transferred primary energy), gas plants and fractioning machines (for the 37.53%) and public power plants (for the 19.43%).

The so-obtained secondary energy production counted for 3948.91 PJ, representing a decrease of 7.9% in respect to the previous year.

The main sources used to generate secondary energy products were crude oil (which counted for the 37.87% of the total primary energy transformed) and natural gas (the 35.68% of the total).

The principal products of secondary energy are displayed in Table 4, according to their processing facilities. This production was mostly made by refineries and machineries (34.28% of the total secondary energy production), gas plants and fractioning machines (33.08% of the total) and power plants (31.84%), so the main recipients of primary energy production. While the secondary energy production in the first two sectors decreased, the secondary production by power plants increased of a 6.14%.

Table 4 Secondary energy production, in petajoules (PJ), in Mexico, 2018

	2017	2018	Variación porcentual (%) 2018/2017	Estructura porcentual (%) 2018
Producción bruta	4,288.29	3,948.91	-7.91	100
Coquizadoras y hornos	38.77	31.31	-19.26	0.79
Coque de carbón	34.35	31.31	-8.87	0.79
Otros[1]	4.42	0.00	-100.00	0.00
Refinerías y despuntadoras	1,617.52	1,353.75	-16.31	34.28
Coque de petróleo	43.82	27.23	-37.86	0.69
Gas licuado	24.39	15.10	-38.09	0.38
Gasolinas y naftas	484.37	422.80	-12.71	10.71
Querosenos	85.56	76.79	-10.26	1.94
Diésel	335.03	267.06	-20.29	6.76
Combustóleo	508.16	432.94	-14.80	10.96
Productos no energéticos	58.85	48.45	-17.67	1.23
Gas seco	77.34	63.38	-18.05	1.61
Otros2	0.00	0.00	0.00	0.00
Plantas de gas y fraccionadoras	1,447.29	1,306.37	-9.74	33.08
Gas licuado	194.82	169.92	-12.78	4.30
Gasolinas y naftas	100.09	90.47	-9.61	2.29
Querosenos	0.00	0.00	0.00	0.00
Combustóleo	0.00	0.00	0.00	0.00
Productos no energéticos	104.40	0.00	-100.00	0.00
Gas seco	1,047.95	90.45	-91.37	2.29
Otros[2]	0.03	955.53	3,338,149.75	24.20
Electricidad	1,184.71	1,257.48	6.14	31.84
Centrales eléctricas públicas	615.81	616.22	0.07	15.60
Centrales eléctricas PIE	316.54	319.45	0.92	8.09
Centrales eléctricas autogeneración	238.09	270.52	13.62	6.85
Centrales eléctricas generadoras	14.27	51.28	259.40	1.30

Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

This external commerce in 2018 had a deficit of 4406.21 PJ, which increased by 17.47% from the previous year. This was mainly due by the reduction in exports of gasolines and naphthas (-9.08%) and fuel oil (-7.47%) and the increase in imports of dry gas (14.91%), diesel (17.56%), kerosene (33.46%) and gasolines and naphthas (19%).

Table 5 Secondary energy external commerce, in petajoules (PJ), in Mexico, 2018

	2017	2018	Variación porcentual (%) 2018/2017
Exportaciones totales	**365.55**	**348.74**	*-4.60*
Coque de carbón	0.07	1.18	*1,614.36*
Coque de petróleo	0.03	0.10	*290.02*
Gas licuado	8.60	2.88	*-66.52*
Gasolinas y naftas	84.74	77.04	*-9.08*
Querosenos	0.00	0.00	*0.00*
Diésel	0.00	8.94	*0.00*
Combustóleo	242.11	224.02	*-7.47*
Productos no energéticos	0.16	0.00	*-100.00*
Gas seco	1.50	7.94	*427.61*
Electricidad	28.35	26.65	*-6.00*
Importaciones totales	**4,116.39**	**4,754.96**	*15.51*
Coque de carbón	31.53	19.18	*-39.17*
Coque de petróleo	140.20	151.56	*8.10*
Gas licuado	224.87	248.94	*10.71*
Gasolinas y naftas	1,061.00	1,262.58	*19.00*
Querosenos	91.19	121.70	*33.46*
Diésel	559.82	658.10	*17.56*
Combustóleo	92.49	87.56	*-5.33*
Productos no energéticos	0.00	0.00	*0.00*
Gas seco[1]	1,906.90	2,191.16	*14.91*
Electricidad	8.39	14.19	*68.97*
Saldo neto total	**-3,750.84**	**-4,406.21**	*17.47*
Coque carbón	-31.46	-18.00	*-42.78*
Coque de petróleo	-140.17	-151.46	*8.05*
Gas licuado	-216.27	-246.06	*13.78*
Gasolinas y naftas	-976.26	-1,185.53	*21.44*
Querosenos	-91.19	-121.70	*33.46*
Diésel	-559.82	-649.15	*15.96*
Combustóleo	149.62	136.45	*-8.80*
Prod. no energéticos	0.16	0.00	*-100.00*
Gas seco	-1,905.40	-2,183.22	*14.58*
Electricidad	19.96	12.47	*-37.54*

Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

The energy balance of payments of Mexico in 2018 (the values sum of primary and secondary energy balances of payments) had a surplus only in crude oil of 2690.27 PJ and in fuel oil of 311.58 PJ. The major deficit was for dry gas (-2183.2 PJ).

4.2.2 Energy consumption

The national energy consumption in Mexico in 2018, defined as the sum of energy sector consumption and final energy consumption minus recirculating energy consumption (the consumption of energy which is used to generate other energy), was estimated in 9236.86 PJ, which represented a decrease of 0.14% in respect to the previous year.

Table 6 National energy consumption, in petajoules (PJ), in Mexico, 2018

	2017	2018	Variación porcentual (%) 2018/2017	Estructura porcentual (%) 2018
Consumo nacional	9,249.75	9,236.86	-0.14	100.0
Consumo sector energét	2,969.93	3,173.87	6.87	34.4
Consumo transformación	1,854.83	1,786.75	-3.67	19.3
Consumo propio	924.55	1,182.85	27.94	12.8
Pérdidas por distribución	190.55	204.27	7.20	2.2
Consumo final total	5,500.59	5,393.45	-1.95	58.4
Consumo no energético	136.07	109.74	-19.35	1.2
Consumo energético	5,364.52	5,283.70	-1.51	57.2
Recirculaciones y Diferencia estadística	779.22	669.54	-14.08	7.2

Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

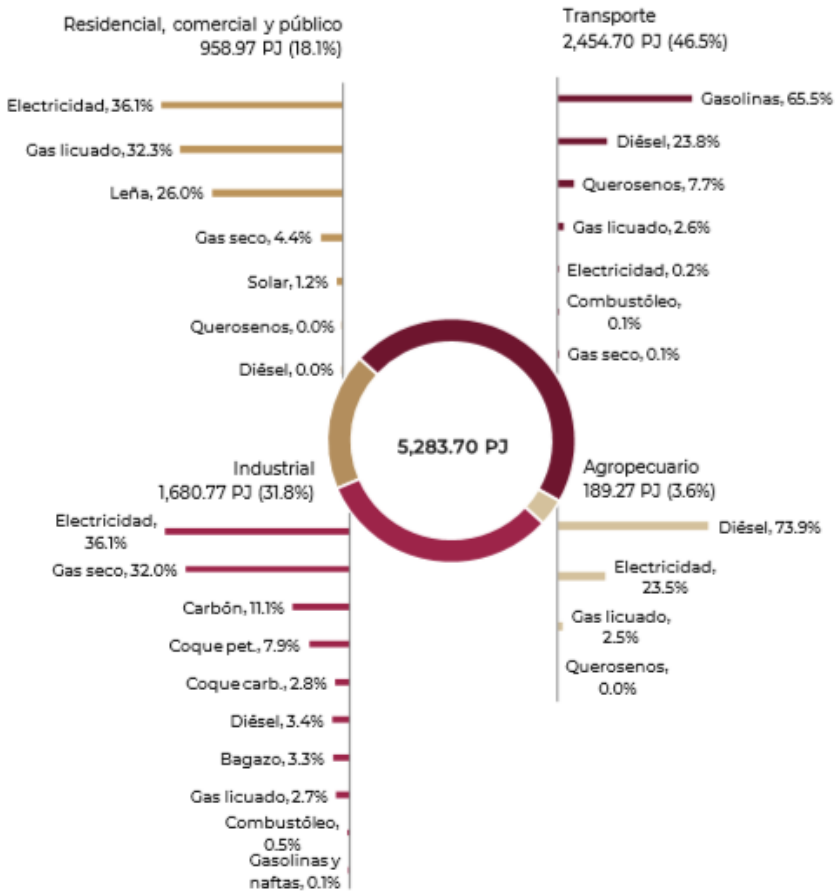
As regards the final energy consumption (5393.45 PJ), it is classified in non-energy-based consumption (109.74 PJ) and energy-based consumption (5283.7 PJ). Within the last set, the most consumed energy components in 2018 were gasolines and naphthas (which counted for almost the 30% of the final energy consumption), electricity (the 18.55%), diesel (the 14.5%), dry gas (10.8%), liquefied gas (7.8%) and biomass (5.65%), see Table 7.

Instead, considering the distribution of energy-based consumption in final energy consumption by economic sector in Mexico, the situation is the one presented in Figure 20. In 2018, transports were the most energy-using sector, with a share of 46.5% over the total final energy-based consumption. Secondly, the industrial sector represented the 31.8% of the consumption, while the set of residential, commercial and public sector had a final energy-based consumption share of 18.1% over the total. The agropecuary sector accounted only for the 3.6% of the total final energy-based consumption. With respect to 2017, in 2018 the transport sector, the residential, public and commercial sector and the agropecuary one increased their final energy-based consumption respectively of 4.1%, 1.2% and 4.04%. The industrial sector consumption decreased of a 10.52%.

