FINAL REPORT

Tunisia

TUNISIA ENERGY PROJECTIONS

This report is an assessment of energy demand in Tunisia between 2018 and 2030.

Authors

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1. Abstract

Tunisia is an emerging country of North Africa, endowed with a young and growing population. Its energy situation is characterized by a significant deficit.

A declining domestic production of fossil fuel, combined with a growing population and economy shift in Tunisia, formerly energy exporter but now a net importer. Since then, the policy makers have striven to decrease energy dependence of the country. Historically, the energy mix of the country has been based on fossil fuel, mainly natural gas and oil. To decrease fossil fuel importation, policy makers have focused their effort on energy efficiency and solar energy. Projections of energy demand until 2030 are studied whether with a top-down or bottom-up approach for the residential, transport, industry and agricultural sectors. Final demand in energy is to increase by 2030, mainly driven by transportation and industry. Dependency on oil product will be increased also, leading to more greenhouse gas emission. Energy efficiency measures in the residential sector happened to be successful to contain demand. But similar policies are needed in the transportation sector.

2. Authors contribution

The table below represents in detail the contribution of each author in the preparation of these projections.

Author name	Contributions
Hamza	1. Collected data for Industrial sector, agricultural sector and parts of residential sector 2. Set up and run the top down approach for the industrial sector 3. Set up and run the top down approach for the agricultural sector 4. Contributions to the report (Section 6.2 and 6.3) 5. Prepared and delivered part of the final presentation
Flore	1. Wrote the abstract, policy and mitigation plans 2. Developed the 3 scenarios used in LEAP 3. Collected data for the residential & transport sectors 4. Set up & implement LEAP model for residential & transport 5. Contribution to conclusion & policy implication
Charline	1. Collected data for “Energy Balance” and “Industry demand” 2. Collected data for the bottom-up approach in the residential sector 3. Set up and run the top-down approach for the transport sector 4. Writing part of final report
Bilal	1. Collected data for "other demands" 2. Gathered data for Subsector of residential sector. 3. LEAP model set up for residential, industry and agriculture sectors 4. CO2 Emissions from Leap 5. Prepared and delivered final presentation 6. Writing part of final report

3. Introduction

Energy planification is one of the main concerns for governments. Firstly, it will help to modulate the production, imports or exports of primary source of energy in order to meet the demand. This ensures energy security in the future. Then, it helps government to anticipate society transformations: equal access to a clean and affordable energy for everyone is a social issue. Finally, it allows to forecast future greenhouse gases emissions and to take measures to meet climate target and control its emissions. Indeed, according to the International Energy Agency, the energy sector accounts for at least two-thirds of global greenhouse gas emissions.

This report focuses on the analysis of the Tunisian energy demand and the forecast of the national energy demand up to 2030. The energy demand is divided into four main sectors: residential, industrial, transport and agricultural. Two methods are used to analyse these sectors: the top-down approach where we used Excel for regressions and the bottom-up model with the application of the software LEAP. In the bottom-up approach, we focused our study on the role of two policy instruments: energy efficiency measures and solar energy. Increase in energy demand has a direct link to increase in GDP, especially in developing countries like Tunisia. However, the increasing role of energy efficiency blurs this direct link and should be taken into account when forecasting demand. Solar energy is a substantial advantage for Tunisia whose annual sunning is one of the best in the world.

This report is introduced with background information about Tunisia. The energy balances for the year 2015 are presented. Then, we detailed our methodology and the data used. Afterwards we focused on the three scenarios used to model energy demand. Finally, the obtained results are presented and allow us to conclude with policies implications.

4. Literature review and Background

4.1. Background about the Country

Tunisia is located in Northwest Africa, surrounded by Algeria, Libya and the Mediterranean Sea. The country has about 12 million of inhabitants and two third of population live in urban areas. The south of the country is desert while the rest is a fertile land, which means that population is concentrated along the Mediterranean coast. The major languages spoken in Tunisia are French and Arabic.

Tunisia is in process of economic reforms, transforming into a liberalized market after decades of state interference in economy. The agriculture products, textile industry, oil production and tourism have been the main drivers of Tunisia's economy. The European Union is the main economic partner of Tunisia with about 80% of exports bounded to EU. Recently, the economic growth has been slowed down due to numerous strikes over the country (the Arab Summer in 2010) and decrease of tourism. It has resulted in a high unemployment rate among the youth and subsequently, a huge pressure on the government.

Regarding the energy sector, Tunisia benefited from natural resources like oil and gas and used to be a net importer of fossil fuel in the 2000s. Yet, production of oil has been declining in the last fifteen years and increase in gas resources was lower than demand increase. Urbanisation and modernization of the society has led to a linear increase of primary energy consumption since 1990, overstepping the national production in 2014. The country ceased thus to be a net exporter of energy and became a net importer in 2014. Consumption of Tunisia doubled between 1992 and 2012.

4.2. Energy Balances of the Country

The total final energy consumption of Tunisia is 320 kTJ. The main energy sources consumed are oil products, natural gas and electricity. Only 10% of the total final energy consumption come from renewable sources. They only use biofuels and waste as renewable sources.

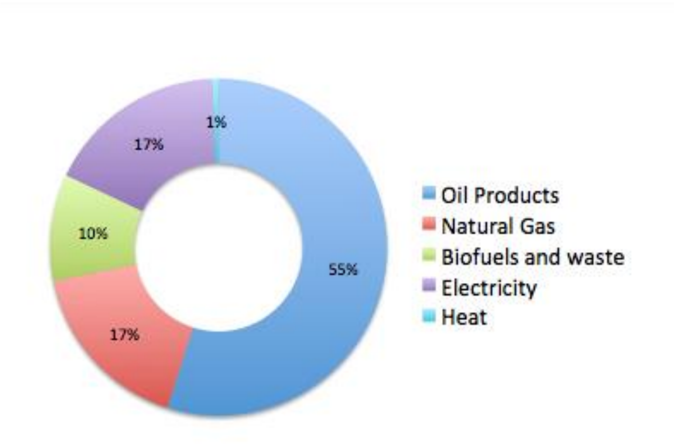

Figure 1 - Total final energy consumption of Tunisia by energy sources.

The total primary spread supply by sector is given by the figure below. The transport sector is the most energy intensive.

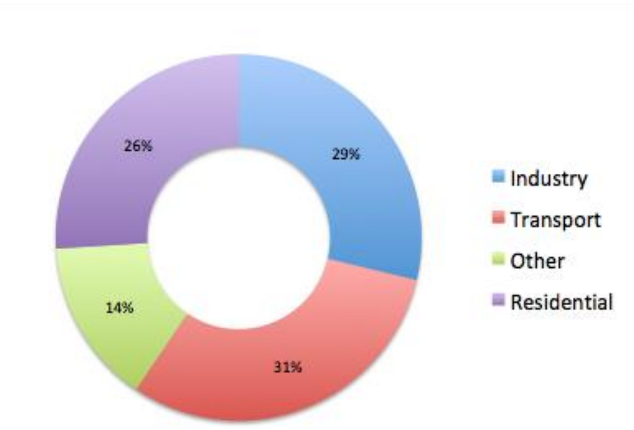

Figure 2- Energy consumption by sector

The fuel uses of each of the four main sectors are presented by those following graphs. The high use of biofuel and waste in the residential sector is mainly due to the use of wood and charcoal in rural households.

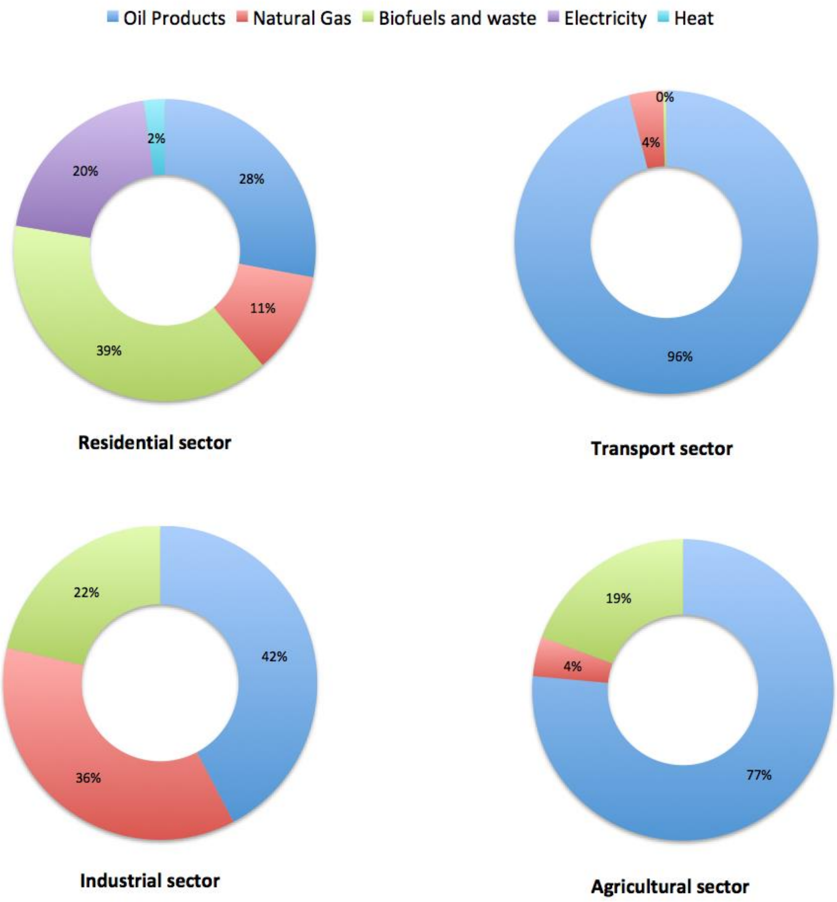

Figure 3 - Fuel use in each sector

4.3. Policies and Mitigation Plans and Main Drivers on the Demand Side

Tunisia's priority is to reduce its dependence on fossil fuel imports, especially Algerian gas and oil. To achieve this goal, the country based its policy on two pillars: diversifying the electric mix thanks to renewables and increasing its energy efficiency.
Energy efficiency has always been a primary concern in Tunisia. In the 80s, the country early realized the importance of energy efficiency to improve a deficient energy balance. Therefore, the National Agency for Energy Management (ANME) in 1985 was created to limit the rise in energy demand. The measures implemented include: free audits for industrial companies to improve their process, promotion of Compact Fluorescent Light (CFL) in households, energy labelling system regarding electrical appliances used in households (fridges, bulbs), campaign of education for the population. For instance, rate of penetration of low energy bulb in households went from 4% in 1999 to 26% in 2009. In 2014, 111 GWh were saved in the industry thanks to the audits. The current agenda of ANME is to improve insulation of residential buildings. The national target is to improve energy efficiency by 30% in 2030 compared to a "business as usual" scenario. As a result, the country was ranked 20th on 111 countries by the World Bank in term of energy efficiency.

Regarding the development of renewables, Tunisia highlighted solar energy. The country benefits indeed from a huge potential with one of the highest sunning in the world. The Tunisian solar plan launched in 2005 forecasts a share of 30% of renewables in the electric mix by 2030, mainly solar-based energy. It promotes the development of private photovoltaic panel and solar water heaters in households and includes economic incentives: installation is financed up to 30%.

It is worth to mention that all these renewable energy and energy efficiency measures only tackle residential and industry sector, while no objectives in term of transportation has been set up till now.

5. Methodology

5.1. Model Set-Up

Two different methods were used to forecast the energy demand of Tunisia. We decided to model the energy demand in the industrial and agricultural sector with a top-down method. For agriculture and industry, data was missing to use the bottom-up approach. Plus, we considered that linear regression based on GDP among others were relevant indicators to model demand in industry. The only disadvantage is that it was quite tricky to study the influence of energy efficiency in the industry sector, although it plays a key role. The residential sector was studied with a bottom-up approach: it was the easiest sector to find data. Plus, the existence of policies regulating energy use in households made it more relevant to use different scenarios in that sector.
In the transport sector, we studied the road and rail sub-sectors both with a bottom-up approach and a top-down approach to compare the two results. Pipelines were studied with top down approach only as we found it hard to build a bottom-up approach. Aviation and navigation were not taken into account because of the lack of relevant data.

