Mexico 2030: Energy Efficiency and Economic Growth

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Abstract **- Two scenarios for the economic growth of Mexico are presented based on different developments of the aggregate efficiency of the productive sectors of the country. One of this scenarios takes the assumption that improvements in efficiency, energy usage and energy carriers will keep the same trend that they have followed over the last ten years, while the second one proposes measures to improve the efficiency of three different sectors (energy, transportation and residential) based on the analysis of the end uses given to the energy and the efficiency of the carriers involved. The neoclassical economic theory is used in order to estimate the growth in Gross Domestic Product (GDP) while employing a relationship between the efficiency of the country to exploit its energetic resources and the Total Factor Productivity (TFP). Although this approach has proven a strong correlation between energy efficiency and TFP in developed countries, results suggest that this trend does not apply to Mexico, and might as well not apply for other developing economies, a possible explanation to this can be the low TFP growth that this countries have presented since the economic crisis of 1984 and might be associated to high levels of informal employment and low levels of higher education and qualified labor.**

Keywords: **Exergy; Economic growth; Useful work; Energy efficiency; Total factor productivity.**

I. Introduction

Mexico is the second largest economy in Latin America, just after Brazil. It has the fifteenth-largest nominal Gross Domestic Product (GDP) and the eleventh-largest by purchasing power parity, it was the first Latin American country to join the Organization for Economic Co-operation and Development [1]. Its proximity to the United States and the liberalization of its market has made of exports one of the main contributors to economic development, as it went from representing 7.7% of the national GDP in 1970 to 37.88% in 2017 [2].

The country presented a significant economic development on the decade of the 70's, with an average annual growth of 6.9%, it was strongly affected by the economic crisis of the 80's and only managed to average a yearly increase of 1.88% during that period, it then manage to recover from 1990 to 2000 by growing 3.54% on average and has been keeping an average rate of around 2.1% since the beginning of the 2000's [3].

This slowdown in economic growth has not been enough for the rapidly increasing population of the nation and has led to major social issues regarding economic inequality and a high share of informal labor, which might cause a potential feedback loop to slow the economic development of Mexico [4].

The objective of this paper is to find a link between the growth of the second law efficiency of the processes involved in the energy sector and the Total Factor Productivity (TFP) and propose potential policies that could lead to efficiency gains on the aggregate final to useful exergy efficiency, with the belief that this gain could in turn enhance a faster economic growth for the country.

In order to propose these potential polices, an analysis of the trends in the Mexican energy sector is performed based on the previous work of [5] and energy outlooks and reports of the International Energy Agency. To analyze the effect of these policies, two scenarios are performed, one assuming that the actual trends in the final exergy demand will remain over the following years and a second one where the adoption of the proposed policies will incentive the use of some technologies that will shift the useful work performed to be done by more efficient energy carriers. To develop these different scenarios the Useful Exergy Accounting Methodology (UEAM) is followed and some corrections are made on the previous estimations of transport that take into consideration what is thought to be a more realistic approach for the case of Mexico.

An analysis on different approaches and interpretations to TFP is presented in the discussion as well as a comparison on the trends of this variable in diverse countries with different levels of development and distinct geographical locations

This paper is structured as follows: Section II – Energy vs Economic Growth; Section III – Mexico: Energy and Economy; Section IV – Methodology; Section V – Results; Section VI – Discussion; Section VII – Conclusions.

II. Energy vs Economic Growth

A. Exergy

The UEAM was developed by [6] to study the useful work consumption of specific sector of Portugal and was later employed by [5] to produce results of Mexico for the period of 1971-2009.

Reference [5] used data for the primary and secondary energy consumption of Mexico from [1] and [7] databases. To complete this information with the food and feed supply, information of supply per capita and Mexican livestock and draft animals was obtained from [8] and [9] databases.

The classification defined by the IEA was used in this methodology, consisting of 4 energy consuming sectors defined as: 1) Energy sector own uses: includes the consumption of the fuels and energy producing industries such as coal mining, oil and gas extraction and oil refining; 2) Industry: consumption of each industry specified by subsectors, excluding energy used for transportation; 3) Transportation: covers all transport independently of the economic sector to which they contribute; and 4) Others includes the consumption of residential, commercial and public users, as well as the agriculture and forestry sector, does not include consumption of personal transportation [10].

The first step defined in the UEAM is to convert the above-mentioned primary and secondary energy (E) data to final exergy (B) values by (1), by multiplying the energy according to its carrier by the corresponding exergy factors (Φ).

$$B = E * \Phi \quad (1)$$

Feed supply is converted with [11] data for gross exergy of feed products.

After classifying the final exergy by carrier, the next step is to further allocate this exergy by its useful work category, there are five different categories and they are defined by [5] as Heat, Mechanical drive, Light, Other Electric Uses and Muscle Work.

Once the energy carriers and useful work categories were properly disaggregated, useful exergy values were obtained from the second law of thermodynamics, or final-to-useful efficiency law (2).

$$U = \varepsilon * B \quad (2)$$

Final exergy to useful work efficiencies are dependent on the energy carrier as well as on the end use or useful work category and tend to improve over time, these efficiencies were estimated as in [5].

After computing the useful work for each category, the aggregated second law final-to-useful efficiency is calculated with (3)

$$\varepsilon = \frac{Useful\ exergy\ by\ category\ i}{Total\ final\ exergy\ by\ useful\ work\ category\ i} \quad (3)$$

B. *Economic growth*

As mentioned before, GDP (*Y*) is the standard measure of economic growth and it uses monetary units. A mathematical way of representing the Solow-Sawn theory is through the Cobb-Douglas production function (4), where labor (*L*) and capital (*K*) are considered to contribute by their respective shares, a_L and a_K, which is complementary to the labor ($a_K = 1 - a_L$), while the TFP (*A*) is represented by a third variable, [12].

$$Y_t = A_t\, K_t^{a_k}\, L_t^{a_L} \quad (4)$$

Labor is normally measured by the population growth rate, although must recent models have taken more factors in account such as the average worked hours per individual within the working age group, unemployment rate and the human capital index, which is based on the years of schooling and returns to education that makes contributes to increase the efficiency of the labor force [13].