Table 7 Final energy consumption, in petajoules (PJ), by fuel, in Mexico, 2018

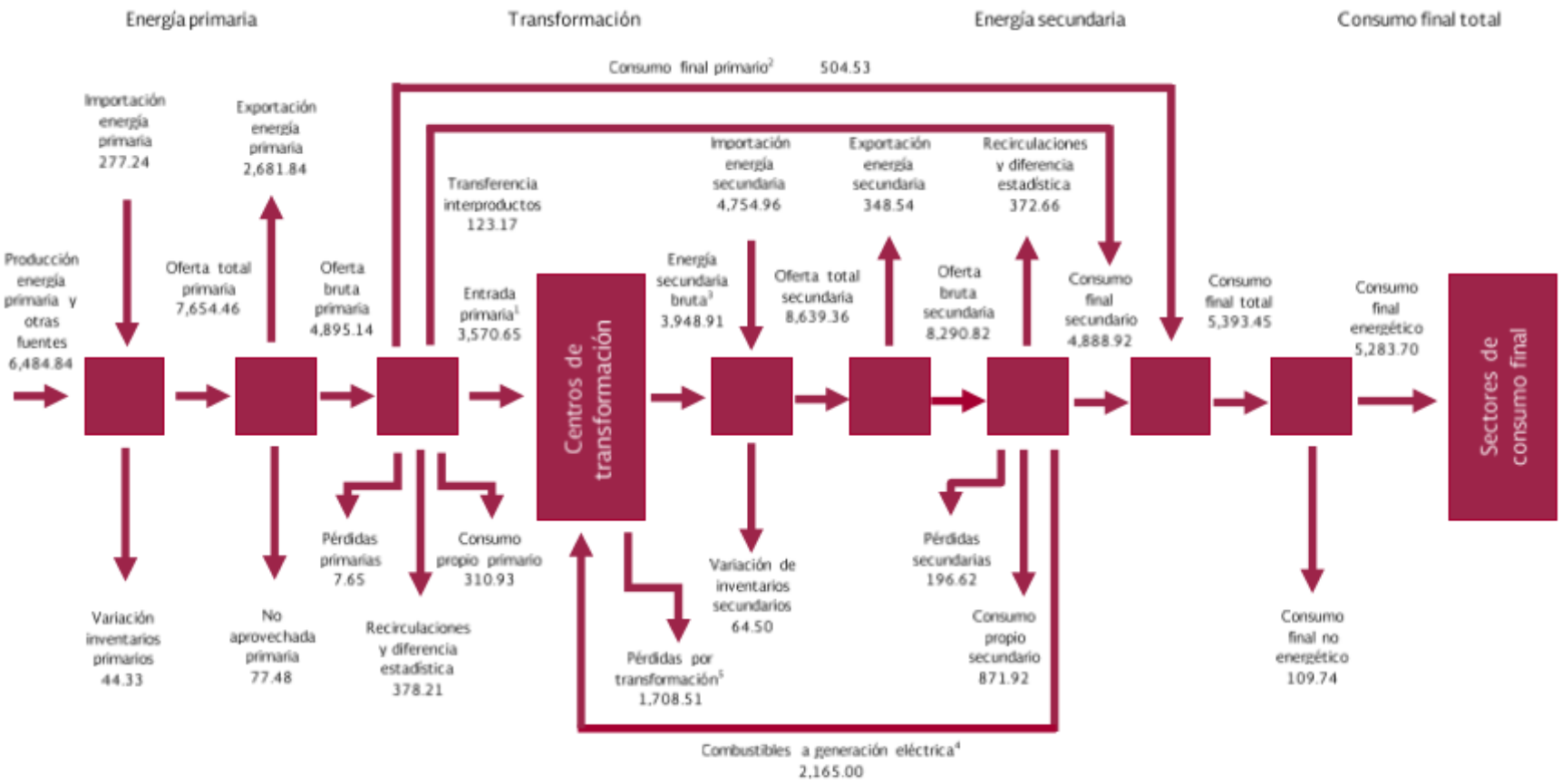
	2017	2018	Variación porcentual (%) 2018/2017	Estructura porcentual (%) 2018
Consumo final total	*5,500.59*	*5,393.45*	-1.95	*100*
Consumo no energético total	136.07	109.74	-19.35	*2.03*
Bagazo de caña	0.24	0.26	11.80	*0.00*
Gas licuado	1.98	2.80	41.02	*0.05*
Gas seco	19.78	13.65	-31.01	*0.25*
Gasolinas y naftas	11.25	5.59	-50.36	*0.10*
Productos no energéticos	102.82	87.45	-14.95	*1.62*
Consumo energético total	5,364.52	5,283.70	-1.51	*97.97*
Carbón	239.15	186.93	-21.83	*3.47*
Solar	10.89	12.53	15.09	*0.23*
Combustóleo	29.94	11.61	-61.23	*0.22*
Coque de carbón	63.75	47.43	-25.61	*0.88*
Querosenos	172.55	189.77	9.98	*3.52*
Coque de petróleo	142.36	132.72	-6.77	*2.46*
Biomasa	300.20	304.80	1.53	*5.65*
Gas licuado	423.27	423.46	0.05	*7.85*
Gas seco	734.69	583.11	-20.63	*10.81*
Electricidad	935.57	1,000.54	6.94	*18.55*
Diésel	807.73	782.59	-3.11	*14.51*
Gasolinas y Naftas	1,504.41	1,608.21	6.90	*29.82*

Figure 20 Energy-based consumption in final energy consumption, in petajoules (PJ), by sector, in Mexico, 2018



Source: Balance Nacional de Energía 2018, Secretaría de Energía SENER

Figure 21 National energy flow, in petajoules (PJ), in Mexico, 2018



Fuente: Sistema de Información Energética (SIE), Sener.
La suma de los parciales puede no coincidir con los totales, debido al redondeo de las cifras.
1 Carbón: 362.23; Crudo y condensados: 1,422.16; Gas natural: 1,274.12; Nucleoenergía: 156.00; Hidroenergía: 116.95; Geoenergía: 113.18; Energía eólica: 47.12; Bagazo de caña: 64.61; Biogás: 2.84; Solar: 11.45.
2 Carbón: 186.93; Energía solar: 12.53 ; Bagazo de caña: 55.98; Leña: 249.08.
3 Coque de carbón: 31.31; Petrolíferos: 1,502.31; Productos no energéticos: 138.91; Gas seco: 1,018.91 ; Electricidad: 1,257.48; Otros autogeneración: 0.

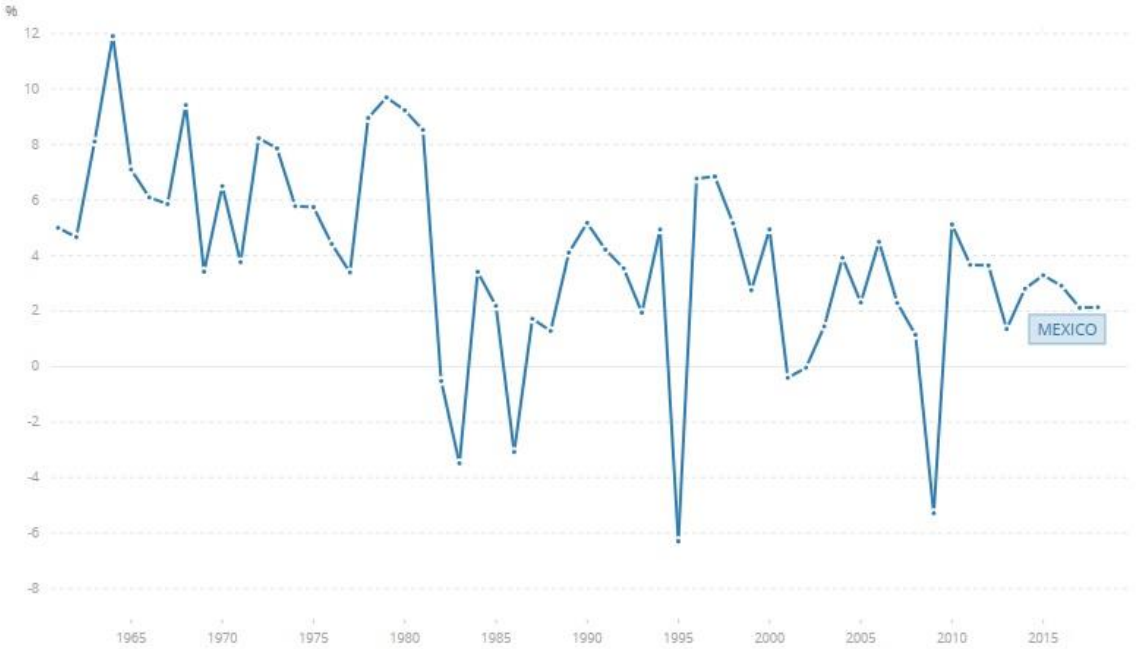
[4] Diésel: 40.21; Combustóleo: 269.71; Gas seco: 1,813.38; Coque de petróleo: 38.04; Gas licuado: 3.66; Otros autogeneración: 5.42.
[5] Coquizadoras: 14.71; Refinerías y despuntadoras: 2.58; Plantas de gas y fraccionadoras: 33.57; Centrales eléctricas públicas: 928.50; Centrales eléctricas PIE: 326.08; Centrales eléctricas autogeneración: 319.8; Centrales eléctricas generación: 83.82.

4.3 The context of Mexico: the need of an inclusive growth

Concerning the macroeconomic framework of Mexico, at the end of 2019 the situation can be defined as challenging and in change.

In the last decades the country has been classified as an emerging economy, because of its overall positive trend in the Gross Domestic Product (GDP) growth and its integration into the globalizing market.

Figure 22 Annual percentage of GDP growth of Mexico



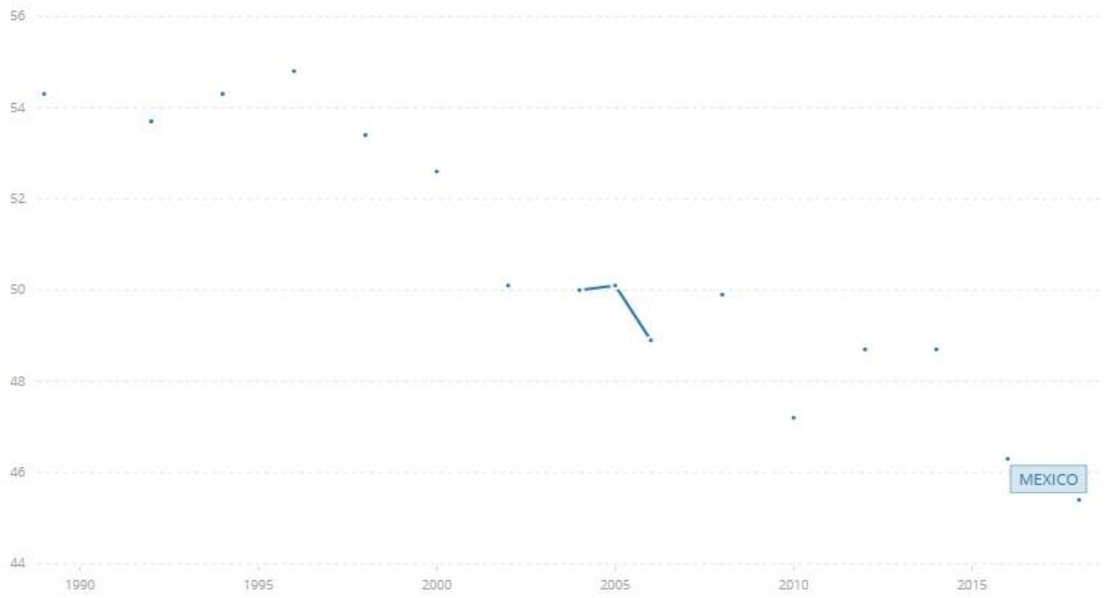
Source: Data from World Bank available from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?end=2018&locations=MX&start=1961&view=chart

Anyhow, in the recent years there has been a debate about persisting or not to position Mexico among the emerging market economies. Annual GDP growth seems to remain stable around a low percentage and, in addition to that, we have to consider that the GDP indicator does not furnish a complete prospective about the socioeconomic situation of a country. In fact, it measures the total value of goods produced and services provided in the country during one year (such that GDP=consumptions C+ investments I+ public spending G+ exports X- imports I), but it doesn't inform us about the distribution of this wealth across the population.

Another relevant indicator is the Gini index, which measures the income inequality ranging from 0 (minimum level of inequality, where income is equally distributed across income groups) to 1 (maximum level of inequality, in which the largest fraction of income

is concentrated among the richest households). Its value in 2018 in Mexico was estimated to be 0.454, and even if it is slightly decreasing over time it still evidences a polarized context.