5.2. Top-Down Model

The top-down method was used to forecast the energy demand in the transport, the industrial and the agricultural sector.
Based on the data available and the literature, potential exogenous variables were used to forecast the energy demand in each sector.
For each sector, a multilinear regression was run and allows to write the energy demand in the sector (Y) as a function of all the potential exogenous variable (X_1, X_2, ... , X_n)

$$Y = f\,(X_1, X_2, \ldots, X_n)$$

To consider if the model was accurate, we used several key statistical tests. Among these, the following has been considered:

- <u>R-squared</u>: It represents the goodness of the fit. Only model with an R-squared superior to 0.75 were considered acceptable.
- <u>Standard errors of the coefficients</u>: It measures how precisely the model estimates the coefficient's unknown value. We selected models with the lowest value of the standard error.
- <u>P-value</u>: It indicates the probability of observing the observed values if we assumed a relationship between the predicted variable and the exogenous variables. He only considered variables with a p-value inferior to 0.05 as explanatory variables.
- <u>Residual plots</u>: After running the regression, we checked if residuals were randomly distributed.

If the multilinear regression with all the potential exogenous variable was considered accurate, we kept only variables with a p-value inferior to 0.05 as significant independent

variables. We re-run the model with only those variables and we checked if this new model was accurate.
Finally, if predicted data concerning the evolution of the significant variables were not available, we did simple linear regression with time to forecast their evolution. Then, we used their predicted values to forecast the energy demand for each sector.

The potential exogenous variable chosen and the significant independent variable retained for each sector are developed below. The key statistical parameters for each regression are given in appendix 1.

5.2.1. Transport

Three sub-sectors were developed: road, rail and pipeline.
The table below sums up the potential exogenous variables chosen and the significant independent variables used in the model.

Sub sector	Fuel	Potential exogenous variable	Significant independent variable
Road	Oil products	Population, GDP, imports of oil products, exports of oil products, barrel price, urban population, part of tunisian household with a car.	Population and part of tunisian with a car, imports of oil product
Rails	Electricity	GDP, population, goods transported by railways, kilometers of rail lines, passengers carried by railways, electricity price	Population and kilometers of rail lines.
	Oil products	GDP, population, barrel price, goods transported by railways, kilometers of rail lines, passenger carried by railways, imports of oil products	Kilometers of rail lines and passengers carried by railways
Pipeline	Natural gas	GDP, Population, GNI per capita, imports of NG	GNI per capita
	Electricity	GDP, population, electricity price, primary production of energy	None

5.2.2. Industrial Sector

The three sub sectors that were analysed are:
- Non metallic minerals
- Food and tobacco
- Industries n.e.s

The table below sums up the potential exogenous variables chosen and the significant independent variables used in the model.

Sub sector	Potential exogenous variable	Significant exogenous variable
Non metallic minerals	Rural Population, GNI per capita, Agriculture (% of GDP), Population (people), GDP (USD), GDP per capita (USD)	Population, GNI per capita
Food and Tobacco	Rural Population, GNI per capita, Agriculture (% of GDP), Population (people), GDP (USD), GDP per capita (USD)	Population, GNI per capita.
	Rural Population, GNI per capita, Agriculture (% of GDP), Population (people), GDP (USD), GDP per capita (USD)	Population, GNI per capita
Industries n.e.s	Rural Population, GNI per capita, Agriculture (% of GDP), Population (people), GDP (USD), GDP per capita (USD)	Population, GNI per capita

5.2.3. Agricultural Sector

From other demands, the sub sector that was analysed was agricultural. The energy data - values were only available from 2008-2015 unlike the industrial sector (2000-2015), for the sake of analysis the values from 2000-2008 were taken with a simple time-regression of energy demand.

Potential exogenous variable	Significant exogenous variable
Population (people), Agriculture(% of GDP), Rural Population, GDP (USD), GDP per capita (USD)	Agriculture (% of GDP), Rural Population

5.3. Bottom-up models

5.3.1. Residential Sector

Data for the residential demand was based on Labidi and Abdesallem, 2018", the enquiries from the National Society of Gas and Electricity from 2004 and the Enerdata report "Energy efficiency trends in Mediterranean countries" (GIZ 2012).

We studied the demand of energy from base year 2010, using the number of households in Tunisia. There are about 2.6 million households in Tunisia, with an average size of 4.15 in 2010. The national population is expected to grow at a rate of 1.2% per year until 2030. In 2010, 70% of the population was living in urban area, and we expect this figure to reach 90% in 2030.

As around 99% of the population has already access to electricity, no boom in electricity consumption in households is expected. The future energy demand of households is shaped by two parameters: on the one hand, the standard of living is increasing as households are getting equipped with TV, fridges or air conditioning. On the other hand, energy efficiency is improving thanks to government initiatives. These two effects counterbalance each other.

To know the main use of energy in households, we relied on an enquiry of the Tunisian National Society of Electricity and Gas from 2014. Those results are presented in figure 4.

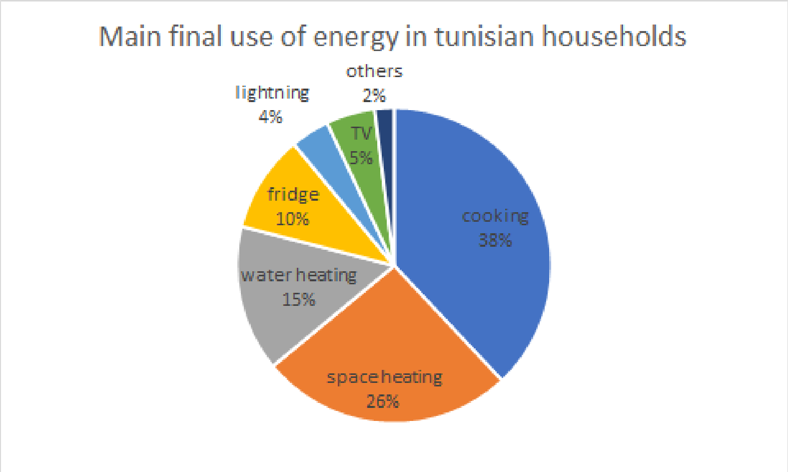

Figure 4

source: Tunisian National Society of Electricity and Gas

Regarding electricity demand in households, we referred to Labidi and Abdesallem, 2*018*. The results are in figure 5.

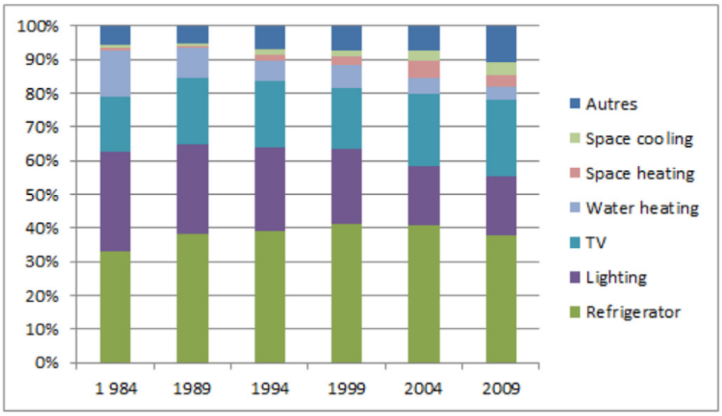

Figure 5- main use of electricity in tunisian households, 2017

Source Labidi & Abdesallem (2018)

The tree, built according to the two previous graphs, can be found in appendix.

More details are given on the forecasted use of electronic devices and cooking appliance. All the following data are part of the “business as usual” scenario, and automatically inherited by the oher scenarios.

- Fridge:

The number of fridges is expected to grow from 70% in 2010 to 90% in 2030 in urban and electrified rural areas, with the rising standard of living. The energy consumption per year per household is 383 kWh, the same estimate is used for the rural sector as well. The estimate is based on the average consumption of the four predominant refrigerators available in the Tunisian market namely LG, Bosch, Electrolux and Samsung.

- TV:

It was found in literature that the number of TV for 100 inhabitants were 75 in 2000 and 83 in 2010. We forecasted a liner evolution of TV per households and set the saturation level to 2,7 TV per households, as it is the average in Europe. TV consumption is 263 kWh per household in 2010.

- Other electronic devices:

We considered that all the other electronic devices represented about 200 kWh per year (average for north African countries) and we considered that 83% of urban population was equipped with other electric appliances in 2010, and 95% 2030. The particular value of 95% reflects the trend of increasing equipment of households.

- Cooking:

In 2010, 56% of urban households used LPG to cook, 37% used natural gas and 3% kerosene, 3% charcoal and 1% electricity. Natural gas is being replaced by LPG, which is more efficient. Therefore, in 2030, we considered that 70% of households use LPG and 20% natural gas, 3% charcoal and 5% electricity. The specific figures regarding the cooking demand for rural households couldn’t be found. However, from the data of the rest of the African countries, it has been assumed that in rural areas there is more wood consumption and less LPG (liquefied petroleum gas) than in urban area. So, we considered that 60% households used wood, 30% charcoal, 8% kerosene and 2% LPG. Energy consumption of LPG is 0,17 ton of oil equivalent (toe) per household, 0,014 for kerosene and charcoal, 0,32 toe for natural gas and 0,0004 for electricity. Wood consumption in rural areas is 3500 kg.

All these activity level in % are the estimated averages of results found in UNSD’s statistics for Tunisia

- Water heating:

79% of urban households use LPG to heat water, with an energy intensity of 1150 kWh per household. 10% use electricity, consuming 1300 kWh per year and 8% use natural gas with a consumption of 1200 kWh per year. The remaining use solar, consuming 800 kWh.

- Space heating:

Only 80% of urban households have space heating, 30% of them use electricity for 1000 kWh per year and the others use LPG for 900 kWh.

- Lighting:

In urban households, in 2010, 74% of households used incandescent light while 26% of them used Compact Fluorescent Light (CFL). The annual consumption of incandescent is 650 kWh for incandescence while it is 200 kWh for CFL.

It was difficult to find data regarding lightning habits in rural households. We used the following table, considering that all rural households of Tunisia had "high" income compared to other African countries. We considered that 70% of rural household used electricity for 500 kWh and 20% of them used 15L of kerosene per year and 50% rely on LPG with 450 kWh per year.

End Use	Rural Household Income		
	Low	**Medium**	**High**
Cooking	Wood, residues, dung	Wood, residues, dung, kerosene, biogas and LPG	Wood, kerosene, biogas, LPG, coal and electricity
Lighting	Candles, kerosene, wood	Candles, kerosene, LPG and electricity	Kerosene, electricity
Space conditioning	Wood, residues and dung	Wood, residues, dung and LPG	Wood, residues, dung, coal, LPG and electricity
Other appliances	Often none	Grid or genset-based electricity and batteries	Grid or genset-based electricity and batteries

Source: AFREPREN, 1999

5.3.2. Transport Sector

We used data of the "Tunisian national statistic institute"", UN data and the papers *Mraihi, ben Abdallah and Abid, 2013; Perez Martinez and Sorba, 2010* and *Perez Martinez and Miranda, 2014.* The tree is given in appendix. We only modelized energy demand in LEAP for passengers and freights on road and rails, which mean that airline and maritime transport and pipelines are not included in our LEAP analysis.

In 2010, the freight value was 5300 ton-km/capita, with 23% by truck and 77% by rail. Truck were using gasoline only, while 97% of trains were diesel engine based and 3% electric engine according to "Railway National Society of Tunisia"

Regarding passengers transportation, the traffic on road was 1170 passengers-km, 57% of them by cars and 43% by public transportation like bus and cars. About 85% of cars run on gasoline, the remaining on diesel. While, all the buses use gasoline. The traffic on rail was 1246 passengers-km in 2010. About 97% of trains were diesel engine based and 3% electric engine. It was very hard to find consistent data regarding traffic in passenger-km and ton-km as the different studies hold very diverging figures. We computed the average. The energy intensity of each fuel was retrieved from "Energy Consumption of Passenger Land Transport Modes", which is not typical of Tunisia situation, but is a global average for Spain.