Solving for TFP and assuming constant returns to scale, the logarithmic derivative of this equation leads to:

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{Y}_t}{Y_t} - a_k \frac{\dot{K}_t}{K_t} - a_L \frac{\dot{L}_t}{L_t} \quad (5)$$

If output per capita and capital per capita are defined as *y=Y/L* and *k=K/L* as done by [14], TFP is defined as:

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{y}_t}{y_t} - a_k \frac{\dot{k}_t}{k_t} \quad (6)$$

Which means that the growth rate of TFP equals the growth rate of GDP per capita minus the growth rate of capital per capita multiplied by its respective share.

C. *Forecasting Economic Growth*

A methodology is defined in [15], in which a relationship between the relative growth of TFP and exergy efficiency over the studied period is described by the constant *C*, obtained through (7).

$$C = \frac{\ln\left(\frac{TFP_t}{TFP_0}\right)}{\ln\left(\frac{EFF_t}{EFF_0}\right)} \quad (7)$$

This constant is employed to estimate the TFP growth as a function of the growth in final to useful efficiency exergy efficiency by means of (8). As shown by [15], by estimating the GDP growth of Portugal using this energy efficiency based TFP, a good approximation of the country's economic development can be obtained for the observed period 1960-2010.

$$TFP_t = \left(\frac{EFF_t}{EFF_0}\right)^C * TFP_0 \quad (8)$$

After testing the results for the exergy efficiency based TFP to explain the historical GDP growth of Portugal, [15], made use of the model developed, combined with participatory scenario building techniques, to define two scenarios for 2030 with the corresponding projections of GDP growth.

To estimate the capital stock for the upcoming years, the PIM method was employed [15]. In this case the estimation of the capital for a certain year (K_t) is dependent on the previous period capital assets (K_{t-1}) , the investment capacity of the present year ($i_{t-1}GDP_{t-2}$) is being added to this value, while at the same time the capital that is not available anymore due to depreciation is being subtracted ($\delta_{t-1}K_{t-1}$). This methodology is described by (9), where i represents the investment capacity as a percentage of the GDP and δ is the depreciation rate of capital, which were estimated to be constant over time at an average value of the historical data.

$$K_t = K_{t-1} + i_{t-1}GDP_{t-2} - \delta_{t-1}K_{t-1} \quad (9)$$

Reference [15] take labor as measured by the total number of hours worked by the engaged population of Portugal over each year and this value is corrected by multiplying the number of hours by the human capital index. In order to calculate the total number of hours labored in the economy (*L*), the hours worked per engaged individual is considered (*h*), as well as the engaged population within the working age limits (15-64 years), the unemployment rate (*td*), and the labor force participation rate (*TP*).

$$L = h * (1 - td) * Pop_{15-64} * TP \quad (10)$$

In order to estimate the final to useful exergy efficiencies up until 2030. In the MEET 2030 project, two workshops were performed with representatives of the largest companies in Portugal (around 40 companies were represented that account for about 20% of the country's GDP) and together with specialised reports and scientific papers developed two different scenarios of technological improvement. With the projection of this efficiency growth, it was possible to make projections of the TFP behaviour for the following years by means of (8).

III. Mexico: Energy and Economy

A. *Energy Sector*

Up until 2014 the Mexican energy sector was mostly controlled by the state. Exploitation of energy resources was performed by the national oil company Petróleos Mexicanos (PEMEX) while power generation was managed mostly by Comisión Federal de Electricidad (CFE). The energy reform approved this decade represents the most significant change for the regulation of this sector since the oil expropriation in 1938, with the creation of ten new articles in the constitution and the update of another twelve, the transformation of both PEMEX and CFE to state productive enterprises, is expected to be business driven and make them compete with the private sector [1]. As state productive enterprises, both companies will be operating as private, with legal, technical, and budgetary management independence and the autonomy to make their own business decisions at a national and international level, while remaining state owned [16].

The energy policies coming from this reform are said to put Mexico in line with the IEA Shared Goals, which seek for the member countries to work on their energy sectors in a way to maximize their contribution to sustainable economic development, population well-being and environment.

Even though the reform has been well received by international energy institutions and investment funds, according to [1], Mexico's historical measures have been focusing on the supply side, leaving aside demand side actions that in energy efficiency and transportation are important and cost effective, specially with trends like the ones showed by Mexico on demography, transport patterns and urban sprawl. Recommendations have been made from the IEA regarding this issue on recalibrating policy and program balance between supply side and demand side considerations.

A point against the reform from the IEA objectives perspective is that contrary to the goal of not distorting electricity prices artificially, Mexico has been subsidizing up to 60 and 70% of electricity bills in some of the residential tariffs. These subsidies are likely to disincentive increase in efficiency and it is suggested that they are replaced by specific social policies for vulnerable groups. Gradually removing subsidies can help to reduce the waste of energy at residential and agriculture levels, increase awareness among the society and incentives to invest in more energy efficient devices.

In order to detect the major areas where efficiency could be potentially improved, the final exergy and useful work consumption trends are analysed by sector, according to the classification of the IEA defined previously.

1) Energy Industry Own Uses

Mexico has been known to be one of the largest oil producers and exporters worldwide, however the output of oil has decreased about 33% from 2004 to 2016, while 50% of the natural gas consumed in the country is being imported. These negative trends have been associated with a reduction on PEMEX funds and the lack of technology to perform extraction from deep water wells and refining heavy oil [1].

The processes of this sector have been almost entirely performed by PEMEX, the lack of competition in this field has led to an increase of aggregate final to useful efficiency of only 4% over the last four decades [5].