Figure 23 World Bank estimation of the Gini Index in Mexico



Source: Data from World Bank available from https://data.worldbank.org/indicator/SI.POV.GINI?locations=MX

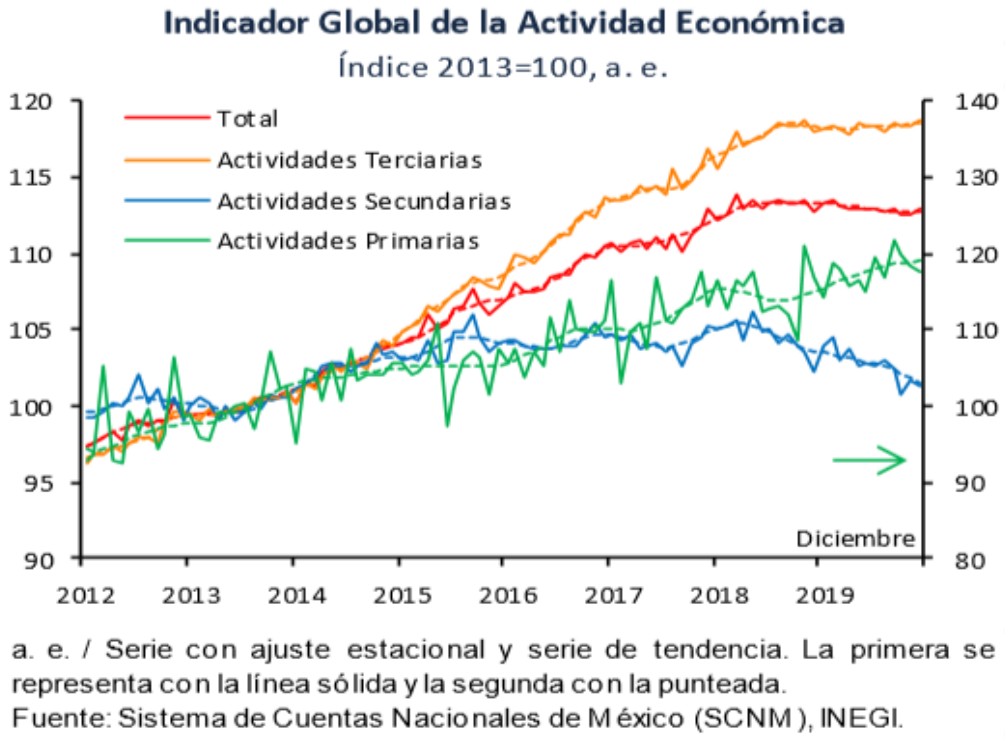
The OECD Economics Surveys MEXICO released on May 2019 as well as the Quarterly Report October-December 2019 of the Banco de México (the Mexican national central bank) describe the current Mexican economic growth as moderate and in need of more equity. Basically, it is denotable that in order to achieve a higher development it could be necessary for the country to gain a wider economic worth more fairly distributed across its population. It is also affirmable that a fair distribution is an essential condition to reach development.

The Mexican situation seems to be quite in compliance with the global trend. In 2019 in fact, the World annual percentual GDP growth was estimated in near 3%, nonetheless according to the World Social Report 2020 of the UNDESA for the same period the 71% of the world population (estimated by the Department in near 7.7 billion people) was supposed to live in growing inequalities countries. The OXFAM Time to care 2020 Report estimated the richest 1% of people owning twice as much wealth as 6.9 billion people, the 90 % of the world's population.

4.3.1 Ameliorating economic activity to raise prosperity

In 2019 the economic growth of Mexico was confirmed to pursue the low increase tendency of the past recent years. The annual percentage GDP growth in 2018 was 2.1%, in 2019 that value decreased of a 0.1 %. This reflected the contraction of the secondary sector (the industry) and the primary sector (the agropecuary), while the tertiary sector (the services) showed a slow increase (as displayed below in Figure 24).

Figure 24 Economic activity in Mexico 2019, by sector

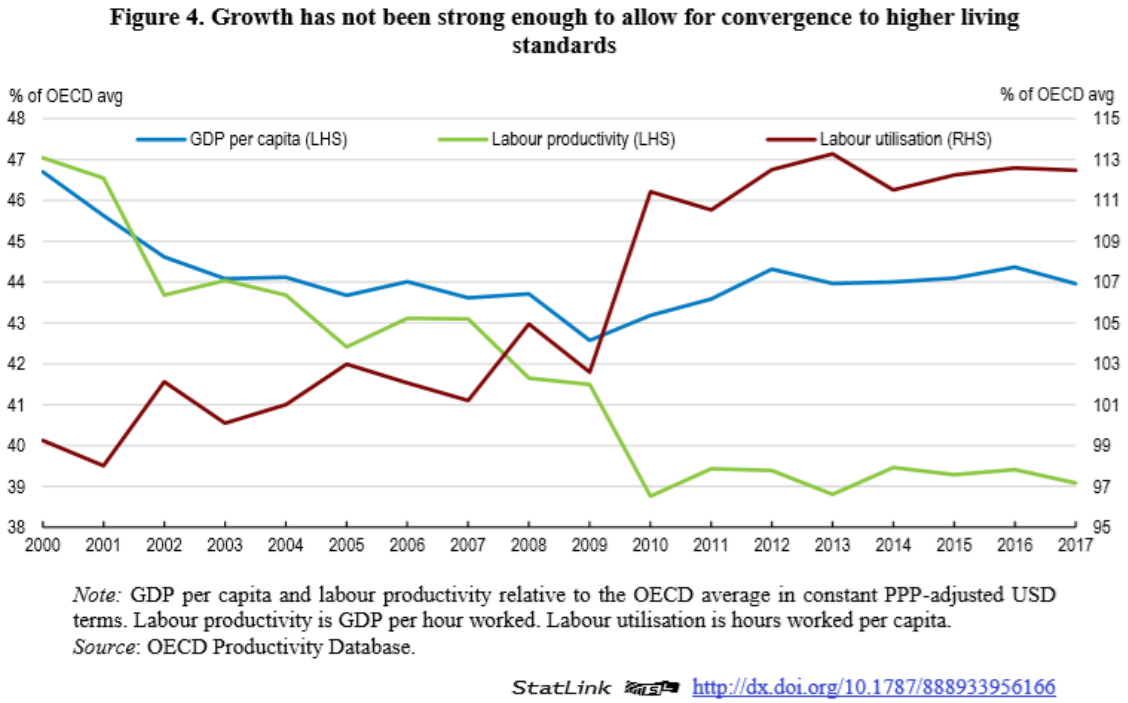


Source: Banco de México Informe Trimestral Octubre-Diciembre 2019

National and international institutions affirm that this moderate growth is not sufficient to guarantee well-being in the country and so a renewed macroeconomic strategy would be necessary, in order to guarantee higher levels of growth and development. Among other factors, are included in this action: boosting productivity, fostering infrastructure, reducing informality, fight criminality, including women and indigenous population, implementing the rule of law, support social spending in education and welfare, maintain financial stability.

A first consideration on the matter can be made taking into account the labour indicators expressed in Figure 25.

Figure 25 Labour measurements in Mexico



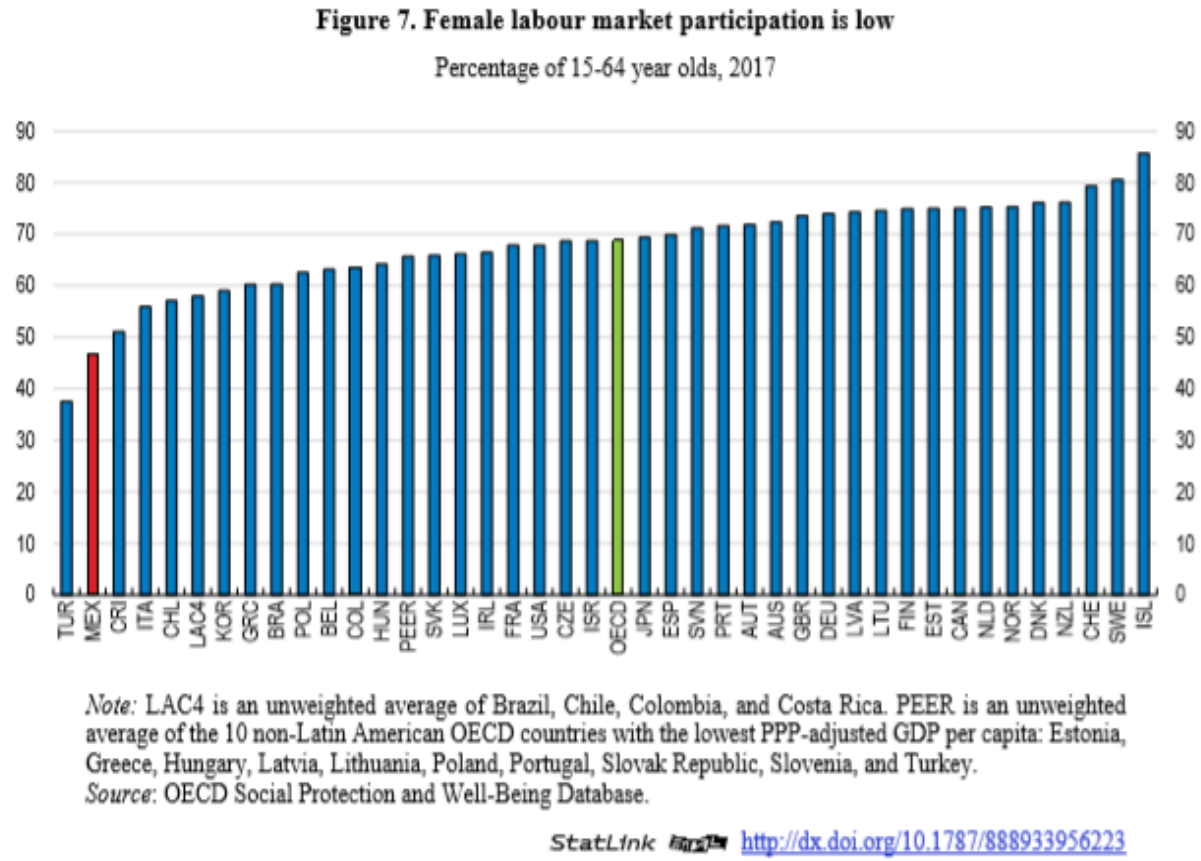
Source: OECD Economic Surveys: Mexico 2019

It is possible to notice that across the years the hours worked per capita (Labour utilisation) in Mexico have steadily more overcome the OECD average, but the national GDP has not so consequently risen, involving a decline in the GDP per hour worked (Labour productivity) among the OECD average.

This suggests that a higher productivity would not be reached simply rising working hours but rather reforming the existing working structure.

The Mexican labour market presents relevant levels of inequality, both in terms of income as well as in living standard conditions. Important portions of the population suffer some forms of social deprivation such as lack of access to food, basic housing, educational and health services as well as social security. Informality is estimated to encompass 60 % of formal jobs and about a quarter of GDP annually. Indigenous people together with the female population remain largely excluded from the from the formal labour market. One third of women is estimated to drop-out school and not being in employment, education or training (NEETs), compared to a 10% of men.

Figure 26 Female population in the labour market



Source: ibidem

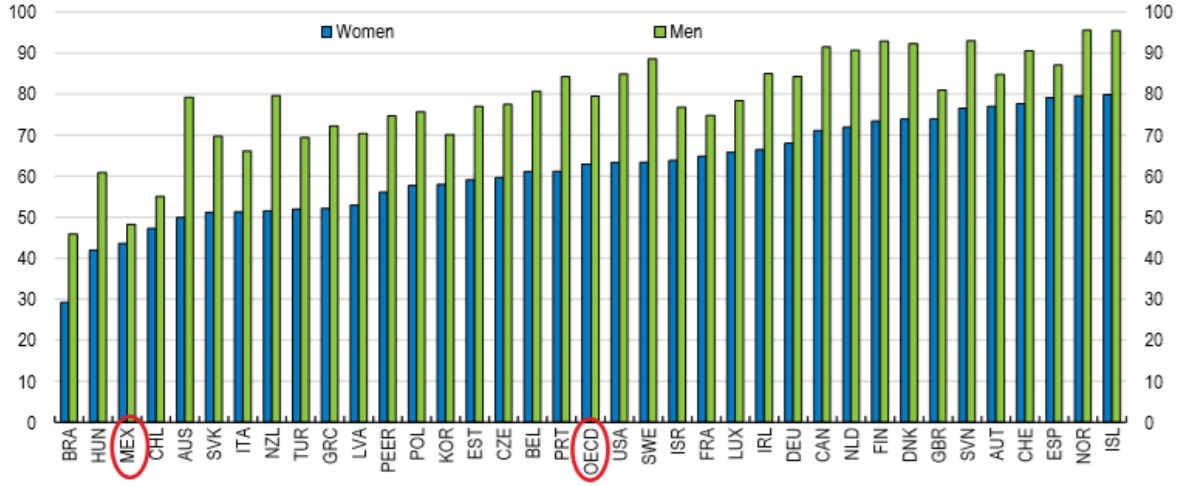
Cultural and social norm play a relevant role in this situation, which is also characterized by dramatic conditions of violence. Social inclusion and promoting higher living standards are supposed to be fundamental pillars to reduce criminality.