5.4. Scenarios

5.4.1. Residential Sector

Three scenarios were developed to forecast household demand until 2030. The first scenario is the "business as usual one", the second one takes into account energy efficiency measures implemented by the government, and the last one, called "Solar break out" consider a massive development of solar panels.

1. **Business as usual - BUS**

We only used two key parameters:
- Population annual growth rate: 1,2%
- Share of urban households in 2030: 90%

The other evolution of household's habits are described in section 5.3.

2. **Energy Efficiency Measures - ENE**

This scenario inherits from characteristics of BUS scenario. It also takes into accounts feasible energy efficiency measures summed up in the following tab. We used the forecasted energy savings in column four in our LEAP analysis.

Identified residential energy efficient projects in Tunisia.

Project description	Objectives	Period	Energy savings (Ktoe/ year)	CO2 Avoided (KtCO2/ year)
Thermal insulation	Install 11 million sqm of roof thermal insulation	2011 –2016	50	117.5
Low consumption light bulbs	Distribute 5 million energy efficient lamps	2009 –2011	70	164.7
Energy efficient refrigerator	Replace 400.000 old refrigerators (over 10 years) by energy efficient refrigerators (class 1 and 2)	2009 –2016	24	56.4
Energy efficient air conditioner	Progressive elimination of energy-consuming air conditioning: elimination of the energy classes 8, 7 and 6	2010 –2018	4	11

Source: Final Report of the European Investment Bank [13].

We also planned an increasing share of solar water heaters up to 30% in 2030, which is considered as a realistic target by the ANME (National Energy Management Agency).

We considered that energy intensity of water heaters run with LPG and natural gas will drop to 800 kWh in 2030, energy intensity of electric space heating will drop to 750 kWh and that of LPG in space heating will drop to 650 kWh. Fridges intensity will drop to 200 kWh. In 2030, encouraged by efficiency policies, 30% of water heaters will be solar, 10 natural gas based, 55% LPG based and 5% electric. Those figures are either official objectives in term of solar energy (30% share of solar water-heaters) and assumption that we made (LPG share is to decrease but there is no clear indication of the final share in 2030). Likewise, 90% of urban households will be equipped with CFL bubs.

3. **Solar Break out - SOL**

Solar is considered as a promising opportunity to decrease the dependence on fossil fuel in the energy mix of Tunisia. With 3200 hours of sunshine per year, the country has a massive potential. The government has been considering this opportunity since the 80's and recently implemented two programs: PROSOL and PROSOL ELEC to develop solar generated energy.

PROSOL & solar water heat (SWH)
PROSOL is a program launched in 2005 to promote solar water heating. It includes a loan mechanism for domestic households willing to install Solar Water Heaters and a governmental subsidy of 20% of system costs. In the best case, the ANME considers that 80% of households could be equipped with solar water heaters. About 10% of water heater will run on LPG, 5% on electricity and 5% on natural gas. The figure 6 shows the fuel mix for water heating in 2030, in all three scenarios.

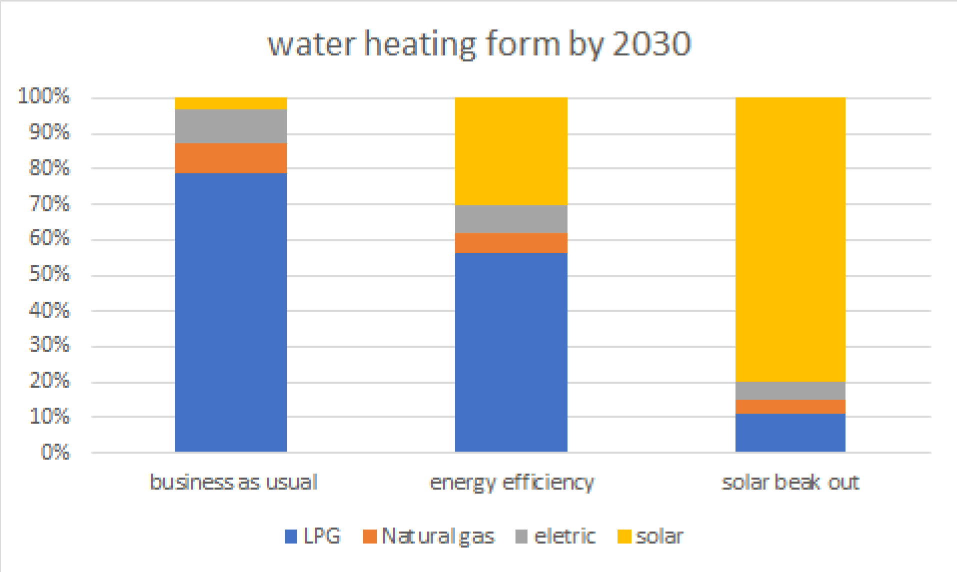

Figure 6

PROSOL ELEC

PROSOL ELEC aims at promoting the installation of photovoltaic (PV) systems in residential buildings since 2010. It is not fully scaled up yet because of technical and financial impediments. The national target is to equip 30% of households with private PV panel by 2030. We considered that in this best-case scenario, 30% of household's electricity consumption was entirely solar-based.

5.4.2. Transport Sector

Tunisian transportations sector almost entirely relies on fossil fuel: gasoline and diesel. A small minority of rail transport is based on electricity. The raising number of private cars raises issue in terms of traffic in cities and air quality issue. The annual growth of private cars was 4% between 2010 and 2018. Yet, no policy has been considered by the government so far to reduce private cars use or increase public transportation and transportation efficiency. Therefore, we only used one scenario: the business as usual. We considered that the motorization rate would remain to 4% until 2030.

Regarding passengers transport on road, the total traffic in passengers-km is expected to grow at 1,2%, like the population growth. This is our assumption as we did not find any particular value for the traffic growth. The share of private cars in road transport increase by 4% every year. We assume that the remaining passengers travel by buses and cars. Passengers traffic by rail with also increase by 1,2% for the same reason. Share of electric and diesel trains remain steady.

Regarding freight transport, the annual growth rate is 1,5%, which is an average of GDP and population growth rate. We also forecasted a shift from truck-based freight toward railways-based freight, with the final share of truck freight being 17% of total freight, and the remaining in rail.

6. Results and discussions

6.1. Residential Sector with Bottom-Up Approach

Figure 7 shows the final households demand in the three scenarios. The residential consumption in 2010 was 70 000 TJ according to UN data, while we reach 52 000TJ with our bottom-up approach. There is 25% gap that proves that our approach is not perfect and we may have left out some energy uses or underestimated them.

In the business as usual, final consumption evolves linearly with time as population and urbanisation increase. Energy savings in scenario 2 permit to save 17% of energy consumed in “business as usual”. In the “solar break out” scenario, the level of consumption is quite the same as in “energy savings”, because households still use the same amount of energy. The difference is that they rely on solar production.

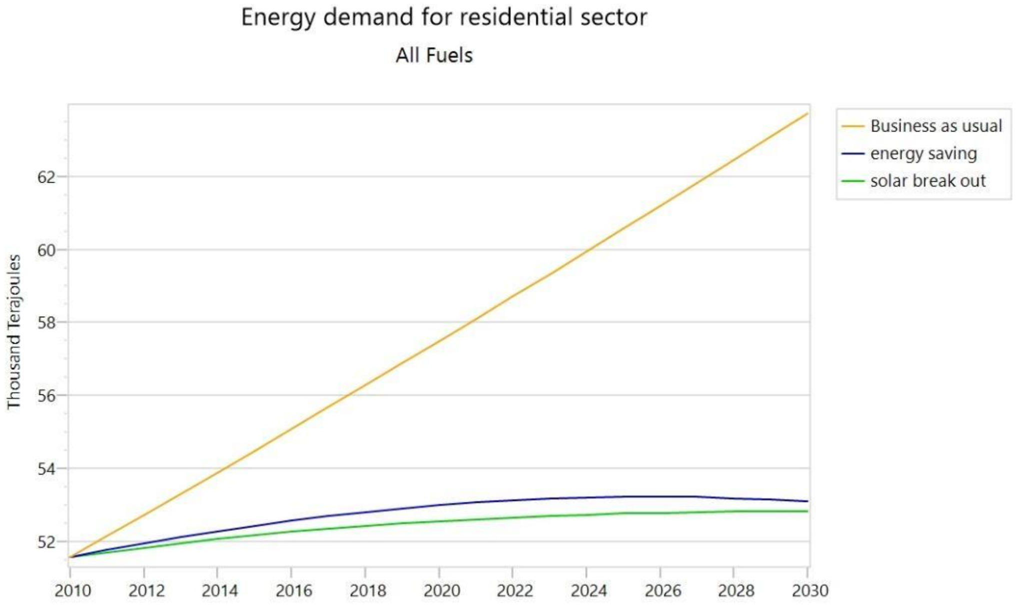

Figure 7

Figure 8 shows the change in energy demand for urban households in 2030 as compared to 2010, for BUS and ENE scenarios. In the ENE scenario, change in light consumption is negative, indicating decrease in energy demand for lighting. This reduction is very likely to happen in reality as the penetration rate of CFL has already beaten the expectations of ANME in 2018. On the other hand, the energy savings in space heating less probable as Tunisia still struggles to implement regulations on thermal insulation of buildings. The most significant increase in consumption is in cooking, equal in both scenarios, as no energy efficiency policy tackles cooking.

This graph reveals the importance for Tunisian authorities to develop policy of energy efficiency in cooking. The efficiency gained in water heating in the ENE scenario may be overestimated: we did no find precise data on the future efficiency of water heaters in the energy efficiency scenario so we had to assume them based on literature.

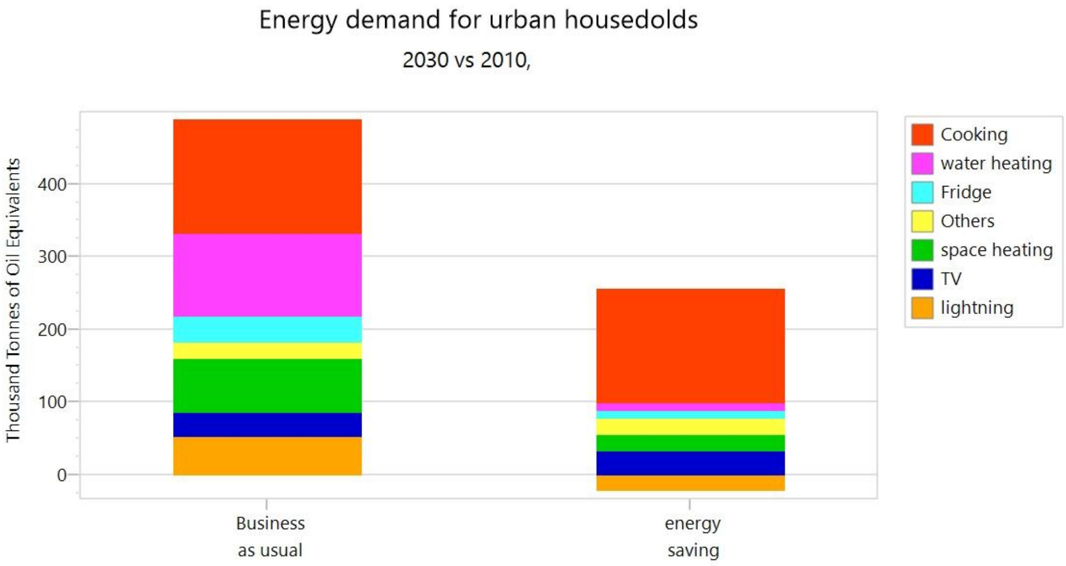

Figure 8

Figure 9 reveals the evolution of electricity demand from national grid. In the SOL scenario, it is possible to decrease electricity consumption compared to 2010 by 15%, while in the energy saving scenario, the consumption is flattened to 13 500 TJ. In the BUS scenario, electricity consumption increases by 46%.

