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# Determinants and Prediction of $CO_2$ Emissions in Tunisia: LMDI Decomposition Approach of an Error Correction Model

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**ABSTRACT**

In order to be able to meet the commitments with regard to its Nationally Determined Planned Contribution submitted to COP 21, Tunisia is committed to effectively reducing its $CO_2$ emissions. Our study detects the main potential factors responsible for the increase in carbon dioxide emissions in Tunisia using the decomposition method (Logarithmic Mean Divisia Index: LMDI). Then, an analysis of the long-term relationship between $CO_2$ emissions and these main factors is established through an error correction model. The forecast of this cointegration relationship by 2030 shows that Tunisia has significant potential for reducing $CO_2$ emissions, especially through the phenomenon of reduction in energy intensity. However, political intervention beyond energy control is necessary in order to achieve Tunisia's environmental objectives.

**Keywords:** $CO_2$ Emissions, LMDI, Cointegration Theory
**JEL Classifications:** C1, Q4, Q5

## 1. INTRODUCTION

Tunisia's economic development has resulted in an increasing demand for energy of around 5% per year since the beginning of the 1990s. This energy demand is mainly covered by the use of fossil fuels, which are the main sources of energy greenhouse gas (GHG) emissions. The concentration of GHGs in the atmosphere continues to increase each year and causes a rise in temperature. It has reached alarming thresholds with a definite impact on the climate. In order to limit global warming, Tunisia participated in the 2015 Paris Conference (COP 21) on climate change where it signed an agreement to limit global warming to <2°C. The observation developed by Tunisia's contribution commits the country to continue efforts to reduce the economy's dependence on conventional sources of energy (oil and gas) and limit GHG emissions. In order to be able to reduce its carbon intensity by 41% in 2030 compared to 2010, Tunisia intends to reduce its GHG emissions in all sectors, and more particularly in the energy sector, which alone represents 75% of emission reductions. A rate of at least 40% reduction in GHG emissions is set for 2030 compared to the 1990 level. It should be noted that $CO_2$ emissions represent the share of the most emitted GHGs, with 79% of emissions in 2010. These emissions reached 28, 8 million tonnes of $CO_2$ ($MTCO_2$), i.e. 2.9 times those from 1980. A fairly realistic problem on the horizon is how to effectively reduce $CO_2$ emissions in Tunisia?

The purpose of our study is to address the following problems: (1) based on the current situation of the Tunisian energy system, what are the main factors responsible for the increase in carbon dioxide emissions? (2) What is the relationship between these $CO_2$ emissions and the main factors influencing them? (3) How can $CO_2$ emissions in Tunisia vary in the future? The remainder of this article is organized as follows. Section 2 presents the methodology of the analysis. Section 3 presents the results of the analysis. Finally, section 4 presents the main conclusions and recommendations.

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## 2. THE METHODOLOGY OF THE ANALYSIS OF DETERMINANTS AND THE PREDICTION OF $CO_2$ EMISSIONS

Studies of the factors that influence $CO_2$ emissions date back to the 1980s.

Ang and Choi (1997) proposed a decomposition method to overcome the problem of residual existence and the difficulty of dealing with the zero value during the decomposition analysis on $CO_2$ emissions.

Ang and Pandiyan (1997) broke down $CO_2$ emissions from manufacturing industry in Mainland China, South Korea and Taiwan.

Two decomposition techniques are commonly used: Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA). According to Ang and Zhang (2000), the difference between these two techniques lies in the type of data. The SDA method uses the input-output model to decompose the evolution of the indicators while the IDA uses only data at the sector level. The IDA method has been used more than the SDA method in the study of energy consumption factors and energy-related emissions (Ang and Su, 2012).

According to Ang (2004), the Modified Fisher Ideal Method and the Mean Logarithmic Divisia Index (LMDI) are preferred because they have desirable properties that satisfy factor inversion (i.e. say no residual term remains) and robust sign change (i.e. the method can handle zero values in the dataset).

The essence of factor decomposition analysis is to represent carbon emissions as the product of several factor indicators. Since there are several ways to express the weight of different factors, there are also several ways to determine the share of increase of each index. The two main decomposition approaches are Structural Decomposition Analysis (SDA) and Decomposition Index Analysis (IDA).

Ang and Su (2012) reviewed the latest developments in SDA, compared four SDA methods, and provided guidelines for choosing the appropriate method. They also discussed the similarities and differences between SDA and IDA.