It is affirmable that better living conditions as well as an accessible environment can boost productivity. This one constitutes a source of wealth for the country, that doing so would enhance its appeal for business investments, either from internal or external funding sources, creating so a possible virtuous circle able to create further well- being and development.

Figure 27 Proxies of criminality in the country

Figure 8. Security is low, hurting women in particular

Percentage of people who report feeling safe walking alone at night



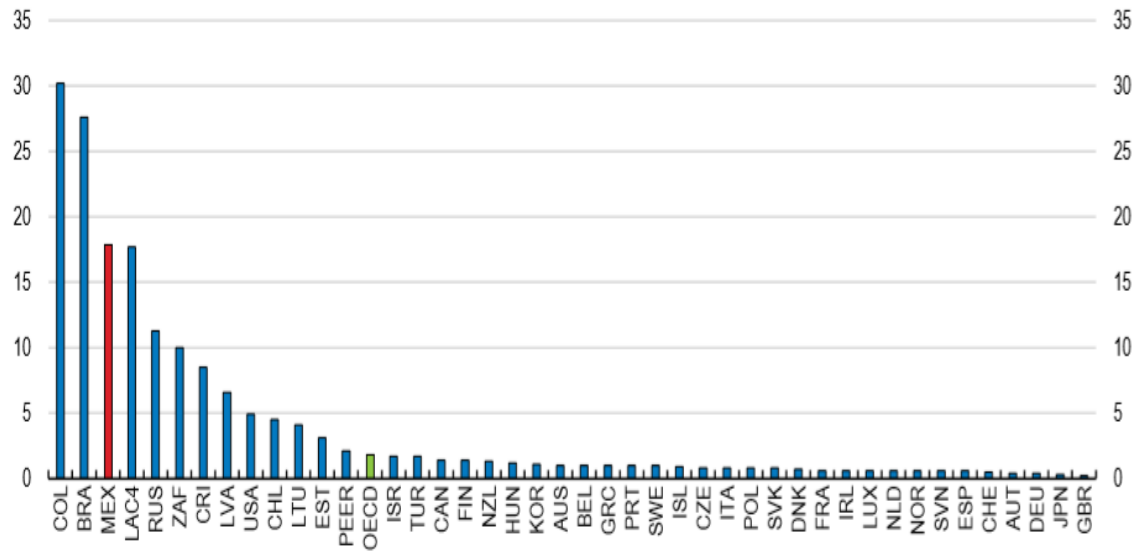
Note: PEER is an unweighted average of the 10 non-Latin American OECD countries with the lowest PPP-adjusted GDP per capita: Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Portugal, Slovak Republic, Slovenia, and Turkey. The reference period is the 3-year average 2014-2016 for all countries.
Source: OECD Better Life Index, 2017.

StatLink http://dx.doi.org/10.1787/888933956242

Figure 35. The high levels of crime and violence continue to grow

A. Age-standardised homicide rate per 100 000 people

2014 or latest available year



Source: OECD Economic Surveys: Mexico 2019

4.3.2 Key policies insights

A consistent redistributive policy could allow a reduction into the inequality gap and should focus on the following area:

-the implementation of an accessible education system at all levels (pre-primary, primary, secondary, university), which could bring positive outcomes simultaneously: including women in the labour market, disincentive informality, increasing contribution to productivity

-the improvement of the infrastructures' quality in sector like housing and public transport, in order to guarantee a better communication within and between metropolitan and rural areas

-the advancement of social services, such as the unemployment insurance scheme and the health system with the aim to prevent vulnerability and incentive a greater participation in the cultural, socioeconomic and political activity

-the clearer definition of competencies across the federal and state level and the promotion of coordination between the two, in the effort to get a more effective resource allocation across the country

These measures could find a primary source of funding in reshaping the tax base and incrementing the performance of the tax system. Historically, tax revenues in Mexico has been quite low in relation to the OECD average and have been especially based on oil taxes. A deeper review of the whole tax system, both in its contents and in the tax collection procedures, could:

-reduce the regulatory loopholes that facilitate tax evasion and avoidance

-introduce more progressivity in the tax brackets system

-lower the high-rates of informality

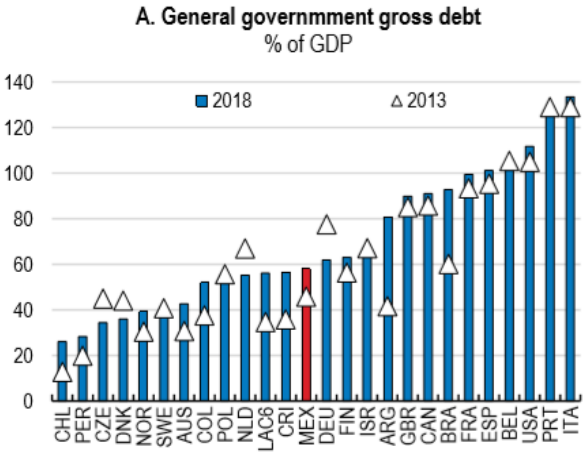
Another important initiative should be the implementing of the rule of law in the country. It is supposable that improving institutional quality could bring more fairness across the society as well as an impartial and effective judicial system would reduce the existing corruption. In 2017 the rate of unrecorded crime was estimated in 93.2%, only 11% of reported cases result in an investigation sent to the court system, and less than 4% result in a conviction and sentence.

The institution of independent competition authorities in key sectors could also be an option for a more efficient management of the resources.

4.3.3 Macroeconomic framework

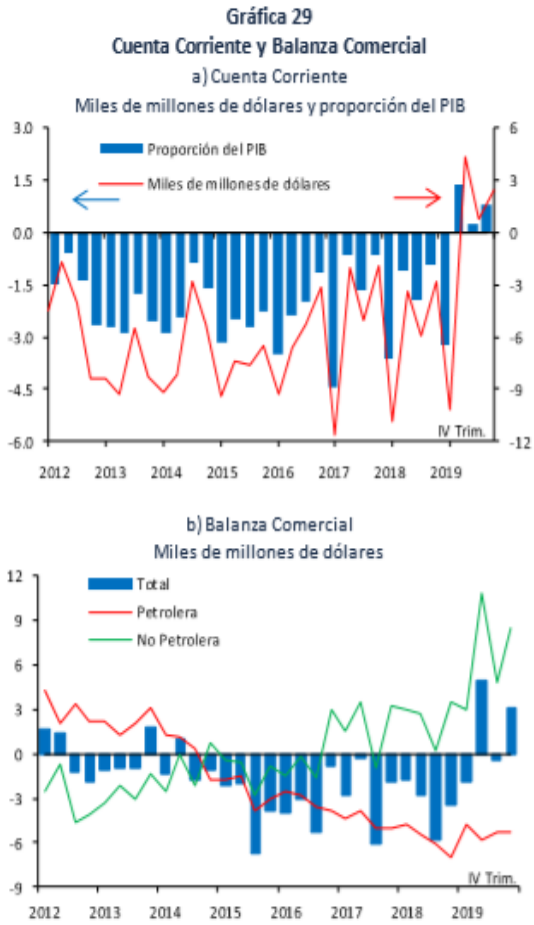
In consideration to the external macroeconomic relations of Mexico, in the following graphs are presented the information about the country public debt (graph 10) and the country current account and balance of payments (graph 11a and 11b).

Figure 28 Mexico public gross debt in 2018



Source: OECD Economic Surveys: Mexico 2019

Figure 29 Mexico current account and balance of payments (b.o.p.) in 2019



Overall, the general macroeconomic framework of Mexico is considered to show resilience to the global market volatility.

The government debt remains elevated but cutting the its ratio to GDP has been a priority in the last years. In 2019 the deficit in the current account has reached the 0.2% of the GDP, showing a slightly decrease from the 1.9 deficit % of GDP in 2018. The main driver of this growth in the balance of payments has been the non-oil related sector, such as professional services, retail trade, tourism and remittances (these ones in 2018 consisted in the almost 3% of the GDP). According to the Banco de México, this increase in the b.o.p. can be explicated in combination of a narrow "quantity effect", consisting in a major volume of exports on imports volume, and a larger "price effect" caused by the price decrease of intermediate import products. The prevalent country of exports destination remained the United States of America (in 2018 the covered the 76% of the sector, followed by Canada with the 7%, India 4%,

Netherlands 2%, Spain 2% and others 9%). This trade will be regulated by the USMCA agreement which substitutes the previous NAFTA agreement.

In 2012 Mexico adopted the General Law on Climate Change, being one of the world's first climate law. Within the framework of the Paris Agreement (entered into force on 4 November 2016) it also committed to substantially reduce its greenhouse gas emissions (GHGs) by 2030. Given that, the share of renewable energies on primary energy supply has risen modestly across the years, remaining fossil fuels the prevalent source with a share of 90%. Even if facing a decreasing trend (determined also by an initial governmental reduction of subsidies to fossil fuels as well as by the deterioration of the implants), the oil production and refining sector is still considered a key area to boost economic productivity in the country. The new government that took office on December 1 2018, with the President Andrés Manuel López Obrador of the MORENA political party, set between the main point of the 2019-2024 National Development Plan (NDP), the principal planning document that establishes the national public policy priorities, the need to foster the growth deriving from the oil production and refining, which should be realized reinforcing PEMEX's (the public owned company that manages the oil sector) budget, restoring its financial status and reducing its taxation and implementing the activity in the oil fields involving private investments. Other priorities related to the agenda, whose objective is "Transform the country's public life to achieve greater well-being for everyone", include some of the points previously stressed:

- strengthening the democratic governance and the full exercise of the human rights, fighting against corruption and promoting gender equality, non-discrimination and inclusion
- enhancing the welfare system, improving housing quality, raise pensions, disability subsidies, minimum wage, unifying health system and increasing the provision of student scholarships, as well as improving educational quality including specific programmes such as "Youths Building the Future" for youths nor in education, employment or training and adopt a new anti-drug policy
- fostering economic development, modernising infrastructures and hydroelectric plants, rehabilitating strategic ports in the south of the country, promoting tourism, expanding microcredit, guarantee minimum prices for small producers of five agricultural products, augment security raising police staff and army

5. Mexico: Empirical analysis

5.1 Data description

5.1.1 The ENIGH surveys and the poverty lines measurement

The main source of information of this work is the Household Income and Expenditure Survey (ENIGH-Encuesta Nacional de Ingresos y Gastos de los Hogares).

This survey is conducted by the Mexican federal statistical institute INEGI (Instituto Nacional de Estadística y Geografía) with a periodicity of two years starting from 1992. Formerly the ENIGH was carried out in 1984,1989 and later also in 2005. The aim of the survey is to provide a general framework of the socioeconomic living conditions of the Mexican population, including their income and expenditure patterns. A change in the survey structure was made in 2008. Before that date, the various kinds of income were mainly divided in "monetary" and "non-monetary", indicating with the first term the income deriving directly from the household economic activity while the second term represented others sources of income, such as benefits, bonuses, subsidies and so on. Starting from 2008, the income voice is structured according to the employment status of the household, being so categorized: income from dependent employment, income from self-employment, property income and social transfers. In each category the "monetary" and "non-monetary" components are mixed. This modification was implemented in order to allow a more direct comparability of the ENIGH survey to the Mexican National Accounts, which constitute a fundamental document in economic analyses. Expenditure was also divided in "monetary" and "non-monetary" in the previous surveys and its structure remained so in the following ones. Figure 30 and 31 describe the income structure in the traditional survey (e.g. 2008) and in the new one, after 2008.