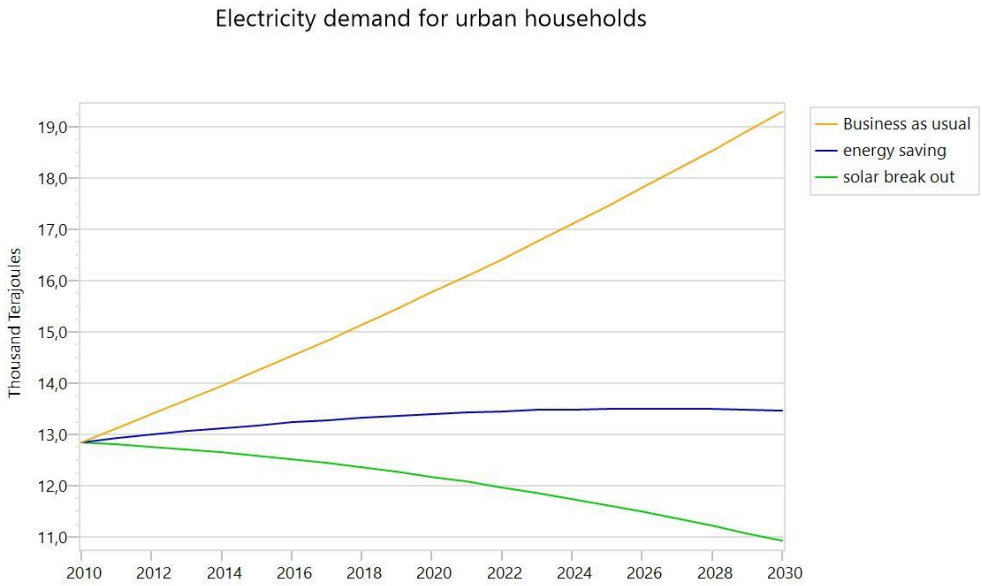

Figure 9

6.2. Transport Sector

6.2.1. Road with Top-Down Approach

The multilinear regression in this sub-sector led to this equation:

$$Y_{Road} = -1278478{,}556 + 0{,}1282062749 * POP - 7322{,}6897300384 * \%CAR + 0{,}8720018133 * IMPORT$$

Where :

- Y_{Road} is the demand of oil products for the road sector [TJ]
- POP is the population [People]
- %CAR is the part of Tunisian household with a car [%]
- IMPORT is imports of oil products [TJ]

A simple linear regression with time did not allow to predict the imports of oils products up to 2030. The regression was not accurate. From 2010 to 2013, there is a huge decrease of imports which can be explained by the Arab Spring. To forecast the evolution of imports of oils products with time, we just suppose that the increase trend from 2013 to 2015 was going to continue. It will lead to an overestimation of the imports of oil products.

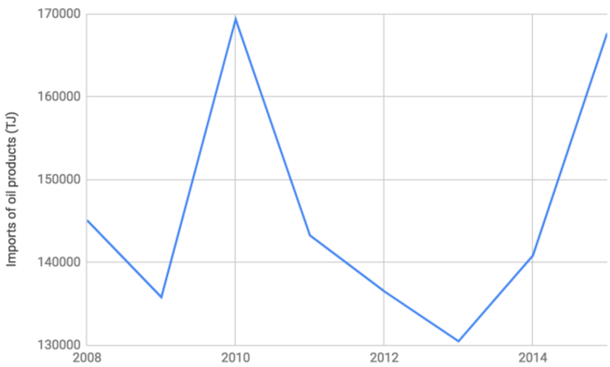

Figure 10- Imports of oil products in Tunisia from 2008 to 2015

The simple linear regression to model the evolution of the part of Tunisian household with a car gave this following equation:

$$\%CAR = 18{,}73571429 + 1{,}080952381 * t$$

Where t corresponds to the year.

We found online available figures for the predicted Tunisian population from 2018 to 2030.

Finally, we forecasted the demand of oil products in the road sector up to 2030. The amount of energy needed in this sector is going to increase and the trend obtained by this method shows a drastic increase. We can criticize these results linked to the fact that we did not find a good method to model the evolution of the imports with years. To have a better estimation in this sub-sector, we used also a bottom-up approach and we compared the two methods. The results are shown in the figure 11.

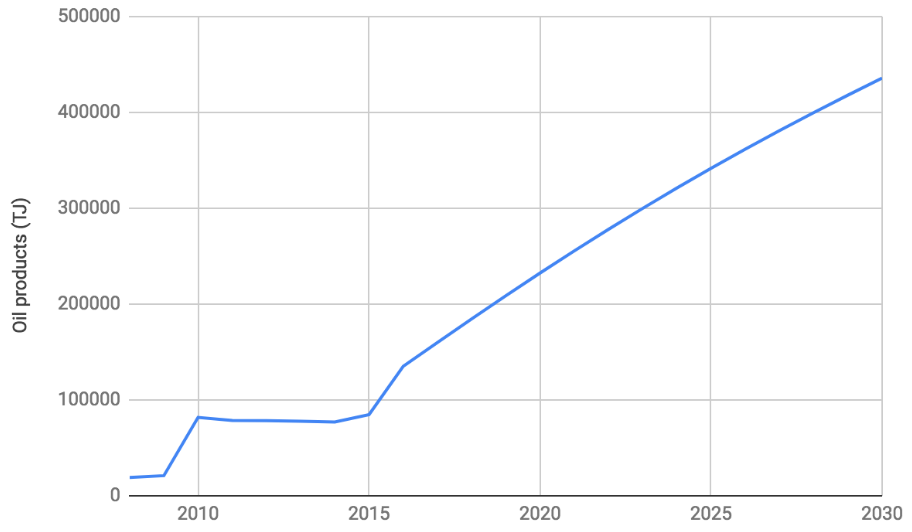

Figure 11- Predicted oil products demand in the road sector in Tunisia

6.2.2. Rail with Top Down Approach

Two energy sources are used in the rail sector in Tunisia. The major one is the electricity and the second is oil products.

Electricity:

The top down approach to model the electricity consumption in the rail sector led to this equation:

$$Ye = 4483{,}345651 - 0{,}0008651329943 * POP + 2{,}425967438 * RAIL$$

Where:
- Ye is the demand of electricity in the rail sector in Tunisia [TJ]
- POP is the population [People]
- RAIL is the rail lines [Total route-km]

We modelled the rail lines as a function of time by this following equation:

$$RAIL = 1955{,}464286 + 38{,}96428571 * t$$

Where t is the year.

Oil products:

The proposed multiple linear regression model to forecast oil products demand in rail sector is:

$$Yo = 12182{,}58423 - 4{,}430208689 * RAIL - 1{,}106166385 * PASSENGERS$$

Where :

- Yo is the demand of oil products [TJ]
- RAIL is the kilometer of rail lines [Total route-km]
- PASSENGERS : passengers carried by railways [People]

Passengers carried by railways was modelized as a function of the year thanks to this equation :

$$PASSENGERS = 1634{,}156133 - 55{,}50451429 * t$$

Where t is the year.

According to this model, the sector is going towards total electrification. The amount of oil products is going to decrease until 2025 when it will reach zero. Then the sector will only rely on electricity.

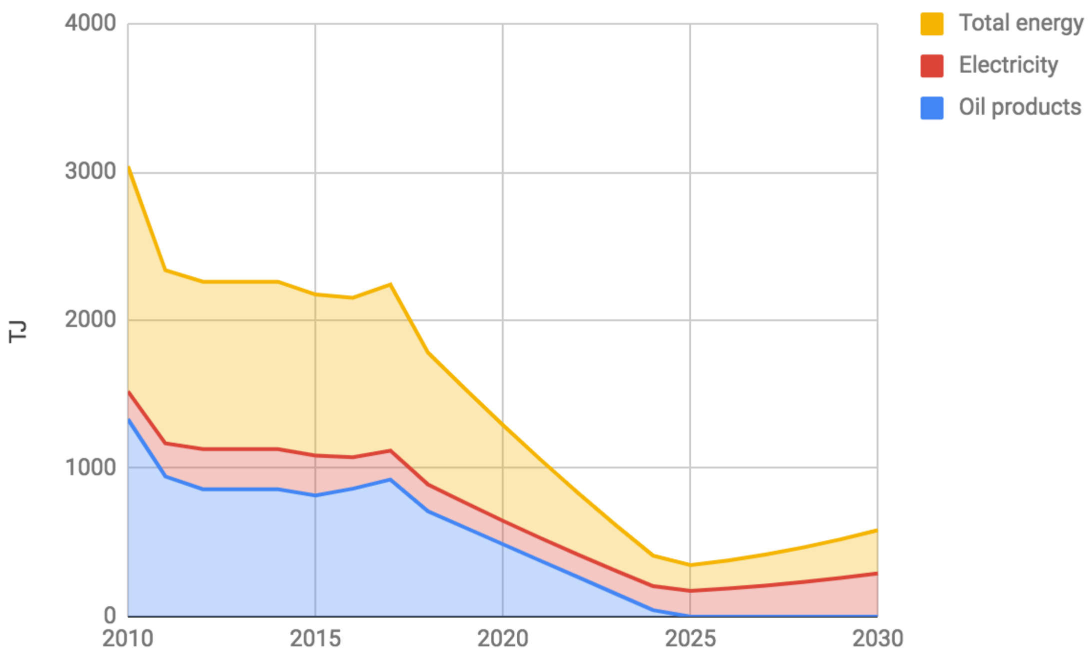

Figure 12- Predicted energy demand in the rail sector in tunisia from 2010 to 2030

6.2.3. Pipeline Transport with Top Down Approach

This sub-sector was very difficult to study because of the lack of data. We only have data for the year 2012 to 2015.

Natural Gas :

The demand of natural gas in the pipeline transport is given by:

$$Y_{NG} = 97074{,}49981 - 8{,}490574425 * GNI$$

Where:

- Y_{NG} is the demand of NG in pipeline sector [TJ]

- GNI is the Gross National Input per capita [Current US$]

The evolution of the GNI with the year can be modelled as followed:

$$GNI = 8736{,}428571 + 294{,}4047619 * t$$

A similar model can be developed where Y_{NG} is just a function of the population (but higher standard errors). In both case the results are the same: the demand of natural gas is supposed to reach 0 quickly. This result cannot be interpreted easily and is a consequence of the lack of data in this subsector. As the share of natural gas in the transport sector is very small, we will consider it close to zero.

Electricity:

The pipeline transport also uses electricity as energy source. Every model tested is not accurate, all R-squared are far too low and p-value too high. We did not find significant variables. But, the amount of electricity used from 2010 to 2015 remains quite constant. In this sub-sector, the electricity is used for pump or compression and it does not evolve a lot from one year to another. So, we can suppose that the amount of electricity will decrease slightly due to a better energy efficiency.

6.2.4. Transport Analysed with the Bottom-Up Approach

Road and rail transports were also analysed with a bottom-up approach, with one scenario only: business as usual.

