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FONT	Times New Roman, 12 pt
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Foreign direct investment and the triangle of growth, inequality and poverty in north Africa

KRIMI Abdelkader

Faculty of Economic and Management, University of Sfax, BP14, Tunisia,
abdelkaderkrimi@yahoo.fr

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Abstract:
This study examines the impact of foreign direct investment (FDI) on poverty in North Africa over the period 1995–2023. It distinguishes between two potentially conflicting effects of FDI on poverty: the growth effect and the inequality effect. The first part of the article provides a theoretical analysis of the relationships linking foreign direct investment to the "growth–inequality–poverty" triangle. The second part is empirical in nature. Using a simultaneous-equations econometric model applied to an unbalanced panel dataset, the study captures the interactions between FDI and the triangle as documented in the existing literature. The results indicate that FDI has a negative effect on inequality and a positive, though relatively modest, effect on economic growth. However, according to the model's estimates, FDI has not had a statistically significant impact on poverty levels in North Africa.
Keywords: FDI, growth, inequality, poverty, and simultaneous equations.

Corresponding author**:* KRIMI Abdelkader*, **e-mail: abdelkaderkrimi@yahoo.fr

1. Introduction

Poverty is a complex and multidimensional phenomenon whose assessment remains challenging. It has attracted sustained attention from the scientific community and international institutions, which seek to understand its determinants and to propose effective strategies to address it. The fight against poverty has become a priority and one of the main Millennium Development Goals adopted in the 2000s at the headquarters of the United Nations.

Economic studies often examine the relationship between foreign direct investment (FDI), per capita income growth, and inequality to understand their effects on poverty. The literature shows that the impact of FDI on poverty through these factors has evolved over time, reflecting both the growing sophistication of academic analysis on the complex interactions between growth and income inequality, and the varying levels of interest in poverty reduction within political circles. Indeed, the body of research on economic growth and poverty incidence is vast. Two main theories can be identified: the first argues that "growth is good for the poor" (Dollar and Kraay, 2000; Ravallion, 2004), while the second suggests that growth exacerbates inequality and does not benefit the poor. This second perspective emphasizes that "growth alone is not sufficient for poverty reduction; it is necessary but must be accompanied by policies that address inequalities both now and, in the future," (Bourguignon, 2003; Cling et al., 2002).

The literature also highlights the interdependence between growth and inequality, complicating policy choices for decision-makers. Should policies prioritize reducing inequality, even if it could impede growth? Or should growth be promoted, even if it leads to greater inequality and disproportionately benefits the rich? These questions are central to the "triangle" of growth, inequality, and poverty that Bourguignon (2003) refers to. To understand the impact of FDI on poverty reduction in North Africa, we need to revisit the effects of FDI on growth and inequality. Specifically, we must explore whether there is a trade-off between the effects of FDI on inequality and growth, and what the net outcome is for poverty incidence.

Our study differs from previous empirical work by examining a rectangular relationship that allows us to test the effect of FDI on the growth, inequality and poverty triangle.

The remainder of the paper is organized as follows: Section 2 provides an overview of the main empirical studies that have addressed the relationship between FDI and the components of the growth, inequality and poverty triangle, which are often treated in a binary manner. Section 3 is devoted to the methodology adopted. Section 4 presents the empirical results. Section 5 discusses the study's limitations and directions for future research. The final section concludes the paper.

2. Theoretical analysis of the relationship between FDI, Growth, Inequality and Poverty

2.1: Foreign Direct Investment and Economic Growth

FDI plays a crucial role in driving economic growth across countries, with its impact on economic dynamics being so significant that it influences growth and competitiveness. Numerous studies in the economic literature have examined the relationship between FDI and growth, particularly in developing countries. Researchers have employed various econometric methods, such as the Granger causality test and the Toda-Yamamoto test, to analyze the link between FDI and economic growth. For example, Chowdhury and Mavrotas (2006) applied the Toda-Yamamoto method to examine the relationship between FDI and GDP growth in three major FDI-receiving countries: Chile, Malaysia, and Thailand, over the period 1969-2000. Their findings revealed that in Chile, GDP growth led to net FDI inflows, while in Malaysia and Thailand, there was a bidirectional causal relationship between GDP growth and FDI inflows.

In another study, Hansen and Rand (2006) explored the links between FDI and economic growth in 31 developing countries from 1970 to 2000, using two-variable autoregressive vector models for GDP and FDI ratios. They concluded that a strong causal relationship exists between these two variables. However, Carkovic and Levine (2005) studied the link between FDI and economic growth in 72 countries and found no evidence that FDI accelerates economic growth, contrasting with the findings of the earlier studies. Given these varying results on the general causal relationship between FDI and economic growth,

researchers have looked at specific sectors or regions to better understand this link. For instance, Alfaro (2003) examined the implications of FDI for growth in the primary, manufacturing, and services sectors. His findings were mixed, and based on data from multiple countries between 1981 and 1999, Alfaro concluded that the impact of FDI on growth is ambiguous. In a more recent study, Lipsey (2000) found that FDI, when combined with educational attainment, significantly contributed to the increase in real per capita income in developing countries from 1970 to 1995. Unlike Bronstein, Gregoric, and Lée (1998), who suggested that FDI alone has a positive, though less pronounced, effect on growth, Lipsey highlighted the importance of educational factors. Moreover, FDI can significantly enhance productivity in the host economy by promoting domestic capital and technological progress (Mello, 1997). According to Mello, the impact of FDI is smaller when the technological gap between the home and host countries is large.

2.2. The relationship between foreign direct investment and inequality

The effects of FDI on inequality can be understood through two main models: the standard international trade model and models of the new institutional economics. Theoretically, the effects of FDI on income distribution are similar to the effects of trade liberalization. In this context, the Stolper-Samuelson (1940) model suggests that international trade alters the relative prices of factors of production, thus influencing their incomes by favoring owners of abundant and exportable factors, while disadvantaging those with no comparative advantage. This can lead to increased inequality, at least in the short term, especially in labor-intensive FDI. Wood and Berge (1997) adapted the Heckscher-Ohlin-Samuelson model to study the specialization of African countries. They replaced the traditional factors of "capital" and "labor" with "human capital" and "land," showing that African countries have a comparative advantage in natural resources, given their limited human capital. Consequently, FDI in capital-intensive sectors would primarily benefit owners of natural resources. In democratic systems, the state's enrichment could potentially contribute to improving overall well-being through institutions. However, in systems with institutional distortions characterized by predatory behaviors and rent-seeking, the increase in FDI could exacerbate inequalities.

3. Methodology

To assess the impact of FDI on poverty in North Africa, a simultaneous equation model is used, which links growth, inequality, and poverty. Several mechanisms contribute to poverty reduction, as shown by Dollar and Kraay (2000), who argue that poverty decreases with rising average income, or through better income redistribution, which reduces inequalities, or through a combination of both policies. In this model, FDI serves as an exogenous external shock, and its effects on poverty are estimated by considering its simultaneous effects on growth and inequality.

The econometric model used here consists of three equations. The first equation explains economic growth (Barro, 2001; Borenztein et al., 1998), the second equation explains inequality (Forbes, 2000; Deininger and Squire, 1998; Lyn and Squire, 2003), and the third equation uses the Human Poverty Index (HPI) as a measure of well-being, as data on absolute poverty rates are unavailable for countries like Libya and Algeria. The HPI focuses on three critical dimensions of human life: longevity, education, and living conditions, which are also considered in the Human Development Index (HDI). These three equations are estimated simultaneously to account for the existing interactions between endogenous variables and the indirect effects of instrumental variables. The explanatory variables are categorized into three types: endogenous variables, common explanatory variables, and specific explanatory variables. These sets are incorporated into the following models.

Growth equation:

$$G_{i,t} = \beta_1 I_{i,t} + E_1 FDI_{i,t} + D_1 X_{i,t} + \mu_{i,t} \quad (1)$$

Inequality equation:

$$I_{i,t} = A_2 G_{i,t} + E_2 FDI_{i,t} + D_2 W_{i,t} + e_{i,t} \quad (2)$$

Poverty equation:

$$HPI_{i,t} = A_3 G_{i,t} + \beta_3 I_{i,t} + E_3 FDI_{i,t} + D_3 Z_{i,t} + \varepsilon_{i,t} \quad (3)$$

The variables "Gi,t", "Ii,t", and "HDI" represent GDP growth, income inequality (measured by the Gini coefficient), and the Human Development Index (HDI), respectively. In the three equations, FDI is assumed to be the only

explanatory variable. The specific variables are represented by the following vectors:

- "X"[1] represents the vector of variables related to economic growth (inflation, education, trade openness).
- "W"[2] represents the vector of variables related to income inequality (Gini Index).
- "Z"[3] represents the vector of variables related to poverty, including population growth, access to drinking water, and the inactive population in both rural and urban areas.

Once the model and its components are defined, we proceed to interpret the relevant econometric results.

4. Discussion and Interpretation of the Results

The interactions between the key variables growth, inequality, and poverty will be explored in the econometric model, emphasizing the role of FDI in each equation. We will first interpret the results of the growth equation, followed by the inequality equation, and conclude with the poverty equation, which will allow us to derive the reduced form of the model.

4.1. The Growth Equation

Equation (1) is used to analyze the effects of FDI, inequality, and other variables that influence growth in North Africa, as outlined in the following table. The results from the growth equation reveal that the trade openness variable is both positive and significant in all estimation methods. This suggests that trade

[1] **Notes for the growth equation table**
(LGDP) is growth; (LINV) is gross fixed capital formation (% of GDP); (LOP) is the trade openness ratio [(X+M)/GDP]; (LEDUS) is the enrolment rate; (LINFL) is the inflation rate; (LGINI) is the GINNI coefficient that represents inequality.

[2] **Notes for the inequality**
(LGDP) is GDP growth.; (LCCRP) is the corruption control; (Linf) is the inflation rate; (Louv) is the trade openness ratio [(X+M)/GDP]; (LINV) is gross fixed capital formation (% of GDP).

[3] **Notes for the Poverty Incidence Equation table**
(LHPI): this is the Human Poverty Index (HDI); (LPIB) is the annual GDP growth rate; (LEDUCS) is the enrolment rate; (LCDEM) is population growth. (LBDP) is the connection of drinking water; (LINACPOP) is the number of the inactive population; (LGINI) is the GINNI coefficient that represents inequality

openness is an important indicator for economic openness policies in North Africa. In contrast, the empirical results from Noomen Lahimer (2009) show that trade openness is not a reliable indicator of economic openness policies in Sub-Saharan Africa. Additionally, the findings indicate that education has a positive but statistically insignificant effect on growth in North Africa. This result can be attributed to the role of the institutional environment in the countries studied, which, despite encouraging access to education, has not sufficiently promoted research and innovation among the educated population.

Table 1: Results of the growth equation in North Africa (1995-2023)

LGDP	2SLS	3SLS
LINV	0.089 (0.638)	0.026 (0.052)
LFDI	0.161* (0.033)	0.108*** (0.40)
LCO	0.123** (0.088)	0.023* (0.001)
LGINI	-0.307*** (0.05)	-0.298*** (0.106)
LEDUCTS	0.063 (0.05)	0.010 (0.025)
LINFL	-0.011 (0.05)	-0.045 (0.069)
CONSTANT	8.978*** (1.11)	11.370*** (2.17)

In parentheses are the absolute values of Student's "t" * Significant at the 1% threshold; ** Significant at the 5% threshold; * Significant at the 10% threshold.**

Turning to the impact of FDI on economic growth, the results indicate that FDI is both significant and positive in both estimation methods. Specifically, a 1-point increase in FDI leads to an increase in economic growth ranging from 0.061 to 0.18 points. The positive effects of FDI on growth are primarily observed through capital accumulation models, as these FDI flows do not

generate the positive technological spillovers associated with endogenous growth models. These effects challenge the hypothesis of "Dutch disease" in North Africa. From an institutional economic perspective, FDI is expected to have neutral or even negative effects on growth, potentially causing tensions and distortions in economic, political, and institutional development. After analyzing the impact of FDI on growth using two estimation methods, we examine the effects of income inequality on growth in North Africa. Drawing on the work of Addison and Cornia (2001), we test for an inverse "U" relationship between inequality and growth, as high inequality tends to impede the equitable distribution of the benefits of growth. To test this, the Gini index is incorporated into the growth equation.

The first results confirm the validity of the linearity hypothesis. An increase in the Gini index by 1 point leads to a decline in growth, ranging from 0.307 (2SLS) to 0.298 (3SLS). These results are in line with the findings of Noomen Lahimer (2009), who reported a coefficient between 0.130 and 0.63 points based on three estimation methods (2SLS, short-term 3SLS, long-term). This contrasts with the findings of Forbes (2000), who found that the effect of inequality on growth was 0.0036, and Deininger and Squire (1998), whose studies found effects between 0.047 and 0.063. However, all of these studies involve heterogeneous panels subject to various biases, making simple controls of silent variables insufficient to account for structural effects. Thus, our results are more aligned with those from Sub-Saharan Africa, particularly the work of Noomen Lahimer (2009). According to the results in Table (1), inequality negatively affects growth in North African countries.

These findings from the growth equation yield several important insights. First, the relationship between FDI and economic growth shows that FDI contributes to economic growth in North Africa. This results from the inflow of foreign capital, improving the balance of payments, and the exploitation of natural resources, which are then processed into manufactured goods by multinational companies. Furthermore, the trade openness ratio is a key indicator in the region's openness policies. On the other hand, domestic investment does not appear to significantly impact growth, which may indicate

a crowding-out effect where multinational firms reduce the space for domestic companies.

The second key point is the negative relationship between inequality and economic growth. These negative effects can be attributed to barriers between social classes and economic distortions. Finally, the analysis of education's effect on growth shows a positive but statistically insignificant relationship. As noted by Collier (2007), concentrating access to education in one segment of the population can increase disparity, exacerbating inequalities and fostering institutional distortion. This analysis underscores the important role income inequality plays in determining economic growth.

4.2. The inequality equation

In this equation, we explore the effects of FDI, institutional variables, and growth on inequality. The level of inequality in North Africa is largely explained by the institutional characteristics of these countries. In this context, we test the effect of corruption control on inequality. The results from both estimation methods indicate that a 1-point increase in the corruption control variable leads to a reduction in inequality in North Africa, ranging from 0.9 to 1.8. This finding suggests that combating corruption can help reduce inequality in the region. Corruption directly impacts interactions between economic agents, including contract enforcement, property rights, administrative procedures, and the functioning of the public sector. Reducing corruption fosters greater equality in access to opportunities, thereby promoting a fairer redistribution of resources and helping to reduce inequalities.

Table 2: Estimation of the determinants of inequality in North Africa (1995-2023)

Gini	Growth and FDI		With IDE and without growth		With growth and without FDI	
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
LGDP	-2.280** (0.870)	-2.613** (1.286)	.....		-0.089 (0.063)	-0.175 (0.663)
LFDI	0.254*** (0.072)	0.239** (0.096)	0.102*** (0.036)	0.104** (0.056)	.....	

Linv	0.089 (0.063)	.0023 (0.008)	0.018** (0.07)	0.010** (0.007)	0.013*** (0.01)	0.0030*** (0.007)
Linf	-0.037*** (0.008)	-0.058*** (0.008)	-0.012*** (0.011)	-0.014*** (0.008)	-0.035*** (0.008)	-0.066*** (0.008)
LCCRP	-0.007 (0.0112)	-0.009** (0.011)	-0.009 (0.11)	-0.014 (0.12)	-0.008 (0.108)	-0.018* (0.010)
Lopening	0.189*** (0.025)	0.219*** (0.024)	0.139*** (0.021)	0.061*** (0.020)	0.192*** (0.024)	0.221*** (0.023)
CONSTANT	2.138 (0.26)	2.165 (0.25)	2.83 (0.150)	4.837 (0.145)	2.114 (0.253)	2.193 (0.24)

In parentheses are written the absolute values of Student's "t": * Significant at the 1% threshold; ** Significant at the 5% threshold; * Significant at the 10% threshold.**

Economic theories have highlighted the strong connection between FDI and inequality, arguing that FDI is highly sensitive to inequality levels in host countries. The results show that FDI has a positive and significant effect in both estimation methods. Specifically, an increase in FDI by 1 point leads to an increase in the Gini coefficient ranging from 0.239 to 0.254 points. Political economy models provide insight into this outcome, suggesting that multinational corporations indirectly contribute to the concentration of income among the elite, thereby exacerbating inequality. This positive relationship between FDI and inequality is observed in both regressions presented in Table (2). However, these regressions are subject to potential endogeneity between FDI and growth. To address this, the first step involves excluding growth from the equation and then omitting FDI.

The effects of FDI on inequality remain positive and significant across both estimation methods. A 1-point increase in FDI results in a modest rise in the Gini coefficient, ranging from 0.102 points (2SLS) to 0.104 points (3SLS). However, these positive effects of FDI are moderated by the presence of appropriate institutional mechanisms in North Africa. Maria Angels et al. (2002) studied the relationship between political institutions, FDI, and inequality across 119 developing countries. They concluded that the corruption

control index has a significant positive impact on FDI, as a well-functioning democracy encourages foreign investment, which in turn drives economic growth. Consequently, they recommend that governments focus on establishing and maintaining the rule of law and transparency. Henri (2013) further demonstrated that political stability and regulatory frameworks positively influence economic growth in Africa.

Regarding the relationship between inequality and growth, the equation shows that an increase in economic growth by 1 point results in a decrease in inequality of 0.107 points (column 1) to 0.175 points (column 2). This result is robust across both estimation methods. Similar findings were observed in the studies of Mbabazi and Ly (2002) and Noomen Lahimer (2009), which demonstrated that growth reduces inequality, with coefficients of 0.8 and 1.1 points, respectively, in Sub-Saharan Africa. When applying Kuznets' assumptions, the results diverge in the quadratic effect, where the relationship between the logarithm of GDP and the Gini coefficient is confirmed in both columns. Fosu (1992) and d'Haan and Siemann (1996) found that political instability negatively affects economic performance, hindering the ability to reduce inequality. Guillaumont and Brun (1999) shared a similar conclusion, though they contested this effect in the context of African countries, showing that political instability defined by coups and civil wars directly influences economic growth but does not bias accumulation or investment.

From the previous two equations on growth and inequality (inequality with and without FDI, and inequality with and without growth), it is clear that FDI has a positive impact on growth in North Africa in both estimation methods. However, FDI appears to have a negative effect on inequality. Regarding the relationship between inequality and growth, the latter demonstrates a positive effect in reducing inequality. Given these findings on the interplay between FDI, growth, and inequality, several questions arise: Are the positive effects of FDI on growth sufficient to offset inequality in North Africa? Or is there a leverage effect of FDI on the "growth, inequality, and poverty" triangle? The poverty equation will help address these questions.

4.3. The Poverty Equation

The analysis of the poverty equation centers on examining the effects of FDI, income growth, and inequality. Estimating this equation is the primary goal of this study.

Table 3: Estimating the determinants of poverty incidence in North Africa (1995-2023)

LHPI	Growth and FDI		With IDE and without growth		With growth and without FDI	
	2SLS	3SLS	2SLS	3SLS	2SLS	3SLS
LGDP	0.037*** (0.011)	0.098 (0.015)	.....		0.063* (0.022)	0.146*** (0.037)
LFDI	0.018** (0.003)	0.029* (0.0013)	0.012*** (0.132)	0.0130 (0.0246)	.....	
LGINI	1.951** (0.132)	-0.143* (0.014)	-0.123** (0.48)	-0.153** (0.052)	-0.130** (0.450)	-0.168** (0.677)
LEDUC	0.426*** (0.808)	0.040*** (0.480)	0.412*** (0.130)	0.418** (0.134)	0.402*** (0.130)	0. 22*** (0.140)
LCDEM	-0.122 (0.15)	-0.122 (0.144)	-0.320** (2.24)	-0.320** (0.142)	0.310** (0.138)	-0.089 (0.140)
LDWC	0.339** (0.15)	0.339** (0.152)	0.428*** (0.162)	0.428*** (0.157)	1.240** (0.556)	0.370** (0.150)
LINAC POP	-0.042 (0.033)	-0.038 (0.31)	-0.044 (0.031)	-0.027 (0.030)	-0.089 (0.144)	-0.030 (0.018)
CONSTANT	7.935 (6.01)	7.135 (5.80)	12.72 (5.67)	14.72 (5.60)	5.414 (5.67)	5.48 (5.50)

Note : in brackets are the absolute values of Student's "t" * Significant at the 1% threshold; ** Significant at the 5% threshold; * Significant at the 10% threshold.**

The impact of economic growth on the poverty indicator in North Africa is relatively modest, as indicated by the poverty equation. An increase of 1 point in growth results in a rise in the Human Development Index (HDI) from 0.037 to 0.1 (2SLS). According to the World Bank's 2012 Human Development Report, most countries show a positive correlation between high GDP per capita growth and improvements in HDI, with a tendency toward convergence to higher living standards. For instance, between 1980 and 2011, GDP per capita

grew at an average rate of 7.8% per year, resulting in an average annual increase in HDI of 1.73%. In contrast, Ethiopia, with an average annual increase in living standards of just 1.6%, saw little improvement in HDI. The 2010 Human Development Report highlights the progress in human development through various indicators.

For the effects of FDI, the impact mirrors that of economic growth. A 1-point increase in FDI results in a rise in the HDI from 0.018 (Cologne 1) to 0.03 (Cologne 2). Over the long term, FDI does not appear to significantly reduce poverty in North Africa. Education, however, has a positive and significant effect on poverty reduction in both estimation methods. An increase of 1 point in education results in a slight increase in the HDI, from 0.040 (Cologne 1) to 0.426 (Cologne 2). On the other hand, population growth and inactive populations have negative and insignificant effects in both methods. Infrastructure, such as drinking water access, has positive and significant effects on the HDI, which in turn aids in poverty reduction.

Following the analysis of the effects of growth and FDI on the poverty indicator, the effects of exogenous variables, namely growth and FDI, are considered separately. The effect of growth on the HDI is positive and significant in the final two estimation methods. A 1 point increase in growth results in an increase in the HDI from 0.063 (2SLS) to 0.146 (3SLS). When economic growth outpaces population growth, it translates into an improved standard of living, typically measured by GDP per capita. This increase in material wealth corresponds to a better quality of life and enhanced human development. Growth also alleviates poverty, which can be defined as the inability to meet either physiological (absolute) or social (relative) needs.

Regarding FDI's effect on the HDI, it also becomes positive and significant in both methods. A 1-point increase in FDI results in a lighter rise in the HDI, ranging from 0.012 to 0.03 points. The results suggest that inward FDI in North Africa has a direct positive impact on the HDI, particularly from 1995 to 2021. These results highlight several points:

First, they underscore the importance of FDI for sustainable development in North Africa, particularly for improving social conditions and the population's standard of living. The fact that FDI inflows significantly affect the

HDI supports theories of endogenous growth and sustainable development. In these theories, integrating foreign investment into the local economy yields substantial direct benefits for domestic businesses and the active workforce. Consequently, FDI improves the quality of life and worker qualifications in North Africa.

Moreover, the arrival of foreign investors and workers creates ripple and imitation effects across the population. The efforts of companies and the state to build a workforce capable of meeting investment need lead to societal changes, adapting to new lifestyles. Multinational companies' involvement in building rural infrastructure such as education, drinking water access, and rural electrification plays a key role in this process. However, the high vulnerability of North African economies to the international economic and financial environment limits the expected economic impact of foreign investments. These limitations may explain the relatively modest increase in the HDI (0.012 to 0.03 points).

In conclusion, the effects of growth and FDI on poverty reduction in North Africa are limited. Regarding the impact of inequality on the HDI, the estimates in Table (3) show that inequality has negative and significant effects in both estimation methods. A 1-point decrease in inequality leads to an increase in the HDI from 0.143 to 1.951 points. Conversely, an increase in the Gini coefficient exacerbates poverty. These results suggest that reducing inequality is a powerful tool for redistributing wealth and reducing poverty in North Africa.

The simultaneous equations for all three models show that FDI has a reciprocal effect between growth and inequality. In the growth equation, FDI positively affects growth, and growth in turn influences inequality. Additionally, FDI influences inequality and inequality impacts economic growth through various social and political mechanisms, contributing to social unrest, as seen in the Arab countries.