One important potential usage of the ENIGH survey is to evaluate the condition of poverty. The information contained in it permit to estimate various forms of poverty and consequently to have a wider view at the time of policy making. Poverty can be defined as "the lack of resources to access to an adequate living standard". As highlighted in the previous chapter describing poverty indicators, it can be classified along the dimensions subjective/objective, unidimensional/multidimensional and headcount/intensity.

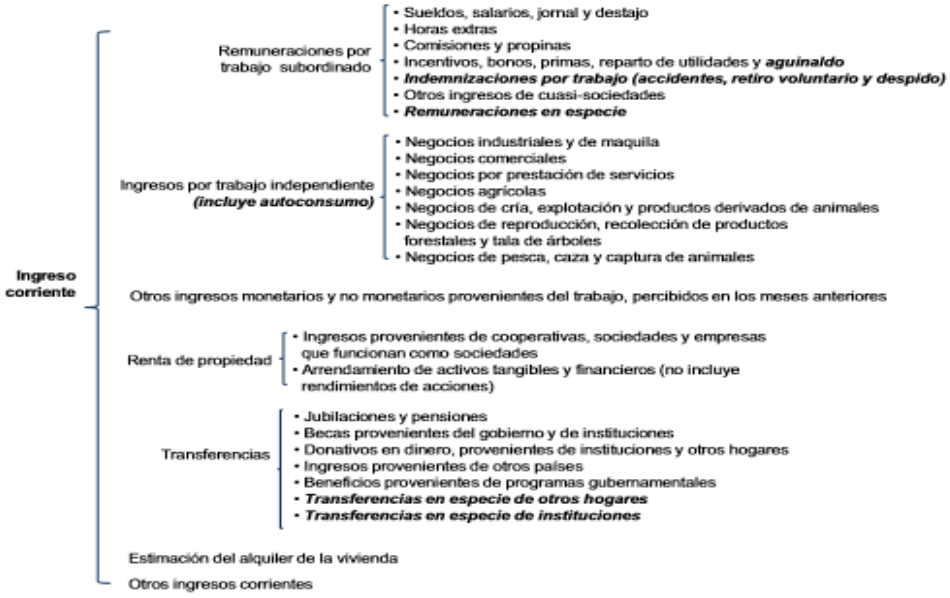
Figure 30 Income structure in the traditional ENIGH (before 2008)

Esquema 1
Construcción tradicional de la Encuesta de Ingresos y Gastos de los Hogares, 1984-2012

Fuente: Elaboración propia, con información del Instituto Nacional de Estadística y Geografía, 2012c.

Figure 31 Income structure in the new ENIGH (after 2008)

Esquema 2
Nueva construcción de la Encuesta de Ingresos y Gastos de los Hogares, 2008-2012



Fuente: Elaboración propia, con información del Instituto Nacional de Estadística y Geografía, 2012d.

Nota: El INEGI construyó las variables de ingreso del Módulo de Condiciones Socioeconómicas con este esquema. Aunque, lamentablemente, las transferencias en especie de otros hogares y de instituciones no se incluyeron en este módulo.

Source: del Castillo Negrete (2015)

The following paragraphs present one of the main techniques to measure poverty: the poverty lines method.

When poverty is measured, it is important to be aware of which dimensions have been considered in the measuring process. For instance, it is common to measure poverty by using total expenditure or income condition (see Chapter 2 paragraph 2.3). The permanent income hypothesis suggests an explanation of the difference between those two, stating that the expenditure of the individual is conditioned by its expected long-term average income [Friedman, 1957]. In unidimensional poverty measurements, only one dimension (such as the household income) is considered. For example, this study considered two poverty lines:

- the World Bank 1.90 $ a day per person poverty line
- the income poverty line of the CONEVAL (Consejo Nacional de Evaluacíon de la Política de Desarrollo Social), the National Council for the Evaluation of Social Development Policy, a public Mexican monitoring authority aimed to measure poverty and to evaluate the federal social programmes and policies

The concept of international poverty line was introduced in 1990 by a group of independent researchers and the World Bank. The goal was to measure world's poverty and the task was performed starting from the national poverty lines of some of the world's poorest countries. These lines were converted in US dollars using purchasing power parity (PPP) exchange rates. PPP rates estimation presents a wider degree of comparability as they price the same goods or services across different countries using the same currency. In order to be poor, a threshold was identified at 1 $ per day per person. On this base, a person owning less than that amount daily had to be considered poor while a person owning more was not. This World Bank poverty line has been subsequently revised: in 2008, according to the $ PPP prices of 2005, the value of 1 $ PPP per day per person was raised to 1.25 $ PPP per day per person. The latest update refers to 2015, basing on the 2011 $ PPP prices, and it sets the poverty threshold at 1.90 $ PPP per day per person. A first consideration that emerges regarding this World Bank poverty line is that it adopts a quite restricted definition of poverty, often referred to as extreme poverty. The selected threshold value is not sufficient to meet essential needs such as nutrition, clothing and shelter.

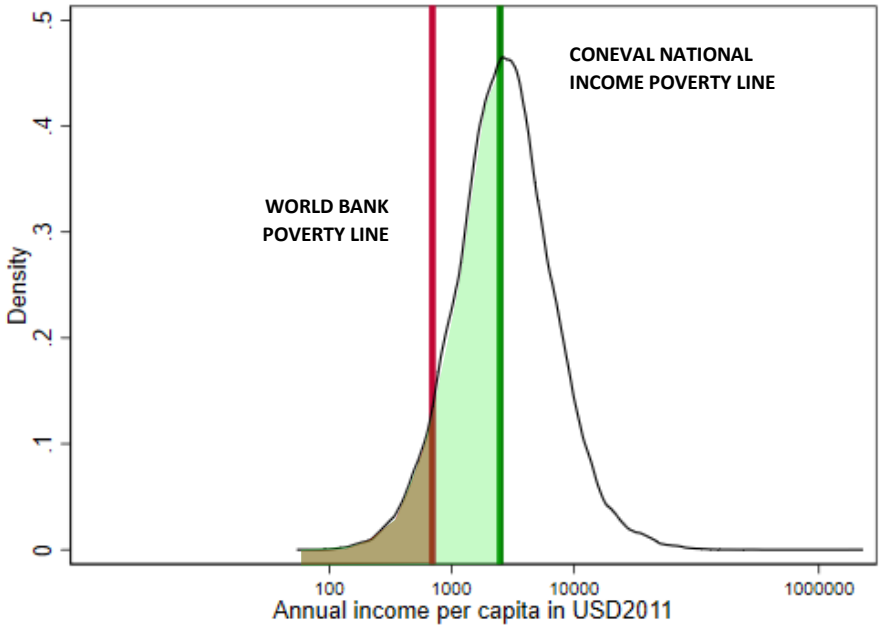
This means that: if on one side the people below the 1.90 $ PPP a day per person poverty line have to be surely considered poor, on the other side a large portion of the population above the 1.90 $ PPP a day per person poverty line cannot match essential needs to live or to properly participate in the social, economic, cultural and political life of a society, even if being not counted as poor. For this reason, the World Bank poverty line is considered a measurement of extreme poverty. It is therefore possible to conclude that the World Bank 1.90 $ PPP a day per person poverty line does not constitute a sufficiently acceptable instrument to evaluate poverty. The problem needs to be found in its methodology: a poverty threshold defined in an extremely poor country does not sufficiently represents the poverty phenomenon in a more developed country.
In order to get a more complete and deep view on the matter, other sources of information are required. For instance, considering each country's national poverty line can be an option.

The national poverty line is generally provided by the national statistical office of the country, on a periodical base. In the case of Mexico, the computation of the national poverty line is made by the CONEVAL according to the data of ENIGH Surveys, which are realized by the INEGI national statistical office.In determining the poverty threshold, a positive rather than a normative approach is used (see Chapter 3, paragraph 3.1.2).
The normative approach is considered to be more recommendable because it is supposed to adequately represent the population, identifying a consumption pattern able to fulfil the person's needs to achieve proper living standards and equal opportunities to participate in the society. The difficult task to formulate this approach is that it involves a higher degree of value judgements. For this reason, the CONEVAL has adopted until now a positive approach, with the purpose of maintaining a more technical and value neutral setting. Based on the ENIGH surveys observations, a group of households whose calories consumption meets the minimum standard recommended is selected as reference. The corresponding income of this reference group is computed, distinguishing between households living in a rural or urban area. The resulting values are affirmed to constitute an absolute poverty threshold for each of the two sets of households, which is adopted to identify the poorest portion of the population.

Figure 32 compares the World Bank and the CONEVAL income poverty lines computed by using the 2008 ENIGH survey. Poverty lines' values have been expressed in 2011 $ US dollars PPP (Purchase Power Parity) on a yearly base.

The number of people with income under the World Bank poverty threshold and it has been divided by the total population, obtaining a headcount ratio of poor people equal to 6% of the total population. The same threshold has been applied to urban and rural households. The CONEVAL income poverty lines instead distinguish a poverty threshold for people's living in a rural area and another one for those living in an urban area, both in terms of calories consumption. I have therefore considered a weighted count of the people under the rural and urban poverty thresholds and the resulting number has been divided over the total population, getting a headcount ratio of 46 % of poor people over the total population. The CONEVAL income poverty line (green area) identifies a poor much larger fraction of the population compared to the World Bank poverty line (red area). The headcount of poor households based on the 5.5$ per day per person World Bank threshold results to be more in line with the measure provided by the CONEVAL poverty line.

Figure 32 Comparison between the World Bank 1.90$ per day poverty line and the CONEVAL national income poverty line



Source: Author's elaboration of ENIGH 2008 data

If more than one dimension is examined, such as income and access to social services like proper housing condition, healthcare, education, integration facilities, the measurement is described as multidimensional. For example:

- the Multidimensional poverty measurement provided by the CONEVAL, that consists in the intersection between the portion of the population that is lacking social services and the portion of the population with an income under the minimum level (which in this case is defined as the amount of money necessary to afford the cost of a basket including essential goods and services). According to that, the poor person is the one that at the same time lacks at least one social service and whose income is under the minimum level.
- the Integrated poverty measurement of the EVALÚA (Consejo de Evaluación del Desarrollo Social de la Ciudad de México), the public authority of the State of Mexico City that evaluates the social development programmes, is a measure realized through the union of the two portions of the population described above. This means that in order to be poor is sufficient to lack the access to one social service or to have an income under the minimum level.

In the next paragraphs there is a focus on the unidimensional poverty measurements and specifically to the two previously described. Starting from these measurements the analysis will then proceed to the energy poverty measurements.

5.1.2 The analysis of the expenditure in the ENIGH survey 2008

The present work adopts a methodology primarily based on the expenditure analysis.

The dataset, the ENIGH survey of 2008, has been organized in 29,468 observations starting from the information derived by the population and the expenditure documents associated to the survey. Each observation corresponds to a household, formed by one or more individuals, living in a specific dwelling. Originally in the survey, more than one household were linked on a same dwelling. This possibly reflects a sociocultural and economic condition of the Mexican context, but in order to achieve a better comparability between the individuals expenditure, each household has been considered as a single unit even if she was sharing the dwelling with other households.

After that, it has been computed the total annual income and the total annual expenditure, which are expressed in Mexican pesos, for each individual using the per-capita classification. For the expenditure variable, it has been considered only the monetary component. For income, the total income variable (formed by the sum of the monetary and non-monetary components) has been taken into account. The results in the survey have been extended to the whole Mexican population, by applying the weights provided by the survey. In this way the analysis can be considered representative of the country.