The basis of SDA is input-output analysis, which helps to distinguish between direct and indirect impacts of other sectors when analyzing changes in energy consumption and $CO_2$ emissions of a specific sector. Leontief and Ford (1972) used the SDA method to decompose air pollution factors in the United States in 1972.

Following this initial study, many studies employing the SDA method have been conducted from a specific regional or industry perspective. For example:

Chang (2008) analyzed the evolution of industrial $CO_2$ emissions in Taiwan. The industrial energy coefficient, the $CO_2$ emission factor, exports and domestic final demand were the factors positively related to the increase in emissions.

Zhang and Qi (2011) used the SDA method to analyze $CO_2$ emissions from production in China over the period 1992-2002. The results showed that final demand for goods and services mainly increased $CO_2$ emissions while technical improvement could reduce emissions.

However, data that is more detailed is required to use the SDA method and this is the limitation of this method. IDA can overcome this shortcoming and has become the widely used method in the analysis of energy consumption and emissions.

Howarth (1991) decomposed the change in energy consumption in manufacturing industry in eight OECD countries from 1973 to 1987 into three factors, including aggregate manufacturing activity, industry structure and energy intensity.

Zhang (2009) used the Laspeyres index to decompose $CO_2$ emissions in China into four factors: energy intensity, carbon intensity, structural changes and economic activities.

Ben Hammamia et al. (2014) also used the IDA method to decompose energy intensity in Tunisia into efficiency effect and structure effect. The results show that the effect of improving energy efficiency is the main contributor to the reduction of energy intensity in Tunisia.

The Laspeyres index and the Divisia index are the two types of the IDA index. In the Divisia index, the Logarithmic Mean Divisia Index (LMDI) is the most popular method. Ang and Choi (1997) develop the LMDI method. It has a deep theoretical basis and strong adaptability, so it is considered a rather good research method and is widely used. Since its emergence, a large number of papers have used this method to research energy intensity, greenhouse gas emissions, and other environmental issues in different countries. For example:

Wang et al. (2005) used the LMDI method to analyze the variation in global carbon dioxide emissions over the period 1957-2000. They found that improving energy intensity is the main contributing factor to lower carbon dioxide emissions.

Malla (2009) analyzed the changes in $CO_2$ emitted by the electricity generation sector in seven countries in Asia-Pacific and North America during the period 1990-2005. He found that energy structure, energy intensity and production were the three main factors influencing carbon dioxide emissions.

Timilsina and Shrestha (2009) took the transport sector of twenty countries in Latin America and the Caribbean and examined the factors influencing $CO_2$ emissions in the sector. Several factors such as fuel composition, economic growth, energy intensity and emission factors could explain the change in emissions growth.

Guo (2010) used the LMDI method to construct an equation for carbon dioxide emissions based on economic scale, energy efficiency, carbon emission index, energy structure, and economic structure. The result showed that the expansion of economic scale is the main factor behind the rapid growth of $CO_2$ emissions in China, while the improvement of energy efficiency is the main factor limiting the growth of $CO_2$ emissions.

Tang (2011) constructed a decomposition model superimposed on the determinants of national carbon dioxide emissions based on the extended Kaya equation and the LMDI method. Their empirical analysis results showed that the strongest and most consistent drivers of $CO_2$ emissions are economic scale and energy intensity.

Hammond and Norman (2012) analyzed energy-related $CO_2$ emissions in manufacturing industry in England and found the contributions of different factors. Output, industrial structure, energy intensity, fuel structure and so on have been included.

Xu (2012) studied the $CO_2$ emissions of the Chinese cement industry during the period 1990-2009. Efficiency policies and industrial standards have been seen as drivers of rising emissions, while growth in cement production has contributed to its decline.

Wang (2013) also studied $CO_2$ emissions from the cement industry in China, but at a different period. They reached different conclusions: Positive factors were cement production and clinker production activities, while the energy intensity factor had negative impacts.

Lin and Ouyang (2014) used the LMDI method to study changes in carbon dioxide emissions from the Chinese non-metallic mineral products industry over the period 1986-2010. The decomposition indicated that labor productivity is the main factor contributing to the growth of $CO_2$ emissions. The reduction in energy intensity is the main reason for the reduction in $CO_2$ emissions.

Zhang (2016) explored the main factors driving the change in carbon intensity (CI) in 29 provinces of China over the period 1995-2012. They found that the intensity of energy consumption was the most important factor in the decrease in CI.

In Tunisia, this method has become increasingly used to study the phenomenon of increasing $CO_2$ emissions.