After analyzing the total effect of FDI on poverty reduction through growth and inequality, these effects are broken down into two components: the indirect effect via growth and inequality equations, and the direct effect through the poverty incidence equation.

5. Limitations and future research

The effect of foreign investment on poverty levels in North Africa extends beyond the relationship between foreign investment, economic performance, and social justice to encompass issues of good governance and domestic investment, which will be addressed in future work.

This article examined the relationship between economic growth, foreign direct investment (FDI) flows, and poverty reduction. However, since economic growth is a relatively broad concept in development economics, we propose several directions for future research as part of a deeper analysis:

1) **Causality effects:** This study is limited to analyzing the correlation between economic growth, inequality, FDI flows, and poverty reduction. In order to identify the direction of influence among these variables, it would be necessary to apply causality tests. This would help clarify whether the relationship between economic growth and FDI inflows is unidirectional or bidirectional.
2) **Incorporating additional economic indicators:** The analysis primarily focused on the impact of economic growth and FDI inflows on poverty reduction. However, this approach could be extended to include other key economic variables, such as domestic investment and the quality of governance.
3) **The impact of economic growth and FDI on poverty in other countries:** This study focuses on developing countries, with particular emphasis on North Africa. Nevertheless, as economic growth and FDI increasingly play a crucial role in poverty reduction -especially in other regions such as the MENA area-it would be valuable to conduct more in-depth analyses in these contexts.
4) **The impact of FDI on economic growth:** Given that FDI inflows are generally driven more by economic factors than by institutional or governance-related factors, a case study approach could be adopted to better understand the impact of FDI on economic growth and, indirectly, on poverty reduction in developing countries.

6. Conclusion

This article provides an empirical study of the relationship between FDI, growth, inequality, and poverty in North African countries, yielding several important findings. FDI's effects on poverty reduction can be understood through three key relationships. The first is its positive impact on economic growth, which contributes to improvements in social well-being. However, the limited integration of FDI with local firms in landlocked countries complicates the transfer of technology. The second relationship shows that FDI exacerbates inequality, driven by the nature of multinational firms and the prevailing institutional conditions. In corrupt or politically unstable states, this often leads to social conflicts.

The third relationship involves the reciprocal effects between growth and inequality, with growth initially increasing inequality but eventually reducing it. The Kuznets curve shows that the impact depends on institutional characteristics. The decline in corruption control leads to institutional consolidation, which helps reduce inequality.

Finally, regarding the direct effect of FDI on poverty reduction, while FDI has a modest positive effect, it is not statistically decisive. Poverty reduction is more closely tied to effective institutional policies that control corruption, reduce inequalities, and ultimately foster poverty alleviation.

In summary, the total effects of FDI on poverty reduction in North Africa are positive but limited. FDI has a positive but smaller effect on growth and a negative effect on inequality, consistent with the model results, which suggest that FDI alone cannot significantly reduce poverty. The negative effects of poor institutional integration with multinational firms hinder wealth distribution and have adverse consequences for the poorest populations.

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Fuel Consumption and Energy use in Tunisia's Public Road Transport: A Descriptive Study

Moez Dhiabi

University of Sfax, Faculty of Economics and Management, Sfax, Tunisia.
Email: moezdhiabi09@gmail.com

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Abstract:
This paper presents a descriptive analysis of fuel consumption and energy use in Tunisia's public road transport sector during the period 2008–2014. The study covers 13 regional transport companies and the National Interurban Transport Company (SNTRI). Based on data on passenger numbers, kilometers traveled, vehicle fleet characteristics, and fuel consumption, the analysis highlights the main determinants of energy demand and compares energy efficiency across companies. The results show that while fuel consumption remained relatively stable, fuel expenditures increased over time. Significant disparities in energy performance persist among transport operators, and improvements in energy efficiency remain limited, pointing to the need for better energy management in the sector.

Keywords: Public road transport; Fuel consumption; Energy efficiency; Descriptive analysis; Tunisi

Corresponding author**:* Moez Dhiabi, ***e-mail: moezdhiabi09@gmail.com

1. Introduction

Urban public transport is one of the pillars of the process of sustainable economic and social development. It is considered one of the most indispensable public services for the daily mobility of citizens in all regions of the country, enabling social activities outside the place of usual residence, namely: working, studying, shopping, etc. From an economic point of view, transport occupies a significant share of international trade, generates wealth, and constitutes a key driver of national economic growth (the transport sector in Tunisia accounted for 7.3% of GDP in 2013 and recorded a growth rate of about 7.1%). From an environmental perspective (noise, pollution, safety), it is necessary to identify the main pollutants caused by traffic (generally suspended particles and lead) and to mobilize technical, financial, and practical management tools to limit fuel consumption.

In Tunisia, public transport is considered a public service. Indeed, the State is the main organizer of passenger public transport, primarily through public enterprises. These modes of transport belong to two major categories: road transport and rail transport.

The impact of greenhouse gas emissions on the environment, together with the burden of fuel subsidies on public finances, compels us to change our transport habits. From this perspective, Tunisia must regularly renew its vision regarding energy use in order to ensure not merely development, but rather sustainable development—one that is accompanied by inclusive and sustained economic growth, energy security, and respect for the environment.

The State is therefore required to regularly provide answers to certain questions:

- What is the current state of energy consumption?
- What are the determining factors of fuel consumption?

To answer these questions, the preparation of an energy balance is very important in order to assess fuel consumption in volume (thousands of liters) as well as fuel expenditures for each regional transport company. This is the objective of this study, which covers the entire road-based collective transport sector, consisting of 13 regional transport companies and the interurban transport company (SNTRI).

2. National Context

Tunisian transport services are provided at nearly 70% by the public sector under the supervision of the Ministry of Transport. The latter's main mission is to plan and ensure the proper functioning of a national transport system, making it a factor of sustainable development.

The classified road network is distributed as follows:

- National roads: 3,938 km
- Regional roads: 5,117 km
- Local roads: 2,453 km
- Roads under classification: 1,242 km

Transport, the second most energy-intensive sector after industry, consumes approximately 2 million toe (tons of oil equivalent) and could reach 5 million toe by 2030, becoming the leading sector in final energy consumption.

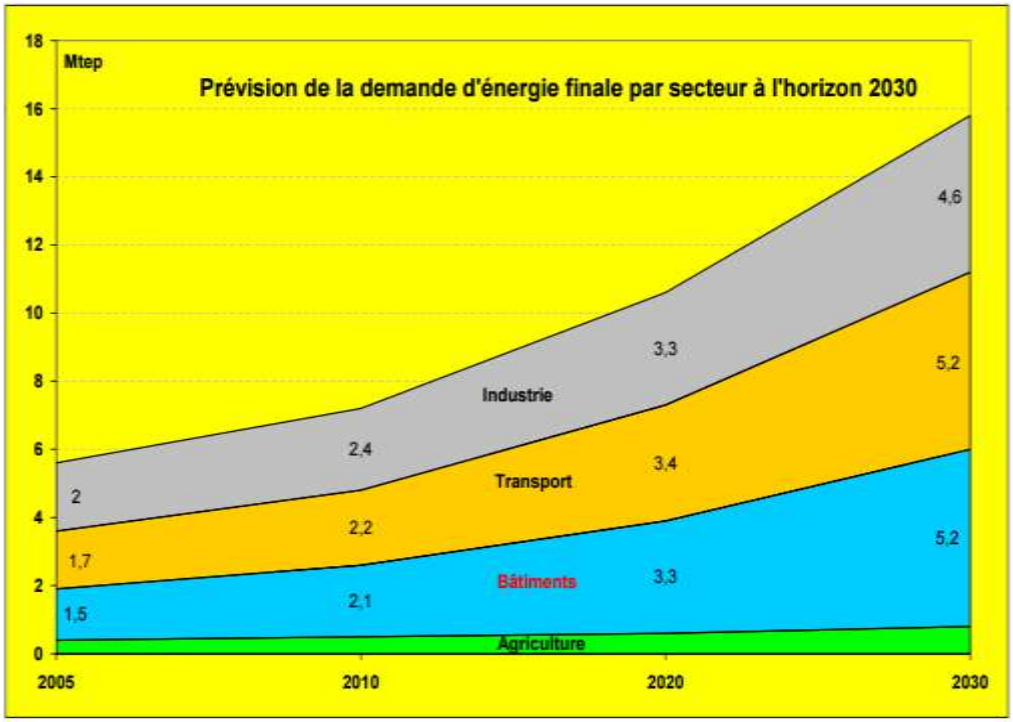

Figure 1:
Forecast of final energy demand (Source: ANME)

Road transport is the most widely used mode. It is also the most energy-intensive among transport modes, followed by rail transport.

Within its energy policy, the State grants significant subsidies to petroleum products and transport (for example, student transport). This burden on the State budget is very large: about 49% of energy subsidies, representing 4.7% of GDP in 2013, which is equivalent to the public deficit of 5.1% of GDP.

3. Energy Balance

In Tunisia, collective public transport is provided by the National Transport Company (SNT), the National Railway Company (SNCFT), the National Interurban Transport Company (SNTRI), as well as regional transport companies.

These companies develop a supply that is intended, in principle, to meet users' needs according to a "**public service**" approach.

4. Determinants of Fuel Demand

Fuel consumption in the transport sector is influenced by many factors, which can be grouped into three categories:

- Mobility demand measured by the number of passengers
- Transport supply quantified by the number of kilometers traveled
- Capital used, represented here by the vehicle fleet. The average age of the fleet affects energy consumption, especially in the absence of proper maintenance of rolling stock.

4.1 Evolution of the Number of Passengers

The number of passengers is an indicator of the intensity of passenger traffic. It measures the degree of demand for public transport.

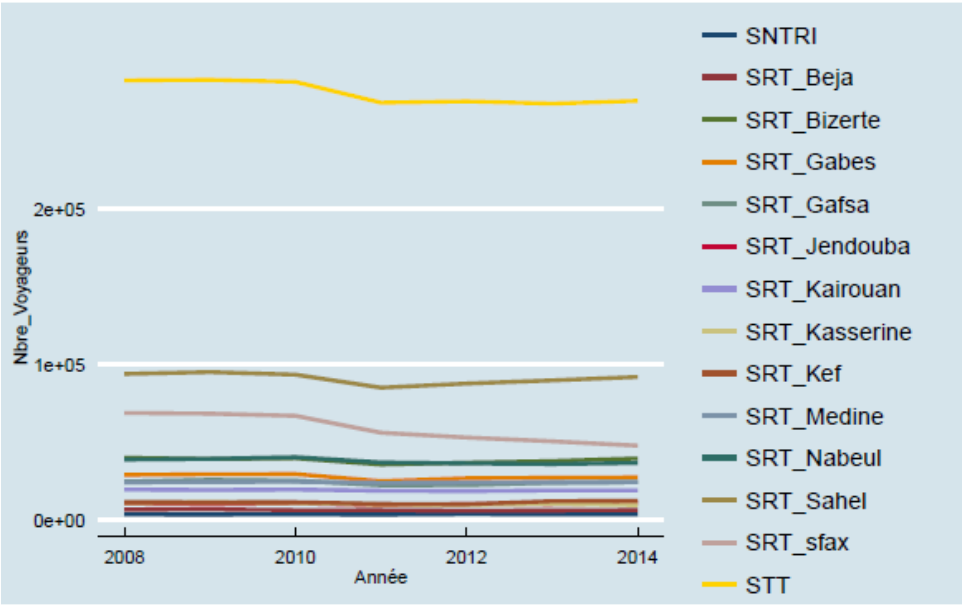

Figure 2: Evolution and distribution of passengers (thousands of passengers)

The number of passengers declined in 2011 due to the poor socio-economic situation triggered by the revolution. Repeated strikes, slowdowns in school and academic activities, and other factors affected passenger traffic. Growth rates of transport demand remained almost zero, with a slight recovery in 2010, except for the Sfax company, which has recorded a considerable decrease in passenger flows since 2010. Companies in coastal regions (North and Center-East) have higher passenger flows than those in the South and Center-West. This difference mainly stems from disparities in economic activity intensity and population density across regions.

Année	2008	2009	2010	2011	2012	2013	2014
Total (milliers) :	663228	665522	665612	700022	616302	620026	584600
Taux de croissance :		0,003	0,000	0,051	-0,119	0,006	-0,057
Moyenne :	47373,	47537	47543	50001	44021	44287	41757
Ecartype :	72265,2	72382,3	71793,7	68833,5	68490,8	68035,5	58570,4
Min :	3700	3650	3758	3600	4000	3800	3700
Max :	282436	282820	281495	268115	269000	267500	229300

Table 1: Descriptive statistics of the number of passengers

Traffic growth is almost zero. Disparities persist over time, with a very large gap between the minimum and maximum values. STT accounts for more than 40% of total passengers. While the average remains almost unchanged, disparities decrease over time, as indicated by a declining standard deviation. The minimum number of passengers corresponds to STRI.

4.2Evolution of the Number of Kilometers Traveled

Kilometers traveled reflect the level of activity of transport companies. This indicator provides information on the intensity of transport service supply.

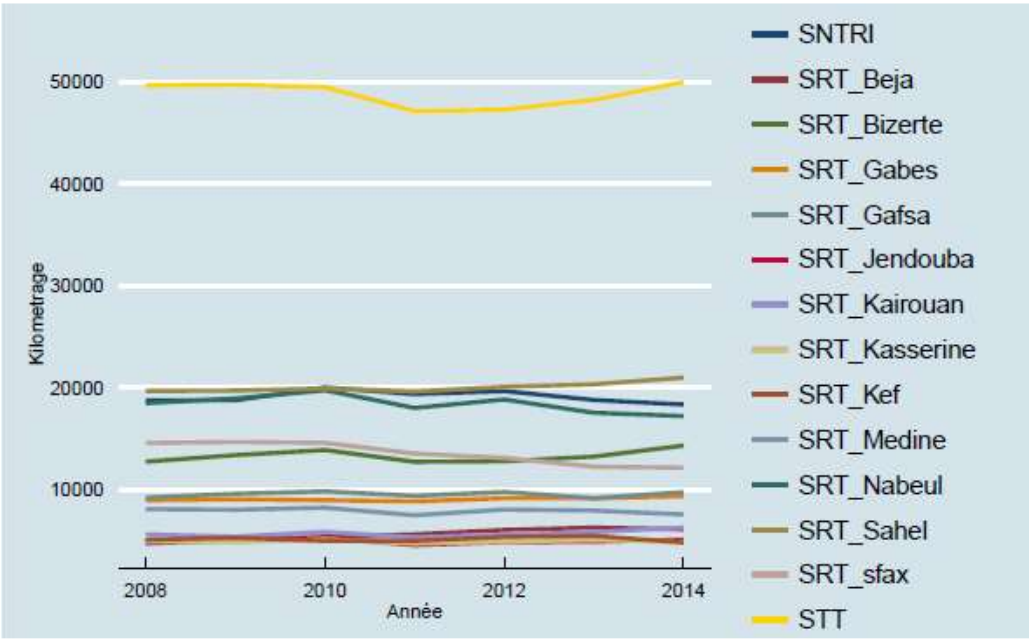

Figure 3: Evolution and distribution of kilometers traveled (thousands of km)

STT tops the ranking of transport companies in terms of kilometers traveled per year, with more than 45 million km, representing on average 26% of total mileage. Other transport companies are divided into two groups:

- SNTRI, Nabeul, Bizerte, Sfax, and Sahel, which operate routes between 10 and 20 million km, i.e., 5% to 10% of the total.
- The remaining companies operate less than 10 million km per year, representing less than 5%.

Année	2008	2009	2010	2011	2012	2013	2014
Total(milliers) :	185801	188085	191006	181449	185314	184252	186737
Taux de croissance :	0,012	0,015	-0,05	0,021	-0,005	0,013	
Moyenne :	13271	13434	13643	12960	13236	13160	13338
Min :	4742	5041	4665	4569	4564	4900	4600
Max :	49657	49724	49491	47139	47294	48249	49997
Écartype :	11832,7	11824,2	11843,1	11280,2	11275,4	11398,0	11849,4683

Table 2: Descriptive statistics of kilometers traveled (thousands of km)

Disparities are also pronounced, with a very high standard deviation. The minimum distance traveled is far from the maximum. The number of kilometers traveled and the overall average remained almost unchanged over time.

4.3Evolution and Evaluation of the Vehicle Fleet

The vehicle fleet defines the capital made available to companies to produce the services they offer.

Société	Moyenne	Pourcentage	Age moyen
SNTRI :	174,5	4,17	81
SRT_Beja :	112,5	3,00	90
SRT_Bizerte :	213,1	5,363	81
SRT_Gabes :	208,8	5,88	105
SRT_Gafsa :	204,4	5,33	106
SRT_Jendouba :	125,5	3,25	108
SRT_Kairouan :	125,7	3,40	114
SRT_Kasserine :	130,4	3,37	108
SRT_Kef :	124,28	3,02	111
SRT_Medine :	197,2	5,14	114
SRT_Nabeul :	257,5	6,70	109
SRT_Sahel :	344,5	8,93	93
SRT_sfax :	389,2	11,42	97
STT :	1203	30,96	93
Ecartype :	280,66		11.26

Table 3: Descriptive statistics of the fleet

Despite disparities in the number of buses in service, the average age of the fleet is almost similar across all companies. As shown in the figure, the distribution of the average age of buses is relatively flat. The condition of the fleet does not differ significantly across companies, with a low standard deviation of 11.26. Fleet renewal is similar (in proportion) across regions. The Bizerte company has the youngest buses, while the Kairouan fleet is the oldest.

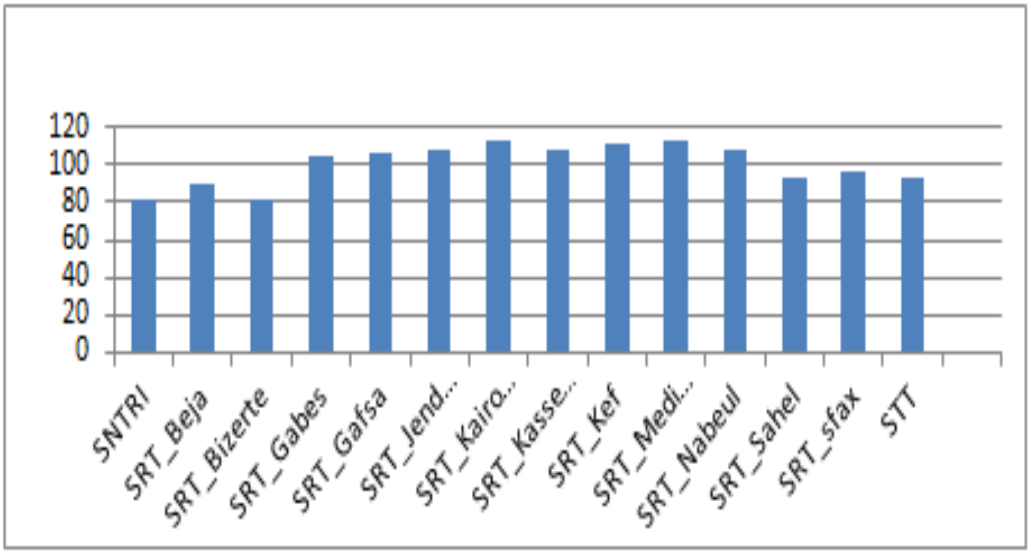

Figure 4: Average age of buses

4.4Fuel Consumption (Thousands of Liters)

Since companies differ in service mode (intra- and/or interurban), in the size of the areas they cover (leading to different mileage), and in transport demand measured by passenger numbers and socio-economic activity intensity, the above values do not fully reveal inter-company differences. We therefore compare companies based on kilometers traveled per bus, consumption per kilometer, and consumption per bus.

4.5Evolution and Distribution of Fuel Consumption Volume

Société	Moyenne	Part(%)	2009	2010	2011	2012	2013	2014
SNTRI :	6995	9,2	-0,015	0,017	-0,016	0,041	-0,058	-0,035
SRT_Bizerte :	4722	6,21	0,028	-0,013	-0,059	0,004	0,033	0,087
SRT_Gabes :	3518	4,62	0,009	0,009	-0,012	-0,091	0,09	-0,028
SRT_Gafsa :	3502	4,6	-0,013	-0,035	-0,121	0,043	-0,062	-0,066
SRT_Jendouba :	1730	2,27	0,048	-0,1	0,034	0,009	0,083	
$SRT_{Kairouan}$:	2159	2,84	-0,037	0,078	-0,089	0,058	0,053	0,06
SRT_Kasserine :	1824	2,4	-0,025	-0,037	-0,042	0,078	0,016	0,001
SRT_Kef :	1809	2,38	-0,018	0,026	-0,1	0,119	-0,07	0,021
SRT_Medine :	3053	4,01	-0,079	0,018	-0,002	0,063	-0,013	-0,035
SRT_Nabeul :	6873	9,04	0,03	0,041	-0,086	0,048	-0,03	0,03
SRT_Sahel :	9170	12,06	0,0013	-0,004	-0,047	0,003	0,02	0,036
SRT_sfax :	6428	8,45	-0,0087	-0,008	-0,118	-0,014	-0,042	0,016
SRT_Beja :	1904	2,5	0,069	0,063	0,074	0,057	0,038	-0.026
STT :	22302	29,35	0,001	-0,004	-0,004	0,003	0,02	0,0211

Table 4: Average consumption (thousands of liters) and growth rate

STT remains the largest fuel consumer, with an average well above 20 million liters since 2008, representing 29% of total public transport consumption. It is followed by the Sahel company with an average share of 12%. SNTRI, Sfax, and Nabeul have average consumption between 5 and 7.5 million liters, with respective shares of 9.2%, 8.45%, and 9%. Other transport companies each consume less than 5 million liters on average.

The companies of Jendouba, Kasserine, Kef, Beja, and Kairouan are the least energy-intensive, with average shares between 2% and 3%. Overall, the North and Center-East consume more energy than the Center-West and the South.

Aggregate consumption was affected by the revolution and fell by 4.7%. The revolution significantly reduced economic activity, leading to decreased transport flows, fewer passengers, and fewer kilometers traveled.

Figure 5: Evolution of total consumption (thousands of liters)

4.6Fuel Consumption per Bus

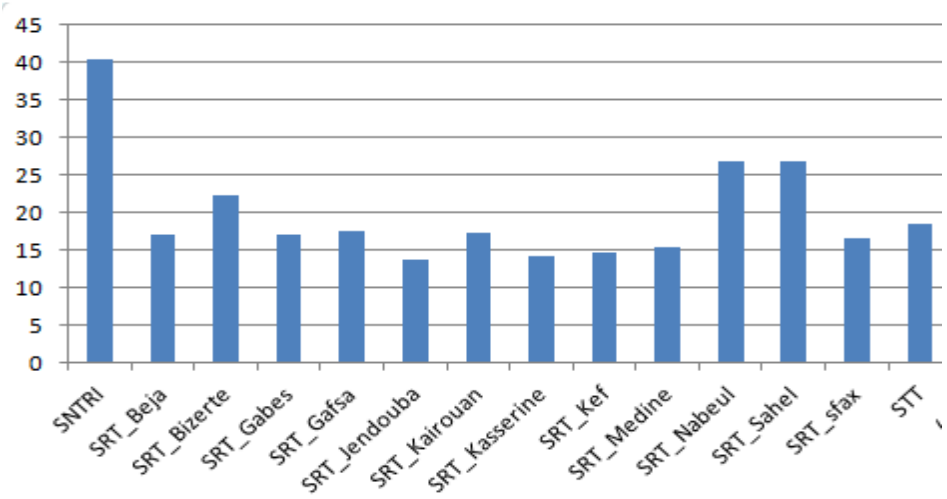

Figure 6: Fuel consumption per bus (thousands of liters)

Société	SNTRI	Beja	Bizerte	Gabes	Gafsa	Jendouba	Kairouan
Moyenne :	40	17	22	16	17	13	17
Société :	Kasserine	Kef	Medine	Nabeul	Sahel	Sfax	STT
Moyenne :	14	14	15	26	26	16	18

Table 5: Fuel consumption per bus (thousands of liters)

On average, a bus in the public collective transport sector consumes 19 thousand liters of diesel per year. The distribution of consumption per kilometer closely follows that of kilometers traveled per bus; both vary in the same direction.