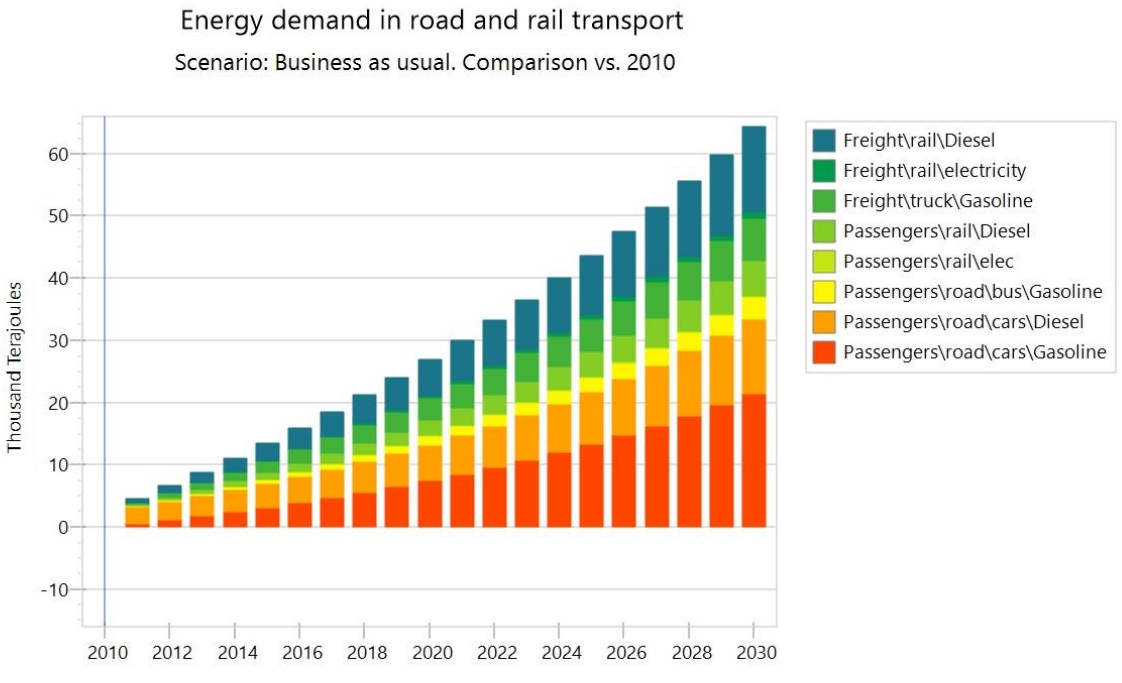

Figure 13

Passengers transport by private cars is the sector with the most significant increase in energy demand: it is multiplied by 3.2. This trend may raise issue in terms of road traffic and air quality, and worsen the energetic balance of Tunisia as more fossil fuel will need to be imported. This confirms the need to implement policy of public transport, efficiency in transportation or development of biofuels and electric cars.

6.2.5. Comparison of Bottom-Up and Top-Down Approach for Road and Rail Sector

On the figure 14, results for road and rail consumption were compared in the top down and bottom up approach. The sudden bump in top down approach between the years 2015 and 2016 is due to increasing imports. We can see that there is a significant gap between those two models. The top down approach predicts twice the consumption of bottom-up approach in 2030. This is partly due to the overestimation of oil products in the road sector in the top-down method and the lack of important data to run correctly LEAP in the rail sub-sector. We finally choose to modelize the road sector by the bottom-up approach and keeps the top-down approach for the rail and pipeline sub-sectors.

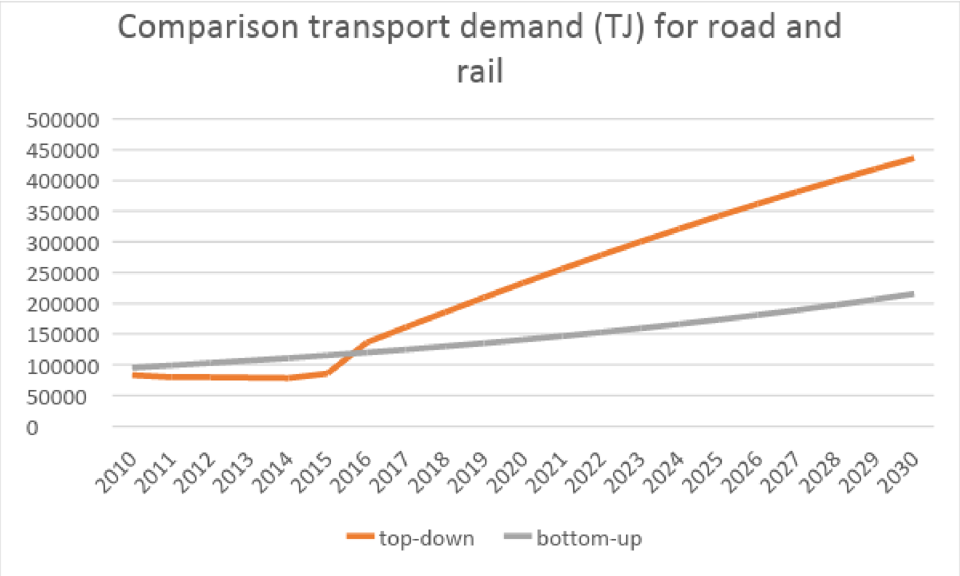

Figure 14 - Comparison of the top-down and bottom-up method for the forecast of the energy demand in the Tunisian transport sector, for road and rail only.

6.2.6. Final Results for Transport Sector in Tunisia (Taking into Account Both Methods)

In this section, road transport is modelized with LEAP, while rail and pipeline are modelized with the top-down method.
In the transport sector, the main energy source is oil products. Its demand is going to increase especially in the road sector. The share of electricity accounts only for 0.0021% in 2030 but it is predicted to increase due to the total electrification of the rail sector. From 2015 to 2030, the total energy demand is going to be multiply by 1.89 according to these predictions. The share of natural gas will reach zero. Indeed, the top-down method in this sector forecasts a decrease of the use of natural gas.

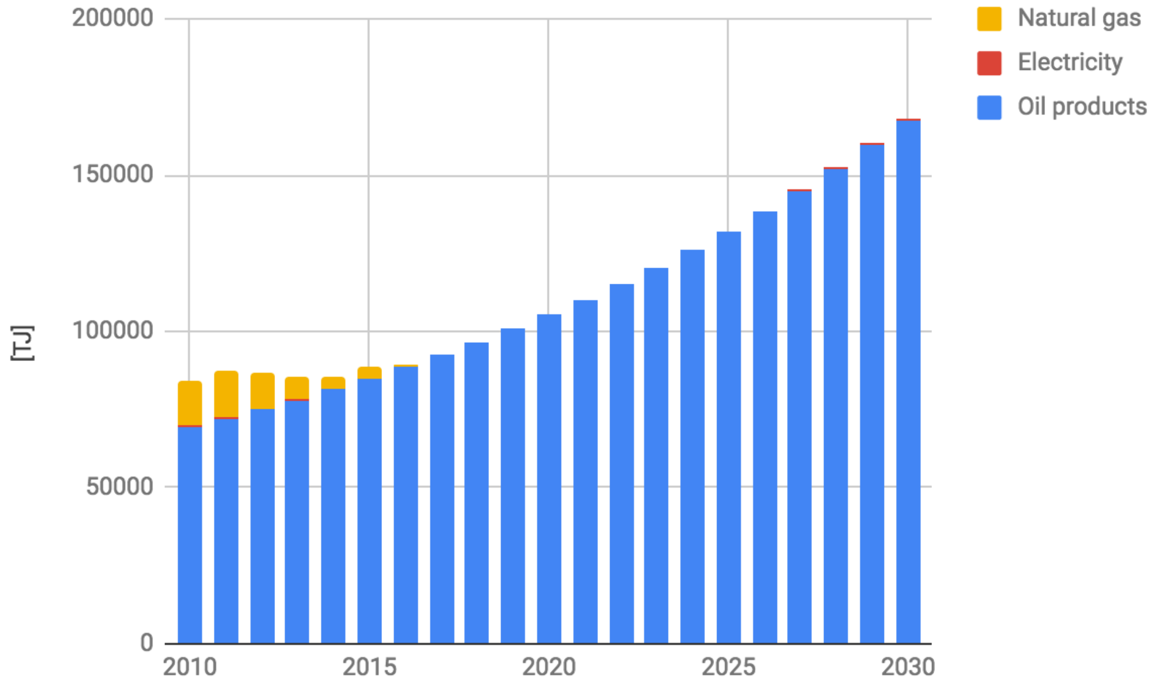

Figure 15- The total energy demand in the tunisian transport sector

6.3. Industrial Sector

The industrial sector was analysed with the relevant exogenous variables mentioned in section 5.2.2, the variables that showed most promising results were the GNI per capita and population. The data values for the exogenous variables were taken from the "*IEA World Energy Balances Report"* A shutdown of the Bizerte refinery occurred between March 2010 and June 2011, resulting in breaks in time series for crude oil and oil products for the years 2009 to 2011 which can be seen in the figure below:

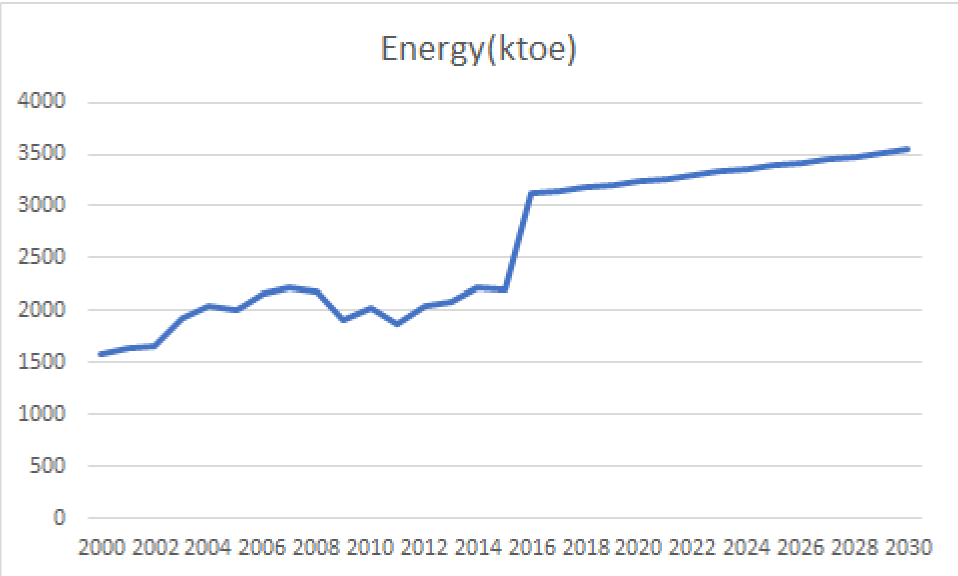

Figure 16 - Industrial Energy Demand Projections of Tunisia

The sudden increase in the values of energy demand after 2015 seems to be because of the chosen which shows energy dependence on three different variables (Rural population, GNI per capita, Agriculture (% of GDP)) all of which values were found by using a linear regression with time after 2015.

The individual top down analysis of different sub sectors of industry are presented in the annex 1 Section 2.

Industrial Fuel Demand

All the sub-sectors were analysed on their dependence of fuel demand. The individual fuel demand was projected for the sub sectors and then added up in the top down model. The overall fuel demand seems to indicate that oil products are to be the most demanded fuel type in Tunisia while a decreasing trend for natural gas was observed.