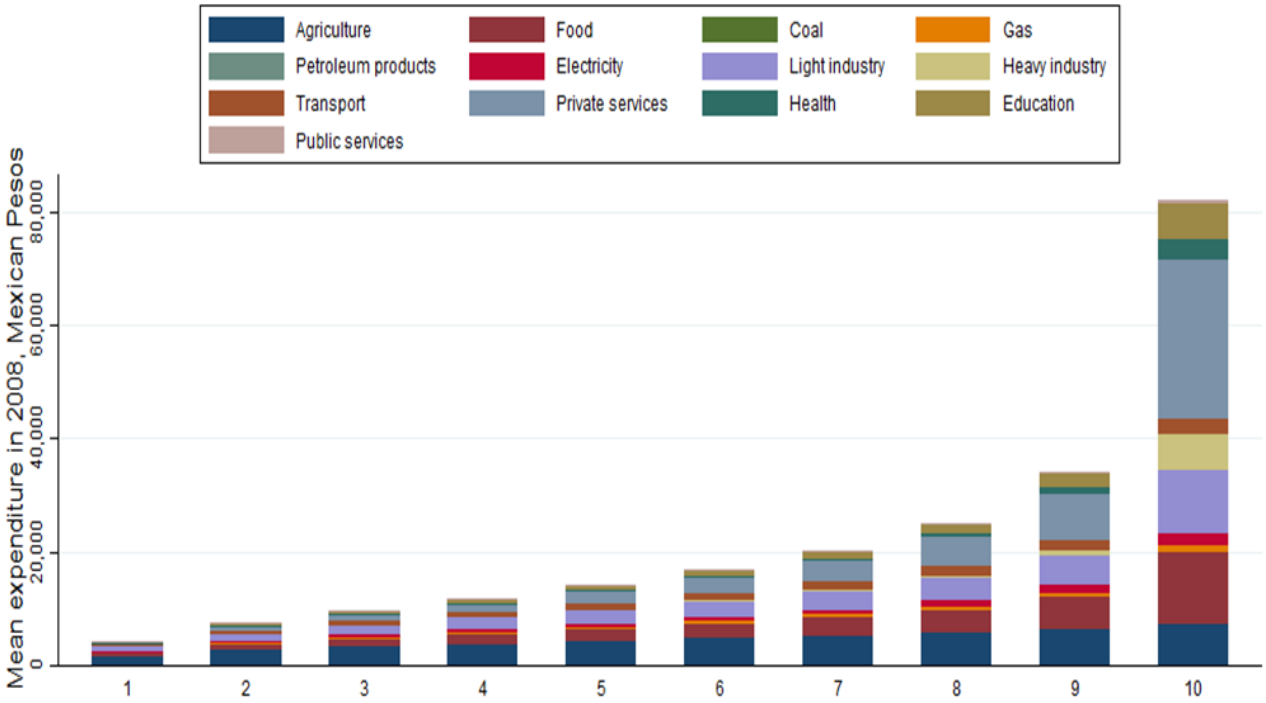
Figure 4 and 5 show the distributions of expenditure by type of good and income across deciles of population, ordered from the lowest values of expenditure/income (the poorest decile of the population) to the highest values (the richest decile). Both of them put into evidence a relevant dissimilarity in the amount of annual expenditure (Graph 33) or annual income (Graph 34) among the deciles of the population.

The annual expenditure of the richest individuals (decile 10, Graph 33) is 20 times higher than the annual expenditure of the poorest ones (decile 1, Graph 33).

As for the annual income, the gap between the two extremes of the population is even higher, considering that the annual income of the richest individuals (decile 10, Graph 34) is more than 30 times than the annual income of the poorest ones (decile 1, Graph 34).

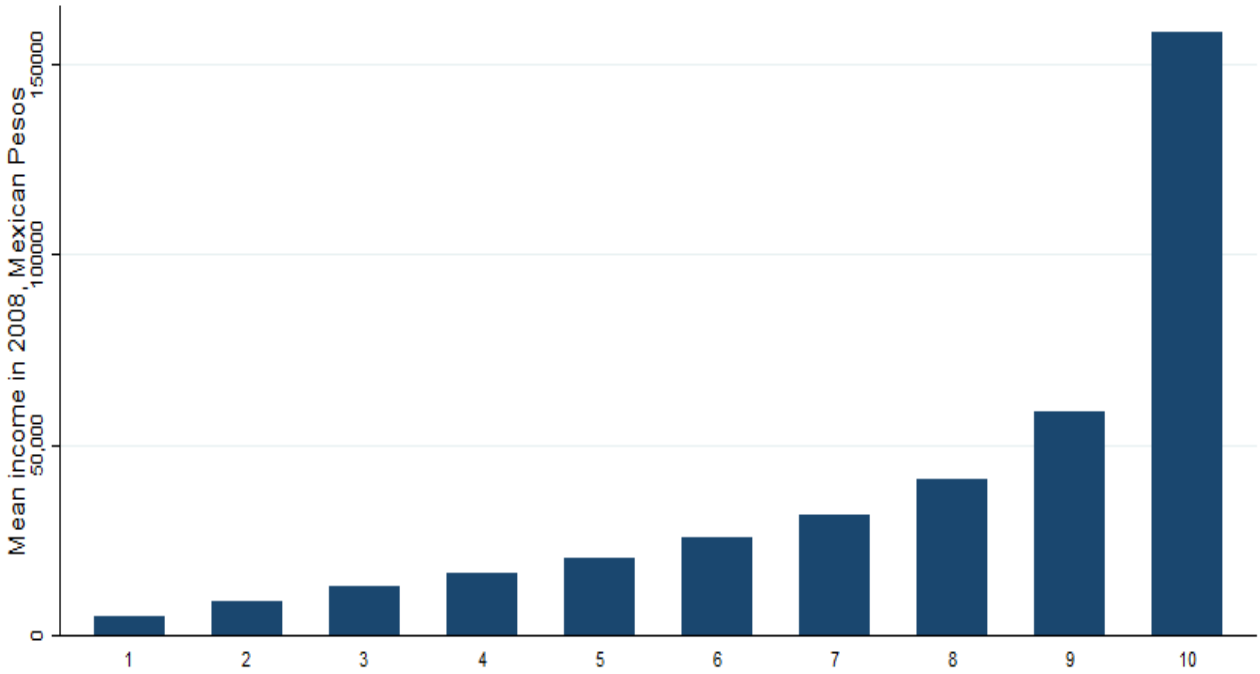
This trend states for a condition of drastic inequality among the country, meaning that there is a huge disproportion of the expenditure and income levels between people belonging to different income/expenditure groups.

Figure 33 Annual average per capita expenditure by population deciles, Mexico 2008



Source: Author's elaboration based on ENIGH survey 2008

Figure 34 Annual average per capita income by population deciles, Mexico 2008



Source: Author's elaboration based on ENIGH survey 2008

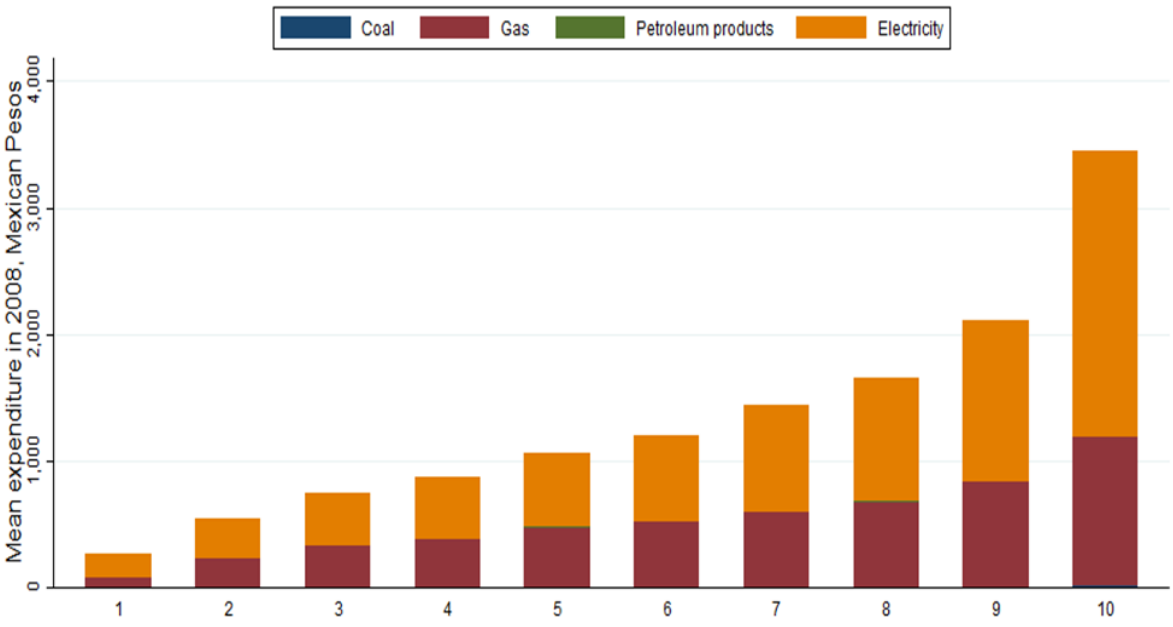
This inequality condition can be seen as cause and consequence of a deepen condition of poverty. Looking at the expenditure and income data, inequality can be considered a consequence of poverty because the lack or inadequacy of resources to some portions of the population is traduced in low expenditure or income levels among those portions of population. At the same time, those expenditure and income inequalities dramatically generate other poverty because poor individuals are not able to face the costs of necessary goods and services nor to adequately participate in the society.

Thence, poverty becomes one of the main different factors that generates inequality in the society, because it divides population in different expenditure or income groups and it consistently influence the standard of their living conditions.

When considering energy poverty, which is defined as a relatively high expenditure on energy commodities including coal expenditure, gas expenditure, petroleum products expenditure and electricity expenditure in the country, for the same period of time (Figure 35), the trend remains the same but the gap between deciles is narrower.

The energy expenditure of the richest individuals (decile 10, Figure 35) is 12 times more than the energy expenditure of the poorest ones (decile 1, Figure 35).

Figure 35 Average annual per capita energy expenditure by population deciles, Mexico 2008



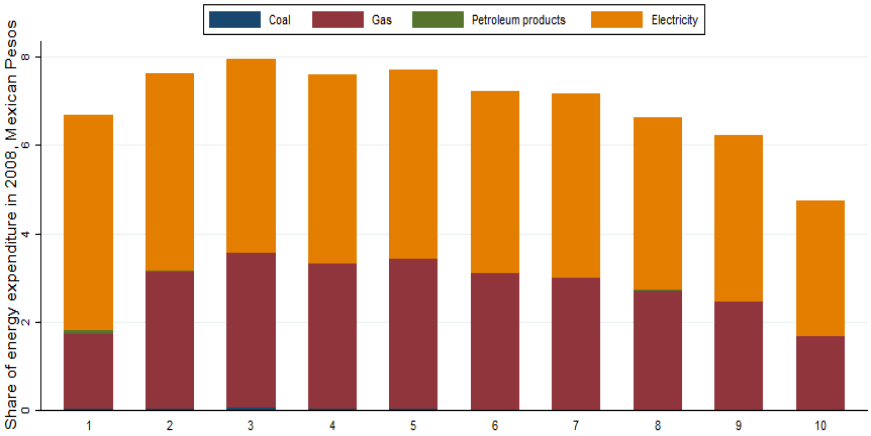
Source: Author's elaboration based on ENIGH survey 2008

In order to analyse the impact of energy expenditure on individuals' budget, for each decile of population it has been computed the share of energy expenditure on the overall expenditure. In this case (Figure 36 a), the trend in the population deciles distribution is almost inverted. The share of energy expenditure of the poorest decile (1, Figure 36 a) is almost 1.5 times the share of energy expenditure of the richest decile (10, Figure 36 a). This means that energy expenditure burdens more on the expenditure budget of the poorest individuals in respect to the one of the richest individuals. So, inequality is still present, even if with a lower degree in comparison with the trends of the overall expenditure or income distributions.