SNTRI ranks first because its buses travel the longest distances, followed by the companies of Nabeul, Bizerte, and Sahel. The Tunis company ranks fourth

4.6Fuel Consumption per 100 Kilometers

This indicator measures the energy efficiency of transport companies. It reflects the average fuel consumed by a bus traveling 100 km.

Société	SNTRI	Beja	Bizerte	Gabes	Gafsa	Jendouba	Kairouan
Moyenne :	36	34	35	39	37	35	38
Société :	Kasserine	Kef	Medine	Nabeul	Sahel	Sfax	STT
Moyenne :	39	35	38	37	46	47	46

Table 6: Consumption per 100 km (liters)

The average energy efficiency of the public transport sector is 38.7 liters per 100 km.

SNTRI consumes 36 liters per 100 km. Although it provides only interurban services, which allow buses to operate under relatively favorable conditions, this consumption level remains high, indicating that it is energy-intensive. Indeed, its buses travel on highways, allowing fewer stops due to congestion and operation at speeds that are theoretically energy-efficient.

Among regional companies, Beja is the most efficient, with buses consuming about 34 liters per 100 km. Sfax is the least efficient, with an average consumption of 47 liters per 100 km, followed by Tunis and Sahel with average

consumption of 45 liters per 100 km. Other regional companies record an average consumption of 37 liters per 100 km.

Within regional companies, trends of overconsumption and differences in energy efficiency are observed. These findings may stem from differences in urban layout and infrastructure, which affect traffic fluidity. This translates into congestion and a varying number of stops per bus depending on the region, which may explain why the companies of Sfax, Sahel, and Tunis exhibit poor energy performance.

Finally, this overconsumption trend may also be due to driver behavior. Unnecessary acceleration and braking increase instantaneous fuel consumption.

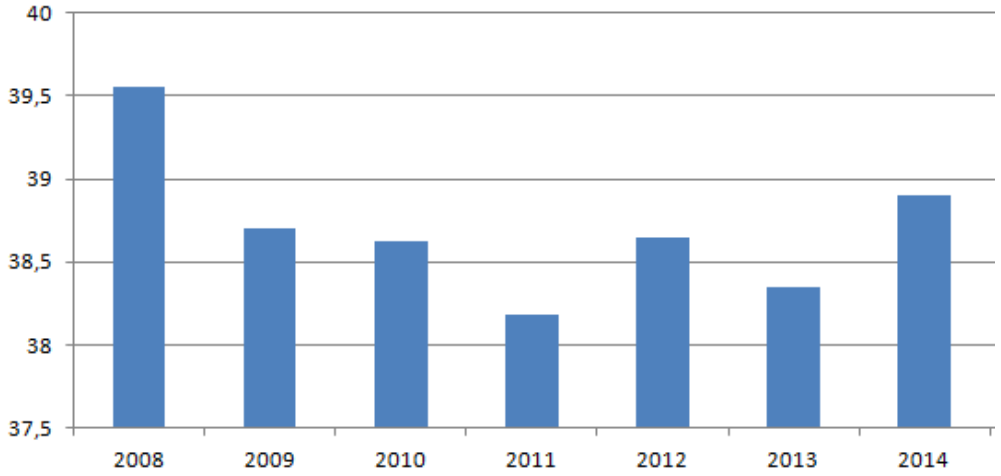

Figure 7: Evolution of fuel consumption per bus per km (liters)

Average energy efficiency improved from 2008 to 2011, with a continuous decline in consumption per 100 km. The situation deteriorated in 2012 with a 1.2% increase, followed by an improvement in 2013 with a 0.7% decrease. Consumption per km increased again in 2014 by 1.4% compared to 2013. On average over the 2008–2014 period, the improvement in energy efficiency is almost zero, with a change of -0.2%. Regional transport companies therefore need to intensify efforts toward better energy efficiency.

4.7Fuel Expenditures by Regional Transport Company

Socité	Moyenne	2009	2010	2011	2012	2013	2014
SNTRI :	6261	0,01	0,05	0,07	0,02	0,06	-0,01
SRT_Bizerte :	4304	0,03	0,08	-0,03	0,01	0,13	0,14
SRT_Gabes :	3448	0,07	-0,01	-0,03	0,25	0,01	0,06
SRT_Gafsa :	3410	-0,02	0,01	-0,07	0,07	0,05	-0,03
SRT_Jendouba :	1585	0,09	0,01	0,04	0,06	0,17	
SRT_Kairouan :	1916	-0,08	0,18	-0,03	0,21	0,05	0,10
SRT_Kasserine :	1668	-0,01	0,10	-0,14	0,13	0,14	0,03
SRT_Kef :	1599	0,01	0,02	0,02	0,04	0,08	0,05
SRT_Medine :	3130	-0,07	0,06	0,05	0,08	0,09	-0,003
SRT_Nabeul :	6139	0,01	0,11	0,01	0,03	0,07	0,04
SRT_Sahel :	7821	0,14	-0,06	0,06	0,00	0,10	0,12
SRT_sfax :	5788	-0,01	0,04	-0,07	0,01	0,09	0,22
SRT_Beja :	2123	0,11	0,43	0,7	0,13	0,011	0.036
STT :	19046	0,13	-0,059	0,10	-0,002	0,10	0,100

Table 7: Average fuel expenditures (thousands of dinars) and growth rate

Fuel expenditures increased over time, with a slowdown in 2011, except for STT, SNTRI, Jendouba, Médenine, Nabeul, and Sahel, which recorded higher fuel spending in 2011.

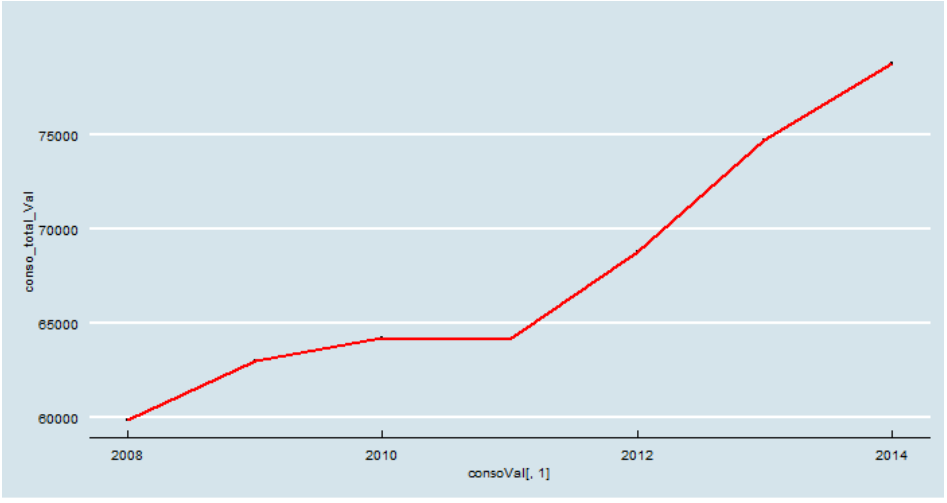

Figure 8: Fuel expenditures (thousands of dinars)

Despite stagnation in consumption volumes, fuel expenditures continue to rise over time.

5. Conclusion

The energy balance of the transport sector over the 2008–2014 period shows that fuel consumption and its main determinants evolved in a nearly stationary manner.

However, fuel expenditures increased over time, and disparities among transport companies are evident. SST dominates all other companies, accounting for more than 40% of passengers, 26% of kilometers traveled, 30% of the fleet, and 29% of total fuel consumption—far ahead of the South and West, which maintain low levels. The comparison among companies reveals that Beja is the most energy-efficient company, with the lowest fuel consumption per 100 km per bus.

Sfax, just behind Tunis and Sahel, is the least energy-efficient. Other regional companies behave in a fairly similar manner. Although energy efficiency in the sector has improved, it remains insufficient, with an average gain of only 0.2%.

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How do non-performing loans affect productivity? Evidence from Tunisian banks using a parametric hyperbolic distance function

Mahdhi Ali [1,2,3], Ghorbel Abdelfattah[2,3]

[1] *Higher Institute of Industrial Management, University of Sfax, Technopole of Sfax, BP 1164, Sfax 3021, Tunisia. (ali.mahdhi@isgis.usf.tn)*
[2] *Faculty of Economic and Management Sciences, University of Sfax, R airport Km4, BP14, Sfax 3018, Tunisia.*
[3] *CODECI Laboratory, University of Sfax, R Airport Km4, BP14, Sfax 3018, Tunisia.*

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Abstract:

As solving the problem of the high level of non-performing loans presents a key factor in strengthening the soundness of the banking system, Tunisian government has considered the reduction of the nonperforming loans burden of a paramount importance. In this paper, we construct a new total factor productivity (TFP) index using a parametric hyperbolic distance function, which simultaneously credits for an expansion in economic outputs (loans and others earning assets) along with contractions undesirable output (nonperforming loans). This new TFP index provides more fruitful and meaningful economic decomposition. In addition to the first three parts (technical change, efficiency change and scale effect change), our index offers one more part related to undesirable output reflecting its effect on productivity. Subsequently, this index is employed to evaluate the TFP change for 10 listed

Corresponding author**:* Mahdhi Ali*, **e-mail: ali.mahdhi@isgis.usf.tn

Tunisian banks during 1992–2014. The results indicate that over the studied period, the banking sector experienced a progress in term of Efficiency change as well as a technical change by 0.5%, and 0.3%, respectively. However, these improvements were offset by regress in term of scale effect change and NPLs effect change. Thus, over the entire period (1992-2014), there was no significant change in the average TFP. Public banks are found to have been more successful than the private ones in capturing benefits from changes in technology and efficiency. In addition, the scale changes and undesirable output effects are found to be problematic for the private and public banks indicating that they do not operate at an optimal scale and do not efficiently manage their risk.

Keywords: bank Efficiency, Productivity Change, Hyperbolic distance functions, Undesirable output, NPLs, Tunisian banks

1. Introduction

Over the past two decades, banking and financial systems have undergone dramatic changes and developments worldwide. On one side, banking deregulation, financial integration and merger-acquisition contribute to the profound transformation of banking operational environment. On the other side, driven by the technological innovation, banks are able to create a range of new products and reduce costs in providing financial services. Inspired by these developments, a large body of efficiency and productivity studies was carried out in order to inform regulators and practitioners of banking sector performance, help governors review banking and financial regulation, and assist bank managers to assess and supervise their managerial ability. In the literature of performance evaluation studies, a substantial number of researchers focused on technical efficiency, cost efficiency and profit efficiency using either non-parametric or/and parametric frontier methodologies. Another strand of academic studies focused on the productivity measurement and its decomposition using either nonparametric or/and parametric frontier approaches.

Analyzing the productivity of banking systems is interesting from a policy perspective because an increase in productivity is expected to induce lower

prices, enhance service quality, and improve resource allocation of the entire economy.

However, it's worth noting that the productivity alters as a result of the differences in the production technology, the efficiency of the production process, and the scale of operations. Hence, a change in productivity can be decomposed into several sources: technical efficiency change, scale efficiency change and technological change. Technical efficiency change measures the capacity of a bank to enhance its production position relative to the production frontier from one period to another. Scale efficiency change measures changes in the scale of this bank's operations relative to the most productive scale over time. Meanwhile, technological change captures the shift in the production frontier from one period to another, reflecting the improvement or the deterioration in the performance of best-practice banks.

Our study extends the traditional parametric Malmquist productivity index to a new index that takes into account undesirable outputs (NPLs). So, by using the estimated hyperbolic distance function, the Diewert's (1976) Lemme of quadratic identity and the general approach described in Orea (2002), it was possible to define a new TFP index, which provides a more significant and rewarding economic decomposition. The new TFP index offers an additional source reflecting the undesirable outputs effect on productivity. This new measure of productivity change is applied to investigate the productivity evolution of Tunisian banks during 1992–2014

It should be noted that the Tunisian context deserves to be studied for several reasons. First, the financial system remains excessively bank-based despite the reforms undertaken to establish a market-based financial sector. Second, external finance to Tunisian firms is provided mainly by banks. Moreover, according to numerous reports of the World Bank (2004, 2014), the International Monetary Fund (2002, 2010, 2015) and rating agencies (Fitch Ratings, 2006, 2007), the high level of nonperforming loans remains potentially a major source of vulnerability for the whole Tunisian banking system.

In fact, nonperforming loans impose costs on the economy and hinder efforts to further liberalize capital movements. Large non provisioned nonperforming loans increase the cost of bank intermediation and keep interest rates high, so that interest paying loans are penalized in order to subsidize bad

loans, contributing to the weakness of the Tunisian banks and putting them in a competitive disadvantage vis-à-vis foreign banks, namely their European counterparts. Most importantly, large under provisioned provisioning nonperforming loans create a negative perception of Tunisian banking system. This is likely depriving Tunisia of better access to international capital markets, as it affects investor confidence.

Therefore, we can assert that this paper addresses a gap in banking literature by introducing, for the first time, a productivity growth decomposition specific to Tunisian banks, shedding light on the impact of nonperforming loans. Past studies have treated nonperforming loans in various ways, such as uncontrollable inputs (Drake and Hall, 2003; Hughes and Mester, 2010), a quality variable (Hughes and Mester, 1998), or undesirable outputs in the banking production process (Berg et al., 1992; Fukuyama and Weber, 2008; Park and Weber, 2006; Barros et al., 2012; Assaf et al., 2013; Glass et al., 2014; Mamatzakis et al., 2015). In line with recent literature, we categorize nonperforming loans as undesirable outputs in our productivity decomposition. Given the substantial volume of nonperforming loans in Tunisia, we anticipate that they exert an influence on bank productivity. It is plausible that banks may encounter challenges in receiving principal and interest payments on these loans, depending on the financial health of the borrowers. Consequently, these overdue loans could elevate the operating costs of banks in the short run, potentially penalizing overall bank productivity.

This study contributes to the existing literature in both theoretical and empirical dimensions. By introducing a new measure of productivity change based on the hyperbolic distance function, we diversify methodological choices for practical researches. Also, by examining productivity features of banks in Tunisia, we cover the lack in researches dealing with the Tunisian banking sector.

The remaining part of the paper is structured as follows. Section 2 provides a literature review on bank productivity; Section 3 describes the methodology; Section 4 defines bank inputs and outputs and outlines practical implementations; Section 5 discusses the findings; while the last Section presents the conclusions.

2. Literature review

This section draws attention to the literature on bank productivity, focusing on non-Parametric frontier approach (e.g. DEA) and parametric frontier approach (e.g. SFA, DFA and TFA) used to decompose total factor productivity (TFP) growth. According to Kumbhakar and Lovell (2003), both approaches require the calculation or estimation of production technology presentation to answer the following questions; whether the Tunisian banking industry has experienced productivity progress/ or regress; what is the major driver of productivity change? Nevertheless, in a stochastic environment, only the parametric approach is able to provide responses to both questions. In what follows, we present studies using both approaches to measure bank productivity.

2.1. Non-parametric studies

A structured survey of the relevant literature is reported in Table 1. As documented in the comprehensive review by Fethi and Pasiouras (2010), the dominant strand of empirical research on bank productivity prior to 2010 relies on Data Envelopment Analysis (DEA) combined with the Malmquist productivity index (Malmquist, 1953). The Malmquist Total Factor Productivity (TFP) index measures productivity change between two periods by computing the ratio of distance functions relative to a common production technology (Casu et al., 2004). When derived from an output distance function, an index value greater (less) than unity indicates productivity growth (decline) between the reference and subsequent periods.

The Malmquist framework has been widely applied in banking studies, including Berg et al. (1992), Grifell-Tatjé and Lovell (1997), Mlima (1999), Wheelock and Wilson (1999), Rebelo and Mendes (2000), Alam (2001), Mukherjee et al. (2001), Casu et al. (2004), Tortosa-Ausina et al. (2008), Fiordelisi and Molyneux (2010), and Kao and Liu (2014). A substantial body of work focuses on productivity change during periods of financial deregulation in the 1980s and 1990s. Evidence from Norway (Berg et al., 1992) and Sweden (Mlima, 1999) suggests that deregulation was initially associated with productivity declines, followed by strong post-reform recoveries, particularly among commercial banks. Similar findings are reported for Portugal, where productivity gains were largely driven by technological progress during the 1990s (Rebelo and Mendes, 2000).

For the United States, studies by Wheelock and Wilson (1999), Alam (2001), and Mukherjee et al. (2001) document the presence of technological progress alongside heterogeneous productivity outcomes across banks. While long-run productivity growth is observed, transitional periods are characterized by rising inefficiencies and uneven adoption of new technologies.

Research on emerging and transition economies further enriches the literature. Studies on Portugal (Canhoto and Dermine, 2003), Turkey (Isik and Hassan, 2003a, 2003b), and Greece (Tsionas et al., 2003) generally report productivity improvements following liberalization, though the sources of growth differ. In particular, productivity gains in Turkey are mainly attributed to efficiency improvements, whereas technological change plays a dominant role in other contexts. Financial crises, however, tend to induce temporary productivity regressions driven by technological setbacks.

Methodological refinements addressing the deterministic nature of DEA-based Malmquist indices have been proposed through bootstrapping techniques (Gilbert and Wilson, 1998; Tortosa-Ausina et al., 2008), allowing for statistical inference and confidence interval construction. More recently, Kao and Liu (2014) advocate a probabilistic version of the Malmquist index to account for externalities inherent in banking operations, providing more informative productivity assessments.

Cross-country analyses, particularly within Europe, reveal heterogeneous productivity trajectories. Casu et al. (2004) report modest productivity growth in British, French, and German banks, contrasted with stronger performance in Spanish and Italian institutions. Fiordelisi and Molyneux (2010) further demonstrate that technological change constitutes the primary channel through which productivity growth enhances shareholder value.

Finally, the traditional Malmquist index has been extended by Luenberger (1992) into the Luenberger productivity indicator, which allows for the simultaneous expansion of outputs and contraction of inputs. Applications of this indicator in banking—covering Korea, Spain, Europe, China, and India (Park and Weber, 2006; Epure et al., 2011; Williams et al., 2011; Chang et al., 2012; Fujii et al., 2014)—suggest that it offers a flexible and informative alternative for analyzing productivity dynamics in the banking sector.

Table .1: Survey of Non Parametric productivity studies in banking sector

Authors	Applied countries	Period	Methodology	Decomposition	International Comparison
Berg.al(1992)	Norway	1980-89	Malmquist (DEA)	Without decomposition	No
Mlima (1999)	Swede	1984-95	Malmquist (DEA)	Without decomposition	No
Rebelo and Mendes (2000)	Portugal	1990-97	Malmquist (DEA)	TC, EC	No
Wheelock and Wilson (1999)	US	1984-83	Malmquist (DEA)	TC, EC, SEC	No
Alam (2001)	US		Malmquist (DEA)	TC, EC	No
Mukherjee *et al.* (2001)	US	1984-90	Malmquist (DEA)	TC, EC, SEC	No
Canhoto and Dermine (2003)	Portugal		Malmquist (DEA)	TC, EC	No
Isik and Hassan (2003a)	Turkey	1981-90	Malmquist (DEA)	TC, EC, SEC	No
Isik and and Hassan (2003b)	Turkey	1992-96	Malmquist (DEA)	TC, EC, SEC	No
Grifell-Tatje and Lovell (1997)	Spain	1986-93	Malmquist (DEA) Generalized	TC, EC, SEC	No
Tsionas *et al.* (2003)	Greece	1993-98	Malmquist (DEA) Bootstrap	TC, EC	No

Gilbert and Wilson (1998)	Korea	1980-84	Malmquist (DEA) bootstrap	TC, EC, SEC	No
Tortosa-Ausina *et al.* (2008)	Spain	1992–98	Malmquist (DEA) bootstrap	TC, EC, SEC	No
Kao and Liu (2014)	Taiwan		Malmquist (DEA) stochastic	Without decomposition	No
Casu et al. (2004)	Europe	1994-2000	Malmquist (DEA)	TC, EC, SEC;	yes
Fiordelisi and Molyneux (2010)	Europe		Malmquist (DEA)	TC, EC, SEC;	yes
Park and Weber (2006)	Korea	1992-2002	Luenberger productivity (DEA)	TC, EC	No
Epure et al. (2011)	Spain	1998-2006	Luenberger productivity (DEA)	TC, EC, SEC	No
Williams et al. (2011)	Europe	1996-2003	Luenberger productivity (DEA)	TC, EC	No
Chang et al. (2012)	China	2002-2009	Luenberger productivity (DEA)	TC, EC	No
Fujii et al. (2014)	India	2004-2011	Luenberger productivity (DEA)	TC, EC	No

Efficiency Changes (EC), Technical Change (TC), Scale Efficiency Change (SEC)

2.2. Parametric studies

A survey of the relevant literature is presented in Table 2. Numerous studies have employed different econometric model specifications—namely cost, profit, and distance functions—to estimate total factor productivity (TFP) change in the banking sector. Existing research is particularly extensive for the U.S. and European banking industries (e.g., Kim and Weiss, 1989; Stiroh, 2000; Chaffai et al., 2001; Kumbhakar et al., 2001; Orea, 2002; Berger and Mester, 2003; Kumbhakar and Sarkar, 2003; Casu et al., 2004; Koutsomanoli-Filippaki et al., 2009; Feng and Serletis, 2010; Boucinha et al., 2013; Casu et al., 2013; Feng and Zhang, 2012, 2014). In what follows, we review these studies according to the econometric specifications adopted.

Studies based on cost functions constitute an important strand of the literature. Kim and Weiss (1989) estimated a system comprising a translog cost function and factor cost-share equations to examine the impact of branch expansion on TFP growth in Israeli banks over the period 1979–1982. Their results indicated an average annual TFP growth of 7.79%, with technical change contributing more than branch expansion, although both were significant drivers, particularly for small banks. Similarly, Stiroh (2000) analyzed productivity growth in U.S. bank holding companies during the 1990s using alternative cost-function-based econometric approaches. Across different specifications, the results were robust, indicating an average annual productivity growth of approximately 0.4%.

Using panel data for Indian banks from 1985 to 1996, Kumbhakar and Sarkar (2003) estimated a translog shadow cost function combined with shadow cost-share equations within a seemingly unrelated regression framework. They decomposed TFP growth into scale, technological change, and a residual component influenced by regulatory distortions. Their findings revealed a decline in productivity growth during deregulation, followed by a recovery afterward, with scale effects emerging as the primary driver across ownership types. Employing stochastic frontier methods, Boucinha et al. (2013) estimated a cost function for Portuguese banks and found that technological progress was the dominant source of TFP growth between 1992 and 2006.

Other studies have relied on profit functions. Berger and Mester (2003) used cost and profit functions to assess productivity changes in U.S. banks from

1991 to 1997, defining productivity growth as changes in best-practice technology and inefficiency. Kumbhakar et al. (2001), using a translog profit function, decomposed productivity growth for Spanish savings banks into technical change and efficiency change, identifying significant technological progress alongside substantial inefficiency. Extending this approach, Lozano-Vivas and Pasiouras (2014) incorporated off-balance-sheet activities in a parametric productivity framework applied to an international sample.

A third strand of the literature employs distance functions. Chaffai et al. (2001) used a stochastic output distance function to decompose the Malmquist productivity index for banking industries in major European countries, finding that environmental factors were more influential than pure technological change. Orea (2002) proposed a parametric decomposition of a generalized Malmquist index using a distance function and showed that TFP growth in Spanish savings banks was mainly driven by technical progress, with a positive contribution from scale effects. Koutsomanoli-Filippaki et al. (2009) parameterized a directional distance function to estimate the Luenberger productivity indicator for Central and Eastern European banks, concluding that technological change was the main source of productivity growth.

More recently, Feng and Zhang (2012, 2014) employed a true random-effects stochastic distance frontier model to account for unobserved heterogeneity among U.S. banks and measured TFP growth using the output-distance-function-based Divisia index proposed by Feng and Serletis (2010). Casu et al. (2004) compared parametric and non-parametric productivity measures for European banks, finding that productivity growth was largely driven by technical change rather than efficiency catch-up. Casu et al. (2013) further combined DEA, SFA, and meta-frontier analysis to examine productivity change in Indian banks, highlighting technology heterogeneity across ownership structures.