Daldoul and Dakhlaoui (2016) adopted the LMDI method to study the effects of five factors on total carbon dioxide ($CO_2$) emissions from road vehicles in Tunisia between 1980 and 2011. The results show that rapid economic growth and vehicle ownership were the most important factors contributing to the increase in $CO_2$ emissions.

In our study, we use the logarithmic mean Divisia index (LMDI) to detect the potential factors responsible for the increase in carbon emissions in Tunisia.

The factor decomposition analysis method will allow carbon emissions to be represented as the product of several factor indicators. Indeed, since there are several ways of expressing the weight of different factors, there are also several ways of determining the share of the increase of each index.

We use in our study the Kaya equation developed by Yoichi Kaya in 1989:

$$CO2 = \frac{CO2}{TEC} \times \frac{TEC}{GDP} \times \frac{GDP}{POP} \times POP \quad (1)$$

Where, TEC represents total energy consumption, GDP represents gross domestic product and POP represents population. We adjust the Kaya equation and we substitute GDP by industrial value added and POP by the number of people employed in industry. The equation is now:

$$CO2 = \frac{CO2}{CFF} \times \frac{CFF}{TEC} \times \frac{TEC}{IAV} \times \frac{IAV}{PEI} \times PEI$$

$$= CD \times S \times EI \times LP \times IS \quad (2)$$

Where CFF represents the consumption of fossil fuels, TEC represents the total energy consumption, IAV represents the industrial added value and PEI represents the number of Persons Employed in the Industry.

The factors in the right side of equation (2) represent the following meanings: (CD) is the effect of carbon density defined as the emissions of carbon dioxide caused per unit of fossil fuel consumption. (S) is the effect of energy structure defined as the proportion of fossil fuel to total energy consumption. (EI) represents the effect of energy intensity defined as energy consumption per unit of industrial value added. (LP) is the effect of labor productivity defined as industrial value added per capita and (IS) is the effect of industrial scale, which is equal to PEI.

Using the LMDI decomposition method, these factors can be transformed into the following form:

$$CD_{eff} = \frac{co_2(t) - co_2(0)}{ln[\frac{co_2(t)}{co_2(0)}]} * \ln\left[\frac{CD(t)}{CD(0)}\right] \quad (3)$$

$$S_{eff} = \frac{co_2(t) - co_2(0)}{ln[\frac{co_2(t)}{co_2(0)}]} * \ln\left[\frac{S(t)}{S(0)}\right] \quad (4)$$

$$EI_{eff} = \frac{co_2(t) - co_2(0)}{ln[\frac{co_2(t)}{co_2(0)}]} * \ln\left[\frac{EI(t)}{EI(0)}\right] \quad (5)$$

$$LP_{eff} = \frac{co_2(t) - co_2(0)}{ln[\frac{co_2(t)}{co_2(0)}]} * \ln\left[\frac{LP(t)}{LP(0)}\right] \quad (6)$$

$$IS_{eff} = \frac{co_2(t) - co_2(0)}{ln[\frac{co_2(t)}{co_2(0)}]} * \ln\left[\frac{IS(t)}{IS(0)}\right] \quad (7)$$

If we can calculate the values of these effects in year 0, we can analyse the contributions of these factors to the evolution of $CO_2$ emissions during each period. However, few documents analyse the influencing factors of $CO_2$ emissions and their potential for future reduction. Our study therefore proposes to build the long-term relationship between $CO_2$ emissions and these main influencing factors resulting from decomposition analysis. Indeed, the cointegration theory, proposed by Engle and Granger (1987), was commonly used to analyse the influencing factors of $CO_2$ emissions. However, forecasting this relationship will further assess the potential for reducing $CO_2$ emissions in the future. This is why we will then explore the possible variation of these emissions by 2030.

## 3. THE INTERPRETATION OF RESULTS

### 3.1. The Decomposition Analysis of $CO_2$ Emissions by the LMDI Method

Using the LMDI decomposition method, $CO_2$ emissions in Tunisia are broken down, between 1991 and 2019, into five effects: The effect of carbon density, the effect of energy structure, the effect of energy intensity, the effect of labor productivity and the effect of industrial scale. The results are presented in table 1 and shown in Figure 1.

During the period 2006-2010, carbon dioxide emissions increased by approximately 4668 $MTCO_2$, the largest increase in the five periods. This sharp increase is explained by the acceleration of the process of urbanization during this period. This has favoured the development of industries with high-energy consumption in Tunisia, as evidenced by the increase in industrial added value.