The main contributors for the consumption of final exergy on this sector are the oil and gas extracting and oil refining industries, adding up a share of 98% in 1971 and being almost constant by reaching 96% in the year 2009 [5]

Oil production is expected to rise to 3.4mb/d for the year 2040 from the actual 2.5mb/d produced today, while gas demand is projected to grow fast until 2029 according to the Energy Department (SENER for its Spanish acronym) [1]. These projections suggest that a growing demand of useful work will come for this sector and therefore improvements in efficiency could be welcome in order to make the best of the primary energy resources available.

Given that the mechanical power and medium heat temperature processes represent the highest useful work category shares, with 55% and 32% respectively in 2009, and that these are fuelled mostly by natural gas and oil [5], a potential improvement in efficiency could be derived from the shifting of both mechanical work and heating from fossil fuels to electric power, which has a significantly higher conversion efficiency.

Although the share of electricity for these purposes has already been increasing over the last decade [5], limitations to this effort in the extraction industry could be presented when considering the increasing share of oil and gas coming from offshore wells over time [17], and the expectation of this trend to continue due to the immersion on deep water wells coming from the reform. On the other hand, technologies as immersion electric heaters have proven to be a reliable alternative in the oil refining industry, especially in processes such as pipeline heating, storage heating, freeze protection and sterilization, presenting significant technological and efficiency advantages [18].

2) Industry

The industrial sector is the second largest consumer of energy in Mexico, accounting for 33.6% of the total final consumption, its consumption has grown 11.6% from 2005 to 2015 [1].

The main energy carriers employed in the industry are natural gas with a 31.8% share, electricity 30.8%, and oil products 28.5%, while coal and biofuels account for only about a 9% share together. The consumption of electricity and natural gas have increased 35.2% and 19.2% respectively since 2004, while oil consumption has fallen 9.3% in the same period [1].

The final to useful efficiency in this sector has shown the best performance over all, it grew from 17% to 33% over a period of forty years mainly driven by electrification and the need of increasing productivity to be able to compete against international firms since the signing of the NAFTA in 1994 [5].

Over the last ten years, about 40% of the final exergy demand has come from non-specified industries, which makes it hard to follow up technological efficiency improvements. Other industries like steel and iron, chemical and petrochemical, and the non-metallic minerals, accounted for another 40% of the energy consumption, these industries are known to be high energy intensive and this is reflected on the end uses of the sector, where mechanical work and high temperature heat processes accounted for 70% of the useful work performed, while the other electric uses category have been increasing significantly over the last years [5].

Steel and chemical industries have improved significantly, declining their energy intensities between 20 and 50% since the year 2000, mostly due to efficiency gains derived by improving motor-driven systems, as well as the efficiency standards defined by the government, progress in this areas is expected to continue thanks to the next generation of motors harmonising with US standards, and the fact that motors consume almost 70% of the electricity of the sector [1].

3) Transportation

Transport is the largest energy consuming sector in Mexico, with a share of 43.4% of total final consumption, the demand has increased 22.7% from 2005 to 2015, which is a faster rate than the average total consumption, this is the result of a historical low fuel cost and relatively easy access to car ownership due to crossborder flow of used vehicles from the US [1].

Oil products are the main fuel of the transport sector, with a share of 99.8% of the energy demand, leaving only a negligible 0.2% of the sector powered by electricity [5], mainly used by public transportation within the largest cities of the country. With oil production projected to grow from 3.4mb/d in 2029 compared to the actual 2.5mb/d [1], the situation of the sector doesn't seem likely to change during the following years.

The second law efficiency of this sector is not only the lowest but is also the one with the most mediocre growth, going from

12 to 15% over the last forty years [5]. This could be attributed to the high average age of the vehicle fleet in Mexico, which for light duty vehicles was of 13 years in 2014 [19], this has been mainly a consequence of the law for used imported vehicles included in the NAFTA that gradually reduces the minimum age of cars that can be imported [20]. According to the report "Used Vehicles: A Global Overview" [21], Mexico is the largest importer of used vehicles from the US, such that in the period of 2005-2014, 44% of the added country's vehicle fleet was composed by used imported [22].

The high share of transport in the total final consumption of Mexico together with the inefficiencies of the sector gives to it an important weight for producing an impact on the overall country's energy consumption [1].

While developed countries like Norway and the Netherlands have move fast on the integration of electric vehicles, a low adoption rate is expected from Mexico due to some obstacles such as the high upfront costs and scarce supporting infrastructure. These barriers are extended by other social factors, such as the already slow modernization of the national fleet and the uncertain cost of electricity. These problems lead to expect transport electrification as a long-term process. Social policies are not helping either, an example is Mexico City, where vehicles priced under $350,000 MXN (around $18,000 USD) are exempt to pay ownership taxes, incentivizing the use of cheap, less efficient vehicles [23].

A strengthening of sectoral policies especially in transport is urgently required as given the energy consumption trends in Mexico it is expected that even by achieving a 71% share of clean electricity by the year 2046, GHG emissions might increase due to the consumption of fossil fuels from this sector [1].

Given the mobility trends of Mexico, a potential policy that could be applied in order to reduce the average age of the vehicle fleet and therefore contribute to a significant increase in the overall efficiency of the sector is what was applied in Portugal as "Renove carro", which consisted on three main policy instruments: including a CO2 component in the annual circulation tax; including a second CO2 component in the vehicle purchase tax; and giving a fixed economic incentive to replace vehicles (2008-2010) through a subsidy [24].

The objective of these instruments was to promote the introduction of more efficient vehicles with low CO2 emissions, as they promoted for instance a 50% reduction of the circulation tax for hybrid vehicles, while at the same time reduce the emissions of old vehicles, providing a subsidy of $1000 EUR and $1349 EUR if the cars were older than ten and fifteen years respectively. This led to the replacement of 37,326 old vehicles in 2010 and the abatement of 37,476 tons of CO2 in the same period [24].