Finally, it is worth noting the emergence of semi-parametric approaches in the efficiency and productivity literature (Sun and Kumbhakar, 2013; Sun et al., 2015), which aim to relax functional form assumptions while retaining desirable statistical properties.

Table 2 : Survey of Parametric productivity studies in banking sector

Authors	Applied countries	Period	Methodology	Decomposition	International Comparison
Stiroh (2000)	US	1991-97	TFP: cost and profit functions	Without decomposition	No
Berger and Mester (2003)	US	1991-97	TFP: cost and profit functions	1)Change in best practice Change in 2)inefficiency Change in 3)business conditions	No
Lozano-Vivas and Pasiouras (2014)	84 countries	1999-2006	TFP: cost and profit functions	1)Change in best practice Change in 2)inefficiency Change in 3)business conditions	Yes
Feng and Zhang (2012)	US	1997–2006	Divisa productivity index: Parametric output distance function	1)Technical change 2)Efficiency change	No
Feng and Zhang (2014)	US	1997–2010	Divisa productivity index: Parametric output distance function	1)Technical change 2)Efficiency change	No

Chaffai et al. (2001)	France, Germany, Italy, and Spain	1993- 97	Malmquist: Parametric output distance function	1)pure technological effect and 2)environmental effect	Yes
Kumbhakar et al. (2001)	Spain	1986-95	TFP: profit function	1)Technical change 2)Efficiency change	No
Orea (2002)	Spain	(1985-1998),	Malmquist: Parametric output distance function	1) Efficiency Changes 2)Technical Change 3)Scale Effect	No
Casu et al. (2004)	Europe	1994-2000	Malmquist: Parametric output distance function	1) Scale efficiency change 2)Technical efficiency change 3) Technological change	Yes
Koutsomanoli-Filippaki et al. (2009)	Central and Eastern European countries	1998-2003	Luenberger productivity index: directional distance function	1)Technical efficiency change 2) Technological change	Yes
Boucinha et al. (2013)	Portugal	1992-2006	TFP: cost function	1) Scale efficiency change	No

				2)Technical efficiency change 3) Technological change	
Kim and Weiss (1989)	‘’Israeli’’	1979-1982	TFP: cost function	1)scale economy and output growth, 2) branching effect, and 3) technological change effect	No
Kumbhakar and Sarkar (2003)	Indian	1985-1996	TFP: cost function	1) scale factor, 2)technological change, and 3)miscellaneous part	No
Casu et al. (2013))	Indian	1992-2009	metafrontier - Divisa and Malmquist-cost function	1) Scale efficiency change 2)Technical efficiency change 3) Technological change	No

To end with, a part from enhancing the literature concerning parametric productivity, our study aims to take into account the impact of undesirable outputs contribution on TFP change, by further exploring the main effects of non-performing loans on Tunisian banks' productivity change.

3. Methodology and Empirical Procedure

3.1. Technology

We assume that the production technology T and a set of entities (k=1…K) use a vector of N inputs vector $x \in \Re_+^N$ into M desirable output vector $y \in \Re_+^M$, and J undesirable outputs vector $b \in \Re_+^j$, by a compact production possibility set

$$T \equiv \{(x,y,b) : x \text{ can produce } (y,b)\} \tag{1}$$

which satisfies the customary axioms listed in Färe and Primont (1995). Following Cuesta et al. (2009), the hyperbolic distance function is defined by

$$D_H(x,y,b) = \min_{\delta} \{ \delta > 0 : (x, \frac{y}{\delta}, \delta b) \in T\} \tag{2}$$

This represents the simultaneous maximum expansion of y and contraction of b undesirable outputs that places the economic entity on the boundary of the technology T. The range of this hyperbolic distance function is $0 < D_H \leq 1$.

The hyperbolic distance function (2) treats desirable outputs and undesirable outputs asymmetrically. If $D_H(x,y,b) = 1$, the provided observation lies on the boundary of the production possibility set, where it is not possible to expand its output (*y*) or reduce its (*b*) simultaneously under the existing technology. In this context, the economic entity is defined as an efficient producer. If $D_H(x,y,b) < 1$, nevertheless, this economic entity has the potential to enhance its efficiency by simultaneously increasing its output (*y)* and reducing its (*b*) compared to the efficient producer, therefore it is regarded as an inefficient producer.

The technology T exhibits a non-decreasing behaviour in the desirable output and a non-increasing pattern in the undesirable output and inputs. Additionally, it adheres to the principle of almost homogeneity.

$$D_H(x,\theta y,\theta^{-1} b) = \theta\, D_H(x,y,b), \quad \forall \theta > 0 \tag{3}$$

which means that if the desirable outputs y are increased by a given proportion and the undesirable outputs b are reduced by the same proportion for

a given set of inputs, then the hyperbolic distance function increases by that same proportion[1].

We can also extend the hyperbolic distance function in equation (2) and define an

$\tilde{x}$ - input saving hyperbolic distance function D_{ISH} as:

$$D_{ISH}(\tilde{x},x,y,b) = \min_{\delta}\{\ \delta > 0: (\delta\tilde{x},x,\ \frac{y}{\delta}\ ,\delta b\ ) \in\ T\} \tag{4}$$

which has properties as the hyperbolic distance function and satisfies almost homogeneity given by

$$D_{ISH}(\theta^{-1}\tilde{x},x,\theta y,\theta^{-1}b)\ =\ \theta\ D_{ISH}(\tilde{x},x,y,b),\quad \forall\theta\rangle 0 \tag{5}$$

The enhanced hyperbolic distance function D_{EH} further reduces all inputs. It is introduced by Cuesta et al. (2009) and also defined as:

$$D_{EH}(x,y,b) = \min_{\delta}\{\ \delta > 0: (\delta x,\ \frac{y}{\delta}\ ,\delta b\ ) \in\ T\} \tag{6}$$

which satisfies almost homogeneity given by

$$D_{EH}(\theta^{-1}x,\theta y,\theta^{-1}b)\ =\ \theta\ D_{EH}(x,y,b),\quad \forall\theta\rangle 0 \tag{7}$$

3.2. Translog Specification and Stochastic Frontier Approach

To assess efficiency, we employ a translog functional form for the parametric distance function, as specified by Coelli and Perelman (1999). This choice is motivated by the desirable properties of flexibility, ease of calculation, and the imposition of homogeneity.

The stochastic translog panel data specification, with N inputs, M desirable outputs and J undesirable outputs is defined as:

[1] As noted by Cuesta et al. (2009), Cuesta and Zofío's (2005) proof of the almost homogeneity property for the hyperbolic distance function ignoring undesirable outputs can be easily extended to D_H and our remaining two other distance functions.

$$\ln D_{kt}\ (x_{kt}, y_{kt}, b_{kt}) = \alpha_0 + \sum_{n=1}^{N} \alpha_n \ln x_{n,kt} + \sum_{m=1}^{M} \beta_m \ln y_{m,kt} + \sum_{j=1}^{J} \gamma_j \ln b_{j,kt}$$

$$+0.5\sum_{j=1}^{J}\sum_{j'=1}^{J} \gamma_{jj'} \ln b_{j,kt} \ln b_{j',kt} + 0.5\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \ln x_{n,kt} \ln x_{n',kt} + 0.5\sum_{m=1}^{M}\sum_{m'=1}^{M} \beta_{mm'} \ln y_{m,kt} \ln y_{m',kt}$$

$$+\sum_{m=1}^{M}\sum_{n=1}^{N} \delta_{mn} \ln y_{m,kt} \ln x_{n,kt} + \sum_{n=1}^{N}\sum_{j=1}^{J} \psi_{nj} \ln x_{n,kt} \ln b_{j,kt} + \sum_{m=1}^{M}\sum_{j=1}^{J} \lambda_{mj} \ln y_{m,kt} \ln b_{j,kt} + v_{kt}$$

$$= TL\ (x_{kt}, y_{kt}, b_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt}$$

$$k = 1...K, \quad t = 1...T \qquad (8)$$

Where D_{kt} is the distance function for entitie *k* at time *t*, t is also a time variable that represents technology, and ε_{kt} is a random term distributed around zero, $v_{kt} \sim \aleph\left(0, \sigma_{\varepsilon}^2\right)$

Using the almost homogeneity condition in equation (3) and choosing y_M as the normalizing variable for the hyperbolic distance function in equation (8), we have

$$D_{H,kt}\ (x_{kt}, \frac{y_{kt}}{y_{M,kt}}, y_{M,kt} \times b_{kt}) = \frac{D_{H,kt}}{y_{M,kt}} \qquad (9)$$

Taking logarithm on both sides of equation (9) and combining with equation (8), we obtain

$$\ln\left(\frac{D_{H,kt}}{y_{M,kt}}\right) = TL\ (x_{kt}, y^*_{kt}, b^*_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt} \qquad (10)$$

which yield

$$-\ln\left(y_{M,kt}\right) = TL\ (x_{kt}, y^*_{kt}, b^*_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt} - \ln\left(D_{H,kt}\right) \qquad (11)$$

where TL represents the translog function, $y^*_{kt} = \frac{y_{kt}}{y_{M,kt}}$, $b^*_{kt} = y_{M,kt} \times b_{kt}$ and all terms involving y_M are null.

Defining $u_{kt} = \ln\left(D_{H,kt}\right)$ as an inefficiency term in the stochastic frontier analysis framework, we get the estimated econometric function as:

$$-\ln\left(y_{M,kt}\right) = TL\ (x_{kt}, y^{*}_{kt}, b^{*}_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt} - u_{kt} \qquad (12)$$

Similarly, using the almost homogeneity conditions in equations (5) and (7), we have following functions to be estimated respectively for the input saving hyperbolic distance function and the enhanced hyperbolic distance function as:

$$-\ln\left(y_{M,kt}\right) = TL\ (\tilde{x}^{*}_{kt}, x_{kt}, y^{*}_{kt}, b^{*}_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt} - u_{kt} \qquad (13)$$

$$-\ln\left(y_{M,kt}\right) = TL\ (x^{*}_{kt}, y^{*}_{kt}, b^{*}_{kt}, \alpha, \beta, \gamma, \delta, \psi, \lambda) + v_{kt} - u_{kt} \qquad (14)$$

Where $\tilde{x}^{*}_{kt} = y_{M,kt} \times w_{kt}$, $x^{*}_{kt} = y_{M,kt} \times x_{kt}$, $y^{*}_{kt} = \dfrac{y_{kt}}{y_{M,kt}}$ and $b^{*}_{kt} = y_{M,kt} \times b_{kt}$

We use stochastic frontier analysis (SFA) to estimate hyperbolic functions. This study employs a one-step model proposed by Battese and Coelli (1995). The translog HDFs to be estimated is given by:

$$-\ln y_{Mkt} = TL\ (.) \underbrace{- u_{kt} + v_{kt}}_{\varepsilon_{kt}} \qquad (15)$$

Where, $-\ln y_{Mkt}$ corresponds to the dependent variable and the $\varepsilon_{kt} = v_{kt} - u_{kt}$ is the composed error term. The v_{kt} are assumed to be independently and identically distributed as $\aleph\left(0, \sigma^{2}_{v}\right)$, independently distributed of the u_{kt}. The inefficiency term u_{kt} is nonnegative. the truncation point is $-\mu_{kt}$. The truncated inefficiency term u_{kt} is independently but not identically distributed and takes the form $u_{kt} \rightarrow \aleph\left(\mu_{kt}, \sigma^{2}_{u}\right)$; $\mu_{kt} = \delta_{0} + \delta z_{kt}$, where z_{kt} captures the observed bank-specific and environmental factors which explain the differences in efficiency across banks and *δ* is a vector of parameters to be estimated.

The efficiency of the *k*th bank is then given by:

$$Eff_{kt} = \exp\left(-u_{kt} \left| \varepsilon_{kt}\right.\right) = \exp\left(-\delta_{0} - \delta z_{kt}\right) \qquad (16)$$

Here, we also use maximum likelihood estimation to determine values of the unknown parameters in the above model. The expressions for the likelihood

function and efficiency point estimator are presented in Battese and Coelli (1993).

Overall TFP change adjusted to undesirable outputs and its decomposition

Naturally, as distance functions can be estimated parametrically, they also constitute the building blocks for the measurement of productivity change and its decomposition into basic sources of efficiency change and technical change. Though, to apprehend technological change, the function needs to include a time trend variable. Thus, (8) is extended to

$$\ln D_H\ (x_{kt}, y_{kt}, b_{kt}) = \alpha_0 + \sum_{n=1}^{N} \alpha_n \ln x_{n,kt} + \sum_{m=1}^{M} \beta_m \ln y_{m,kt} + \sum_{j=1}^{J} \gamma_j \ln b_{j,kt}$$

$$+0.5\sum_{j=1}^{J}\sum_{j'=1}^{J} \gamma_{jj'} \ln b_{j,kt} \ln b_{j',kt} + 0.5\sum_{n=1}^{N}\sum_{n'=1}^{N} \alpha_{nn'} \ln x_{n,kt} \ln x_{n',kt} + 0.5\sum_{m=1}^{M}\sum_{m'=1}^{M} \beta_{mm'} \ln y_{m,kt} \ln y_{m',kt}$$

$$+\sum_{m=1}^{M}\sum_{n=1}^{N} \delta_{mn} \ln y_{m,kt} \ln x_{n,kt} + \sum_{n=1}^{N}\sum_{j=1}^{J} \psi_{nj} \ln x_{n,kt} \ln b_{j,kt} + \sum_{m=1}^{M}\sum_{j=1}^{J} \lambda_{mj} \ln y_{m,kt} \ln b_{j,kt}$$

$$+\pi_t t + 0.5\pi_{tt} t^2 + \sum_{n=1}^{N} \alpha_{nt}\, t \ln x_{n,kt} + \sum_{m=1}^{M} \beta_{mt}\, t \ln y_{m,kt} + \sum_{j=1}^{J} \gamma_{jt}\, t \ln b_{j,kt} + \rho \ln E_{kt}$$

$$+\sum_{n=1}^{N} \rho_{xn} \ln E_{kt} \ln x_{n,kt} + \sum_{m=1}^{M} \rho_{ym} \ln E_{kt} \ln y_{m,kt} + \sum_{j=1}^{J} \rho_{jb} \ln E_{kt} \ln b_{j,kt} + v_{kt}$$

$$= TL\ (x_{kt}, y_{kt}, b_{kt}, t, \alpha, \beta, \gamma, \delta, \psi, \lambda, \pi, \rho) + v_{kt}$$

$$k = 1 \ldots K, \quad t = 1 \ldots T \qquad (17)$$

Where *E* is a quasi- fixed input; *t* is a time trend representing technological change and appears in three different forms: (i) standalone in a first and second order; (ii) cross products with inputs; and (iii) cross products with outputs (desirables and undesirables).

As equation (17) can be interpreted as a quadratic function in the variables of lny, lnb, lnx, and t, we can apply Diewert's (1976) Quadratic Identity Lemma to this distance function (refer to appendix A.5.1). Following Orea (2002), we use the identity to write the change in the hyperbolic distance function with undesirable output (17), from one period to the next for each bank k as:

$$\ln D_H\left(x^{t+1}, y^{t+1}, b^{t+1}, t+1\right) - \ln D_H\left(x^t, y^t, b^t, t\right)$$
$$= \frac{1}{2}\sum_{m=1}^{M}\left(\frac{\partial \ln D_H(.,t+1)}{\partial \ln y_m} + \frac{\partial \ln D_H(.,t)}{\partial \ln y_m}\right)\left(\ln y_m^{t+1} - \ln y_m^t\right)$$
$$+ \frac{1}{2}\sum_{n=1}^{N}\left(\frac{\partial \ln D_H(.,t+1)}{\partial \ln x_n} + \frac{\partial \ln D_H(.,t)}{\partial \ln x_n}\right)\left(\ln x_n^{t+1} - \ln x_n^t\right)$$
$$+ \frac{1}{2}\sum_{j=1}^{J}\left(\frac{\partial \ln D_H(.,t+1)}{\partial \ln b_j} + \frac{\partial \ln D_H(.,t)}{\partial \ln b_j}\right)\left(\ln b_j^{t+1} - \ln b_j^t\right)$$
$$+ \frac{1}{2}\left(\frac{\partial \ln D_H(.,t+1)}{\partial t} + \frac{\partial \ln D_H(.,t)}{\partial t}\right) \qquad (18)$$

A logarithmic Hyperbolic Malmquist productivity index $\ln HM(.,t)$ can be defined as

$$\ln(ATFPC) = \ln HM(.,t) = \frac{1}{2}\sum_{m=1}^{M}\left(\frac{\partial \ln D_H(.,t+1)}{\partial \ln y_m} + \frac{\partial \ln D_H(.,t)}{\partial \ln y_m}\right)\left(\ln y_m^{t+1} - \ln y_m^t\right)$$
$$- \frac{1}{2}\sum_{n=1}^{N}\left(\frac{-\partial \ln D_H(.,t+1)}{\partial \ln x_n} + \frac{-\partial \ln D_H(.,t)}{\partial \ln x_n}\right)\left(\ln x_n^{t+1} - \ln x_n^t\right)$$
$$- \frac{1}{2}\sum_{j=1}^{J}\left(\frac{-\partial \ln D_H(.,t+1)}{\partial \ln b_j} + \frac{-\partial \ln D_H(.,t)}{\partial \ln b_j}\right)\left(\ln b_j^{t+1} - \ln b_j^t\right) \qquad (19)$$

The left-hand side of equation (3) can be interpreted as a logarithmic index of Adjusted Total Factor Productivity Change (ATFPC, adjusted for undesirable outputs). In a comprehensive sense, ATFPC is defined by subtracting the weighted average growth rates of inputs (x) and undesirable outputs (b) from that of desirable outputs (y). The weights used in this calculation are the distance elasticities of inputs, undesirable outputs, and desirable outputs[2], respectively. Rearranging equation (18), ln (ATFPC) can be decomposed as:

$$\ln(ATFPC) = \ln HM(.,t) = \ln D_H(.,t+1) - \ln D_H(.,t)$$
$$- \frac{1}{2}\left(\frac{\partial \ln D_H(.,t+1)}{\partial t} + \frac{\partial \ln D_H(.,t)}{\partial t}\right) \qquad (20)$$

[2] Note that the distance elasticities of inputs and undesirable outputs are negative, while the distance elasticities of desirable outputs are positive.

Equation (20) parametrically decomposes the logarithmic **A**djusted **T**otal **F**actor productivity **C**hange into two meaningful parts adjusted to undesirable outputs namely, the changes in adjusted technical efficiency (indicative of catching up) and changes in adjusted technology (indicative of innovation) follow a decomposition that aligns with the non-parametric decomposition of the Hyperbolic Malmquist productivity index into efficiency change and technology change, as introduced in Chapter 2 of this thesis. As highlighted by Orea (2002), the negative sign of the second term in equation (20) transforms technical progress into a positive value and vice versa.

If we exclude the undesirable output in equation (19), we obtain the logarithmic conventional total factor productivity change (TFPC) as follows: [insert the expression for TFPC].

$$\ln\left(\text{TFPC}\right)=\text{lnM}\left(.,t\right)=\frac{1}{2}\sum_{m=1}^{M}\left(\frac{\partial \ln D_{H}\left(.,t+1\right)}{\partial \ln y_{m}}+\frac{\partial \ln D_{H}\left(.,t\right)}{\partial \ln y_{m}}\right)\left(\ln y_{m}^{t+1}-\ln y_{m}^{t}\right)$$
$$-\frac{1}{2}\sum_{n=1}^{N}\left(\frac{-\partial \ln D_{H}\left(.,t+1\right)}{\partial \ln x_{n}}+\frac{-\partial \ln D_{H}\left(.,t\right)}{\partial \ln x_{n}}\right)\left(\ln x_{n}^{t+1}-\ln x_{n}^{t}\right) \qquad (21)$$

Therefore, the relationship between our adjusted TFP change and the conventional TFP change is

$$\text{lnHM}\left(.,t\right)=\text{lnM}\left(.,t\right)-\frac{1}{2}\sum_{j=1}^{J}\left(\frac{-\partial \ln D_{H}\left(.,t+1\right)}{\partial \ln b_{j}}+\frac{-\partial \ln D_{H}\left(.,t\right)}{\partial \ln b_{j}}\right)\left(\ln b_{j}^{t+1}-\ln b_{j}^{t}\right) \qquad (22)$$

Equation (22) ignores the contribution of scale economies to productivity change that can only be recognized under the best practice technology allowing for various returns to scale. Therefore, productivity change and its decomposition need to be redefined under the best practice technology.

To extend the decomposition of $\text{lnHM}\left(.,t\right)$ and to allow for the effect of various returns to scale, Orea drew on the ideas suggested by Denny et al. (1981) and developed a generalized Malmquist productivity index that can incorporate the scale effect. Using input distance elasticity shares rather than distance elasticities, a generalized Hyperbolic Malmquist productivity index can be defined as

$$\ln GHM(.,t) = \ln D_H(.,t+1) - \ln D_H(.,t) - \frac{1}{2}\left(\frac{\partial \ln D_H(.,t+1)}{\partial t} + \frac{\partial \ln D_H(.,t)}{\partial t}\right)$$
$$-\frac{1}{2}\sum_{j=1}^{J}\left(\frac{-\partial \ln D_H(.,t+1)}{\partial \ln b_j} + \frac{-\partial \ln D_H(.,t)}{\partial \ln b_j}\right)\left(\ln b_j^{t+1} - \ln b_j^{t}\right) \quad (23)$$
$$+\frac{1}{2}\sum_{n=1}^{N}\left(RTS(.,t+1).e_n(.,t+1) + RTS(.,t).e_n(.,t)\right)\left(\ln x_n^{t+1} - \ln x_n^{t}\right)$$
$$= \ln HM(.,t) + \frac{1}{2}\sum_{n=1}^{N}\left(RTS(.,t+1).e_n(.,t+1) + RTS(.,t).e_n(.,t)\right)\left(\ln x_n^{t+1} - \ln x_n^{t}\right)$$

Where $e_n(.,t) = \dfrac{\partial \ln D_H(.,t)/\partial \ln x_n}{\sum_{n=1}^{N}\partial \ln D_H(.,t)/\partial \ln x_n}$ and $RTS(.,t) = \left(-\sum_{n=1}^{N}\partial \ln D_H(.,t)/\partial \ln x_n\right) - 1$

To calculate the $\ln GHM(.,t)$ and its four sources we need the estimation of the translog Hyperbolic distance function [8] by imposing almost homogeneity in outputs and making an assumption about the error structure. The estimated parameters are then used to calculate technical **Eff**iciency **C**hange (**EFFC**), **T**echnical **C**hange (**TC**), **Sc**ale **Ef**fect (**SCEF**) and **U**ndesirable **O**utputs **Ef**fect (**UOEF**). The generalized lnATFPC is the sum of these four components. The multiplicative form of the generalized ATFPC is given by (24), as follows:

$$ATFPC = GHM = EFFC \times TC \times UOEF \times SCEF \quad (24)$$

Where, $EFFC = \exp\left(\ln D_H(.,t+1) - \ln D_H(.,t)\right) = \dfrac{D_H(.,t+1)}{D_H(.,t)} = e^{\left(-u_{t+1} + u_t\right)}$;

$$TC = \exp\left(-\frac{1}{2}\left(\frac{\partial \ln D_H(.,t+1)}{\partial t} + \frac{\partial \ln D_H(.,t)}{\partial t}\right)\right) \quad ;$$

$$UOEF = \exp\left(-\frac{1}{2}\sum_{j=1}^{J}\left(\frac{-\partial \ln D_H(.,t+1)}{\partial \ln b_j} + \frac{-\partial \ln D_H(.,t)}{\partial \ln b_j}\right)\left(\ln b_j^{t+1} - \ln b_j^{t}\right)\right) ;$$

$$SCEF = \exp\left(\frac{1}{2}\sum_{n=1}^{N}\left(RTS(.,t+1).e_n(.,t+1) + RTS(.,t).e_n(.,t)\right)\left(\ln x_n^{t+1} - \ln x_n^{t}\right)\right)$$

Data

This study uses data from the balance sheets and income statements of individual commercial banks obtained from Tunisian bank association (TBA) for the period from 1992 to 2014. The balanced panel data, which consist of 230

observations, include 10 commercial banks. These 10 banks consist of 7 private banks and 3 state banks.