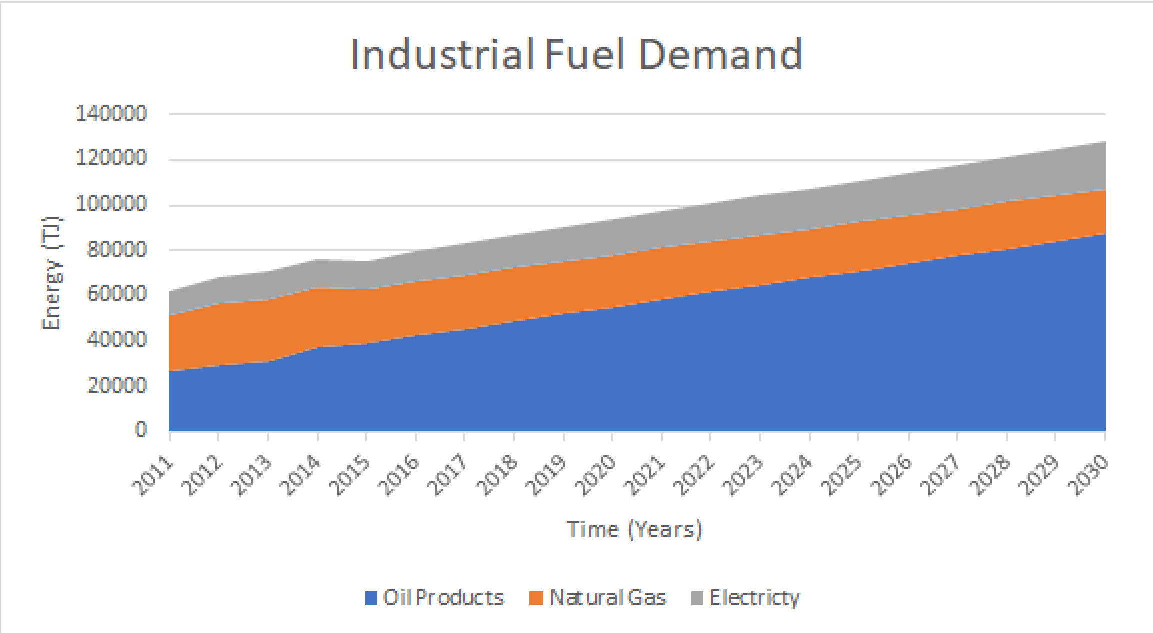

Figure 17 - Overall Industrial Fuel Demand Projections of Tunisia

6.4. Agricultural Sector

The energy data was only available from 2008-2015 which was not enough. Hence, the final projections are not reliable. The data used was from the "*IEA Energy Data Balances Report 2008-2015*"
The values for Energy between 2000-2008 were calculated using regression with time.
The variable (Agricultural contribution to GDP %) gives the highest value of p-value among all the variables used.
Among these Agriculture (% of GDP and Rural Population) resulted in the highest p-value in regression analysis, and were eliminated.
The regression analysis with population resulted in good results with a p-value of 3.25E-06 and R-squared value of 0.8.

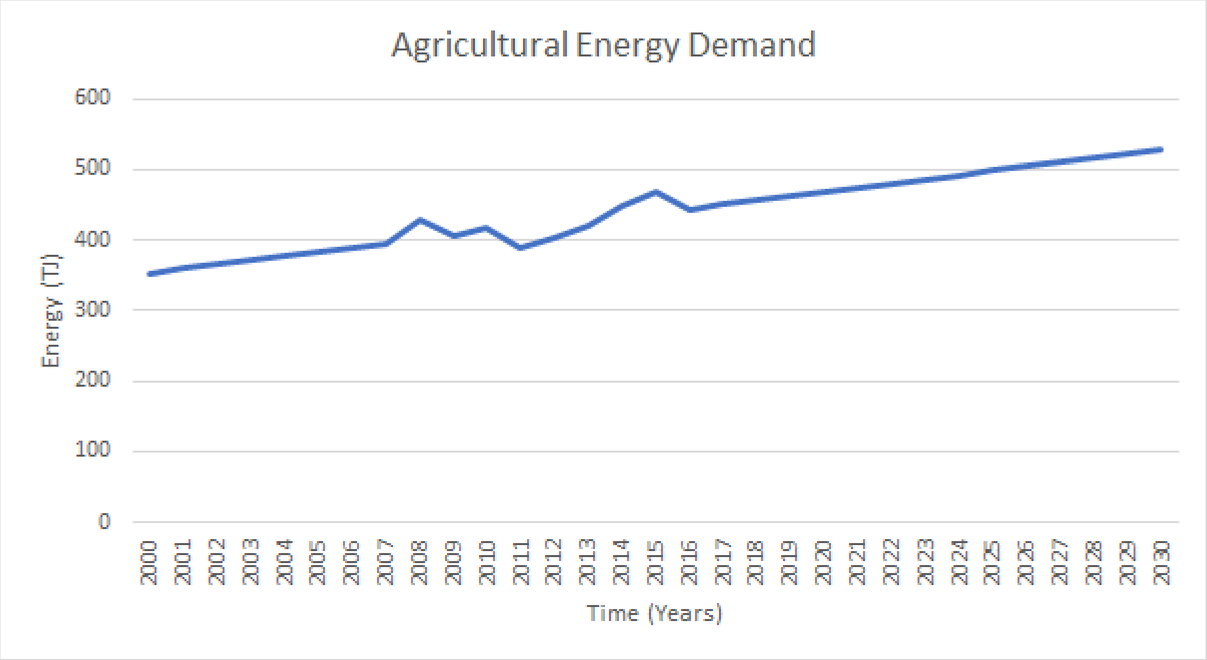

Figure 18 - Agricultural Energy Demand Projections of Tunisia

The following figure shows the projections for the fuel demand in the agricultural sector according to which Oil products dominate in demand while electricity follows.

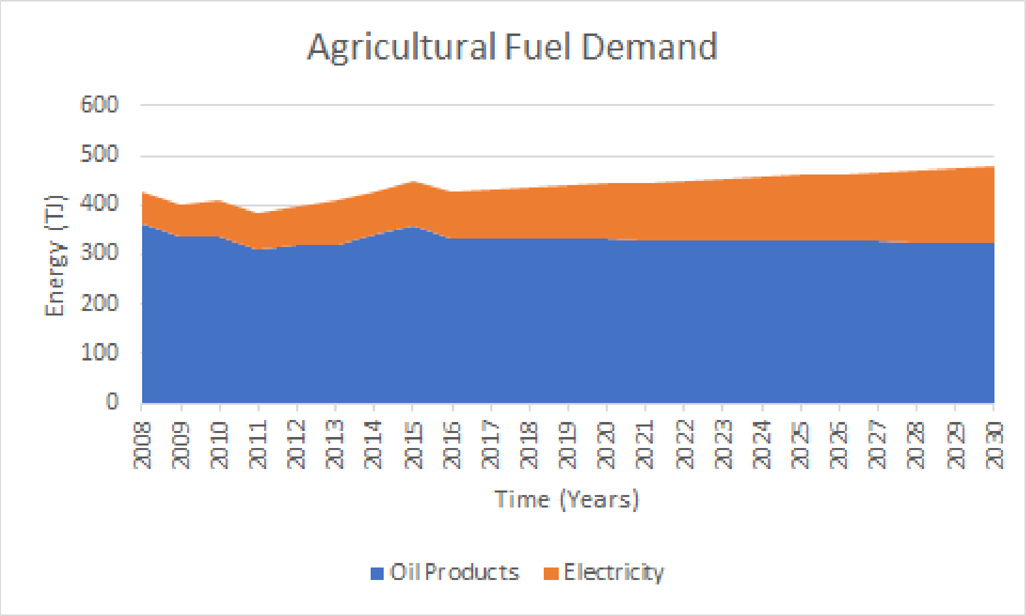

Figure 19 - Agricultural Fuel Demand Projections of Tunisia

6.5. Final Energy Consumption

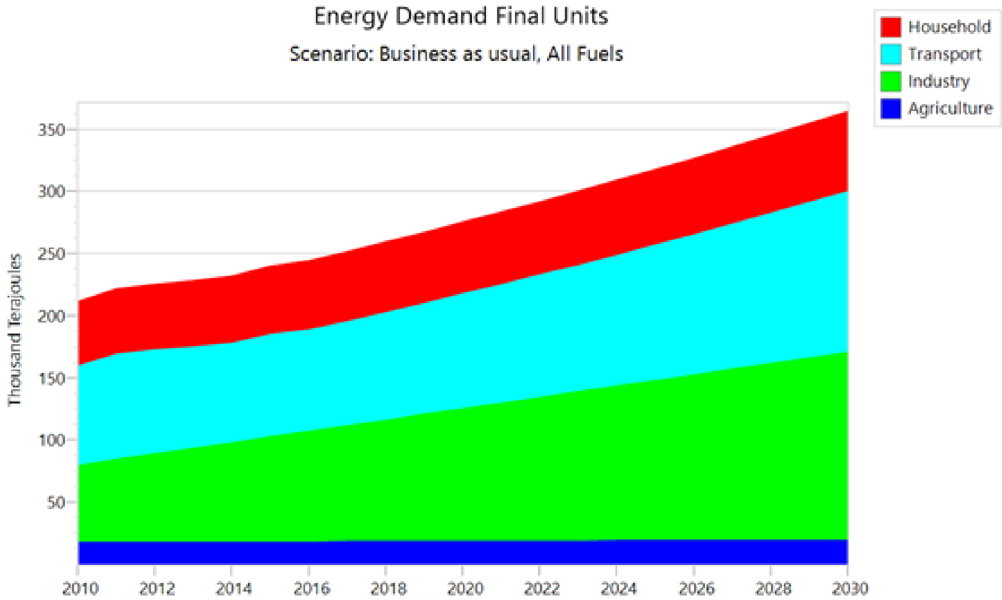

Figure 20 - Consumption of each sector in the BUS scenario

In figure 23, we can see that the most energy consuming sectors will be transports and industry. The growing share of industry can be explained by the top down approach. This method does not take into account measures of efficiency. It is often too optimistic and overestimate energy consumption, so this result is to be taken with caution.

Regarding transport, as it was mentioned previously, the growing number of car users explain the growth. No policy of energy efficiency has been developed yet in the transportation. To reduce air pollution, road traffic and fossil fuel importation, it is inevitable to develop public transport, promote biofuels and electric cars, or to limit road traffic.

Even in the BUS scenario, the residential sector, computed with bottom-up approach, is not expected to grow significantly as most of the country is already electrified, and equipped with electric appliances.

Agriculture, computed with top-down approach, remains steady and as mentioned earlier, due to lack of data, the projections of this sector are not reliable.

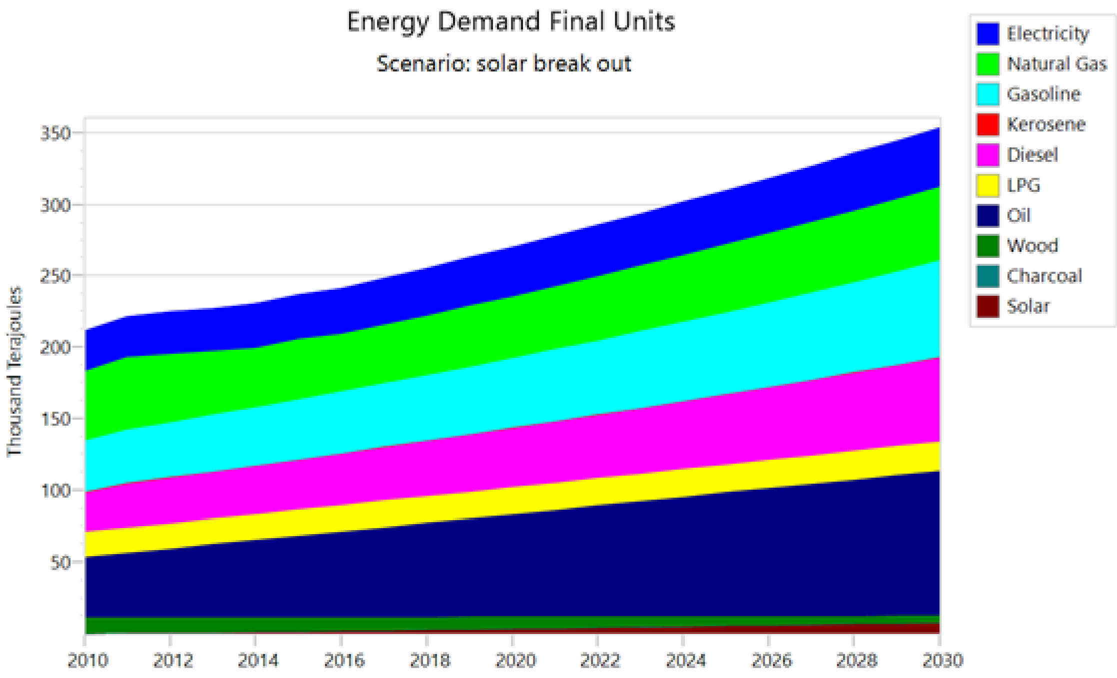

Figure 21 - Use of each fuel in the SOL scenario

In figure 24, we can see that the fuel whose consumption will increase the most is oil. This is due to the consumption of oil in the industry. Once again, those results are to be taken with caution as we may have overestimated energy consumption in the industry because of the top down method.