4) *Other Energy Uses*

This sector includes consumption of residential, commercial, and public users, as well as the energy consumed by the agriculture, fishing and forestry sectors. Residential consumers account for 15% of the total energy demand, this trend has kept relatively unchanged over the last decade, while the services sector, including public services and agriculture, has grown 35.5% during the same period and has come to represent 8.1% of the total demand in 2014 from 6.9% in 2004 [1].

Regarding the energy carriers used in this sector, the consumption of oil, electricity, and combustible renewables are the more significant representing 38.8%, 34.3% and 22.2% respectively, the last one having still a significant share due to the economic situation of most of the population that still use wood for cooking and water heating. Even though the demand of oil remains the highest, it has been decreasing together with the combustible renewables as electrification has been reaching more rural areas. Natural gas and solar thermal have a share of 4% and 0.7% respectively, as liquified petroleum gas has a higher availability than natural gas and infrastructure for its residential distribution is still lacking in most parts of the country [5].

Even though most of the energy consumed in mexican homes is used for low temperature heat purposes, it is not employed in space heating, as showed by [25], 65% of the residential consumption is used for water heating, while cooking is the next end use in the list with a share of 17.2%, this lefts the door open to a significant efficiency improvement by shifting the energy carrier to solar thermal heating, considering Mexico's solar power potential (with an average daily irradiation of 5.5kWh/m^2) and its above average amount of sun hours per year across the whole country [26].

Buildings in the country consume 25% its final energy and the urbanization process and the growth in the service sector is likely to increase this share. Although air condition can represent up to 50% of the energy consumption in buildings, and the forthcoming climate conditions are likely to increase the need for it [1], as of 2014 less than 15% of the population counted with one [27].

Currently there are replacement programs going on in order to decrease the use of low efficient refrigerators, air conditioning systems and fluorescent lights. The Efficient lighting program saved 9.6TWh of electricity in the period of 2010-2015 being applied in 11.3 million households [1].

While Mexico has managed to apply successful energy efficiency programs at the residential level, some measures have been discussed with the objective of reducing emissions such as: removing electricity subsidies that discourages investment to adopt more efficient technologies; promoting distributed generation of solar photovoltaics and solar thermal heating; increasing the adoption of efficient wood stoves; regulating for energy efficient appliances and making it mandatory for new constructions; strengthening incentives to purchase efficient electric appliances [28].

As of today, almost 60% of the household electricity price in Mexico is still subsidized by the government [1]. Although removing this subsidy is a repeatedly discussed measure, some critics have emerged, arguing that due to the income inequality present in Mexico, an increase in the electricity prices could lead to a deterioration of the poverty level of the most vulnerable people, given that there is a low elasticity of demand in this sector of the population, compared to a higher elasticity among the wealthiest [27].

Countries like Portugal have successfully applied programs like "Renováveis na Hora" which was based on three policy instruments: compulsory installation of solar heating systems in new buildings; subsidies for the installation of solar thermal in existing houses; and feed in tariffs for residential generation of electricity. The first two instruments led to an avoidance of 7,980 tons of oil equivalent of energy, while the government subsidized 30% of the investment of the solar system by income tax deduction for existing buildings [24]

B. *Economy*

The average growth of the nation during the last decade has been modest, with a 2.5% increase between 2005 and 2015, at the same time the gross national income per capita raised by 44%, although the GDP per capita ($13,608 USD) remains quite below the IEA average ($32,621 USD) [26]

Mexico's economy has had a deep reorganization after the 80's, that transformed the country from a local manufacture and substituting imports focus to a liberalised economy open to foreign trade, investment and private sector participation, this was mainly achieved through the abolition of import licensing, the privatization of state-owned industries, and NAFTA, which lead exports to double and diversify [5].

Due to NAFTA, manufacturing exports accounted for more than 90% of the export revenue and Mexico position itself as the second largest consumer of US exports ad third largest exporter to the same country. The country's export success has been mainly attributed to the automobile manufacturing, which has grown around 12% yearly since 2004, making Mexico the seventh largest car manufacturer worldwide and the fourth largest exporter, making this industry more important than energy when it comes to export revenue [26].

The massive foreign investment coming into the country after NAFTA led to an economic crisis in 1994 that the nation was able to overcome easily by the end of 1995 and keep a stable but slow growth until today, keeping an annual average of 2.6% over the last 20 years. This insufficient growth was worsened during the 2009 crisis, leading to a negative growth in GDP of -6%, although the economy recovered rapidly, reaching an average yearly growth of 4.4% during the next three years. Expectations for growth of the economy are estimated to be between 1.2 and 3.5% for the upcoming years [29].

Even with the slow growth in the economy during the mentioned period, the labor market in Mexico has kept a low unemployment rate and has manage to keep the growth of employed population above the proportion of the total population increase. Following the definition of labor as the total number of hours worked within an economy by the engaged population, Mexico presents a higher labor growth rate than developed countries such as the US, UK, Japan and Germany and also high compared to Latin American countries under similar economic conditions as Brazil, Colombia and Chile [30].

This labor conditions have been however co-existing with a high level of informal employment. It was reported by INEGI that informal employment in the country accounted for around 60% of the total employment during the period of 2011-2014 [29].

Data from INEGI has shown that informal unemployment differs by state, states like Oaxaca that remains one of the least developed regions in Mexico has informal employment rates of 81.2%, more than 30% above the national average, while states with a better developed labor market like Nuevo León have shares of informal unemployment of 39.5% [3].

On the other hand, the capital stock accumulation in Mexico has managed to keep a stable growth and has sixfold over the period of 1970 to 2014, the investment capacity and the depreciation rates have been kept more or less constant around 22.3% and 3.9% respectively [30].

Shares of capital and labor in the economy are important for the determination of the GDP, as described by the Solow-Swan model and the Cobb-Douglas Production function, [14] has shown that the estimation of this shares plays a significant role on the calculation of the TFP and has proven that informal unemployment can lead to obtain misleading values of capital and labor contribution. While data from the Penn World Table [30] suggest that the share of capital is around 52% and the labor one is complementary, the estimations made by García-Verdú through a household survey show that the actual shares are 34% and 66% respectively, which coincide with the 1/3, 2/3 rule of thumb of economic theory [15]. These methods have been tested in other developing countries with similar levels of informal employment and have produced comparable results [31].