To define outputs and input prices, we follow the widely accepted intermediation approach (Sealey and Lindley, 1977). In our distance functions, in line with Fukuyama and Weber (2009), Barros et al. (2012), Assaf et al. (2011), we consider total loans and other earning assets as desirable outputs and non-performing loans as undesirable output, produced by a set of input such as, labor, physical capital and borrowed funds. Equity is included in the distance functions as a quasi-fixed input (Hughes and Mester, 2013). Table 3 describes the explanatory variables used to estimate the distance functions.

Table 3: Key variables description in our panel data

Variable	Symbol	Name	Description
Outputs	Y1 Y2 b	Total loans Other earning assets Nonperforming loans	Sum of short- and long-term loans Total earning assets less Total loans Total of classified loans [3](class2+3+4)
Inputs	X1 X2 X3	Physical capital Borrowed funds Labour	Fixed assets Total funding Personnel expenses
Other variable	X4=E	Equity	Equity capital

It should be noted that even if non-performing loans do not technically generate productive assets, non-performing loans have a direct impact on banks' provisions and contingencies and net profits. Therefore, they should be included in the banks' production process as an undesirable output (Juo, J. C. 2014). Furthermore, in an analysis of the earnings efficiency of banks, Färe et al. (2004) found that the use of bank capital as a quasi-fixed inputs is sufficient to take into account both risk-based capital requirements and the risk/return trade-

[3] Prudential regulations introduced in 1991 invited banks to classify their assets into four categories according to their delinquency. Banks are required to constitute a loss provision of 20 percent for loans in the second category (0-90 days past due), 50 percent for category three (90-180 past due), and 100 percent for the fourth category (180-360 past due).

off that bank owners face. Thus, we include equity as a quasi-fixed input in estimating the distance functions.

Table .4: Summary statistics of key variables in our panel data

Inputs and outputs	Mean	Median	Max	Min
y1 : Total loans	2 055 049	1 518 318	6 927 167	241 061
y2 : Other earning assets	489 338	327 355	2 597 095	38 568
b : Non performing	471 146	331 982	2 399 618	74 575
x1 : Labor	41 838	32 497	164 744	5 508
x2 : Borrowed funds	2 313 763	1 766 748	7 824 141	284 543
x3 : Physical capital	48 870	41 882	212 814	6 581
x4 : Equity	235 079	173 972	670 302	499

Table 4 presents descriptive statistics of all input and output variables used in this study. These statistics indicate that Borrowed funds plays the most important role in the production process of commercial Tunisian banks. These funds generate costs. A lower funding cost is one of the key factors that determine a bank's net interest margin. A bank has a funding cost advantage when it pays less interest on borrowed funds compared to other banks. This directly improves net interest margins (NIM). So, the borrowed funds are the input most requested to be saved among the inputs.

Empirical Results

All the stochastic frontier models presented above are estimated using maximum likelihood techniques based on the computer program FRONTIER 4.1 (Coelli. 1996). The maximum likelihood estimates of the three distance functions are presented in Table 5.5 To avoid convergence problems, each output and input variable except technology variable t has been divided by its geometric mean; hence the first order coefficients can be interpreted as distance elasticities evaluated at the sample mean.

Estimates of Distance Functions

Table 5 summarizes key information along with parameter estimates for our three models. Notably, the parameters γ corresponding to the estimated proportion of bank inefficiency in the composed total error term are found to be significantly different from zero in all hyperbolic distance functions.

Table 5: Maximum Likelihood Parameter Estimates for Stochastic Hyperbolic Distance Functions

Distance Functiou		Hyperbolic		Enhanced Hyperbolic		borrowed Funds Saving Hyperbolic	
Vbles	parm	Coef	std	Coef	std	Coef	std
Constant	α0	0.10755***	0.02183	-0.0228**	0.00992	0,04115***	0,00977
lnx1	α1	0.02913**	0.01356	0.01336	0.01127	0,02464***	0,00732
lnx2	α2	-0.87921***	0.03366	-0.49416***	0.0197	-0,48420***	0,00944
lnx3	α3	-0.04531**	0.02745	0.00925	0.01511	-0,01190	0,01415
lny2	β2	0.13197***	0.01587	0.09315***	0.01186	0,08440***	0,00797
0.5lnx1lnx1	α11	-0.09543*	0.06636	0.0107	0.04467	-0,05949*	0,03618
0.5lnx2lnx2	α22	-0.62521***	0.14172	-0.34331***	0.09871	-0,06505***	0,02212
0.5lnx3lnx3	α33	-0.18993*	0.12134	-0.19824**	0.07725	-0,04363	0,06600
lnx1lnx2	α12	0.24194***	0.07687	0.02191	0.05329	0,06599**	0,02249
lnx1lnx3	α13	-0.10397**	0.04766	-0.03813	0.03568	-0,04005*	0,02848
lnx2lnx3	α23	0.24042**	0.09934	0.24908***	0.07804	0,03977	0,03136
0.5lny2lny2	β22	0.12226***	0.02793	0.11855***	0.01695	0,04260***	0,01605
lny2lnx1	δ21	0.13055***	0.04427	-0.01408	0.02749	0,05070**	0,02216
lny2lnx2	δ22	-0.12307***	0.03703	-0.03332**	0.01633	-0,01555	0,01280
lny2lnx3	δ23	0.06008*	0.04190	0.04226**	0.01673	0,02609*	0,01526
b	γ1	-0.02469**	0.01503	-0.00459*	0.00335	0,00191	0,00702
0.5lnblnb	γ11	-0.03222***	0.01130	-0.05094***	0.01029	-0,00491	0,00588
lnblny2	λ12	-0.04578***	0.01468	-0.05112***	0.0119	-0,02604***	0,00908
lnblnx1	ψ11	-0.05371***	0.01629	0.0149**	0.00793	-0,03672***	0,01099
lnblnx2	ψ12	0.05736**	0.02494	0.03617**	0.01458	0,00536	0,00753
lnblnx3	ψ13	0.03863*	0.02503	0.01568	0.01344	0,01322	0,01143
lnbln x4	ψ14	0.01835	0.01656	-0.01255	0.01187	0,00883	0,01092
lnx4	α4	-0.03524**	0.01365	-0.00754	0.01056	-0,01458***	0,00820
0.5lnkln x4	α44	-0.05968***	0.01614	-0.025**	0.00924	-0,02183***	0,00755
lnx1ln x4	α14	-0.04830**	0.02561	0.01661	0.01602	-0,02008	0,01627
lnx2ln x4	α24	0.01280	0.03662	-0.02233	0.02584	0,00446	0,01376
lnx3ln x4	α34	-0.05667*	0.03873	0.02026	0.02561	-0,00773***	0,01466
lny2ln x4	δ24	0.07580***	0.02477	0.02052*	0.01559	0,02371**	0,01648
T	ηt	-0.00388	0.00355	-0.00202	0.00285	-0,00238**	0,00166
0.5TT	ηtt	0.00018	0.00033	0.00007	0.00032	0,00022*	0,00015
Tlnx1	ηt1	-0.00031**	0.00018	0.00006	0.00011	-0,00015*	0,00009
Tlnx2	ηt2	-0.00422**	0.00173	-0.00149	0.00127	-0,00169**	0,00086
Tlnx3	ηt3	0.00262	0.00211	0.00091	0.00115	0,00063	0,00063
Tlny2	ηty	0.00550***	0.00151	-0.00197**	0.00094	0,00139**	0,00071
Tlnb	ηtb	0.00176**	0.00087	0.00049	0.0008	0,00079**	0,00046
Constant	△0	-1.07531**	0.66705	-0.01396	0.12145	0,10646***	0,05805
ROA	△1	-0.01055***	0.00197	-0.0071***	0.00077	-0,00468***	0,00101
ROE	△2	0.43069*	0.27688	0.00513	0.08696	-0,00414***	0,00071
KLR	△3	0.01948	0.07977	-0.00783	0.02028	0,05304**	0,02915
LIQR	△4	-3.61337***	0.69339	-0.61496***	0.12774	-1,60797***	0,22995
SR	△5	-1.72941***	0.27059	-0.52944***	0.0969	-1,04771***	0,12581
C4	△6	0.58157	0.57128	0.32126**	0.13573	1,02666***	0,14180
HHI	△7	2.36764***	0.44356	-0.02424	0.14321	1,30384***	0,16545
AD	△8	1.22371***	0.22548	0.18061**	0.07242	0,65259***	0,08074
ID	△9	-0.57502***	0.12899	-0.07062**	0.03283	-0,40486***	0,05525
SZ	△10	0.09539**	0.05613	0.00382	0.01212	-0,01034***	0,00461
OWNER	△11	0.07934**	0.04534	0.00421	0.00822	-0,00553*	0,00406
GDP	△12	-0.02605**	0.00940	-0.00135	0.00225	-0,01673***	0,00461
INF	△13	-0.00366**	0.00214	-0.0003	0.00085	0,00086	0,00058
σ^2		0.01661***	0.0027	0.00808***	0.00010	0,00316***	0,00054
γ		0.96311***	0.01112	0.30661 **	0.1280	0,91328***	0,03096
LLF		350.862		500.701		519,04938	
LR test		149.322		116.925		129,47319	
$\overline{TE}$		0.936		0,970		0.973	

Notes: 1. $\sigma^2 = \sigma_u^2 + \sigma_v^2$; $\gamma = \sigma_u^2 / \left(\sigma_u^2 + \sigma_v^2\right)$; 2. χ^2 critical values for 5% significance level are in the parentheses;

3. ***, ** and * indicate 1%, 5% and 10% significance levels, respectively.

Particularly, these parameters exhibit high values, close to unity, in both the hyperbolic and financial saving hyperbolic distance functions. This indicates that a substantial portion of the variations in observed productions from the frontier can be attributed to bank inefficiency, in contrast to the Enhanced hyperbolic distance function.

The final row in Table 5 presents the results of a one-sided log-likelihood ratio (LR) test comparing the standard response function (OLS) to the full frontier model. The null hypothesis in this test is that $\gamma = 0$ versus the alternative hypothesis that $\gamma > 0$. If the null hypothesis is accepted, it could indicate that σ^2 and Δi are both zero, suggesting that inefficiency effects in the distance function are not present. In such a case, a specification with parameters that can be appropriately estimated using ordinary least squares (OLS) might be suitable (Coelli, 1996). On the contrary, if the null hypothesis is rejected, it might suggest that a standard mean response function is not an adequate representation of the data. Notably, in all three hyperbolic distance functions, the null hypothesis is rejected in favour of the stochastic frontier distance function.

Elasticities

By looking at Table 5, it is clear that in all three specifications, the coefficients of borrowed funds inputs (α2) present the expected significantly negative sign, as any increase in their values would increase distances to the frontier. In contrast, the coefficients of physical capital inputs (α1) show an unexpected positive sign, in all specifications. The coefficients of labor inputs (α3) present the expected significantly negative sign only for the hyperbolic distance function. The coefficients of other earning assets (β2) in all three specifications have the expected positive sign; either of them is significant at the 1% level, signifying that any increase in the quantity of good outputs produced (all else being equal) would result in a smaller distance to the frontier. These findings affirm that, at the sample mean, hyperbolic, Funds saving hyperbolic, and enhanced hyperbolic distance functions exhibit a non-decreasing pattern in desirable outputs.

Table 5: Monotonicity Tests at the sample mean

Variable	Elasticity	Coefficient	Standard Error	Monotonicity	
Hyperbolic distance function					
lnx1	α1	0.02913**	0.01356	non-increasing	Non-satisfied
lnx2	α2	-0.87921***	0.03366	non-increasing	satisfied
lnx3	α3	-0.04531**	0.02745	non-increasing	satisfied
lny2	β2	0.13197***	0.01587	non-decreasing	satisfied
b	γ1	-0.02469**	0.01503	non-increasing	satisfied
lnx4	α4	-0.03524**	0.01365	non-increasing	satisfied
Enhanced Hyperbolic distance function					
lnx1	α1	0.01336	0.01127	non-increasing	Non-satisfied
lnx2	α2	-0.49416***	0.0197	non-increasing	satisfied
lnx3	α3	0.00925	0.01511	non-increasing	Non-satisfied
lny2	β2	0.09315***	0.01186	non-decreasing	satisfied
b	γ1	-0.00459*	0.00335	non-increasing	satisfied
lnx4	α4	-0.00754	0.01056	non-increasing	satisfied
Funds Saving Hyperbolic distance function					
lnx1	α1	0,02464***	0,00732	non-increasing	Non-satisfied
lnx2	α2	-0,48420***	0,00944	non-increasing	satisfied
lnx3	α3	-0,0119	0,01415	non-increasing	satisfied
lny2	β2	0,08440***	0,00797	non-decreasing	satisfied
b	γ1	0,00191	0,00702	non-increasing	Non-satisfied
lnx4	α4	-0,01458***	0,0082	non-increasing	satisfied

The coefficients of undesirable output (γ1) are significantly different from zero and also have the expected negative sign in the hyperbolic distance and enhanced hyperbolic distance functions. This finding indicates that these last distance functions are non-increasing in the undesirable output at the sample mean, as required by the monotonicity condition for this output.

The selection of one specification from the three, which proves a good fit to the data set examined, is a difficult task. Because the three specifications are not nested one inside the other, the LR test has no meaning here. Alternatively, the choice of the appropriate specification could be perceived in two criteria. The first one is the monotonicity conditions; the second is the percentage of the significant parameters.

According to table 6, most of the monotonicity properties are only fulfilled by the hyperbolic distance function specification. In addition, this same specification holds the highest percentage of significant parameters. Thus, the hyperbolic specification can be considered as the most appropriate specification, which attests to a good fit with all the data examined.

Efficiency

The summary statistics of the estimated technical efficiency are presented in Table 5. Tunisian banks have an average hyperbolic, a borrowed saving hyperbolic, and an enhanced hyperbolic technical efficiency $\left(\overline{\text{TE}}\right)$ of 0.936, 0.973, and 0,970, respectively. For average hyperbolic technical efficiency of 0.936, this indicates that on average Tunisian banks could increase loan and other earning assets by 6.8% ((1/0.936)-1 = 0.068) while simultaneously reducing nonperforming loans by 6.4% (1-0.936 = 0.064) when keeping inputs unchanged and using current technology. For Financial saving hyperbolic efficiency, Tunisian banks have a higher average efficiency score, which means on average Tunisian banks could increase loan and other earning assets by 2.7% ((1/0.973)-1 = 0.0277) while simultaneously reducing nonperforming loans and financial funds input by 2.7% (1-0.973=0.027) when keeping fixed assets and labor inputs unchanged and using current technology.

When considering enhanced hyperbolic efficiency, on average Tunisian banks could increase loan and other earning assets by 3.09% ((1/0.97)-1 = 0.0309 while simultaneously reducing nonperforming loans and all inputs by 3% (1-0.97 = 0.03) when using current technology and removing technical inefficiency.

Adjusted total factor productivity change (ATFPC) over time

The ATFP change is estimated with the panel data of all 10 Tunisian banks. It should be noted that the indices begin with the year 1992 which is the base year (index level of 1.00). The ATFP change assigns numerical vales; when a value greater than one indicates positive productivity change or productivity progress, a value less than one notes productivity decline or productivity regress. Percentage change in productivity is given by (Productivity Change – 1) x 100.

The Table 7 and figure 1 report the average values (annually) of ATFP change over time. We may note that the banking sector has experienced no change in mean TFP over the sample period (1992-2014). However, in the first sub-period 1992-96, ATFP exhibited a change at an average of 0.5%, thanks to the restructuring program of the Tunisian banking system, which began in 1987 and intended to enhance the competition within the banking sector, mobilize savings and led to a more efficient allocation of resources.

Table 6 : Average Adjusted total factor productivity change over time

Year	All Banks	Public Banks	Private Banks
1992	1.000	1.000	1.000
1993	0.973	0.983	0.958
1994	1.004	1.04	0.948
1995	1.029	0.997	1.076
1996	1.014	1.064	0.939
1997	0.97	0.97	0.97
1998	0.99	0.975	1.006
1999	1.057	1.065	1.049
2000	0.956	0.974	0.939
2001	1.01	1.01	1.011
2002	0.99	0.99	0.99
2003	0.991	1.011	0.983
2004	0.991	1.024	0.977
2005	1.006	1.004	1.006
2006	0.999	0.991	1.002
2007	1.004	1.015	0.999
2008	1.009	1.013	1.007
2009	0.961	1.033	0.929
2010	1.015	1.017	1.014
2011	0.981	0.972	0.984
2012	1.064	1.027	1.081
2013	0.997	1.01	0.992
2014	0.987	0.934	1.01
1992-96	1.005	1.021	0.980
1997-01	0.997	0.999	0.995

2002-10	0.996	1.011	0.990
2011-14	1.007	0.986	1.017
1992-14	1.000	1.005	0.994

Source : Author's calculations.

Indeed, to successfully achieve this program, reforms have been carried out in connection with interest rate liberalization and credit allocation, introduction of new indirect monetary policy, strengthening prudential regulation, opening the financial sector to foreign financial institutions and promotion of the equity market. In the second sub-period 1997-01, Tunisian banks experienced productivity regress -0.3%, which could be expected since they were undergoing a high volume of NPLs and low level of provisioning. The ratio of gross NPLs to total gross claims declined from 23% in 1997 to 21% in 2000, but it remained high by international standard. Furthermore, the level of provisioning of banks' NPLs that varied between 42% and 59% over this sub-period remained low, although most banks are in compliance with current provisioning regulations[4] set by the BCT.

In the third sub-period (2002-2010), Tunisian banks recorded a productivity regress -0.4% which was more important than the one recorded in the second sub-period. It should be noted that despite the significant improvement in financial soundness indicators over the period 2002-2010, the level of nonperforming loans (NPLs) remained relatively high hampering banks profitability and development and calling for additional provisions. The higher level of NPLs is the fallout of the tourism crisis in 2002, which has not yet been resolved. In the last sub-period 2011-2014 that coincides with the post-revolution period, the ATFP exhibited a change at an average of 0.7% thanks to the establishment of an ambitious program of structural reforms proposed by the government authorities, which included as a priority, the development of the financial sector through the strengthening of banking regulation and in particular the restructuring of public banks. These reforms may be able to improve investments and create a more favorable business climate.

[4] These regulations do not require loans backed by real estate collateral to be provisioned, even though realizing real estate collateral suffers from long delays in judicial procedures.

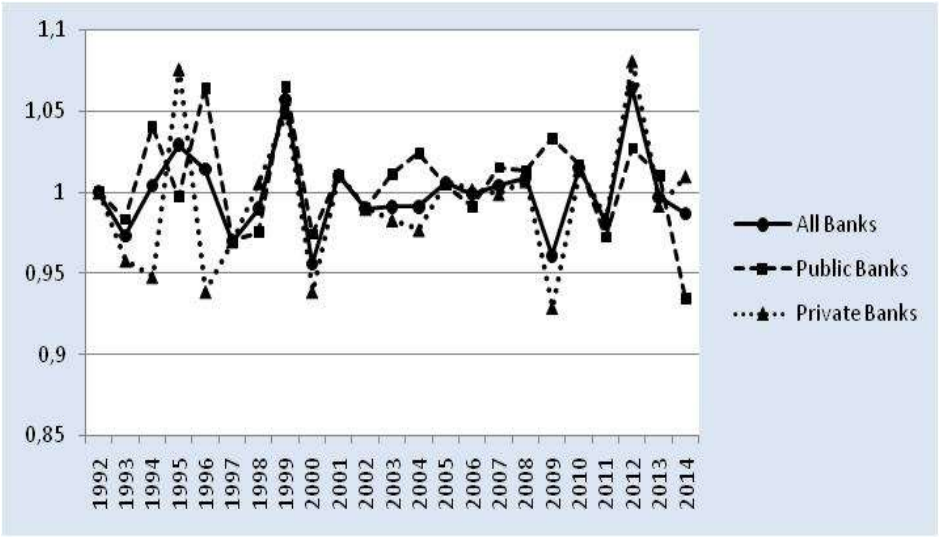

Figure 1: Average total factor productivity change over time

At the bank category level, public banks have the highest ATFP change 0.5% on average while private banks have the lowest ATFP change -0.6% on average. Although the rate of ATFP change remain strikingly different, it is widely agreed that private banks are the main contributors to poor performance. As seen in Figure 5.6.1, the TFP change of all banks follows the similar pattern as the ATFP change of private banks. In other words, the shape of the ATFP change is determined by private banks ATFP change.

Adjusted total factor productivity change decomposition

To shed more light on the contribution of each component of ATFP change, we report the average values of the effect of each component in Table 5.8, according to equation (24) of our model. We may note that over the studied period, banking sector has experienced progress in term of Efficiency change and technical change by 0.5%, and 0.3%, respectively. However, scale effect changes and NPLs effect changes have declined by -0.1% and -0.4%, respectively. Thus, over the entire period (1992-2014), there was no change in the average ATFP.

ATFP progress has been recorded in only ten out of the 23 years reported (1994, 1995, 1996, 2001, 2005, 2007, 2008 2010 and 2012) and the rest exhibited ATFP regress. The rates of ATFP change ranged between 6.4% (2012) and 0.4% (2007 and 1994) showing productivity progress. In contrast,

the rates of ATFP change ranged between -4.4% (2000) and -0.1 % (2006) noting a productivity regress.

The average annual change rates showed that during the first sub-period 1992-96, ATFP change in the banking sector as a whole has improved at the rate of 0.5% due to increases in efficiency change (1.5%) which offset deterioration in the scale effect change, technical change and NPLs effect change. During the second sub-period 1997-2001, ATFP change in all banks, on average, declined at a rate of -0.3% due to large losses in scale effect change (0.3%). During the third sub-period 2002-2010, ATFP change again declined but at a greater rate of -0.4% due to large losses in efficiency changes (-0.3%) and the negative effect of NPLs (-0.6%). In the last sub-period 2011-2014, all banks recorded mean TFP progress of 0.7% which is attributed to potentials gains generated by efficiency change (0.9%), scale effect change (0.1%), and technical change (0.8%).

Table 7: Total factor productivity change decomposition over time (all banks)

	ATFPC	***EFFC***	***TC***	***SCEF***	***UOEF***	**TFPC**
Years	(1)=(2)*(3)*(4)*(5)	(2)	(3)	(4)	(5)	(6)=(2)*(3)*(4)
1992	1.000	1.000	1.000	1.000	1.000	1.000
1993	0.973	1.016	0.996	0.990	0.973	0.974
1994	1.004	1.020	0.997	0.992	0.993	1.012
1995	1.029	1.007	0.998	1.000	1.024	1.034
1996	1.014	1.017	0.999	0.998	0.996	1.028
1997	0.970	0.993	0.999	0.992	0.985	0.954
1998	0.990	0.984	1.000	0.999	1.007	0.974
1999	1.057	1.005	1.000	1.006	1.062	1.069
2000	0.956	1.039	1.000	0.987	0.950	0.981
2001	1.010	1.008	1.001	0.999	1.002	1.018
2002	0.990	0.987	1.002	1.000	1.001	0.979
2003	0.991	0.999	1.002	0.999	0.990	0.992
2004	0.991	1.001	1.003	0.997	0.990	0.993
2005	1.006	1.008	1.003	0.998	0.996	1.015
2006	0.999	1.005	1.004	1.000	0.990	1.008
2007	1.004	1.002	1.004	1.002	0.996	1.011
2008	1.009	1.007	1.005	0.998	1.000	1.019
2009	0.961	0.969	1.005	1.003	0.983	0.939
2010	1.015	1.002	1.006	1.004	1.004	1.026
2011	0.981	0.980	1.007	1.001	0.993	0.969
2012	1.064	1.051	1.008	1.002	1.003	1.130
2013	0.997	1.001	1.008	0.999	0.989	1.005
2014	0.987	1.003	1.009	1.000	0.976	0.998
1992-1996	1.005	1.015	0.998	0.995	0.996	1.012
1997-2001	0.997	1.006	1.000	0.997	1.001	0.999
2002-2010	0.996	0.997	1.003	1.000	0.994	0.998
2011-2014	1.007	1.009	1.008	1.001	0.990	1.026
1992-2014	1.000	1.005	1.003	0.999	0.996	1.006

Source: Author's calculations. ATFPC Adjusted Total Factor

Productivity Change, EFFC Efficiency Change, TC Technical Change, SCEF Scale Effect Change, UOEF Undesirable Output Effect Change and TFPC Total Factor Productivity Change

In order to further refine our analyses, we seek in the following step to know the evolution of each component over the studied period. We note that after, adding-in the additional component of the undesirable output effect (NPLs effect), TFP change declines from 0.6% to reach 0% per year. As seen in Figure 2, the NPLs effect (UOEF) of all banks follows the similar pattern as the ATFP change.