The pessimistic result is that even in the “solar break-out” scenario, the share of solar remains very low in the final use of energy. Indeed, in our model, solar was used only in the residential sector. We did not consider that any solar energy would be provided to industry, this point could be improved. To have a real impact, solar should also be used in industry.

Gasoline and diesel used in the road transport are also to increase.

6.6. Emission Projections

The CO2 emissions for electricity is found from total CO2 emitted by power generation sector and total electricity generated in Tunisia in year 2010. The relevant data is extracted from co2scorecard.org, an organization that keeps track of CO2 emitted by each country.

All three scenarios show an increase in CO2 emissions as shown in Figure 25. Surprisingly, the difference in CO2 emissions in 2030 between three scenarios is not that significant. Emission in the BUS scenario are reduced by less than 10%.

The total CO2 emissions from each sector in Energy Efficiency scenario (ENE) is shown in Figure 26. Emission from the residential sector remains steady, which shows the success of energy efficiency measures and shift toward solar energy. On the contrary, emissions from the transport sector is doubled, and emissions from industry is multiplied by 160%. Once again for industry, we do not take into account energy efficiency measures so that figure may be overestimated. But it remains relevant for transportation. This reveals the necessity for policy-makers to tackle the issue of pollution from the road transport.

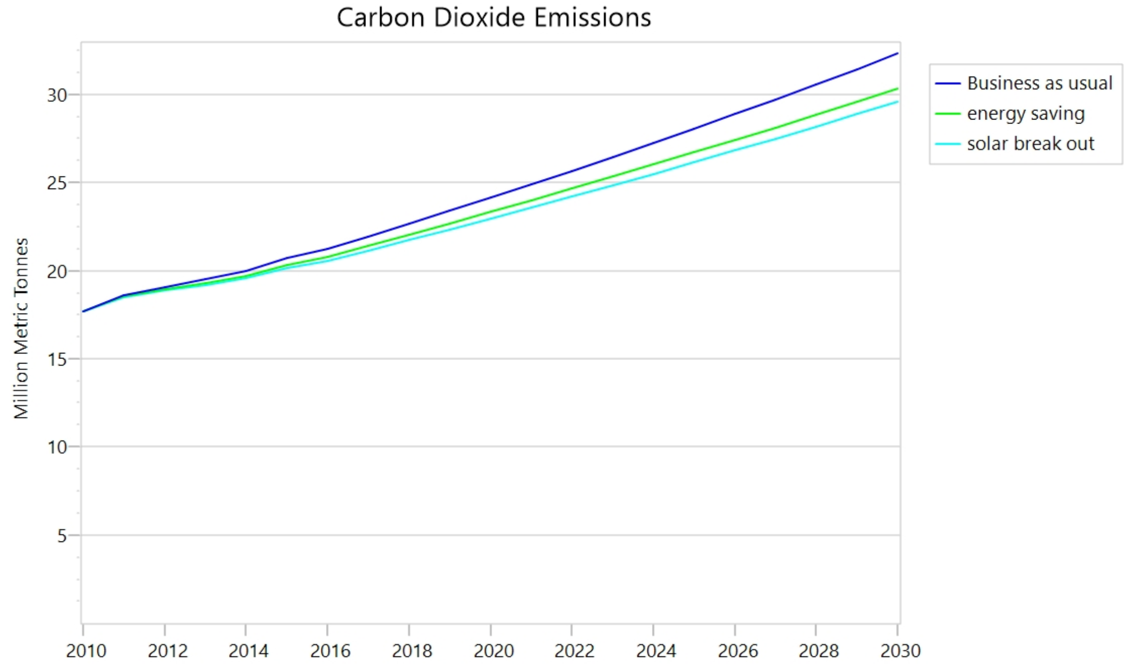

Figure 22 - Total CO2 emissions projection for all three scenarios

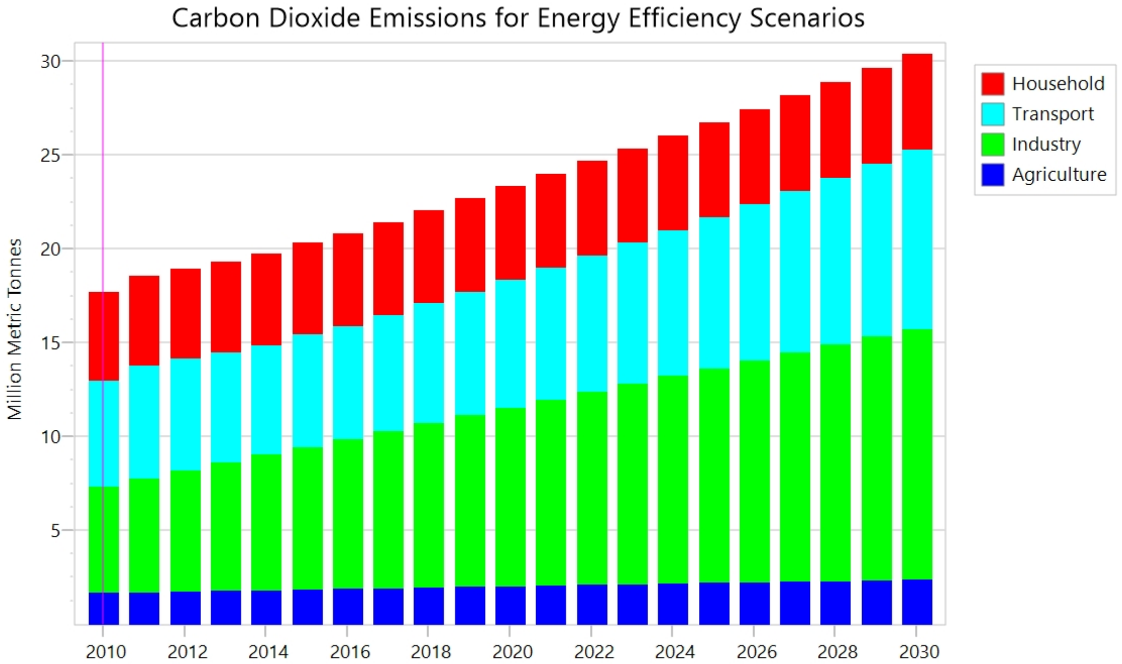

Figure 23 - CO2 emission (ENE scenario for residential, BUS for transport)

7. Conclusion and Policy Implications

Tunisia has already demonstrated its commitment to increase energy efficiency in the residential sector. Measures to reduce lightning consumption and electrical appliances have already been implemented. It the country sticks to its objectives (ENE scenario), electricity consumption could be limited to 13 500 TJ in 2030. This represents a cut of 29% of the projected demand in 2030 in the BUS scenario (19 000 TJ). This proves the worth of the efforts invested in energy efficiency by the government. The “solar break-out” scenario that we developed is the most optimistic and reveals the high potential of solar energy in Tunisia. The project still needs to be carried on and promoted by the national policies (and financial incentive for households) to gain desired results. As a reminder, in the SOL scenario, electricity consumption from the grid in urban area could decrease between 2010 and 2030 by 15%. **To have an impact on the total final use of energy, solar should also be used in the industry.** There are ongoing projects to build large scale solar facilities in the future, but no real achievement yet.

Regarding CO2 emission, our LEAP analysis reveals the pressing need for the government to establish policies of emission reduction in the road transport and industry**. Future pollution emission in the road transport will completely outpace efforts to reduce pollution in the residential sector.** Indeed, pollution of road transport in 2030 accounts for almost four times pollution from residential sector in the ENE scenario. The introduction of electric vehicles or biofuel should be taken into consideration by policy-makers for the future. Inverting the energetic balance will not be possible for Tunisia unless road consumption is regulated. Similarly, some kind of policy instrument, like Carbon tax or Green certificates, should be implemented for industry sector in order to achieve substantial reduction in CO2 emissions.

An easy way to improve our study is to model industry consumption by a bottom-up approach, especially to take into account energy efficiency measures, development of big scale solar facilities and shift of the economy toward less energetic intensive activities like services. More precise data in the road transport and agriculture sector would also have been helpful.

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IEA World Energy Balances Report

https://www.iea.org/statistics/?country=TUNISIA

Annex 1 - Key statistical parameters for the top-down approach

1. Transport sector

1.1. Road subsector (oil products)

Regression Statistics	
Multiple R	0,9520640968
R Square	0,9064260445
Adjusted R Square	0,8362455778
Standard Error	11214,18844
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4872738198	1624246066	12,91564573	0,0158962329
Residual	4	503032089,8	125758022,5		
Total	7	5375770288			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95%*	*Upper 95%*
Intercept	-1278478,556	221651,6905	-5,767962128	0,004484223386	-1893882,306	-663074,8069	-1893882,306	-663074,8069
Population (people)	0,1282062749	0,02253717142	5,68865864	0,004715731154	0,06563305582	0,1907794941	0,06563305582	0,1907794941
Imports of oil products	0,8720018133	0,3198396259	2,72637204	0,05263954357	-0,01601534829	1,760018975	-0,01601534829	1,760018975
Part of tunisian household with	-7322,68973	2079,965631	-3,520582081	0,02443721107	-13097,60011	-1547,779349	-13097,60011	-1547,779349

1.2. Rail subsector

1.2.1. Electricity

Regression Statistics	
Multiple R	0,8767613702
R Square	0,7687105003
Adjusted R Square	0,6761947004
Standard Error	143,7232504
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	343266,1365	171633,0682	8,308964537	0,02572703823
Residual	5	103281,8635	20656,3727		
Total	7	446548			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95%*	*Upper 95%*
Intercept	4483,345651	1955,210732	2,293024264	0,07038292034	-542,6835407	9509,374843	-542,6835407	9509,374843
Population (people)	-0,00086513299	0,0002197803944	-3,936351997	0,0110000227	-0,00143009648	-0,00030016950	-0,00143009648	-0,00030016950
Rail lines (total route-km	2,425967438	0,7692204062	3,153800157	0,02527067791	0,4486234349	4,403311441	0,4486234349	4,403311441

1.2.2. Oil products

Regression Statistics	
Multiple R	0,9727101161
R Square	0,9461649701
Adjusted R Square	0,9102749501
Standard Error	58,17553603
Observations	6

ANOVA

	df	SS	MS	F	Significance F
Regression	2	178444,821	89222,41051	26,36289896	0,01249100662
Residual	3	10153,17898	3384,392992		
Total	5	188598			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	12182,58423	1764,575032	6,903976316	0,006227404956	6566,91894	17798,24952	6566,91894	17798,24952
Rail lines (total route-km)	-4,430208689	0,6470785866	-6,846477044	0,006377954837	-6,489501545	-2,370915832	-6,489501545	-2,370915832
Railways, passengers carried (million passenger-km)	-1,106166385	0,303751449	-3,641682662	0,03569963125	-2,072839062	-0,1394937088	-2,072839062	-0,1394937088

1.3. Pipeline subsector (natural gas)

Regression Statistics	
Multiple R	0,9652119387
R Square	0,9316340866
Adjusted R Square	0,8974511299
Standard Error	1237,83168
Observations	4

ANOVA

	df	SS	MS	F	Significance F
Regression	1	41759850,21	41759850,21	27,25434476	0,0347880613
Residual	2	3064454,536	1532227,268		
Total	3	44824304,75			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95%	Upper 95%
Intercept	97074,49981	17352,20518	5,594360993	0,03049790975	22413,98683	171735,0128	22413,98683	171735,0128
gni per capita (current US $)	-8,490574425	1,626369423	-5,22056939	0,0347880613	-15,48827726	-1,49287159	-15,48827726	-1,49287159

2. Industrial sector

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.919906
R Square	0.846226
Adjusted R	0.807783
Standard E	91.27932
Observatic	16

ANOVA

	df	SS	MS	F	Significance F
Regressior	3	550212	183404	22.01222719	3.61271E-05
Residual	12	99982.98	8331.915		
Total	15	650195			

	Coefficients	andard Erro	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	14814.36	2639.302	5.612983	0.000113767	9063.811918	20564.90217	9063.811918	20564.90217
Rural Popu	-0.00461	0.00087	-5.2977	0.000189051	-0.006504613	-0.002713451	-0.006504613	-0.002713451
GNI per ca	0.339535	0.047561	7.138883	1.18227E-05	0.235907596	0.44316213	0.235907596	0.44316213
Agricultur	81.83798	34.61123	2.364492	0.035757978	6.426588818	157.2493618	6.426588818	157.2493618

2.1 Non metallic Minerals

The variables chosen were:
GNI and Population of which the values were provided from 2011 to 2015.