IV. METHODOLOGY

A. *Exergy*

The historical series of and useful exergy consumptions of Mexico from 1971-2009 were obtained directly from [5] who produced these results from the databases of [3] and [7]by using the UAEM.

The results from [5] however showed some inconsistency within the transportation sector when compared to the study performed by [32]. The last one showed an evolution on the efficiency of gasoline internal combustion engines of 15 different European countries from 9.6 to 10.3% over the studied period, while on the same timeframe Guevara estimated an increase from 10.8 to 12.7%. These numbers don't add up specially if the average age of the vehicle fleet of these regions is taken into account, while the average age in Europe in 2010 was 7.5 years [33] in Mexico it reached 13 years, while almost one quarter of the registered vehicles are older than 16 years [19].

To take into account the significant difference on the average age of the fleet vehicle between the EU and Mexico, a degrading coefficient was considered based on the decaying fuel efficiency over time. This coefficient was estimated by taking the efficiency for European gasoline vehicles as a reference and reducing it from this point onwards on a yearly 0.08%, this measure brought the range of this coefficient from 0.93 for 15 years old vehicles to 1.0 for 7 years old vehicles.

Once the efficiency of the transportation sector was adjusted, the scenario designing process was performed. This process began by taking the estimates of the population growth in Mexico, which is expected to reach almost 132 million people by 2030, an increase of 9.4% in respect from the year 2014, but with a yearly average growth significantly lower than in the previous decades [34].

It was observed from the previously studied period that the relationship of useful work consumption per capita increased with a linear growth, this made it reasonable to assume that this tendency will prevail for the following years, reaching a value of 13.23 GJ/cap, which is almost 40% higher than the per capita consumption of the year 2009.

Having estimated the per capita consumption and with the population projections it was possible to estimate the total useful work demand, which increased 60% in respect to the 2009 values. The trends of the consumption share of the last 10 years of available data, were used to allocate the share that each useful work category would represent from the total mix over the coming years, from these categories the exergy was further allocated in each of the sectors, based again on the trends of the last decade.

While the useful exergy remains constant for both scenarios, the difference in the efficiency of conversion technologies and switch in energy carriers resulting from the implementations of policies is expected to lead to different paths of final exergy consumption and therefore to different trends in final to useful exergy efficiency that in the end are likely to project different economic growth outlooks.

Evolution of the efficiency of heat processes was estimated logarithmically considering the actual efficiencies of the industry in European countries [32] and the limitations due to the geographical conditions of Mexico. On the other hand, for the electricity uses, the same methodology of using the last decade tendencies to estimate future shares was employed, while the efficiency of its end use was extrapolated from the estimations of [35].

1) Baseline Scenario

The case of the energy sector is similar to the industry in the sense that roughly 90 % of the useful work performed is done by medium temperature heat processes and mechanical work, having a share of 35 and 55% respectively [5], which doesn't leave the door open for much improvement in conversion devices. The same criteria was applied as in the industry for a progressive increase in efficiencies following the trend over the last decade. The final exergy was estimated with (1) and was categorized by end use category and energy carrier.

All the worked performed in the transport sector correspond to mechanical, while oil and its derivatives add up for almost 100% of the energy carrier that fuels it. In order to estimate the final exergy projections of transport, an increase in the compression ratio of internal combustion engines was estimated to continue in the following years, however it is also expected to have a diminishing in this efficiency gains due to a projected raise in the average vehicle fleet age allowed by NAFTA [20]. These facts together with the expected lag on electric vehicle adoption due to the low purchasing power of the population and other social factors don't raise much expectations on an increased efficiency of the sector from a shift in the energy carrier [23]. Final exergy estimations were straightforward from (1) and (2).

The others sector's largest consumers are the residentials, and contrary to the rest of the sectors, other than mechanical power, low temperature heat processes are the second largest end use category contributors to the useful work mix. This is mainly attributed to water heating and cooking with 65% and 17.2% of the end use share [25] and they have mostly been obtained through oil products such as liquified petroleum gas and combustible renewables [5]. As for the previously described sectors, the consumption trends over the last decades were used to estimate the final exergy consumption by using the extrapolated energy efficiency values following the UEAM.

2) Improved Policies Scenario

In order to contribute to a faster increase in aggregate final to useful exergy efficiency, potential improvements for the Energy, Transport and Residential sectors are suggested, as well as the assumptions that were inputted in the model in order to measure their effect. These improvements were suggested based on an analysis of the end use categories of each sector and the energy carriers used to perform work.

While most of the work performed in the Energy sector own uses corresponds to mechanical work performed by gas turbines in the extraction processes and medium heat temperature done by oil in the oil refining industry, there has been a slight share over the last decade performing this same work by electric equipment [7]. This becomes relevant as electric motors and medium temperature electric heating systems have significant higher conversion efficiencies than their fossil fuel-based counterparts [36]. This means that shifting from one technology to another can have a significant impact on the aggregate efficiency of the sector.

Shifting oil to electricity in the refining industry would not imply any technical restrictions, as there is actual equipment available in the market with significant advantages over oil heating systems, such as being more environmentally friendly as there are no pollutant by-products in the process, having a comparative smaller size that eases the installation and operation and having both a lower initial investment and maintenance cost [18]. This led to the assumption that by 2030 a shift on medium heat process can be achieved, raising the share of electricity as a carrier from 2 to 12%, while reducing the respective shares of coal, oil and natural gas to perform this work.

Increasing the share of mechanical work produced from electricity could be more complicated given the trends on the location of the oil and gas wells, as offshore extraction has been increasing since the 80's [17] and it is expected to keep raising as deep waters extraction becomes common. This scenario considers the possibility of increasing the share of electric motors from the actual 17.5% to 22% in 2030 by strengthening the environmental regulation of the extraction industry in onshore wells.