In fact, The NPLs effect (UOEF) was consistently the driving force of TFP change. Over the whole period, the NPLs explain the decrease in the TFP change, on average to -0.4%. However, the positive effect of the NPLs recorded by all banks during the second sub-period (1997-2002) attests to the success of the law launched in 1997 governing the creation of private asset management companies (AMCs) charged with the purchase and collection of NPLs. This measure enabled the NPLs ratio to fall from 23% in 1997 to 21% in 2000.

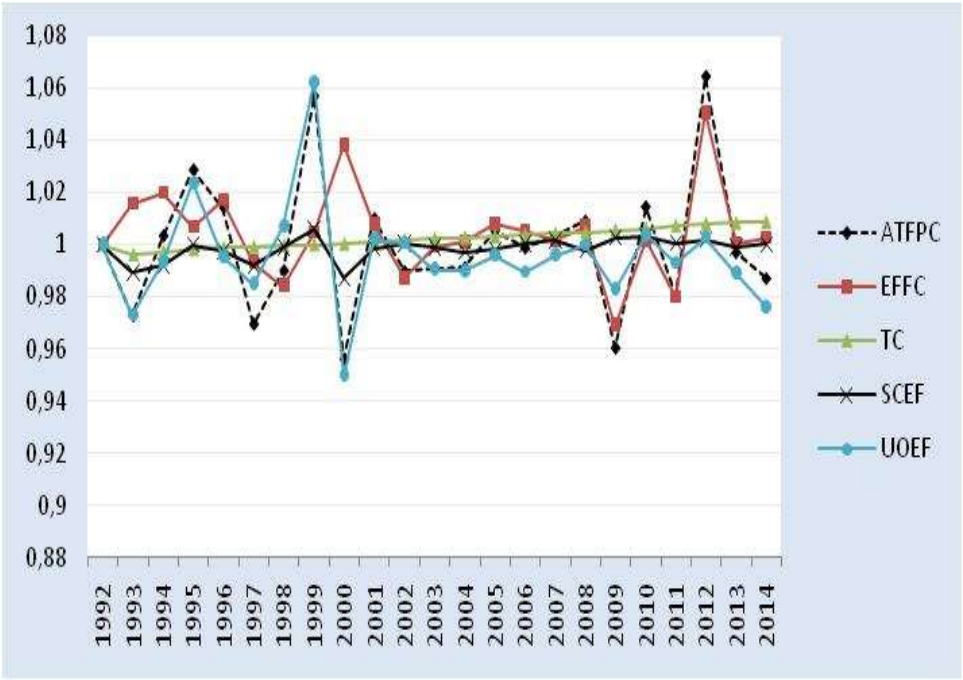

Figure 2: Average TFP change decomposition over time

It is worth noting that the negative effect of NPLs on the TFP change corroborates the results found by Altunbas et al. (2000) and Mamatzakis et al. (2015). Indeed, by incorporating the nonperforming loan ratio as a control variable in the cost function, Altunbas et al. (2000) identified a positive relationship between nonperforming loans and inefficiency. Similarly, Mamatzakis et al. (2015) reported a negative impact of problem loans on Japanese bank performance.

Regarding the technical change, we find strong evidence of technological progress over the whole studied period. Indeed, technology accounts for the increase in ATFP change on average at 0.3%. As seen in Figure 2, the pattern of technical change shows a positive upward trend. It is from 1999 that technological progress has a positive effect on the TFP change. This might be due to a program of modernization of the banking system implemented under the leadership of the BCT. This program aims primarily to set up an infrastructure for cash clearing between banks, expand the use of credit cards, strengthen the information technology safety of banks and modernize the training bank staff. Since October 2002, banks have been required to replicate all electronic information on an independent backup server.

Turning to the scale effect change, we find the negative impact of scale over the whole studied period. This result is consistent with the expectation that the Tunisian banks are operating with decreasing economies of scale (see chapter 3 of the present thesis). Therefore, the scale effect contributes around -0.1% on average to TFP change. Specifically, the negative contributions of scale to ATFP change in the first (1992-1996) sub-period and the second (1997-2001) one were -0.5 % and -0.3%, respectively. However, the third (2002-2010) sub-period and the fourth (2011-2014) sub-period exhibit slight positive scale effects, which are 0.0% and 0.1% respectively. These effects are not enough to offset the negative ones. Our findings coincide with the view suggesting that the wave of restructuring-spanning from the privatization to the Merger- is not sufficient to internalize the negative scale effect.

Figure 2 provides a clear image that technical efficiency change is very imperative to explain the APTF change. Indeed, the efficiency change is very volatile over the sample period and the whole pattern of ATFP change has been

highly influenced. So, the efficiency change contributes around 0.5% on average to TFP change. This could be explained by reforms being carried out in connection with interest rate liberalization and credit allocation, introduction of new indirect monetary policy, strengthening of prudential regulation, opening of the financial sector to foreign financial institutions and promotion of the equity market.

Adjusted total factor productivity change decomposition respecting banks ownership status

At this level of analysis, we have thus far assumed that private and public banks originated from the same legal and business environment. However, it might be questionable to aggregate private and public banks into a common frontier. In this phase, we test whether there is a significant difference between the technology employed by private and public banks. Public and private banks might have different objectives that are not closely aligned. Generally, the principal goal of the government is to try to maximize social welfare. Therefore, public banks might be seen as vehicles for raising capital to finance projects with high social returns, but possibly low profit returns. In contrast, private banks are more incentive to maximize profits or to minimize costs over a longer term in order to survive. Finally, public banks seem to endure serious agency problems when compared to private banks.

Following the procedures outlined in Elyasiani and Mehdian (1992), as well as Isik and Hassan (2002) and others, we utilize a set of parametric tests (t-test and sd-test) and non-parametric tests (Kolmogorov–Smirnov and Mann–Whitney [Wilcoxon Rank-Sum]) to examine the null hypothesis of identical frontiers between the efficiency and productivity of private and public banks.

Table 8: Summary of parametric and non- parametric tests for the null hypothesis that public (pub) and private (priv) banks possess identical technologies

Productivity measures(b)	**Test groups(a)**							
	Parametric test				**Non-Parametric test**			
Individual test s	t- test		sd-test		Mann–Whitney [Wilcoxon Rank-Sum test		Kolmogorov–Smirnov [K–S] test	
null hypotheses H0	Mean priv = Mean pub		$\frac{\sigma(priv)}{\sigma(pub)}=1$		Median priv = Median pub		Dist.private = Dist.public	
Test statistics	T (prob >t)	decision (d)	F (prob < F)	decision (d)	Z (prob > z)	decision (d)	k-s (prob >k-s)	decision (d)
ATFP	-1.045 (0.301)	Acc H0	1.6382 (0.266)	Acc H0	-1.315 (0.1885)	Acc H0	0.2727 (0.387)	Acc H0
EFFC	-0.096 (0.923)	Acc H0	1.6069 (0.285)	Acc H0	-0.211 (0.832 6)	Acc H0	0.1818 (0.860)	Acc H0
TC	-2.197 (0.033)	Rej H0	0.8313 (0.676)	Acc H0	-1.989 (0.0467)	Rej H0	0.2727 (0.387)	Acc H0
SCEF	-0.297 (0.767)	Acc H0	2.6242 (0.032)	Rej H0	0.095 (0.924 6)	Acc H0	0.1818 (0.860)	Acc H0
UOEF	-0.625 (0.535)	Acc H0	3.7900 (0.003)	Rej H0	-1.973 (0.0485)	Rej H0	0.3636 (0.109)	Acc H0

Source: *Author's calculations. (a) The null hypothesis that public (pub) and private (priv) banks are drawn from the same productivity population. The numbers in parentheses are the p-values associated with the relative test.(b) ATFPC Adjusted Total Factor Productivity Change, EFFC Efficiency Change, TC Technical Change, SCEF Scale Effect Change, Undesirable Output Effect Change and TFPC Total Factor Productivity Change. (d)* Acc H0: Accept H0, Rej H0: Reject H0

However, in table 9, we do not find statistically significant difference in the mean between the efficiency and productivity of public and private banks. The t-test results are further confirmed by the results derived from the non-parametric Mann–Whitney [Wilcoxon Rank-Sum] and Kolmogorov–Smirnov tests. Hence, we conclude that there is no significant statistical difference between the efficiency and productivity of public and private banks.

Based on the previous tests, we failed to reject the null hypothesis at the 5% levels of significance indicating that the public and private banks are drawn from the same population and have identical technologies. Furthermore, the results from the sdtest for equality of variances do not reject the null hypothesis suggesting that the variances among the private owned and public owned banks are equal. Thus, we can assume that the variances among the private and public banks are equal.

In order to identify the significance of individual relationships between the decomposed components and the ATFPC index, the Pearson and Spearman rank order correlation coefficients are presented in Table 10. The Pearson correlation results confirmed that there were positive and statistically significant relationships (at 5% and 10% levels) between the ATFPC index and EFFC, SCEF and UOEF components. For all banks, the Pearson correlation coefficient between UOEF and ATFPC is 0.772, representing a high order relationship when compared to those associated with EFFC and SCEF. Furthermore, the same analysis was repeated for private banks and public ones. In the case of private banks, the highest Pearson coefficient is estimated between UOEF and ATFPC (0.817), while in the case of public banks, the highest Pearson coefficient is estimated between EFFC and ATFPC (0.712). Added to that, the Spearman rank-order correlation coefficients are all statistically different from

zero indicating a strong association between the productivity index and the decomposed components.

All Spearman rank-order correlation coefficients present positive relationships between the decomposed components and the ATFPC index. The correlation coefficients suggest that all components except TC have an impact on the ATFPC index of all banks. UOEF has the greatest negative effect on the productivity change of private banks, whereas EFFC has the strongest positive effect on the productivity change of public banks.

Table 9 : Pearson (p) and Spearman(s) Correlation Coefficients among ATFPC index and Decomposed Components of all, private and public Banks

All banks					
	ATFPC	EFFC	TC	SCEF	UOEF
ATFPC					
P	1				
S	1				
EFFC					
P	0.473**	1			
S	0.420**	1			
TC					
P	0.0211	-0.254	1		
S	0.100	-0.121	1		
SCEF					
P	0.353*	-0.347	0.514**	1	
S	0.558**	-0.374*	0.526**	1	
UOEF					
P	0.772**	0.0464	-0.073	0.482**	1
S	0.779**	-0.131	-0.102	0.672**	1
Private banks					
	ATFPC	EFFC	TC	SCEF	UOEF
ATFPC					
P	1				
S	1				
EFFC					
P	0.456**	1			
S	0.289	1			
TC					

P	0.313	0.099	1		
S	0.2612	0.0620	1		
SCEF					
P	0.6194**	-0.116	0.558**	1	
S	0.672**	-0.396*	0.472**	1	
UOEF					
P	0.817**	0.0453	0.147	0.702**	1
S	0.724**	-0.371*	-0.0055	0.815**	1

Public banks

	ATFPC	EFFC	TC	SCEF	UOEF
ATFPC					
P	1				
S	1				
EFFC					
P	0.712**	1			
S	0.733**	1			
TC					
P	|0.0099	-0.2571	1		
S	-0.1289	-0.2870	1		
SCEF					
P	0.539**	0.105	0.261	1	
S	0.448**	0.0371	0.4060	1	
UOEF					
P	0.487**	-0.0658	-0.151	0.271	1
S	0.627**	-0.0129	-0.1602	0.3549	1

Pearson correlation coefficient- first row of each cell. Spearman rank order correlation coefficient presented in second row of each cell.

*** Correlation is significant at the 0.05 level (2-tailed).*

** Correlation is significant at the 0.1 level (2-tailed).*

*** Spearman Correlation is significant at the 0.05 level (2-tailed).*

Adjusted total factor productivity change decomposition per banks

The average results for ATFP change and its components for all banks are presented in Table 11. The results show that only four banks have recorded an average ATFP progress over the sample period. The highest average progress in ATFP has been recorded by Bank 1 (2.4%) followed by bank 3 (1.1%), bank 5(0.3%) and Bank 8 (0.6%). The average regress in ATFP is observed in Bank

6 (-0.2%), Bank 4 (-0.9%), Bank 2 (-1.2%), Bank 7 (-0.1%), Bank 9(-0.8%) and Bank 10 (-3.7%).

Table 10: Adjusted Total Factor Productivity Change decomposition per type of banks.

Banks	*NAME*	ATFPC (1)=(2)*(3)*(4)*(5)	*EFFC* (2)	*TC* (3)	*SCEF* (4)	*UOEF* (5)
bank1	*BNA*	**1,024**	**1,013**	**1,006**	**1,001**	**1,004**
bank2	*STB*	**0,988**	**0,996**	**1,005**	**0,998**	**0,990**
bank3	*BH*	**1,011**	**1,003**	**1,003**	**1,000**	**1,005**
bank4	*UIB*	**0,991**	**1,008**	**1,003**	**0,994**	**0,987**
bank5	*ATTIJARI*	**1,003**	**1,003**	**1,003**	**0,998**	**1,000**
bank 6	*UBCI*	**0,998**	**1,000**	**1,001**	**0,998**	**0,999**
bank 7	*BIAT*	**0,999**	**1,001**	**1,004**	**0,997**	**0,998**
bank 8	*BT*	**1,006**	**1,004**	**1,001**	**1,002**	**1,000**
bank 9	*AB*	**0,992**	**1,000**	**1,002**	**1,004**	**0,986**
bank 10	*ATB*	**0,963**	**1,000**	**0,999**	**0,993**	**0,971**

Source: *Author's calculations. ATFPC Adjusted Total Factor Productivity Change, EC Efficiency Change, TC Technical Change, SCEF Scale Effect Change and UOEF Undesirable Output Effect Change.*

The decomposition of ATFP change reveals that the largest improvement in mean ATFP change for Bank1, Bank 3, Bank 5, and Bank 8 is attributed to efficiency progress, technical progress and positive effect of undesirable output. A rather contrasted picture is observed for the Bank 2, Bank 6 and Bank 10 where the efficiency regress and the negative effect of undesirable output are the principal contributor to mean ATFP regress. On the other hand, scale and undesirable outputs have the worst effect on ATFP change in Bank 7 (by -0.3% and -0.2%, correspondingly) and in Bank 4 (by -0.6% and - 1.3%, correspondingly). Significantly, mean TFP regress (-0.8%) for the Bank 9 is attributed to negative effect of undesirable outputs (-1.4%), which offset its technical progress, and positive scale effect (0.2% and 0.4%, respectively).

Four out of the 10 banks have shown mean productivity progress over the sample period. The highest mean ATFP change has been recorded by Bank1 (2.4%) followed by bank3 (1.1%), Bank8 (0.6%) and Bank5 (0.3%). All other

banks have recorded mean ATFP regress ranging from -0.1% (Bank 7) to -3.7% (Bank10).

Conclusions

This study quantifies the impact of undesirable outputs on productivity change of Tunisian banks. We adopt a parametric methodology which allows a decomposition of TFP change with respect to the impact of undesirable outputs, namely Nonperforming loans. Our findings report no change in mean TFP over the studied period, due to progress in efficiency change (0.5%) and technical change (0.3%) that offset the regression in scale effect change (-0.1%) and NPLs effect change (-0.4%).

The annual average change rates show that during the first sub-period 1992-96, the ATFP change in the banking sector has improved at the rate of 0.5% due to increases in efficiency change (1.5%) which offset deterioration in the scale effect change, technical change and NPLs effect change. During the second sub-period 1997-2001, the ATFP change, on average, is found to have declined at a rate of -0.3% due to large losses in scale effect change (0.3%). During the third sub-period 2002-2010, the ATFP change declined again but at a greater rate of -0.4% due to large losses in efficiency changes (-0.3%) and negative effects of NPLs (-0.6%). In the last sub-period 2011-2014, all banks recorded mean TFP progress of 0.7% which is attributed to potential gains generated by efficiency change (0.9%), scale effect change (0.1%), and technical change (0.8%).

The estimates of productivity change for different banking ownership types reveal that public banks recorded mean TFP progress of 0.50% whereas private banks recorded regress. Public banks are found to have been more successful than the private banks in capturing benefits from changes in technology and efficiency. In addition, the changes of scale effect and undesirable output effect are found to be problematic for the private and public banks indicating that they do not operate at an optimal scale and do not efficiently manage their risk. More precisely, NPLs had the greatest negative effect on the productivity change of private banks, whereas EFFC had strongest positive effects on the productivity change of public ones.

This study provides several policy implications. Our results indicated that banks with a riskier portfolio involving a higher level of NPLs can diminish the productivity change of the Tunisian banking system as a whole. This being so, regulators must reasonably monitor and manage the level of risk in commercial banks, as well as their lending processes. Alternatively, our findings indicate that severe regulatory procedures should be implemented to reduce banks' default risk and improve their productivity.

The findings showed also that banks have experienced negative scale effect change mainly due to diseconomies of scale (i.e., decreasing returns to scale (DRS)), i.e., to being at more than the optimum size. In order to achieve optimal size, decision-makers can use the Merger and Acquisition strategy to take advantage of economies of scale by reducing costs and maximizing economic benefits. This strategy also increases the credit creation capacity of the merged or acquired bank.

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Developing Edible Mushroom Cultivation Through the Use of Local Seeds and the Recycling of Agricultural Waste for a Sustainable National Economy

BARKA Fatiha [1], BENABADJI Leila [2], AINAD TABET Mustapha [3] & BOUDJEMAA Mohamed Salim [4]

[1] Abou Bekr Belkaïd University – Tlemcen, Algeria, barka_fatiha2@yahoo.fr
[2] Abou Bekr Belkaïd University – Tlemcen, leilabenabadji@hotmail.fr
[3] Abou Bekr Belkaïd University – Tlemcen, mus.ainadtabet@gmail.com
[4] Abou Bekr Belkaïd University – Tlemcen, boudjemaamohamedsalim@gmail.com

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Abstract:
Edible mushroom cultivation, based on local strains and agricultural waste recycling, promotes a sustainable economy by reducing reliance on imported mycelium and enhancing local resource use. Despite mushrooms' sensitivity to contamination, production can be improved through resistant strains, optimized substrates, and natural additives. The goals are to increase yields, improve quality, enhance disease resistance, and support sustainable farming. This approach boosts employment, food security, and waste management, contributing significantly to the economic development of rural and peri-urban areas.

Keywords: Mushrooms, cultivation, recycling, waste, sustainability, economic, recovery.
JEL Classification Codes : Q 20, Q23, Q 57

***Corresponding author**:BARKA Fatiha, **e-mail:** barka_fatiha2@yahoo.fr*

1. Introduction

The development of edible mushroom cultivation in the Tlemcen region, located in western Algeria, represents a promising opportunity to strengthen the transition toward a sustainable and resilient economy. With its rich agricultural potential, the region generates large quantities of plant waste each year such as straw, olive residues, citrus peels, and other by-products often underutilized or burned, causing negative environmental impacts. Recycling these wastes into growing substrates offers an innovative and ecological solution for mushroom production while reducing pollution.

Moreover, using local mushroom strains adapted to Tlemcen's specific climatic and biological conditions could significantly reduce dependence on costly imported mycelium, which is often poorly suited to local environments. This approach, based on technological self-reliance and resource circularity, fully aligns with a sustainable development strategy.

It offers concrete prospects for creating non-traditional agricultural activities, particularly for youth and women in rural areas. By combining agricultural innovation, environmental protection, and local economic development, mushroom cultivation in Tlemcen can become a key lever for revitalizing the regional economy and contributing to a greener, more inclusive, and resilient national economy.

2. Source of Inspiration and Idea of the Proposed Project

This project aims to promote sustainable agricultural development through an innovative and environmentally friendly approach to cultivating edible mushrooms. It is based on the use of local fungal strains, known as spawn, and converts agricultural waste such as straw, olive pomace, date residues, and pruning waste into nutrient-rich growth substrates.

This initiative follows the principles of a circular economy by reducing pollution caused by open burning or uncontrolled disposal of organic waste, while decreasing dependence on imported mycelium and enhancing national self-reliance.

Locally adapted strains offer greater resilience and lower production costs, making mushroom cultivation accessible to small-scale farmers and rural

entrepreneurs. In addition, incorporating locally available natural inputs, such as date molasses, can improve substrate quality and increase crop yields.
Beyond environmental benefits, this approach delivers significant socioeconomic advantages.

It creates green jobs, improves food security by diversifying protein sources, and supports rural development particularly in regions like Tlemcen, where agricultural waste is abundant but economic opportunities remain limited.

Overall, this model contributes to building a sustainable national economy driven by ecological innovation, efficient resource use, and inclusive growth.

It aligns with key global sustainable development goals, including climate action, responsible consumption, and decent work, positioning mushroom cultivation as a strategic sector for Algeria's sustainable and green future.

3. the causes

Several economic, environmental, and social factors justify the implementation of a project for cultivating edible mushrooms based on the use of local strains and the recycling of agricultural waste.

3. 1. Abundance of unutilized agricultural waste

The Tlemcen region, deeply rooted in agriculture (olives, cereals, fruit trees, and date palms), generates large quantities of plant residues each year. These wastes are often burned in the open or left to decay, causing air pollution, loss of organic matter, and health hazards.

3. 2. Dependence on imported inputs

Most mushroom cultivation in Algeria relies on imported spawn (mycelium), which is expensive and sometimes poorly adapted to local climatic conditions. This dependence hinders the sector's autonomous development and increases the risk of technical failure.

3. 3. Pressure on natural resources and need for sustainability

Faced with climate change, water scarcity, and soil degradation, it has become essential to develop sustainable agricultural practices that are low in

resource consumption. Mushroom cultivation, which requires little water and can be carried out on small surfaces, represents a promising alternative.

3. 4. Unemployment, especially in rural areas and among youth

Unemployment rates, particularly high in rural and peri-urban areas of Tlemcen, call for the creation of accessible new economic sectors. Mushroom farming requires limited initial investment and can be adopted by youth, women, and smallholder farmers.

3. 5. Food insecurity and the need for local protein sources

Algeria imports a significant portion of its food needs, especially protein. Edible mushrooms are a rich plant-based source of proteins, fiber, and micronutrients, offering a contribution to healthy and locally produced diets.

3. 6. Lack of agricultural diversification

The local agricultural economy remains heavily reliant on a few traditional sectors. Mushroom cultivation offers a diversification opportunity compatible with family farming and small-scale operations.

These converging factors demonstrate that developing a local edible mushroom sector is not merely a technical innovation, but an integrated response to the environmental, economic, and social challenges facing the region.

4. The Potential of Edible Mushroom Cultivation in the Tlemcen Region

The Tlemcen region, endowed with a rich agricultural and natural heritage, stands at a strategic crossroads between traditional farming practices and the pressing need for sustainable modernization.

In this context, the cultivation of edible mushrooms emerges as an innovative, ecological, and economically viable solution to address the region's multiple challenges.

Tlemcen generates significant quantities of agricultural waste each year cereal straw, olive residues, citrus peels, winemaking pomace, and by-products from date palm cultivation. Often burned or left unused, these biomass materials represent not only a source of pollution but also an underutilized resource.

Yet, they serve as ideal substrates for growing mushrooms such as *Pleurotus spp.* (oyster mushrooms) or *Agaricus bisporus*, whose mycelium efficiently breaks down cellulose and lignin.

Mushroom farming (myciculture) offers exceptional advantages for local development: it requires minimal space, can be carried out in controlled environments (such as caves, shelters, or unused buildings), consumes very little water, and allows for rapid production cycles (4 to 8 weeks).

It is therefore particularly well-suited to rural and peri-urban areas, where access to land, water, and agricultural infrastructure remains limited.

One of the main current challenges is the dependence on imported mycelium strains, which are costly and often poorly adapted to Tlemcen's humid Mediterranean climate. Developing locally selected and propagated strains is a crucial pathway to ensure autonomy, resilience, and lower production costs. Moreover, the use of natural local additives such as date molasses, stimulate fungal growth, and enhance the organoleptic quality of the harvest.