The energy intensity factor (EI), defined as the energy consumption per unit of industrial added value, resulted in a decrease of −1335 $MTCO_2$. In fact, during this period, energy consumption grew at a much slower pace than GDP; hence, this phase of declining energy intensity illustrates a "decoupling" between economic growth and energy during this period. However, improving energy efficiency remains the driving force that played the major and preponderant role in reducing energy intensity during this period because the implementation of energy conservation policies made it possible to improve energy efficiency, which allowed a better level of energy intensity, Ben Hammamia et al. (2014). Therefore, our country should continue to strengthen the policy of energy conservation in industry in the future. It is necessary to improve industrial production technology because if energy efficiency is low, energy intensity will be high. Traditional technologies should be renewed and new methods based on green technologies will significantly reduce pollution and meet the demand of the low carbon economy.

The carbon density factor (CD) was the most important factor for the increase in $CO_2$ emissions with 4349 $MTCO_2$. The increase in CD is explained by the increase in carbon dioxide emissions caused per unit of fossil fuel consumption. This proves that the energy sector is dependent on non-renewable resources (oil and natural gas), the combustion of which is the main cause of the increase in $CO_2$ emissions.

The energy structure (S), defined as the proportion of fossil fuel in relation to total energy consumption, had a negative influence on $CO_2$ emissions during this period. This indicates that the demand for energy is on the rise and energy resources, such as the production of hydrocarbons, are on the decline. This is called the structural deficit in the energy balance. The structural deficit in the energy balance in turn affects the increase in $CO_2$ emissions. The continuous increase in energy demand is always accompanied by an increase in the level of $CO_2$ since it is dependent on fossil fuels. Hence, in order to significantly reduce the structural deficit in the energy balance, sustained growth in energy consumption and stagnation in hydrocarbon production are required.

The positive contribution of the labor productivity (PL) is explained by a positive influence of industrial value added per unit of labor in industry on $CO_2$ emissions. So, it is determined by how the process has developed, probably based on polluting industries. In this case, the orientation of the Tunisian economy towards sectors of industry that consume less energy and pollute, with high added value and low energy intensity can play an important role in the reduction of $CO_2$ emissions.

The industrial scale factor (IS) has generally contributed to the reduction in $CO_2$ emissions. Between 2006 and 2010, its contribution was positive due to the recruitment of workers in the industrial sector during this period. Then, between 2011 and 2014, its contribution becomes negative since fewer employees

**Figure 1:** The results of the decomposition of $CO_2$ emissions by LMDI

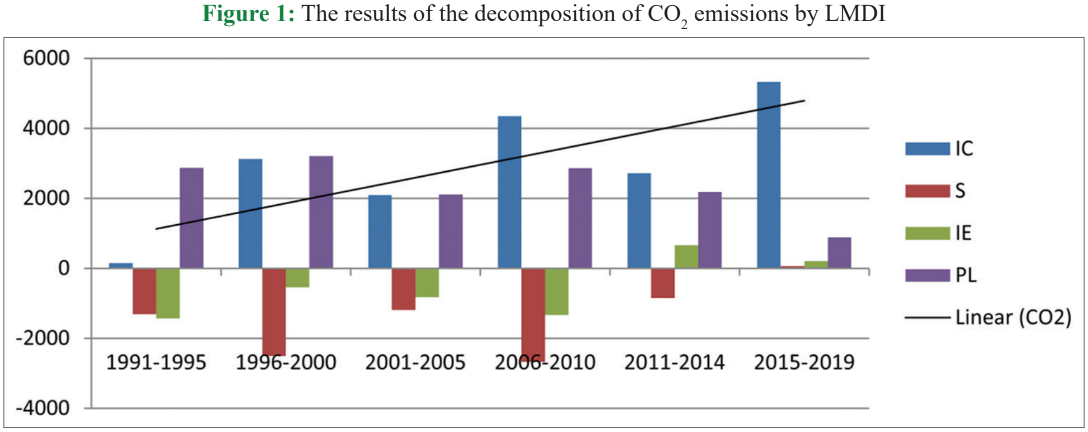


**Table 1: The results of the LMDI decomposition**

| Effects of variables | 1991-1995 | 1996-2000 | 2001-2005 | 2006-2010 | 2011-2014 | 2015-2019 |
|---|---|---|---|---|---|---|
| CDeff | 152,203563 | 3122,45929 | 2093,47383 | 4349,07239 | 2719,1524 | 5326,08021 |
| Seff | −1312,8804 | −2501,5659 | −1193,41 | −2673,9315 | −846,58073 | 65,1127652 |
| EIeff | −1433,6897 | −548,34435 | −824,07473 | −1335,2104 | 662,380571 | 204,101174 |
| LPeff | 2868,28127 | 3202,30618 | 2105,42332 | 2864,5574 | 2180,63115 | 882,243242 |
| ISeff | −28,225791 | −110,23417 | −336,91147 | 1463,60311 | −1906,6614 | −1452,2429 |
| $\Delta$ $CO_2$ | 245,689 | 3164,621 | 1844,501 | 4668,091 | 2808,922 | 5025,29445 |