Given that the main problem with efficiency in the transport sector is the rapidly increasing Mexico's vehicle fleet [3], due to the lack of coverage of public transportation outside of the country's largest cities, a policy that contribute to the replacement of old vehicles and reduce the average fleet age was considered. Such policy was applied in Portugal between 2008 and 2010 and contributed to a significant reduction in CO2 emissions [24]. In contrast with the baseline scenario it is expected that with such a legislation the average age of the vehicle fleet in Mexico can be reduced to 8 years by 2030 from the actual 13 and it is assumed that such improvement will bring a 0.5% increase in the efficiency of the road vehicles.

Considering the trends on the useful work consumption of the residential sector together with the main end use of low temperature heating processes, it is assumed that shifting the useful work performed to achieve this end use by incentivizing the adoption of solar thermal technologies could potentially improve the efficiency of the "Other uses of energy" sector in general. Such a program has been previously issued by Portugal by the means of subsidizing the cost of the equipment through taxes [24]. Considering the declining price of solar water heating [37] and the excellent geographical location of Mexico for solar irradiation [26], it is assumed that reaching a shift from a share of 1 to 10% of solar thermal heating by 2030 is achievable, while this would imply a reduction on the shares of oil and biomass that have low efficiency values.

With this efficiency improvements and shifts in energy usage, the final exergy consumption for this scenario is calculated by reversing the process of the UEAM and having estimated the final exergy for both scenarios allocated by industry and end use it is possible to estimate the trends in the aggregate exergy efficiency with (3).

B. Economic Growth

Therefore, in order to estimate the GDP of the 2014-2030 period, it is necessary to know the TFP as well as labor and capital inputs together with their corresponding shares to the GDP.

The estimation of labor growth was entirely based on the projections of the population growth for Mexico from the [34], although there are other valid methodologies to estimate labor, it was decided to use this one in particular.

Accumulation of capital stock in Mexico has showed a rather defined tendency over the studied period [30], therefore in order to project the growth of capital until 2030, assumptions were made that the depreciation rate will be constant at 3.88%, while the investment capacity will remain at a constant value of 20.56%. These assumptions were used to estimate capital by means of (9).

The shares estimated by [14] were the ones used for the development of the economic growth model, he estimated a constant share of capital to be of 34% by means of household income surveys, which is in line with the theoretical one third, two thirds defined by the Cobb-Douglas production function for capital and labor respectively.

TFP for the 2014-2030 period was estimated following the methodology presented in the MEET 2030 Project [15], by estimating a constant value for the relationship between its historical growth and the historical exergy efficiency, and then establishing a relationship between both, as in (7) and (8).

The TFP as a function of the final to useful exergy efficiency is then tested with the Cobb-Douglas function in order to test the validity of its relationship with growth, and if an accurate approximation is obtained for the available data period, then the second law efficiency values are inputted into the model to estimate the GDP of the forthcoming years.

V. RESULTS

A. Exergy

The assumptions made for the transportation sector translated into an efficiency on average 2% lower than the estimated by [5] during the first two decades of the analysed period. A significant impact is noticed specially after the mid 90's, as in Guevara's work a significant increase in efficiency occurs in this period due to advances in combustion engines technology, these improvements are diminished by the inefficiencies of an old fleet vehicles average age. This is due to the increasing imports of used vehicles from the US that raise after the NAFTA was signed in 1994, which consequently led to a lack of efficiency improvement of this sector in a forty-year period.

These adjustments in the transportation sector translated into a significant impact on the aggregate efficiency, this was expected considering that it is indeed the sector with the largest consumption of final exergy and the one with the lowest efficiency.

Results shown that the industry will keep on being the largest useful work consumer as the population grows and the industry needs to grow with it in order to absorb jobs and satisfy the needs of products for the people. The demand for transportation is also expected to keep increasing as long as the government doesn't take actions regarding the creation of an extended efficient transport system for the masses. The sector corresponding to other energy uses is also expected to increase its demand as population not only increases but adopts the uses of more electronical and electronic appliances at their homes, while the consumption of the energy sector is expected to come from the incentives of increasing productivity and explore deep water wells coming from the energy reform.

The first sector in which two different scenarios were studied was the energy sector own uses, where the baseline scenario reflects a growing demand final exergy of 36% compared to the 2009 values. On the other hand the proposed measure of including policies to shift the energy carriers used in this sector, led to a growth of demand of roughly 10% compared to the base year.

The proposed improvements in policy did not produced a significant impact on the demand of the transport sector. This means that a more radical shift is needed in order to increase the sector efficiency. Although fuel taxes are often recommended to achieve this, this policy was not explore considering the social impact that the removal of the gasoline subsidy caused in 2016 and the actual influence it had on inflation that led to a higher shopping basket and ended up affecting the population segment with the lowest income.

The impact of the policies aiming to the residential sector proved to be the most efficient in terms of reducing final exergy demand, not only an increase in consumption was avoided, but a decrease in demand to 2004 levels was achieved.

The measures proposed for the energy and residential sector proved to be the most efficient in terms of final exergy demand reduction, both focused on identifying the major end uses of each sector and trying to accomplish this same end use by means of more efficient technologies that work on different energy carriers. On the other hand, the only useful work category employed in transportation is mechanical work, and the technologies available, for switching the main energy carrier that is oil, are yet not affordable for a country with the average purchase power conditions of Mexico, this made it harder to propose a similar approach, so the replacement of the actual state of the art technology which is internal combustion engines tried to be incentive to become more efficient but the effect of it was not as impactful as expected.

Fig 1 shows the increase in the efficiency of each consuming sector, as well as the aggregate efficiency for both scenarios. As it can be seen, the scenario in which policies to enhance efficiency improvements proved to have gains of 1.5% over the scenario where no measures are taken as of the undergoing policies.