The following equation models the non-metallic industrial energy demand

$$Y_{Nm} = 16344.2 - 0.02909 * Population + 19.4705 * GNI$$

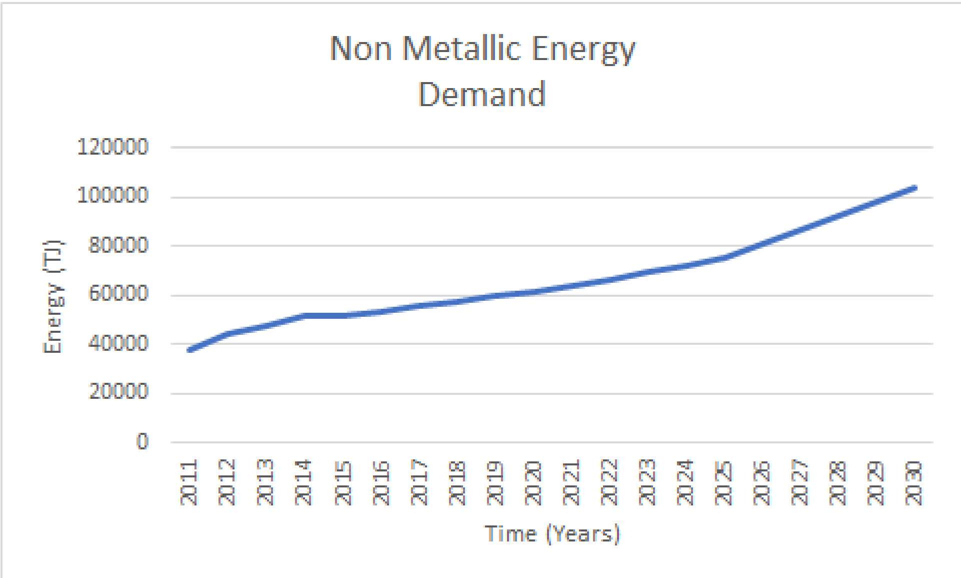


Figure-Non-Metallic Industrial Energy Demand Projections of Tunisia

Initially there seemed to be a problem with the extrapolation of population after 2025 and the demand went on negative, it was observed that the residual plot was a sinusoidal indicating linear regression is not a good fit for the analysis, the population values from 2025 till 2030 were assumed to be constant to avoid this.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.998042
R Square	0.996087
Adjusted R	0.992175
Standard E	514.0098
Observatic	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regressior	2	1.35E+08	67262817	254.5846	0.003912598
Residual	2	528412.2	264206.1		
Total	4	1.35E+08			

	Coefficients	*tandard Erro*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	163442.5	69606.37	2.348097	0.14337	-136049.5018	462934.5532	-136049.5018	462934.5532
Populatior	-0.02909	0.009277	-3.13594	0.08841	-0.069008944	0.010823809	-0.069008944	0.010823809
GNI per ca	19.47045	3.160134	6.161273	0.025345	5.873487288	33.06740445	5.873487288	33.06740445

2.2 Food and Tobacco

The equation describing the model for food and tobacco industrial energy demand came out to be of the form:

$$Y_{\ food\ and\ tobacco} = -16460.3 + -0.002329 * Population - 0.39391 * GNI$$

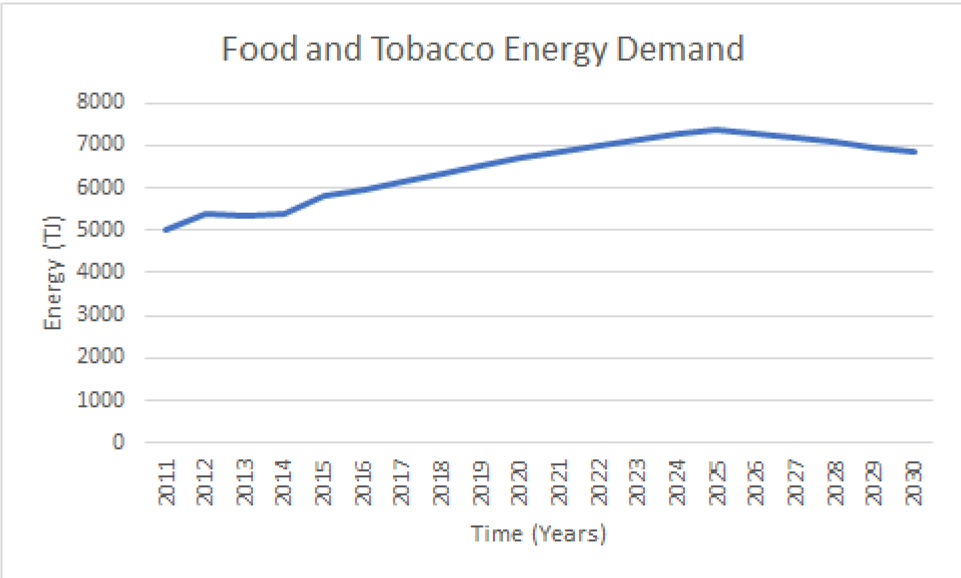


Figure- Food and Tobacco Energy Demand Projections of Tunisia

The demand seems to increase but not much as in comparison to the other industrial sectors.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.909253
R Square	0.82674
Adjusted R	0.65348
Standard E	167.8169
Observatic	5

ANOVA

	df	SS	MS	F	ignificance F
Regressior	2	268765	134382.5	4.771678	0.17326
Residual	2	56325.04	28162.52		
Total	4	325090			

	Coefficients	tandard Err	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-16460.3	22725.49	-0.72431	0.544145	-114240	81319.58305	-114240.2282	81319.58305
Populatior	0.002329	0.003029	0.768959	0.522312	-0.0107	0.0153612	-0.010703063	0.0153612
GNI per ca	-0.36391	1.031739	-0.35272	0.758003	-4.80313	4.075300039	-4.803128799	4.075300039

2.3 N.E.S

A good model with decent p values and R squared values could not be found for this sub sector so a simple regression with time was performed for the sake of analysis.

Y=507486-242.8*Year

$$Y_{nes} = 507486 - 242.8 * Year$$

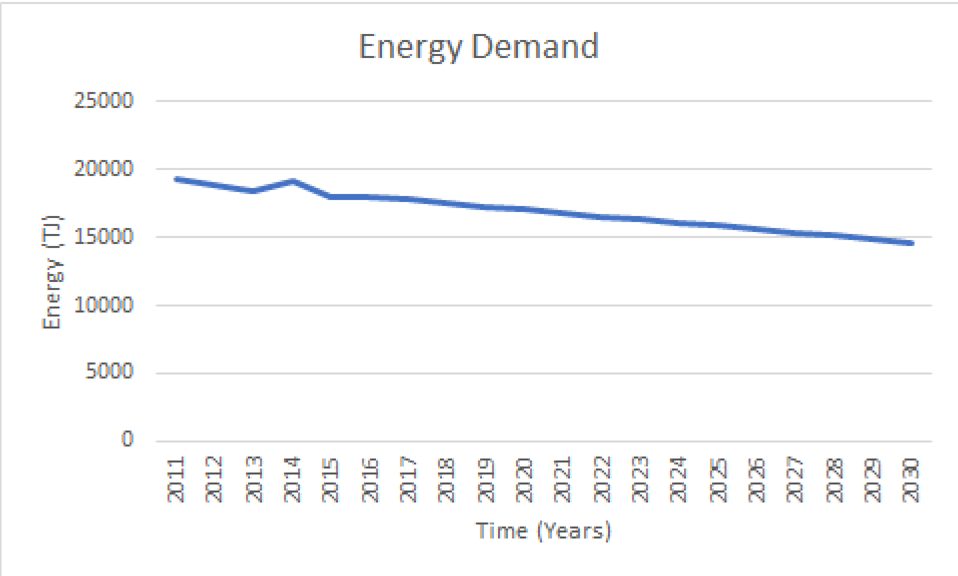


Figure-N.e.s Energy Demand Projections of Tunisia

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.686956
R Square	0.471909
Adjusted R Squa	0.295878
Standard Error	468.936
Observations	5

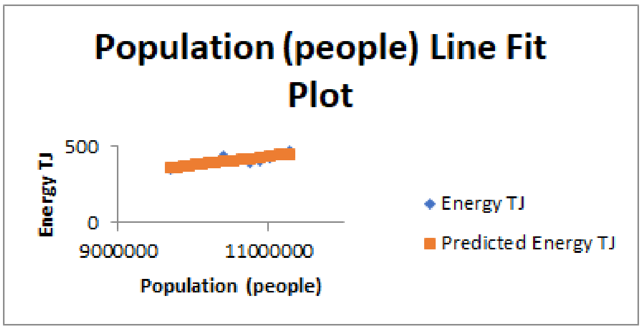
ANOVA

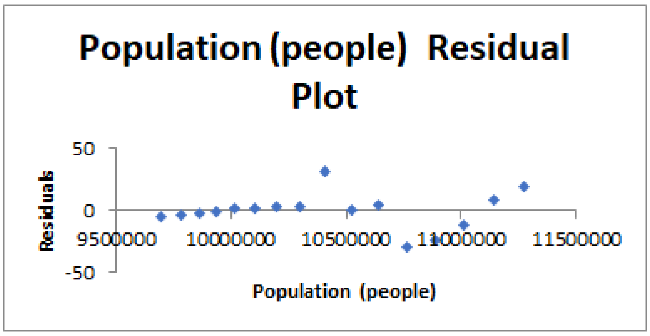
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	589518.4	589518.4	2.680836	0.200085754
Residual	3	659702.8	219900.9		
Total	4	1249221			

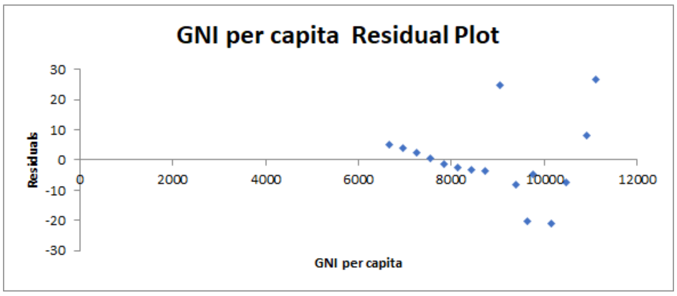
	Coefficients	*andard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	507486	298509	1.700069	0.187677	-442502.8397	1457474.84	-442502.8397	1457474.84
Year	-242.8	148.2906	-1.63733	0.200086	-714.7267786	229.1267786	-714.7267786	229.1267786

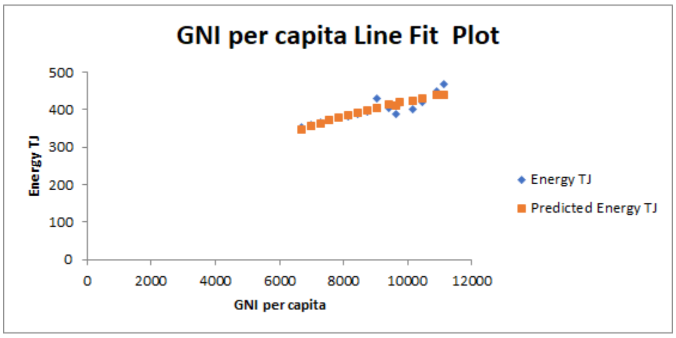
3. Agricultural sector

The following are the residual plots of the agricultural sector with the exogenous variables









Annex 2 - Tree built in LEAP for bottom up approach