1: $\Delta CO_2$ shows the change in $CO_2$ emissions

**Table 2: The ADF test results**

| Variables | Empirical values | Critical values (5%) | Prob | Stationary/ Not-stationary |
|---|---|---|---|---|
| Ln $CO_2$ | 4.972 | −1.957 | 1.000 | Not-stationary |
| Ln LP | −2.484 | −3.005 | 0.133 | Not-stationary |
| Ln IS | −0.037 | −1.956 | 0.660 | Not-stationary |
| Ln EI | 0.436 | −1.958 | 0.799 | Not-stationary |
| Ln $DCO_2$ | −8.524 | −3.005 | 0.000 | Stationary |
| Ln DLP | −5.858 | −3.633 | 0.0005 | Stationary |
| Ln DIS | −3.771 | −3.633 | 0.038 | Stationary |
| Ln DEI | −8.371 | −3.633 | 0.000 | Stationary |

**Table 3: The growth rates of variables**

| Variables | Scenario 1 (%) | Scenario 2 (%) |
|---|---|---|
| EI | −13.69 | −15.84 |
| LP | 12.30 | 11.80 |
| IS | 4.01 | 3.81 |

are employed after the Tunisian revolution. Creating jobs from green production without any negative effects on the environment seems to be a good alternative.

After having detected the main factors that influence $CO_2$ emissions in Tunisia, our study proposes to study the possibility of the existence of a long-term relationship between them.

### 3.2. The Analysis of the Relationship between $CO_2$ Emissions and its Influencing Factors by an Error Correction Model

The unit root test is performed before proceeding with our analysis. To detect the stationarity of the series, we use the Augmented Dickey-Fuller test (1981). The delay number is chosen by minimizing the information criteria of Akaike Information Criterion (AIC), Schwarz Criterion (SC) and Hannan-Quinn Criterion (HQC). The results of the ADF test are presented in table 2. The unit root hypothesis is not rejected. The three variables therefore have unit roots. They are stationary in first differences where they are integrated of order 1: I (1).

The cointegrating approach developed by Johansen (1988) and subsequently answered by Johansen and Juselius (1990) determined the presence of a cointegrating relationship between the variables. The existence of a cointegrating relation implies the existence of a long-term equilibrium relation between the variables. The results of the estimation of the Error Correction Model by the method of Johansen (1988) show that in the long term, there is a stable relationship between $CO_2$ emissions, energy intensity (IE), productivity of work (LP) and industrial scale (IS).

$$CO2_{t-1} = 1.175\ EI_{t-1} + 0.895\ LP_{t-1} + 1.289\ IS_{t-1} + 0.0112_t + 6.961 \quad (8)$$

There is a positive and significant relationship between $CO_2$ emissions and energy intensity (EI) in Tunisia. A decrease of 1 percentage point in energy intensity could lead to a decrease of 1.175% in $CO_2$ emissions. This relationship suggests that improvements in energy intensity in the industrial sector will lead to a reduction in the level of $CO_2$ emissions. This suggests that policymakers should design appropriate measures of improving energy efficiency in industry to reduce industrial energy intensity in order to reduce pollution.

Labor productivity represents industrial added value per unit of work. Its positive contribution to carbon dioxide emissions indicates that the increase in added value in industry is based on the use of fossil fuels for the energy industry and polluting technologies in manufacturing and construction industry.

Finally, the positive relationship between $CO_2$ emissions and industrial scale (IS) suggests that if fewer employees are employed by polluting industries, it may be beneficial for reducing $CO_2$ emissions. Hence, more employees in a green industry, namely the production of electricity from renewable energy technologies, can lead to a significant reduction in future $CO_2$ emissions.