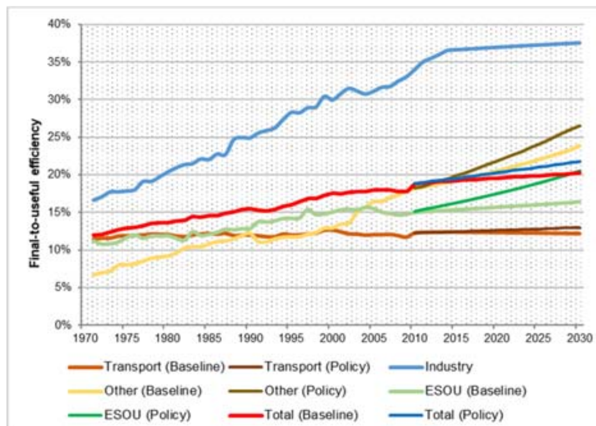

Figure 1. Evolution of the aggregate and by sector final to useful exergy efficiency the year 2030 under different scenarios (except industry).

B. Economic growth

Mexico's GDP has grown just above four times in the period of 1970-2014, even though capital and labor by themselves don't manage to explain the total growth of the economy, the difference is not as significant as the observed by [38] in other developed nations such as US, UK and Japan, this trend also differ for the one presented by [15] for the case of Portugal. A possible explanation of these behavior in the Mexican economy is that given that the population is expanding at a faster rate than the economy, it makes it difficult for the economy to track that growth. Energy efficiency in Mexico has shown a significant increase over time, growing 1.6 times over the studied period, while the TFP had a quick growth over the first decade and then presented a significant setback attributed mainly to the 1982 economic crisis, from which it didn't manage to recover and presented a marginal growth since.

The Cobb-Douglas model is limited due to its assumption of constant shares of capital and labor over time, it was therefore able to follow accurately the development of the measured GDP although the model is not able to reflect the peaks and valleys of the actual GDP that came as consequence of structural changes or economics crisis, this can be observed in Fig.2.

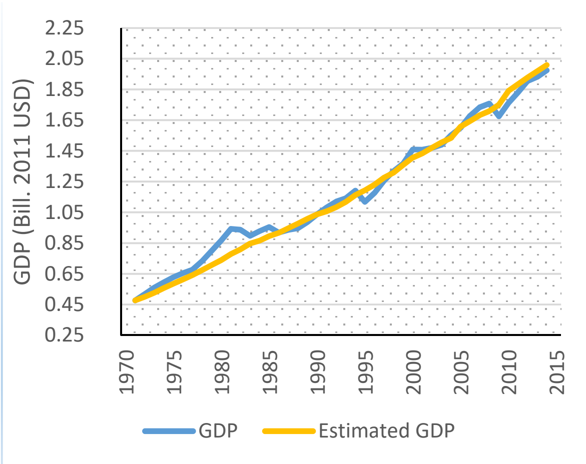

Figure 2. Measured GDP (blue line) vs estimated GDP (yellow line).

The results of the impact of different energy scenarios on the economy are shown in Fig 3, it can be observed that although there is an increase of the GDP in the scenario with policies applied to improve efficiency, the impact is not as significant as in the case study of Portugal. This can be attributed to two reasons, the scenarios developed for Portugal included different development for the labor and capital over time, and the fact that the TFP for the case of Portugal increases in a higher proportion with the increase in efficiency that for the case of Mexico.

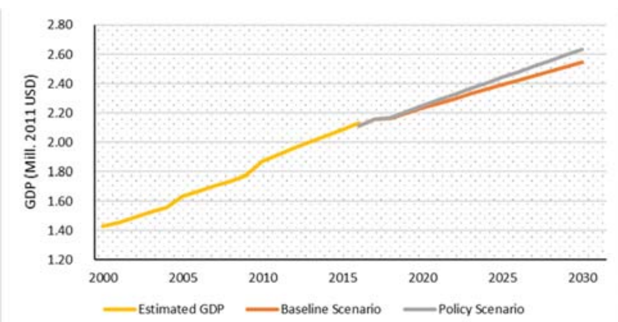

Figure 3. Projections of GDP growth under the two different scenarios by 2030.

It is however worth mentioning that the GDP on the baseline scenario grew at an average rate of 1.33%, while on the scenario with the suggested policies, it grew a yearly 1.57%. While on absolute values the economy grew 18.67% for the first scenario and 21.93% for the second one regarding 2014 values. These growth rates are low for the average trend in developed economies, although they can be attributed to the slowdown in the population growth estimated by the government [34], as the population number has demonstrated to have a significantly higher impact on the growth of the Mexican economy than the rest of the factors of production.

VI. Discussion

In order to estimate the TFP of Mexico it was preferred to use the population growth as a measure of labor over the employed population and the total hours worked in the economy. The major reason to use this approach is the large contribution of the informal employment sector, this occurs in many developing countries and although information regarding this numbers is available for most of the cases, there are reasons to believe there might still be underestimations.

One of these underestimations is associated with the shadow economy, defined as those activities not taxed or legally registered that include black or clandestine labor including criminal activities. The contribution of this type of activities in Mexico was estimated to be 49% of the country's GDP during 1989 and 1990 [39]

As explained by [39] and performed by [14] a way of compensating this data is to use information on household final consumption, which allows to estimate the production and consumption going on in the informal sector and lead to estimate more or less constant values for the contribution of labor and capital to economic growth [31].

An example of TFP underestimation has been observed for the case of Turkey, which has one of the largest informal sectors in relation to its GDP from the OECD countries, along with Mexico. Reference [40] found that establishing an elasticity factor for the degree of substitutability between formal and informal sectors can have a significant impact on the country's productivity. While a lack of representation of informal labor showed a five-fold growth in the TFP of the country in the period of 1952-2012, it was shown that an increase in the share of this informality could represent a growth between 20 and 50% above the baseline estimation depending on the degree of substitution.