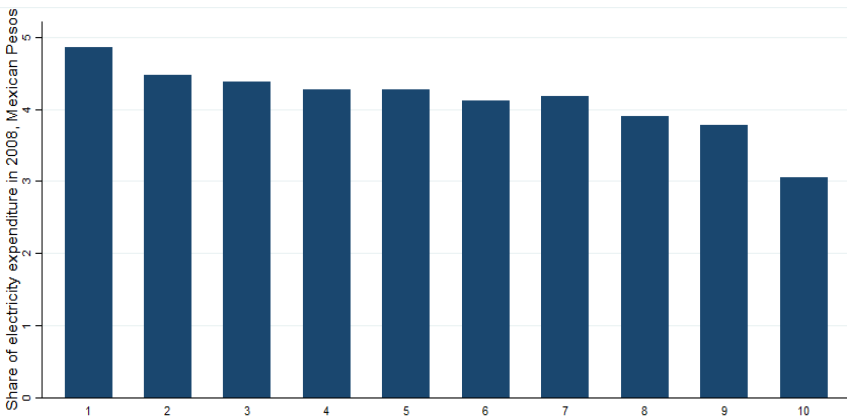
Electricity expenditure is the main driver of this inversion in the trend. The share of electricity expenditure of the poorest decile (1, Figure 36 b) is 1.6 times the share of electricity expenditure of the richest decile (10, Figure 36 b).

Figure 36 Share of per capita energy expenditure (a) and of electricity expenditure (b) by expenditure population deciles, Mexico 2008

a)



b)



Source: Author's elaboration based on ENIGH survey 2008

5.2 Mexico: results

5.2.1 The different outcomes of applying energy poverty indicators

This section focuses on the analysis of energy poverty in Mexico by using the selection of energy poverty indicators described is Chapter 3.

The indicators refer to the headcount of poor individuals on the population at the country level, in urban areas (considered as the areas with a population equal to 2 500 people or more) and in the rural areas (considered as the areas with a population of less than 2 500 people).

The first set of energy poverty indicators (Table 8) is based on energy expenditure, s_{ie}, and total expenditure, S_i. Indicators γ_1 and γ_2 computes energy poverty using a standard threshold as reference (respectively the 10% of the energy expenditure share and two times the median energy expenditure share of the population). Indicators γ_3 and γ_4 refers to energy poverty as the condition of having simultaneously an energy expenditure share higher than the median value in the population and a residual expenditure (total expenditure S_i minus energy expenditure s_{ie}) lower than a positive threshold (s_J and s_K).

Table 8 Energy poverty indicators (expenditure) values, in 2008

EXPENDITURE-BASED INDICATOR	COUNTRY LEVEL	URBAN AREA	RURAL AREA
$\gamma_1 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{S_i} \geq 0.1\right)$	20%	21%	17%
$\gamma_2 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{S_i} \geq 2 * P50(\frac{s_{ie}}{S_i})\right)$	19%	18.5%	23%
$\gamma_3 = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(S_i - s_{ie}) < s_J]\}$	7%	8%	7%
$\gamma_4 = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(S_i - s_{ie}) < s_K]\}$	16%	17%	14%

Source: Author's elaboration based on ENIGH survey 2008

Looking at the results of these measurements, a first evidence is the similarity between the γ_1 and γ_2 values. The usage of the initial British threshold of 10% provides a result that is in line with the one offered by the more general indicator γ_2, whose threshold is two times the median energy expenditure share of the considered population.

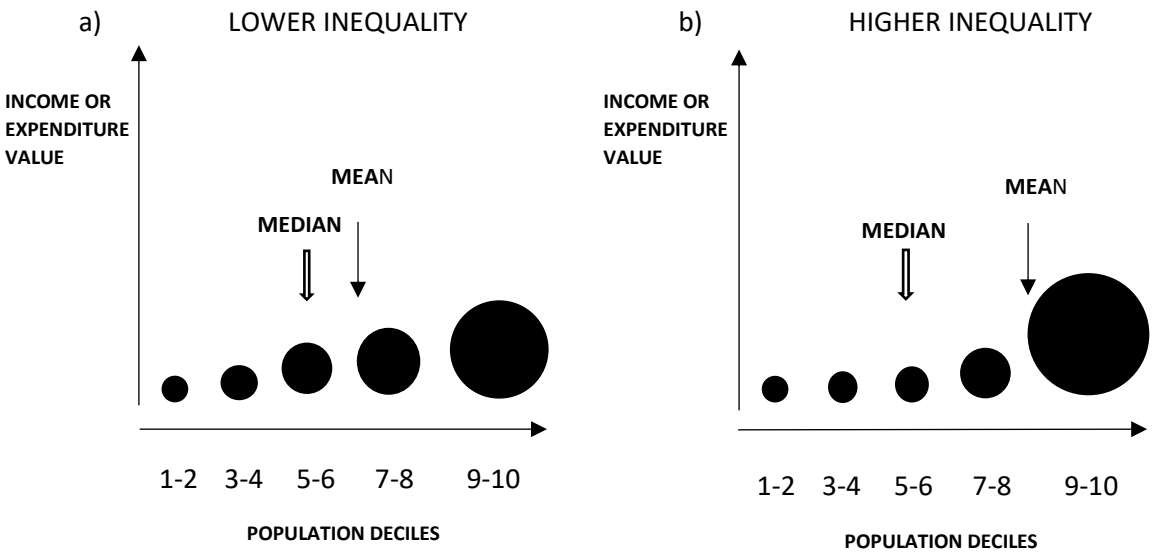
According to γ_1 and γ_2 indicators, the energy poor individual is the one whose energy consumption overcomes a certain threshold. The thresholds are computed basing on historical trends, but this does not necessarily mean that they are the most adequate to capture energy poverty in the context. In addition, these two indicators do not allow to understand the reason why the individuals overcome the energy poverty threshold.

The γ_3 indicator introduces the concept of the residual expenditure. In addition to having an energy expenditure above the median value, the individual is considered energy poor if its residual expenditure (the remaining expenditure after having purchased energy products) is below the threshold s_J. S_J is a variant of the at-poverty risk threshold defined by the statistical office of the European Union Eurostat as the 60% of the median income of the considered population. It is here used considering the expenditure condition instead of the income one.

The value of the γ_3 indicator is very low in respect to γ_1 and γ_2 because it rules out all those households that 1) spent a large share of overall consumption on energy and 2) have a sufficiently high residual income. The number of households that spend more than the median (not twice the median as in indicator γ_2) is 44%. When we only consider those with a residual income below the threshold s_J, we are left with 7 and 8% of households being classified as energy poor. The trend persists in a certain way also among the corresponding income-based indicators γ_1' γ_2' γ_3', where the original Eurostat threshold γ_J is used. It is so possible to consider s_J and γ_J as factors at the origin of this lowering. Considering that the Eurostat threshold is likely to have been defined observing the income (or expenditure) distribution in EU countries, where there is less inequality, the application of the threshold to high-inequality countries seems to be not adequate. This can be explained looking at the structure of the median and the mean of a variable in its distribution.

In a lower inequality context (Figure 37, a), as could be some EU countries, the median of a variable, such as income or expenditure, is closer to the mean and is more representative of the total disposable wealth (income or expenditure) of the country's population. In a higher inequality context (Figure 37, b), as some developing countries, the median of the variable is far below the mean. This is driven by few high-income outliers, which accumulate the biggest quantity of income or expenditure. Therefore, in this situation the median value of income or expenditure is not representative of the total disposable wealth (income or expenditure) of the country's population.

Figure 37 Median and mean in lower and higher inequality contexts



Source: Author's elaboration

For this reason, the indicator γ_4 is calculated using 60% of the income mean (s_K) as opposed to the 60% of the income median (s_J).

S_K is supposed to be a possibly more representative threshold for the Mexican framework than the Eurostat one s_J, and being s_K an higher value threshold it is more likely to have a bigger number of individuals with a residual expenditure lower than the threshold. Thus, the headcount of energy poor in γ_4 is higher and possibly more reflective of energy poverty in Mexico.

The same evidence occurs in the corresponding income-based indicator γ_4' (Table 9).

The income-based energy poverty indicators set (Table 9) includes at first the four indicators used for expenditure analysis (Table 8), but instead of the expenditure condition the income one is taken into account.

The trend remains similar to the expenditure-based indicators set, with the visible exception of γ_1'. This income-based indicator presents a lower headcount of energy poor in respect to the relative expenditure-based γ_1.

Table 9 Energy poverty indicators (income) values, in 2008

INCOME-BASED INDICATOR	COUNTRY LEVEL	URBAN AREA	RURAL AREA
$\gamma_1' = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{\gamma_i} \geq 0.1\right)$	10%	10%	13%
$\gamma_2' = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{\gamma_i} \geq 2 * P50(\frac{s_{ie}}{\gamma_i})\right)$	23%	22%	28%
$\gamma_3' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_J]\}$	9%	9%	11%
$\gamma_4' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_K]\}$	19%	19%	21%
$\gamma_5' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_P\}$	5.5%	5%	10%

Source: Author's elaboration based on ENIGH survey 2008

Given the elevated inequality in the income condition in the Mexico, it is affirmable that a consistent part of the population live with low-level incomes.

As the case of the γ_1' indicator, the usage of the 0.1 threshold could be not appropriate. Considered the low values of income (the denominator in the share of energy within the indicator γ_1') it is possible for the individuals to not overcome the threshold, and thus not being counted as energy poor, even if living in an energy poverty condition.

Secondly, to this set of income-based measurements it is added a variant of γ_3' and γ_4', which is γ_5'.

In γ_5', the main structure is closer to the one of the previous two indicators: the individual is energy poor if at the same time its energy expenditure is above the median value and its residual income, (the remaining income after having purchased energy products), is below a certain threshold. The threshold in γ_5' is γ_P, which is defined as the median income of the poor identified by the national poverty line (so in the case the CONEVAL income poverty line). The value of the indicator γ_5' is the lowest one (it is closer to γ_3' and to the corresponding γ_3 indicator's values). This lowering is attributable to a methodological error similar to the one described in paragraph 5.1.1 in relation to the World Bank poverty line. The threshold γ_P is computed within an existing set of poor individuals. Therefore:

-if on the one hand the indicator γ_5' surely captures a number of energy poor individuals who simultaneously afford an energy expenditure above median and have a residual income lower than the national poor median income

-on the other hand it does not take into account a number of poor individuals (which in the Mexican context is very consistent) that being poor by definition cannot afford an adequate level of goods and services, including energy products, but because they have a very low level of energy expenditure or they have a residual income higher than the median poor income, these individuals do not overcome the thresholds and are not counted as energy poor even if being poor

In relation to that, it has to be considered that in the survey the 15% of the observations related to the share of energy expenditure over the overall expenditure of the individual has a zero value. This might bring the attention to the so-called phenomenon of "hidden energy poverty". It means that there could be individuals that has a so reduced level of expenditure or income that they do not afford at all an energy expenditure or they do it in an informal or illegal way. These individuals are not counted as energy poor, but they are supposed to live in a poverty and energy poverty condition.

Observing the energy poverty indicators results in the urban and rural areas, there is a few percentage points differences among the two, both in the expenditure-based (Table 8) and in the income-based (Table 9) indicators.

In the first set, energy poverty is likely to be more present in urban areas according to γ_1, $\gamma_3$and γ_4, while γ_2 identifies a higher energy poverty in rural areas. One possible explanation of this trend could be the concomitant higher availability of energy products and higher expenditure capability that lead to overcome (in γ_1) or not stay below (in the second indicator that composes γ_3 and γ_4) the energy poverty threshold and so to be counted as energy poor.

In the second set of indicators (income-based), energy poverty seems to be more relevant in rural areas according to the all indicators. This could be due to the lower income availability in those areas, and the consequent probability to more easily overcome (in γ_1 and γ_2) or not stay below (in the second indicator that composes γ_3, γ_4 and γ_5) the energy poverty threshold, being so counted as energy poor.

5.2.2 The comparison to the ENIGH Survey 2018

The same sets of indicators have been computed in relation to the dataset of the ENIGH survey 2018. In Table 10 there are the expenditure-based indicators, while in Table 11 the income-based ones.