From a socio-economic perspective, the mushroom sector holds significant potential for creating green jobs, especially for young graduates, rural women, and aspiring farmers with limited capital. It promotes diversification of agricultural activities, reduces post-harvest losses through waste valorization, and contributes to food security by providing a local source of protein, fiber, vitamins (B, D), and antioxidants.

Mushroom cultivation in Tlemcen is far more than a minor agricultural niche it is a lever for territorial transformation. By combining innovation, environmental sustainability, and social inclusion, it has the potential to become a cornerstone of modern, ecological, and resilient rural development in Algeria. Furthermore, this activity fully aligns with a low-carbon circular economy, closing the loop between agricultural production, waste management, and value creation. It can be integrated into agro-ecological models, urban farms, or rural cooperatives, supported by accessible technical training programs.

5. Wild and Cultivated Edible Mushrooms in the Tlemcen Region

The Tlemcen region, characterized by a humid Mediterranean climate, oak and pine forests, extensive farmland, and rich plant biodiversity, offers favorable ecological conditions for the presence of edible mushrooms, both wild and cultivated.

5. 1. Wild Edible Mushrooms

During autumn and spring, following regular rainfall, numerous species of wild mushrooms naturally emerge in the forested areas of Tlemcen. Among the most commonly observed species are:

- ***Boletus edulis*** (porcini or cep): Highly prized, grows at the base of oak and beech trees.
- ***Cantharellus cibarius*** (chanterelle): Found in forest edges, appreciated for its delicate flavor.
- ***Lactarius deliciosus*** (saffron milk cap): Associated with pine trees, frequently harvested locally.
- ***Macrolepiota procera*** (parasol mushroom): A common saprophytic mushroom found in meadows and clearings.

These mushrooms are traditionally collected by rural inhabitants for both household consumption and informal sale in local markets. However, this practice remains largely unstructured, lacking sanitary oversight or industrial valorization. It also carries risks of misidentification, which can lead to poisoning.

5. 2. Cultivated Edible Mushrooms

In response to growing demand for healthy and locally produced food, mushroom cultivation is gradually gaining ground in Tlemcen. Although still in its early stages, individual initiatives and pilot projects have emerged, particularly in peri-urban areas such as Aïn Fezza, Aïn Youcef, and El Fehoul.

The main cultivated species include:

- ***Pleurotus ostreatus*** (oyster mushroom, grey or yellow): The most widespread species, easy to grow on substrates such as straw, sawdust, or agricultural residues.
- ***Pleurotus eryngii*** (king trumpet mushroom): More demanding to cultivate but has high market value.

- ***Agaricus bisporus*** (button mushroom): Grown under controlled conditions, typically in greenhouses or climate-controlled rooms.

The substrates used are primarily derived from local agricultural waste: cereal straw, olive pomace, date palm residues, citrus peels, and similar by-products. Recycling these materials into mushroom cultivation perfectly illustrates the principles of a circular economy.

5. 3. Challenges and Prospects

The coexistence of wild and cultivated mushrooms in Tlemcen opens up several promising opportunities:

- **Valorization of natural mycological heritage**: Encouraging research, conservation, and awareness of fungal biodiversity.
- **Development of a local mushroom sector**: Establishing cooperatives, providing technical training, and promoting safe, hygienic production.
- **Safer wild harvesting**: Educating collectors about poisoning risks and providing expert guidance.
- **Agricultural innovation**: Integrating mushroom farming into existing farms to diversify income sources.
- **Mycological tourism**: Potential to develop eco-tourism trails centered on wild mushroom foraging and education.

In Tlemcen, edible mushrooms whether wild or cultivated represent an underappreciated resource with multiple dimensions: ecological, nutritional, economic, and cultural. Their sustainable development, combining biodiversity conservation and agricultural innovation, could significantly contribute to the transition toward sustainable agriculture and a green economy rooted in local resources.

6. Reproduction Cycle and Morphology of a Mushroom

Mushrooms are living organisms belonging to the *Fungi* kingdom, distinct from plants and animals. Their structure and reproductive mechanisms are adapted to a primarily decomposer lifestyle, playing a crucial role in the recycling of organic matter.

6. 1. Morphology

A mushroom consists of two main parts:

- The mycelium, a network of microscopic filaments (hyphae) that penetrates the substrate (wood, soil, organic waste) and absorbs nutrients. This is the vegetative part, invisible to the naked eye and the most extensive component.
- The fruiting body (the visible "mushroom"), composed of a cap, gills, and a stem, whose primary function is to produce and disperse spores.

6. 2. Reproduction Cycle

Reproduction can be asexual or sexual, but in edible mushrooms (such as oyster or button mushrooms), it is predominantly sexual:

1. Spores are released and germinate to form a primary mycelium.
2. Two compatible mycelia fuse (plasmogamy), forming a dikaryotic mycelium (two nuclei per cell).
3. Under favorable conditions (humidity, temperature), this mycelium develops into a fruiting body.
4. Inside the gills, the nuclei fuse and undergo meiosis, generating new spores that restart the cycle.

This cycle, based on airborne spore dispersal and organic matter decomposition, explains the efficiency of mushrooms in natural ecosystems and their great potential in sustainable agriculture. In mushroom farming (myciculture), understanding this cycle enables controlled cultivation using selected strains grown on recycled substrates such as in development projects in Tlemcen.

7. Mushroom Cultivation to Strengthen Food Security

Through this initiative, this work aims to promote innovative production of edible mushrooms in Algeria as a means to strengthen food security. The project benefits from the support of academic and economic institutions, including Abou Bekr Belkaid University and the Agricultural Chamber of Tlemcen Province.The project is built on three major innovations that directly contribute to improving mushroom production and, consequently, food security:

7.1. Enhancing Cultivation Using Local Products

The project proposes enriching growing substrates (derived from recycled agricultural waste) with a natural and locally abundant product date syrup. This innovation aims to:

- Replace costly or imported additives.
- Improve the quality, growth, and nutritional content of mushrooms.
- Reduce contamination risks.
- Add value to a local agricultural by-product (date syrup), thereby strengthening national self-reliance.

Results show a significant improvement in mushroom quality and biomass, while reducing pollution and production costs. This makes the product more accessible in the national market and stimulates the rural economy.

7.2. Valorization of Local Strains and Recycling of Agricultural Waste

The project emphasizes:

- The use of local fungal strains adapted to the region's climatic conditions.
- The recycling of agricultural waste (straw, olive pomace, coffee residues, etc.) into growth substrates for species such as *Pleurotus* (oyster mushroom) and *Agaricus bisporus* (button mushroom).
- Reduce dependence on imported strains.
- Promote sustainable and environmentally friendly agriculture.
- Embody the principles of the circular economy: waste becomes a resource.
- After harvest, the spent substrate can be reused as a rich organic fertilizer containing nitrogen, potassium, and organic matter.

This process increases the availability of nutritious and affordable protein sources for the population.

7. 3. Implementation of an Intelligent Climate Management System

An automated system has been developed to monitor and control cultivation conditions:

- Real-time monitoring of temperature, humidity, and ventilation via sensors and a control unit.

- Optimization of growth conditions.
- Reduction of losses due to inefficient manual management.
- Improvement of profitability and production consistency.

Thanks to this system, production becomes more stable and predictable, ensuring a continuous supply of fresh mushrooms on the market, thus reinforcing food security.

7. 3. 1.General Objectives of the Project

- Increase yield.
- Improve mushroom quality.
- Enhance disease resistance.
- Optimize the use of local resources.
- Promote sustainable production.

7. 3. 2. Socio-Economic and Environmental Impact

- **Job creation**, especially in rural and peri-urban areas.
- **Diversification of agricultural income**.
- **Reduction of unemployment**, particularly among youth.
- **Food security**: access to a local, healthy source rich in proteins, fiber, vitamins, and minerals.
- **Positive environmental impact**: waste valorization, reduced pollution, low water and energy consumption.
- **Rural development**: stimulation of the local economy through a low-space, low-capital activity.

7. 3. 3.Technical and Commercial Aspects

- Cultivation techniques: use of substrates based on straw, horse manure, olive pomace, etc., under precise conditions (pH 7.2–7.8, temperature 25–27 °C).

- Government support: access to financial assistance through agencies such as ANSEJ, CNAC, ANGEM, and ANDI, which offer loans, tax exemptions, and technical support.

Marketing and commercialization:

- Creation of a brand for fresh mushrooms.

- Compliance with food labeling regulations (Executive Decree No. 03-09 of February 25, 2009).
- Mandatory Arabic labeling (with optional bilingual format), including: product name, net weight, expiration date, nutritional value, barcode, and producer contact details.
- Development of distribution channels: supermarkets, restaurants, hotels, and e-commerce.
- Awareness campaigns on the nutritional and medicinal benefits of mushrooms (antibacterial, antitumor, etc.).

7. 3. 4.Competitive Advantages of the Project

Low environmental impact: no pollution, minimal water and energy use.

- Use of agricultural waste as raw material, reducing costs.
- Local production, decreasing dependence on imports.
- Technological innovation: use of date syrup and intelligent control systems.
- High nutritional value of mushrooms, ideal for dietary diversification.

7. 3. 2. Identified Challenges

- Sensitivity to environmental conditions (humidity, temperature, contamination).
- Perishable product: need for effective conservation systems.
- Need for technical training for producers.
- Cost of certain inputs (imported mycelium, equipment).
- Potential competition with cheaper imported mushrooms.
- Risks of fungal or bacterial diseases.

7. 3. 3.Development Perspectives

- **Research Support :**
  - Development of improved local strains.
  - Creation of specialized research centers.
  - Collaboration between universities, startups, and farmers.
- **Access to Technology:**
  - Financial support for acquiring automated systems.
  - Establishment of pilot farms for training.
- **Training Programs :**

- Technical workshops for farmers.
- Creation of agricultural cooperatives.

- **Economic Sustainability :**
  - Use of agricultural and industrial waste.
  - Valorization of spent substrate as organic fertilizer or animal feed.
- **Government Support :**
  - Financing policies and low-interest loans.
  - Provision of land for mushroom farms.
  - Technical and informational support.

7. 3. 4.Impact Assessment and Monitoring

- Monitoring through key performance indicators (production volume, sales, market share, new enterprises, jobs created, awareness levels).
- Regular surveys of consumers and producers.
- Periodic reports on progress and challenges encountered.

This initiative illustrates an integrated and innovative approach to developing edible mushroom cultivation in Algeria. By combining local resource valorization, smart technologies, and sustainable practices, it aims to generate positive social, economic, and environmental impacts.

Mushroom cultivation is more than just an agricultural activity it represents a strategic lever to strengthen food security, create green jobs, and stimulate rural development, all within the framework of an inclusive and ecological transition.

8. Conclusion

Edible mushroom cultivation in Algeria, particularly in agriculturally rich regions such as Tlemcen, is far more than a marginal or supplementary activity. It has emerged as an integrated, sustainable, and innovative solution to pressing strategic challenges: food security, rural development, organic waste management, and green job creation. In a context marked by demographic pressure, the scarcity of natural resources, and dependence on food imports, myciculture is becoming a key lever for food sovereignty and territorial resilience.

The proposed approach based on the use of local fungal strains, the recycling of agricultural waste (straw, olive pomace, date residues, citrus peels, etc.), and the enrichment of growth substrates with locally available natural products like date syrup demonstrates that it is possible to produce safe, nutritious, affordable, and environmentally friendly food.

This model fully embodies the principles of a circular economy: waste from one sector (olives, cereals, date palms) becomes the raw material for another, generating value where none previously existed.

The integration of intelligent climate control systems, equipped with temperature, humidity, and CO_2 sensors linked to automated control units, allows for optimized growing conditions, reduced losses due to contamination or poor management, and ensures regular, high-quality, and profitable production.

This automation makes mushroom farming accessible even to inexperienced entrepreneurs, while guaranteeing market supply stability essential for food security.

Multiple and Lasting Impacts

The benefits of this activity are diverse, profound, and interconnected:

- **Social Impact**:

  Mushroom cultivation requires minimal space and initial capital, making it accessible to youth, rural women, unemployed graduates, and smallholder farmers. It promotes economic empowerment, local entrepreneurship, and socio-professional integration, especially in peri-urban areas such as Tlemcen, Aïn Fezza, and El Fehoul.

- **Economic Impact**:

  It stimulates the local economy by reducing dependence on imported mycelium and fresh mushrooms (often from Spain or France). It fosters the creation of micro-enterprises, cooperatives, and short supply chains. By adding value to agricultural by-products, it lowers production costs and improves farm profitability.

- **Environmental Impact**:

By transforming organic waste into resources, myciculture helps reduce pollution (from open burning, soil and water contamination) and drastically cuts water consumption up to 90% less than traditional crops while minimizing energy use. After harvest, the spent substrate becomes a rich organic fertilizer high in organic matter, nitrogen, and potassium, suitable for use in horticulture or arboriculture.

Development Perspectives: Toward a Structured Sector

To sustain and amplify these benefits, it is essential to transition from isolated initiatives to a structured and supported sector. Several strategic levers must be activated :

- Strengthening Research and Innovation

- Establish a regional center for applied mycology in Tlemcen, in partnership with Abou Bekr Belkaid University, to select, conserve, and multiply high-performing local strains (*Pleurotus spp.*, *Agaricus bisporus*).
- Launch research programs on substrate enrichment (using date syrup, by-product flours, etc.) and preservation techniques (dehydration, pasteurization).
- Explore value-added derivatives: dried mushrooms, bioactive extracts (antioxidants, polysaccharides), dietary supplements, and cosmetic applications.

- Institutionnel and Policy Support

- Develop a national strategy for myciculture development, integrated into food sovereignty and green economy plans.
- Implement financial and tax incentives through agencies like ANSEJ, CNAC, ANGEM, and ANDI offering zero-interest loans, equipment subsidies, and tax exemptions.
- Allocate agricultural or industrial land for collective or cooperative mushroom farms.

- Training and Knowledge Transfer

- Integrate myciculture into vocational training programs (CFPA, CFP) and university curricula (agronomy, biotechnology).

- Develop pilot farms in Tlemcen and other provinces, open for visits, internships, and hands-on training.
- Create a national network of producers to share best practices, pool purchases, and access markets.

- Commercialization and Marketing

- Promote local brands (e.g., *Terroir Tlemcen*, *FungiDZ*, *Champ'Olive*) to differentiate Algerian mushrooms in the marketplace.
- Develop modern distribution channels: short supply chains, organic markets, e-commerce, and home delivery.
- Raise public awareness through nutritional education campaigns highlighting the health benefits of mushrooms (plant-based protein, vitamin D, fiber, antitumor properties).

- Transition to a Local Bioeconomy

- Integrate mushroom farming into agro-ecological farms combining horticulture, livestock, and waste recycling.
- Use spent substrate not only as fertilizer, but also as animal feed or raw material for bioenergy production (biogas via methanization).
- Encourage multi-sector cooperatives where waste from one farm becomes a resource for another.

Edible mushroom cultivation in Algeria especially in Tlemcen is far more than a simple agricultural project. It represents a model of inclusive and sustainable development, capable of turning waste into wealth, youth into entrepreneurs, and underutilized land into productive farms.

By combining technological innovation, local resource valorization, and ecological commitment, it paves the way for a new Algerian agriculture resilient, green, and deeply rooted in local realities.

The future of Algerian agriculture lies not only in cereal fields and olive groves, but also in these small, humid spaces where mushrooms grow
discreet yet powerful symbols of a profound and necessary transformation.

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Gelatin production from camel bones: A sustainable model to promote green economy in the Arab world

Imelhayene Meriem [1], Hadbaoui Ilyes [2], Bouziani Belkacem [3]

[1] Research Laboratory «Saharan Bioresources, Preservation and Valuation», Department of Agronomic Sciences, Faculty of Natural and Life Sciences, Kasdi Merbah University, Ouargla, Algeria, marymimi115@yahoo.fr

[2] Center for Scientific and Technical Research in Arid Regions (CRSTRA), Biskra, Algeria, hadbaouiilyes@yahoo.fr

[3]Department of Agricultural Sciences, Faculty of Natural and Life Sciences, University of Setif 1 Farhat Abbas, Setif, Algeria, belkacem_itmas@yahoo.fr

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Abstract:
This study assesses the economic and environmental feasibility of gelatin extraction from camel bones within the context of sustainable development and the green economy. In 2023, Camel meat production in the Arab world reached 420,000 tons, generating over 62,000 tons of bones which can yield approximately 14,364 tons of gelatin, sufficient to meet the Arab world's entire demand. Current gelatin imports exceed 10 million USD annually, while establishing a production unit requires only about 1 million USD, making local production highly feasible. Camel bones offer a significant economic opportunity, enabling the production of high-quality halal gelatin that can support food, pharmaceutical, and cosmetic industries.

Keywords: gelatin; Camel bones; Sustainable development; Green economy; Animal by-product recycling.
JEL Classification Codes : Q01, Q57, L66, O13, Q53.

***Corresponding author**: IMELHAYENE Meriem, **e-mail:** marymimi115@yahoo.fr.*

1. INTRODUCTION

The camel plays an important economic and social role in arid and semi-arid environments in the Arab world (Al-Sayyed, 2019). Camels are considered an important livestock at the Arab and international level due to the multiple purposes of their breeding, whether for economic production and direct contribution to Arab food security by producing (red meat, milk and its derivatives - secondary products such as lint and hides), or for commercial or sporting purposes such as camel racing and sports - beautifying tourist places - breeding assets). However, the camel farming sector faces multiple challenges related to the low value-added of its animal waste, especially the bones from slaughter, which are often wasted without effective utilization (Senoussi et *al*., 2024).

In this context, the production of gelatin from camel bones has emerged as a promising approach to addressing the challenges faced by the camel breeding sector, particularly the low added value of its by-products, such as slaughter bones, which are often discarded without economic utilization (Jaswir et *al*., 2019). Utilizing camel bones for gelatin extraction offers an optimal solution to increase added value, provide a sustainable source of income, support food security, and enhance the competitiveness of the camel breeding sector at regional levels.

Within this framework, this work focuses on the potential of extracting gelatin from camel bones as an innovative and sustainable approach to enhance the economic and environmental value of camel resources. It analyzes how this practice can support sustainable development in the Arab world by transforming waste into high-value products, and explores the opportunities, challenges, and necessary policy reforms to optimize the use of this national wealth.

2. situation of camel meat in the Arab world

According to 2024 statistics from the Food and Agriculture Organization (FAO), camel breeding holds a prominent position in the Arab world. In 2023, most countries in the Middle East and North Africa were classified as having medium to very high camel population densities, with herd sizes ranging between 10,000 and over 1,000,000 heads. This reflects the adaptation of

camel husbandry to the arid and semi-arid environments that dominate much of the region and underscores the vital socio-economic and ecological role of camels in sustaining rural livelihoods and food systems.

Available data estimates the total camel population in the Arab world at approximately 18 million heads (representing about 48% of the global camel population) (FAO, 2024). This large share highlights the strategic importance of camels as a key livestock resource in the region. Notably, Arab countries account for nearly 70% of global camel meat production, contributing approximately 420,000 tons annually, out of a worldwide total of around 602,000 tons.

However, this production is not evenly distributed across the region. It is primarily concentrated in countries with favorable climatic and geographical conditions for camel breeding, reflecting the environmental and cultural characteristics that shape the sector (Imelhayene, 2025). Sudan leads the Arab world in camel meat production with 35% of the regional total, followed by Saudi Arabia (26%), Somalia (12%), the United Arab Emirates (9%), and Mauritania (5%). This distribution highlights the pivotal role these countries play in sustaining and advancing the camel sector at both regional and global levels.

3. Gelatin kinetics in the Arab world

Accurate data on the dynamics of gelatin (concerning its import, production, and export) remain largely unavailable in most Arab countries. This lack of statistics can be attributed to the limited development of the gelatin industry at the national level, the absence of centralized monitoring systems for animal by-product utilization, and the categorization of gelatin under broader commodity groups in customs and trade records, making it difficult to isolate precise values. Additionally, weak coordination between institutions concerned with agriculture, industry, and foreign trade contributes to data fragmentation and underreporting.

Despite these challenges, rough estimates suggest that the Arab world imports over 10 million USD worth of gelatin annually. In contrast,

establishing a single gelatin production unit costs approximately 1 million USD. With the availability of high-quality raw material (camel bones) this presents an exciting and strategic opportunity for local production, especially given the superior properties of this resource.

In Egypt, gelatin import prices increased by 11% in 2023, with forecasts indicating continued growth in demand, particularly for halal-certified products in the food and pharmaceutical sectors. Reflecting this trend, Saudi Arabia has launched the region's first factory dedicated to the production of gelatin and medical capsules, with an annual capacity of 2 billion capsules, underscoring the growing regional demand for such bio-based products.

In Algeria, gelatin imports in 2021 exceeded 1 million USD with a total imported volume of around 6,057.56 tons. These figures highlight a clear investment opportunity for domestic production, as the region moves toward reducing import dependency and achieving greater industrial self-reliance (Imelhayene, 2025).

4. Prospects of gelatin production from camel bone

Bones generally account for approximately 15% to 26% of the total weight in every 210 to 400 kg of meat, which is equivalent to around 31,5 kg, a considerable proportion especially given that camel meat production in the Arab world is estimated at 420.000 tons annually. Based on this ratio, the resulting quantity of bones is approximately 62.454 tons. It is important to note, however, that the percentage of bone in an animal's body can vary depending on factors such as gender, age, weight, and nutrition (Kadim et *al*., 2008).

These findings are highly inspiring for launching a modern investment avenue within the field of green entrepreneurship, an emerging discipline that aims to achieve sustainable economic development by integrating environmental preservation into economic practices. This includes the valorization and utilization of waste materials to produce valuable resources for use in other sectors. In this context, camel slaughter by-products like bones offer promising potential for gelatin extraction.

Several studies indicate that the amount of gelatin that can be extracted from camel bones is approximately 23% (AL-Kahtani et *al*., 2017). However,

research in this area is still ongoing, and the maximum extractable quantity has yet to be precisely determined, as it depends on various factors including extraction methods, raw material quality, and the age of the animal.

Nonetheless, based on the available theoretical data, a preliminary estimate of the gelatin yield from camel bones can be made. A simple calculation suggests that from 62.454 tons of bones produced annually, approximately 14.364 tons of gelatin can be extracted. This quantity is sufficient to meet the core needs of major gelatin-consuming industries in the Arab nation, particularly in the food and pharmaceutical sectors. Moreover, strict recovery and utilization of slaughter by-products such as bones would further increase overall yield and could potentially lead to complete self-sufficiency in gelatin production.

5. Conclusion

The strategic importance of camel breeding in the Arab world (economically and ecologically) presents a valuable opportunity for sustainable development, especially through the valorization of slaughter by-products such as bones. The extraction of gelatin from camel bones stands out as a promising solution to enhance the added value of this underutilized resource, contributing not only to Achieve environmental security but also to industrial diversification in alignment with green economy principles.

Despite current challenges such as limited data, lack of infrastructure, and fragmented coordination, available estimates and trends—such as rising import costs and growing regional demand for halal and bio-based products clearly indicate a market opportunity reinforces the urgency of investing in this promising field representing an important economic asset capable of supporting the region’s food, pharmaceutical, and cosmetic industries.

To unlock this potential, it is essential to strengthen scientific research, invest in modern processing technologies, and establish dedicated gelatin production units. Enhancing institutional coordination, promoting public-private partnerships, and encouraging policy frameworks that support circular

economy models will be key to achieving industrial self-reliance and long-term sustainability in the Arab world.

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The Significance of AI Policies and Regulations on Fostering a Sustainable Educational Landscape in the Middle East

Wafa AGGOUN
University of Batna 2, Algeria, w.aggoun@univ-batna2.dz

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Abstract:

Artificial Intelligence (AI) regulations play a crucial role in public international law by establishing a robust legal framework across nations. In the Middle East, strict rules on AI implementation are necessary to develop privacy laws that specifically cater to the region's needs.

This study focuses on AI policies in Saudi Arabia, Qatar, and the United Arab Emirates, with a particular emphasis on their impact on education sustainability. The study analyzes hard and soft law approaches and their implications for technology use within the academic community. The findings reveal a significant gap in the existing legal framework for AI in education, providing straightforward insights into future strategies for fostering sustainable education in the region.