### 3.3. The Analysis of $CO_2$ Emissions Scenarios

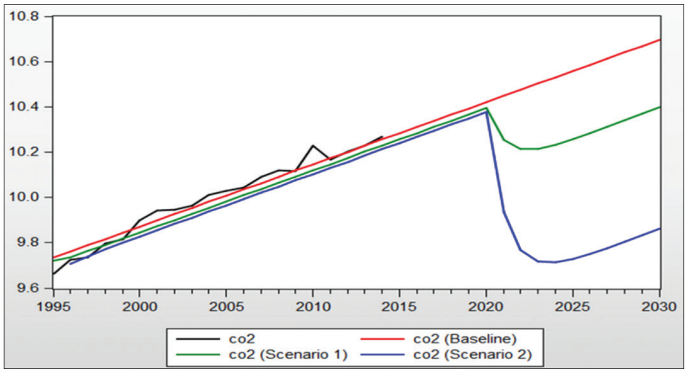
After applying the cointegration method and identifying the model,

We will be based on this result of the Error Correction Model estimate of equation (8) in order to be able to forecast carbon dioxide emissions in Tunisia and calculate their possible reduction potentials between 2020 and 2030.

We establish two different scenarios for the future in order to capture the uncertainties: Scenario 1 in which the growth rates of the variables are identical to the historical trend and Scenario 2 in which advanced emission reduction measures will be taken. Table 3 shows growth rates used in both scenarios.

The results show that by 2030, $CO_2$ emissions can decrease by −2.76% according to scenario 1 and −7.78% according to scenario 2, as shown in Figure 2. We note that there is significant potential for reducing carbon dioxide emissions in the future. However, in order to achieve its environmental objectives, the situation requires political intervention beyond the control of energy because this potential remains low compared to the expectations of the State's commitments, namely the objectives of COP 21 which sets a rate of at least 40% reduction in greenhouse gas emissions by 2030

**Figure 2:** The result of the scenario analysis




compared to the 1990 level.

## 4. CONCLUSION ET RECOMMENDATIONS

According to our analysis, the reduction in energy intensity was the main factor responsible for the decrease in carbon dioxide emissions in Tunisia. Indeed, the decrease in energy intensity means that the country can produce more with the same amount of energy: It can therefore be more energy efficient and achieve a gain in energy productivity. This productivity gain is necessarily accompanied by a reduction in $CO_2$ emissions.

However, the potential for future reduction remains low compared to the country's commitment to reducing $CO_2$ emissions and limiting global warming. In this sense, we offer several policy suggestions with the aim of reducing $CO_2$ emissions.

First, there is a need to strengthen the internal management of industries in order to reduce energy intensity. For example, it is necessary to set up a mechanism for the disposal of products from industries with high energy consumption. If the energy intensity cannot reach the norm, the production should be phased out. For energy consumption in the industrial sector in Tunisia, energy intensity can be reduced by improving energy efficiency.

Second, there is a need to improve industrial production technology because if energy efficiency is low, energy intensity will be high. Traditional technologies should be renewed and new methods based on green technologies will significantly reduce pollution and meet the demand of the low carbon economy. Among the production technologies to be renewed in industries, the technique of using heat. In the process of producing chemical raw materials and chemicals, a lot of heat is required. However, the traditional heating system like alcohol lamp heating, electric heating, steam heating, water, oil and sand bath are inefficient and produce many by-products, resulting in wastage of energy. Microwave heating is a kind of new method which greatly reduces heating time and energy, improves heat transfer rate, and meets the demand of low carbon economy.

Third, we need to reduce the structural deficit in the energy balance. The policy of promoting renewable energies will allow a virtual stagnation in the production of natural gas. Accompanied by sustained growth in energy consumption, through the energy efficiency policy, the energy balance will achieve its balance between supply and demand.

Fourth, we propose reducing the consumption of fossil fuels in the electricity industry. Faced with this situation marked by heavy dependence on fossil fuels, Tunisia must embark on the path of an energy transition based on the development of renewable energies. The orientation of the energy sector towards the energy transition must correlate between economic growth and the growing need for energy. The diversification of primary sources, namely a penetration of solar energy and wind energy in the Tunisian electricity mix will make it possible to reduce the $CO_2$ emissions released by the electricity industry.

Fifth, we suggest the creation of employment from green production without any negative effects on the environment. Renewable energy promotion projects can be a good alternative in order to create jobs and effectively reduce $CO_2$ emissions. The creation of jobs dedicated to the promotion of renewable energies in industries will improve the well-being of the population with regard to positive externalities on the social and environmental level.

Finally, using the carbon tax will make it possible to limit $CO_2$ emissions so as not to be able to exceed a certain limit for the release of greenhouse gases into the atmosphere.

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