These would suggest that a deeper analysis of the informality in Latin America and its impact on TFP and therefore in economic growth could bring a better understanding of its relationship with energy efficiency, as many countries from the region show a similar tendency of a marginal development of their productivities. This is a region of particular interest for the study of the impact of informality on growth, considering the estimates of 40% of the GDP being produced informally and 70% of the labor force being employed this way [41].

The differences of expenditure in human capital between developed and developing countries can be observed as advanced countries invest on natural resources and human capital to develop technology, while developing countries expenditure focuses on human capital that is devoted within their political and economic institutions in order to incentive the adoption of these foreign technologies. This leads the TFP to differ in accordance to the degree of development of countries, while innovations in technology contributes for the growth of advanced countries, developing countries need to spend to acquire and diffuse them [42]

The results of [43] proved that structural changes in the economy did not have the impact on TFP and economic growth that was expected from them, attributing this poor performance to internal factors as monopolized markets, excessive regulations, low quality of human capital, deficient public infrastructure and inefficient tax system.

Reference [44] performed a similar analysis and compared the results to the ones obtained for the US economy. They tried to attribute the low productivity of Mexico as a result of an industry transformation towards lower productive sectors and to the low contributions of high qualified factors, such as college-educated workers, to value added growth.

Although the transformation of the Mexican economy from a closed one to an exporting one brought an increase in the production of goods of medium and high technology to levels higher than those of the BRIC countries, and led to a share from 6.1 to 13.2% of the total US imports from 1990 to 2015, this outstanding performance in exports has not been enough to break the inertia of the slow and volatile economic growth associated with slow productivity growth.

These trends would indicate that a shift from low to high productive industries is taking place, however it has been shown that high technology industries in Mexico don't depend strongly on knowledge but rather on labor intensive processes and therefore the contribution of highly qualified workers is not as significant

These findings coincide with the work of [45] who argued that although labor was the main source of economic growth of Mexico during the 60's, the country has reached a phase of economic development where labor and capital resources can't keep contributing to growth in the manufacturing sector.

Many approaches have been developed to explain the TFP in economy, some have shown significant correlations that have helped understanding the development of advance countries and their relationship with technological breakthroughs. These relations however have proven not to be so clear for countries at different stages of development and with different economic growth drivers. There is a significant importance in understanding this topic, as identifying properly the sources of growth can lead to an efficient design of policies that can help developing countries to catch up with the fastest growing economies.

It is noticeable that for the particular case of Mexico, structural changes that were expected to drive growth were not able to do so, therefore important attention must be put into some of the common factors found in different research works such as informal labor, efficient economic and social policies, investment in education and human capital, and an effort to switch from a labor-intensive to a knowledge-intensive manufacturing country.

VII. Conclusions

The slowdown in the growth of the Mexican economy over the last year have been contributing to increase inequality and enhance other social problems as informal employment that contributes itself to keep the country from growing faster. After analysing the relationship that exist in Mexico between the efficient use of its energy resources and economic growth, through the UEAM and the Solow-Swan approach for growth several conclusions were obtained.

Improvements in the way energy is being use in the extraction and transformation processes within the energy industry could contribute significantly to reduce the final energy demand of the country, considering that the energy reform aims to boost the productivity of the sector it wouldn't be so hard to think that such a policy or goal of further electrifying the sector could become a reality, especially if its implemented before the new wells and refineries begin construction and operation.

Transport is the largest consumer of the final energy in the country and has also proven to be the less efficient. The suggested policy to increase the efficiency of transport did not prove to be an effective measure, therefore it would be recommended to make a more in-depth analysis of transport in Mexico given its overall impact in the energy sector, considering the effect that it is having on the air quality in the country's largest cities, where it could potentially bring a spike in environmental and health care cost for the government.

The proposed policy of incentivizing solar thermal heating for water for residential and commercial users could come in the form of a subsidy, although it proved to be relatively costly in terms of abated CO2 for the case of Portugal [24], the decreasing price on the technology due to the learning curve and the geographical conditions of Mexico could bring this cost down and make it more affordable both from governmental and end user perspectives. This could be a potential line of research to contribute to decrease the energy demand for the residential sector as well as the emissions coming from households.

The application of the suggested policies could be limited by financial constraints, as it is not considering the cost of applying them, neither by the government, investors or users perspective.

Although results shown that an increase in exergy efficiency could boost economic activity, the impact of the energy usage in Mexico didn't prove to have such a strong relation with economic growth as it has demonstrated to be in some developed countries. Part of this might be explained by the low productivity of the country that to some extent is attributed to the high share of informal labor and low levels of education that don't incentive a demand for high qualified jobs.

The main intention of this paper was to propose alternatives on the energy side that could enhance the economic development of the country in the near future, although the weak relationship found for these two variables would suggest that policies to fasten economic growth should be focus rather on labor and productivity, as it is the main driver of Mexico's economy. Potential policies to enhance this increase in labor productivity should aim to incentive the formalization of the labor sector, invest more efficiently in education and create more jobs for high qualified professionals. This doesn't mean that no focus should be put into energy, as once labor force becomes more productive, an efficient use of energetic resources might enhance economic growth on a larger extent.

. Another interesting aspect that could be included in the elaboration of forthcoming works related to this scenario creation methodology would be the estimation of CO2 emissions, since they are expected to slow down as a result of the country's renewable energy goal of achieving a 37.5% of clean electricity by 2030 [46], but can be counterproductive if the conventional electricity mix switch to higher CO2 intensive energy carriers or if the demand side is not controlled.

The use of longer time series for both economic growth and energy sector of Mexico could be of help to develop more accurate scenarios and understand better how this relationship has evolved over time, as the time series used for this work is relative short when compared to other works performed for instance on the US, UK and Japan.

Given that this is the first work following this methodology for a developing country, further research of this topic in developing countries with different growth tendencies as those from Latin America, Africa and Asia would be more than welcome in order to keep trying to understand how the economy grows and its link to the use of energy in our societies.

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