Table 10 Energy poverty indicators (expenditure) values, in 2018

EXPENDITURE-BASED INDICATOR	COUNTRY LEVEL	URBAN AREA	RURAL AREA
$\gamma_1 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{S_i} \geq 0.1\right)$	44%	46%	35%
$\gamma_2 = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{S_i} \geq 2 * P50(\frac{s_{ie}}{S_i})\right)$	19%	18%	18%
$\gamma_3 = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(S_i - s_{ie}) < s_J]\}$	9%	10%	9%
$\gamma_4 = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(S_i - s_{ie}) < s_K]\}$	21%	21%	17%

Source: Author's elaboration based on ENIGH survey 2018

Table 11 Energy poverty indicators (income) values, in 2018

INCOME-BASED INDICATOR	COUNTRY LEVEL	URBAN AREA	RURAL AREA
$\gamma_1' = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{\gamma_i} \geq 0.1\right)$	4%	4%	5%
$\gamma_2' = \frac{1}{n}\sum_{i=1}^{n} w_i I\left(\frac{s_{ie}}{\gamma_i} \geq 2 * P50(\frac{s_{ie}}{\gamma_i})\right)$	20%	19%	20.5%
$\gamma_3' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_J]\}$	7%	7.5%	7%
$\gamma_4' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_K]\}$	16%	17%	14.5%
$\gamma_5' = \frac{1}{n}\sum_{i=1}^{n} w_i \{I[s_{ie} > P50(s_{ie})] * I[(\gamma_i - s_{ie}) < \gamma_P\}$	4%	5%	5%

Source: Author's elaboration based on ENIGH survey 2018

According to the survey data, the strong inequality trend within expenditure and income condition of the Mexican households persisted also in 2018.

As for the energy poverty computation, both the expenditure (γ_1, γ_2, γ_3 and γ_4) and the income-based indicators (γ_1', γ_2', γ_3', γ_4' and γ_5') show consistent results with respect to 2008 and they highlight a few percentage-points diminution of energy poverty. However, two important exceptions are provided by indicators γ_1 and γ_1', which correspondingly detect an above the average (44% of the total population) and a below the average (4% of the total population) energy poverty computation. Firstly, looking at the very distinct outcomes provided by both γ_1 and γ_1' in relation to the indicators γ_2 and γ_2', it is affirmable that the original UK threshold of the 10% of energy expenditure share is no longer representative of the Mexican context, considering that the double of the median share of energy expenditure over total expenditure in the country in 2018 was 18%. Secondly, the two results of γ_1 and γ_1' can be considered, in a certain way, as complementary ones. In fact, they both put into evidence how households' energy expenditure and households' income followed different paths. Considering that in both γ_1 and γ_1' is present the same value of energy expenditure, precisely the median energy expenditure which in respect to 2008 increased by 21%, it is deducible that the different results of γ_1 and γ_1' is given by their denominators, which respectively are the median expenditure of the total population S_i and the median income of the total population γ_I. In relation to 2008, S_i decreased by 31% while γ_I increased by 51%. It has to be considered that, according to the academic literature, income can be a less reliable variable in respect to the expenditure as it is supposed to be more volatile and more difficult to be estimated. Anyhow the survey suggests that over years an increase in income did not lead to a relative increase in expenditure. This evidence can had been driven by a multitude of factors, such as the saving attitude of the household, but it should require a further deepen study of the microeconomic and macroeconomic framework of the country in order to be explained.

5.2.3 Implications of energy poverty measurements' usage

Previous academic studies on energy poverty in different countries of the world have provided interesting results on the quantification of this phenomenon.

Using a comprehensive energy poverty index (based on capturing energy accessibility, affordability and availability), Khanna et. al measured energy poverty in some relevant south and south-east Asian emerging economies, identifying the following values for 2014: in India the population living in an energy poverty condition resulted in 51.23 % of the total population, in the Philippines 44.05%, in Indonesia 33.64%, in Thailand 18.67% and in Cambodia 69.61% [Khanna et al. 2019].

Another study about forest fringe villages in the state of Madhya Pradesh in India adopted an energy access index, and the percentage of population having access to energy resulted to be the 48% of the total population, so the 52% had not [Yadava et Sinha, 2019].

With respect to Ghana, Crenstil et al. computed a headcount index of energy poor in the country, an intensity index of energy deprivation among the population and a multidimensional energy poverty index, consisting in the product of the previous two. The corresponding values in 2014 were 65.7%, 55.3% and 36.3% of the total population.

As for Mexico, Ochoa and Ed calculated that in 2012 the 70.7% of the population was meeting basic energy service-related needs, thus in some different modalities the remaining 29.3% of the population faced energy poverty [Ochoa and Ed, 2016].

Many academic studies dealt with energy poverty in Greece. Ntaintasis et al. developed two composites indicators of energy poverty (mixing objective and subjective indices); their results in the Attika region in Greece estimated the related energy poor population in 2017 to be respectively the 37% and the 43.5% of the total considered population [Ntaintasis et al., 2019].

Boemi and Papadopoulos adopted a multidimensional indicator approach to study energy poverty. Basing on low-income households living conditions of a survey population of Northern Greece in 2015, they found the 37% of the sample's households living in conditions of energy deprivation [Boemi and Papadopoulos, 2019].

It is interesting to notice that a huge portion of the sample's households was forced to adopt a modest lifestyle and lowered its living standard in order to cope with the situation, facing difficulties to support a decent living condition.

Papada and Kaliampakos adopted the original threshold of 10% of income on energy expenditure to measure energy poverty in Greece, and they computed that the energy poor households in their survey population were the 58% of the total [Papada and Kaliampakos, 2016]. In addition, they found that the 75% of the total households in the survey had to reduce other essential needs in order to manage energy payments. Within the poor population, as so defined by the poverty thresholds of the Greek national statistical office, the energy poor were the 90%.

I think that these latter findings are strictly relevant for the present analysis of the Mexican context. For 2008, according to poverty income thresholds of the CONEVAL Mexican public institute, the poor individuals in Mexico were the 46% of the total population. For 2018, this headcount was 42%. According to the CONEVAL declarations, these poverty thresholds were computed using a positive approach (based on historical observations) and in minimum absolute terms. This means that these thresholds do not represent the necessary amount of income to afford a social, economic and political adequate living standard, thus the poor population is supposed to be higher than the estimated one [Consejo Nacional de Evaluación de la Política de Desarrollo Social CONEVAL, 2018].

Notwithstanding this fact, assuming the lower estimated headcounts 46% and 42% as reference value of the poor population respectively in 2008 and 2018, the energy poverty indicators define energy poor ranging from the 7% to the 20% of the total population in the expenditure-based indicators (γ_1, γ_2, γ_3 and γ_4), and from the 5.5% to the 23% in the income-based indicators (γ_1', γ_2', γ_3', γ_4 'and γ_5') in 2008, and from the 9% to the 44% (expenditure based indicators) or from the 4% to the 20% (income based indicators) in 2018.

I argue that these energy poor headcounts are too small in comparison the poor population in the country, considering that I suppose energy poverty should concern almost the totality of the poor population and possibly a degree of non-poor individuals that, even if living in a standard condition, have to afford elevated energy expenses for fundamental needs, for example, because of the presence in the housing of energy-using appliances for ill people, for elderly people as well as people with disabilities [Snell et al., 2014; 2015].

Many individuals in the survey are not counted as energy poor by the indicators, because the individual's share of energy expenditure do not overcome the threshold share (γ_1, γ_2, γ_1', γ_2') or the individual's residual income is above the income poverty threshold (γ_3, γ_4, γ_3', γ_4 ',γ_5'). However, this does not mean that the individual meet the essential required energy spending, and thus is not energy poor, but rather that, given the general poverty condition context, the individual lowers its energy spending below an adequate minimum value in order to cope with other needs.

This is a factor that neither the indicators using a standard threshold (γ_1, γ_2, γ_1', γ_2') nor the indicators based on positive thresholds (γ_3, γ_4, γ_3', γ_4 ',γ_5') capture. For this reason, I retain that the usage of a normative approach to define the energy poverty thresholds should be explored and possibly adopted at the time to estimate the impacts of the energy phenomenon.

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6. Conclusions

This thesis has centred on energy poverty and on the modalities to measure it. Energy poverty is a phenomenon mainly defined as the inability for a household to meet some essential needs associated to energy using. From an economic point of view, this means that the energy poor is the individual whose energy consumption does not reach an adequate level to fulfil essential energy-related needs.

Therefore, the key point of the measuring process is to assess the "adequate level of energy" required by the household. To do so, it is possible to use qualitative indicators and quantitative indicators. Within these latter ones, it is common to define an energy poverty threshold. This is a numerical value that indicates the "adequate level of energy" required, and thus is able to differentiate among a population the energy poor households and the non-energy poor ones.

In energy poverty literature, three main approaches to define energy poverty thresholds are identified. The standard approach uses a previously defined fixed value (like the 10% of energy expenditure share) as threshold. The positive approach adopts as energy poverty threshold a proxy value computed on historical trends of the phenomenon. Within the normative approach, the energy poverty threshold is an estimation of the energy required to meet some essential energy needs.

In the thesis, I applied a selection of quantitative headcount unidimensional energy poverty indicators, based on the expenditure and income conditions of the household, on the country of Mexico, using the data of the ENIGH National Households Income and Expenditure Surveys of 2008 and 2018 provided by the Mexican national statistical office INEGI.

These quantitative indicators adopted a standard (γ_1, γ_2, γ_1', γ_2') or a positive (γ_3, γ_4, γ_3', γ_4', γ_5') energy threshold. The results of the analysis ranked energy poverty in the country between 7%-20% (expenditure based indicators) and 5.5%-23% (income based indicators) of the total population in 2008 and between 9%-44% (expenditure based indicators) and 4%-20% (income based indicators) in 2018. I argued that these indicators significatively underestimated the extent of energy poverty in the country. This has been expressed in the consideration of the strong inequality in the expenditure and income condition across the Mexican population and the concomitant relevant poverty in the

country, which according to the CONEVAL National Council for the Evaluation of Social Development Policy, a public Mexican monitoring authority, counted for the 46% of the total population in 2008 and the 42% in 2018. The poverty thresholds adopted by the CONEVAL institute were also determined using a positive approach.

These quantitative headcount unidimensional energy poverty indicators, adopting standard and positive thresholds, are able to set a reference value for energy poverty identifying energy poor and non-energy poor populations, but they do not explain why the household is energy poor or not. They do not highlight the household behaviour at facing energy needs in relation to other needs. In the present case, I gave an explanation of the indicators underestimation with the fact that a relevant number of poor households is supposed to have lowered its own energy consumption under a minimum adequate level, such that energy consumption would not compromise a large portion of its own budget. For this reason, the households resulted to not being energy poor, even if living in an energy deprivation condition.

This situation could be addressed adding qualitative or intensity and multidimensional indicators, which could capture more facets of energy poverty. Anyhow, as mentioned in energy poverty literature [Pelz et al., 2018], the usage of such indicators could reduce the comparability of the analysis results. Therefore, another possibility could be the adoption of a normative approach in determining the energy poverty threshold, as recommended by the CONEVAL Mexican public monitoring authority [CONEVAL, 2017], for example identifying a basket of essential energy goods and services. This could implicate a wider degree of value judgements for the national statistical offices, as well as an eventual reduction in the comparability of the so defined normative energy poverty thresholds between countries, but at the same time could generate more representative results of the energy poverty phenomenon in the country.

Assuming the above, I would conclude the work with two further brief considerations: indicators in the economic discipline provide an estimation of a considered phenomenon, but they are arguably informative themselves. They need to be complemented by a previous understanding of the phenomenon in analysis.

At the same time, the usage of indicators can represent a very useful and important instrument for policymaking, aimed to study and monitor specific issues at people's attention.