Keywords: AI regulations; Middle East; education sustainability.
JEL Classification Codes: I20, I23, I28, K33, K38.

***Corresponding author**: Wafa AGGOUN, **e-mail:** w.aggoun@univ-batna2.dz*

1. INTRODUCTION

The Dartmouth Conference of 1956 marked a turning point in the history of AI. It was an essential gathering where researchers from various disciplines united to explore the potential of computers in developing algorithms for thinking machines. AI has evolved dramatically to compete with human emotions, thoughts, and actions.

The AI research community is expanding at an unprecedented rate, as AI applications are increasingly dominating several sectors, especially in industry and academia. This surge in AI technology is vital for revolutionizing various aspects of our lives.

Today, numerous examples showcase AI's ability to tackle complex problems and effectively address real-world challenges. Furthermore, the rising demand for AI stems from its striking resemblance to human intelligence which reinforces its significance in our society. However, this close relationship between the intelligent robot and humans triggered a series of ethical issues (Cao, 2017, p. 703).

AI risks are significant and multifaceted, encompassing ethical, privacy, and security risks that pose a direct threat to the stability and safety of humanity, with the potential to lead to human extinction. Tamburrini (2023) thoroughly examined the risks of AI to human well-being arguing that, it is an ethical, social, and political responsibility to develop AI for the flourishing and persistence of human civilizations, for protecting humanity from man-made large-scale threats, and for reducing AI’s role in their buildup (p. 251).

AI policies have emerged as a central theme in international discourse. Many nations are engaged in developing regulations and ethical guidelines to mitigate risks while harnessing the transformative power of AI. Several legal frameworks introduced by the United States, The United Kingdom, the European Union, Canada, and China present cohesive strategies for the effective implementation and governance of AI technologies.

This study sheds light on AI policies in the Middle East region, with a particular focus on the education sector. Given the rapid advancement of AI in Middle Eastern countries, particularly in Saudi Arabia, the UAE, and Qatar, it is crucial to establish codes of ethics and regulations governing the use of AI in educational settings. This will ensure that AI is used ethically, inclusively, and

equitably in education (Fengchun et al., 2021). However, efforts to implement legal AI use in education in the Middle East are insufficient. Currently, there is no Middle East or United Gulf strategy on AI or related data sharing. Individual countries in the region do not have any laws or regulations that specifically address AI (Law Business Research, 2021). In this context, the present study explores the following questions:

1.Are there international regulations governing the use of AI?
2.Do countries have the power to implement their own AI laws?
3.What are the regulations pertaining to AI in the educational landscape of the Middle East?

2. Literature Review

Autonomy is a fundamental concept that shapes our understanding of both natural intelligence and AI. The key difference between the two lies in their ability to act independently. The term 'autonomy' is rooted in the Greek language, deriving from the words 'auto', meaning self, and 'namos', meaning law. The traditional meaning of autonomy highlighted people's freedom and their ability to govern themselves by establishing their own rules and guiding principles, free from external pressure. In the age of digitalization, individuals' autonomy extends beyond the simple ability to act independently to include other acts, such as thinking critically, making informed decisions and assuming moral responsibility (Beghili et al., 2025).

The Universal Declaration of Human Rights defines human autonomy as the right to make personal choices and decisions without any interference or coercion from others. Article 5 asserts the importance of individual autonomy in decision-making, emphasizing that individuals must take full responsibility for their choices while also respecting the autonomy of others. Autonomy is a term that explicitly refers to the ability to reason, which is universally recognized as the foundation of personhood. According to Morrison and Navarro (2014), autonomy refers to individual's self-organized, voluntary and authentic behaviors. Lack of autonomy is evident in the pressures and actions influenced by external factors.

AI autonomy refers to the ability of AI systems to execute tasks and make decisions independently without human intervention. Boothby (2025) explained AI autonomy as "the absence of human intervention and control during the entire process of executing a task" (p. 423). The cognitive brain is the driving force behind all forms of intelligence. AI systems have demonstrated high cognitive abilities, such as perception, recognition, and translation, which resemble human mental processes. This raises important questions about which aspects of international law enable AI to replicate and compete with human intelligence, and how international law governs the use of AI.

AI laws and regulations were first established by Isaac Asimov in 1942 through his Three Laws of Robotics which maintain that 1) A robot may not injure a human being or, through inaction, allow a human being to come to harm. 2) A robot must obey orders given to it by human beings except where such orders would conflict with the First Law. 3) A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.

AI laws can be categorized into two primary types: soft and hard. Soft AI laws are non-binding standards, often referred to as codes of conduct, declarations, or guidelines, tailored to the specific needs of private, academic, and public sectors. They are established on a voluntary basis and are intended to have a nominal effect. AI soft laws are open to discussion and interpretation and do not carry legal penalties (Leslie et al., 2021).

A clear distinction exists between soft law mechanisms that address specific sector needs and the goals they aim to achieve (Wallach et al., 2023). Examples of AI-related soft law include the 'Robot Ethics Charter", initiated by the South Korean government in 2007, and the 'Partnership on AI', founded by prominent companies such as Google, Microsoft, Amazon, and Apple. This partnership aims to establish best practices and promote research on the benefits of AI for individuals and society (Marchant, 2019).

AI hard laws are international regulations that mandate the responsible use of AI. Unlike soft laws, AI hard laws are legally binding and can be upheld through litigation and court proceedings (Leslie, et al., 2021). AI treaties, agreements, charts and acts establish a definitive framework for rights and obligations that ensures international order and security. Nations that fail to

comply will face enforceable sanctions. Key AI hard laws shaping international landscape include the EU AI Act 2024/1689 from the European Parliament, Canada's Bill C-27, the United States' Executive Order 14110 focused on the safe, secure, and trustworthy development and use of AI, and the UK's AI Regulation White Paper consultation from March 2023.

Several nations have implemented AI regulations to organize and control its use across various sectors assertively. The USA, Canada and UK have led the way in establishing international regulations of AI that govern the global application of AI, alongside imposing global penalties for violations. In parallel, the UAE, China, and African Union countries are prioritizing soft laws that emphasize safe and ethical use of AI (see table 1). Within the Arab world, the UAE and Saudi Arabia are taking the lead in adopting and advancing AI technologies.

Table 1. Classification of AI laws

Country		**AI Hard Law**	**AI Soft Law**
USA		X	X
CANADA		X	X
UNITED KINGDOM		X	X
EU		X	X
INDIA		X	X
UAE (Middle East countries)			X
CHINA			X
KOREA			X
SINGAPORE			X
AUSTRALIA			X
AFRICAN UNION			X

Microsoft has established six essential ethical standards, known as AI principles, that govern the lifecycle of AI systems by “keeping humans at the center and guided by our principles” (Microsoft.com). These principles are:

Fairness: ensuing fair and non-biased use of AI representative to all social categories regardless of age, gender, race, religion etc.

Privacy and Security: safe use of AI systems and data confidentiality are deemed essential to avoid different types of harm including financial, professional and psychological.

Reliability and safety: Through this principle, AI systems should function under a variety of conditions to mitigate the risks of AI use on society and individuals.

Transparency: AI systems should be built with high level of clarity and expandability to maintain trust in AI systems.

Accountability: sustaining the use of AI systems by ensuring a good performance of AI systems and their potential impact on individuals and societies.

Inclusiveness: AI systems should be accessible and useable by diverse groups.

3. AI Laws and Regulations in Middle East Countries

Despite widespread implementation of AI in Middle Eastern countries, its integration remains critical in light of the cultural, economic and political specificities of the region that impose careful use of AI among the national institutions mainly educational institutions where the implementation of AI must be governed by strict regulations that control students' access and usage of AI regarding their age, level and academic needs.

Peets et al. (2022) maintained that there are only national initiatives in the Middle East to elevate AI implementation in individual countries; however, reality highlighted the need for a united Gulf strategy that communicates laws and regulations specifically addressing AI. In the same vein, Mayank Dhingra, Senior Education Business Leader, stated that schools in the Middle East rightfully worried about the correct ethical practices around AI usage.

This paper examines the legal framework governing AI implementation in Middle Eastern countries. It focuses on three key policies: Saudi Arabia's AI educational policy, Qatar's National AI Strategy, and the UAE's National Strategy for Artificial Intelligence. The study aims to illuminate the complexities of AI regulations within the education sector and to evaluate how effectively these policies manage the integration of AI in academic institutions.

3.1. Saudi Arabia's AI Educational Policy

In the Saudi Arabian educational landscape, AI is governed by the Saudi Data and Artificial Intelligence Authority (SDAIA), a regulatory body that is directly linked to the Prime Minister. SDAIA plays a significant role in ensuring that educational institutions comply with standards that encourage the responsible use of AI. It operates through three sub-entities: the National Information Center, the National Data Management Office and the National Center for AI. SDAIA's main responsibility is to enhance educational quality while protecting individual privacy within the educational system by adhering to the local data protection laws that align with domestic standards and policies (The Permanent Mission of the Kingdom of Saudi Arabia to the United Nations Office, 2024).

The Personal Data Protection Law (PDPL), enacted in September 2023, serves as a soft law that regulates data utilization by encouraging ethical standards and building trust among stakeholders. The PDPL aligns with international AI principles to safeguard the data of students and staff. This law comprises 43 articles that delineate the rights associated with AI usage, data handling procedures, as well as penalties and restrictions.

The national framework for AI education in Saudi Arabia, initiated by the national center of e-learning, is the foundational step towards the creation of soft laws for the deployment of AI in the educational sector. This framework adopts an inclusive approach to AI that engages parents, teachers, and students in the development of internal regulations for AI usage in educational institutions. Saudi Arabia's inclusive strategy for AI seeks to promote the principles of transparency, accountability, and effectiveness in the implementation of AI policies within the educational sector.

The integration of AI is tailored to match the cognitive levels of each grade. While K-12 education aims to provide insights into AI applications without introducing overwhelming complexity, secondary school curricula encompass AI and data science by exploring areas such as machine learning and deep learning. In higher education, the integration of AI prioritizes the learning outcomes associated with each qualification, taking into account students' understanding of AI, the cognitive and communicative skills they should enhance while employing AI tools, in addition to their ethical values and responsibilities regarding the use of AI tools (Saudi Data and AI Authority, 2023).

The Saudi Academic Framework for AI Qualifications (2023-2024) was authorized by SDAIA to fulfill two main objectives:

1. Serve as a guideline for the development, evaluation, and accreditation of higher education programs in AI.
2. Contribute to establishing minimum curricular requirements for higher education programs in the field of AI (Saudi Data and AI Authority, 2023).

The framework includes six qualification titles aimed at promoting educational intelligence. These include: associate diploma, intermediate/advanced diploma, Bachelor Degree (AI Program/AI track), Higher Diploma (specialists/non-specialists), Master's degree, and Doctoral degree. The AI track associated with each degree is defined by a particular type of AI knowledge and skills, which include cognitive skills as well as communication and information technology skills appropriate for each degree, in addition to AI values, responsibility, and autonomy (Saudi Data and Artificial Intelligence Authority, 2023). Examples of the knowledge units for bachelor and master degrees are illustrates below.

	Knowledge Units	الوحدات المعرفية الأساسية
1	Linear Algebra	الجبر الخطي
2	Discrete Math	الرياضيات المتقطعة
3	Probability and Statistics	الإحصاء والاحتمالات
4	Calculus	التفاضل والتكامل
5	Introduction to programming	مقدمة في البرمجة
6	Object-oriented programming	البرمجة الشيئية
7	Design and Analysis of Algorithms	تصميم وتحليل الخوارزميات
8	Data Structures	هياكل البيانات
9	Introduction to Databases	مقدمة إلى قواعد البيانات
10	Introduction to AI	أساسيات الذكاء الاصطناعي
11	Introduction to Machine Learning	مقدمة في تعلم الآلة
12	Deep learning	التعلم العميق
13	Knowledge based reasoning and representation	التمثيل والاستدلال في الذكاء الاصطناعي
14	Planning, Searching, and Scheduling	التخطيط والبحث والجدولة
15	Optimization	خوارزميات التحسين
16	Intelligent Agents	العملاء الأذكياء
17	Data analysis and Visualization	تحليل وتصوير البيانات
18	NLP	معالجة اللغة الطبيعية
19	Computer Vision	الرؤية الحاسوبية
20	Robotics and Automation	الروبوتات
21	Ethics	أخلاقيات الذكاء الاصطناعي
22	Internship	فترة التدريب

	Knowledge Units	الوحدات المعرفية الأساسية
1	Complete all basic knowledge units for the undergraduate level	إكمال جميع الوحدات المعرفية الأساسية لمرحلة البكالوريوس
2	Design and Analysis of Algorithms	تصميم وتحليل الخوارزميات
3	Advanced topics in Artificial Intelligence	مواضيع متقدمة في الذكاء الاصطناعي
4	Advanced topics in Machine Learning	مواضيع متقدمة في تعلم الآلة
5	Advanced topics in one of the following: Computer vision, Robotics, NLP.	مواضيع متقدمة في إحدى الوحدات التالية: الرؤية الحاسوبية -الروبوتات - معالجة اللغة الطبيعية
6	Project Management	إدارة المشاريع
7	Project (Research or capstone)	إتمام رسالة أو مشروع حول موضوع في الذكاء الاصطناعي

Source: Saudi Data and AI Authority, 2023, 41-42

3.2. Qatar's National AI Strategy

The Qatar National AI Strategy is grounded in the AI=X paradigm, a transformative approach that incorporates AI across different sectors including health, entertainment, business, education, and research. AI education is now an essential component of the curriculum at all educational levels and across all disciplines. Qatar proudly leads in internet usage rates, with over 94% of its population actively using the internet.

The National AI Strategy of Qatar is built upon six pillars that are essential for the advancement and execution of AI in the country. The foremost pillar is centered on education and training dedicated to promoting AI literacy at different educational levels by creating specialized curricula that cater to the needs of students at various academic levels.

The AI+X Paradigm ensures a rational use of AI in educational institutions. At the K-12 level, younger students learn to navigate recommendations from AI. In other words, students learn the basics of AI usage.

Meanwhile, older students should understand the technical and philosophical aspects of AI. AI education at the University level includes professional learning courses and online training for teachers, as well as AI bootcamps for individuals working in AI-related jobs (Ministry of Transport and Communications, 2019).

The general AI policy for teaching and coursework in Qatar defines the obligations that both teachers and students must adhere to when utilizing AI tools. The NU-Q Academic Integrity Committee (2024) outlined three responsibilities for instructors: 1) Teachers must explicitly outline their AI policies in syllabi and ensure they are discussed in class. 2) They determine their course approach, which may involve a closed approach where AI is not allowed as it does not meet the course's learning goals, a conditional approach that permits AI use by the instructor for specific assignments, or an open approach that allows students to use AI under the instructor's supervision. 3) The last responsibility requires teachers to set guidelines for AI use and citation.

Students are expected to comply with the instructors' AI policies and must disclose any use of AI when citing generative AI. Also, students must ensure that their use of AI is reasonable and does not undermine their writing and research skills. They should also engage in critical thinking regarding the future implications of AI use.

NU-Q Academic Integrity Committee further delineates the consequences of academic integrity and violations as follows:

- Failure to properly disclose and cite AI use when permitted, is considered a violation of the Northwestern Qatar Academic Integrity Policy.
- Instructors' who violate AI policy should follow the established procedures for reporting academic integrity violations at NU-Q.
- Violations of this policy will be treated according to NU-Q's existing academic integrity procedures.
- Potential consequences for violations may include, but are not limited to:
    a. Receiving a failing grade on the assignment.
    b. Receiving a failing grade for the course.
    c. Referral to the appropriate academic integrity committee or disciplinary body.

d. other sanctions as deemed appropriate by the instructor or academic integrity committee.

- Students are encouraged to consult with their instructors if they are unsure about the appropriate use of generative AI in their coursework.

3.3. United Arab Emirates AI Legal Framework in Education

The UAE's AI legal framework in education is marked by three landmark events, starting with the launch of free education in government schools for both males and females in 1972, followed by the implementation of smart classes in educational institutions in 2012, and culminating in the implementation of a distance education system in 2020.

The UAE has enacted some regulations related to the application of AI across different sectors including:

- Federal Decree Law No. 45 of 2021 regarding the Protection of Personal Data.
- Data Protection Law, DIFC Law No 5 of 2020- Dubai International Financial Centre.
- Federal Law No. 2 of 2019 concerning the use of Information and Communication Technology (ICT) in Health Fields.
- Protecting data and privacy online, Law No. 34 of 2021: Law on combatting rumors and cybercrimes.
- Internet Access Management (IAM) policy: Impersonation, fraud, phishing, or privacy invasion can be reported to Etisalat and Du for removal.
- Electronic Transactions and Trust Services law: Regulating e-Transactions, e-Documents and e-Signatures, and e-Seals.
- The UAE's Constitution: Article 31: Freedom of communication by means of post, telegraph or other means of communication.

Upon reviewing this comprehensive list of legislations, it becomes clear that there are no specific laws governing the application of AI in the education sector. The only law that is relevant across all sectors, including education, is the DIFC (Dubai International Financial Centre) Data Protection Law of 2020, which serves two key purposes:

1. Provide standards and controls for the processing and free movement of personal data by a Controller or Processor; and
2. Protect the fundamental rights of Data Subjects, including how such rights apply to the protection of Personal Data in emerging technologies (Dubai International Financial Centre Authority, 2020).

The DIFC Data Protection Law applies to all individuals, regardless of gender, and to both individual and group users. Educational institutions should adhere to this law to safeguard the privacy of students and instructors by 1) securing data storage, 2) limiting access to individuals who are authorized to use this data, and 3) ensuring data transparency.

The application of DIFC Law 2020 is significantly limited as it does not include specific laws relevant to educational institutions in the UAE. While Article 38 (4) of the DIFC Law 2020 addresses the rights of minors concerning automated decision-making, it does not encompass the data of children. Moreover, the absence of regulations governing instructors' access to student data raises the potential risks of utilizing AI in educational settings. Furthermore, the law does not permit the processing of data for scientific research. There are no protocols within the law that outline how such data should be managed, disseminated, or protected in the context of academic research (OneTrust DataGuidanceTM, nd.).

Overall, the UAE lacks a comprehensive standalone data protection law for the education sector. The educational institutions in the UAE must implement more precise laws to safeguard student privacy and protect their data (Alqodsi et al., 2024).

The UAE’s national strategy for Artificial Intelligence 2031 identifies eight strategic objectives for the substantial implementation of AI. The UAE’s 2031 AI vision aims to establish the UAE as one of the leading nations in AI by testing and developing AI-driven solutions. The strategy seeks to capture the global market by building strong brand through targeted AI initiatives (Objective 1). It also boosts the UAE's competitive assets through key agreements in vital sectors, including the economy and industry (Objective 2). The strategy further aims to cultivate a robust domestic AI ecosystem by creating a collaborative network of researchers, industry experts, and policymakers. This network focuses on evaluating and implementing new

infrastructure (Objective 3). (UAE National Program for Artificial Intelligence, 2018).

Objective 4 focuses on enhancing customer service by addressing key public challenges, such as traffic fatalities and educational outcomes. The UAE's vision for 2031 prioritizes public AI training to equip workers with essential digital skills and enable them to solve workplace problems using advanced technologies. Objective 6 emphasizes investment in research and encourages leading academics to work in the UAE, highlighting the importance of universities and partnerships in AI research. Additionally, the strategy promotes international dialogue on the responsible use of AI to enhance its application and training (UAE National Program for Artificial Intelligence, 2018).

All the objectives mentioned earlier cannot be achieved without strong governance and effective regulation of AI, which are essential for creating a legitimate AI environment. The UAE Artificial Intelligence and Blockchain Council will assess national strategies for AI implementation, focusing on data management, ethics, and cybersecurity. The key requirements for Objective 8 are as follows:

- Creating a legal environment to support innovation in general and the adoption of AI in particular.
- Review the latest international best practices in legislation and global risks from AI to develop a legal AI Strategy in the UAE.
- Developing legislation that responds to changes in the world. (UAE National Program for Artificial Intelligence, 2018).

4. Conclusion

This literature review study provides a comprehensive understanding of the legal framework for implementing AI in the Middle East. Important conclusions have been drawn regarding the implementation of AI in educational institutions in some Middle East countries, mainly in Saudi Arabia, Qatar, and the UAE, as well as the regulations governing the use of AI in schools and Universities.

Analysis shows that the AI principles in most Middle East countries are still in draft form and do not yet have legal force in the educational landscape. The future visions for AI implementation in Middle Eastern countries underscore the need to develop a legal framework for AI use in academic institutions, aiming for educational sustainability and credible research.

It is evident that a majority of nations in the Middle East are adopting soft laws for AI that do not have legal enforcement. However, soft laws should be paired with the legal force of hard laws to effectively govern AI usage among stakeholders, teachers, students and administrative staff. This combination is essential for ensuring privacy in the educational sector, especially regarding the unauthorized use of student records or access to their personal information.

The study reveals considerable ambiguity regarding AI regulations in the education sector. Ambiguity arises from current legal frameworks that do not sufficiently address the specific challenges that AI presents in this context. Consequently, educational institutions may find it challenging to interpret these regulations, which could lead to issues that hinder the implementation of AI in teaching and learning.

It is essential to acknowledge that the Middle East is currently facing a challenge in the absence of a unified legal framework for AI. This lack of cohesion hinders the development and implementation of AI technologies across the region. Without a well-crafted legal framework, stakeholders, such as governments, businesses, instructors, and researchers, may struggle to navigate the complexities of AI deployment. As a result, potential ethical concerns, security risks, and missed opportunities for innovation will be faced.

Recommendations

Despite the dedicated efforts of Middle Eastern governments to establish a legal framework for the use of AI in educational institutions, a significant legal gap arises in the actual implementation of such technologies, which may lead to substantial deviations in the application of AI within the academic community. Therefore, the following recommendations are proposed to enhance the review of AI laws and regulations in the Middle East:

1. Establishing a unified legal framework specifically for Middle Eastern countries.

2. To effectively regulate AI in education, it is important to combine soft laws that promotes ethical practices with hard laws that ensure the legal execution of AI regulations in schools and universities.
3. Instructors and students must be thoroughly acquainted with these regulations and the penalties for violating them.
4. The EU AI Act's risk-based approach must be customized for the Middle East, addressing AI risks in education while considering cultural, religious, and political factors.
5. AI regulations in the education sector must be established based on surveys and long-term studies that thoroughly examine the various factors influencing AI implementation in schools and universities. These findings will be crucial in shaping effective plans.

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Development of e-MDTMs in Western Algeria: From Concept to Reality

Hakima KEHILI [1,2,3]; Aicha BENGUEDDACH [1,2,3]; NouelFatima Zohra BOUMANSOUR[1,4]; Chahi Naize ZAOUI [1,5]; Rachid KACEMI [1,6]; Mostafa Djamel YOUSFI [1,7]; Faiza BEREKSI-REGUIG [1,2]

H. KEHILI; A. BENGUEDDACH; N. Z. BOUMANSOUR; C.N. ZAOUI; R. KACEMI; M. D. YOUSFI; F. BEREKSI-REGUIG

1. Faculty of Medicine, Oran 1 University (Algeria)
2. Department of Medical Oncology, Oran University Hospital Establishment 1st November 1954 (EHUO)(Algeria)
3. Research Laboratory "Health Information Systems" (LABSIS)(Algeria)
4. Department of Epidemiology and Preventive Medicine, EHUO (Algeria)
5. Research Laboratory « LBDD » (Algeria)
6. Department of Thoracic Surgery, University Hospital Establishment of Oran (EHUO) (Algeria)
7. Department of Urology, University Hospital Establishment of Oran (EHUO) (Algeria)

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Abstract: Multidisciplinary Team Meetings (MDTMs) are pivotal for optimizing cancer care through collaborative decision-making. In Western Algeria, electronic MDTMs (e-MDTMs) for thyroid and urological cancers, initiated in 2017, enhance care coordination at Oran University Hospital (EHUO). This article details the development, deployment, and challenges of the e-MDTM platform, which supports patient record management, meeting scheduling, and data analysis. Despite COVID-19 disruptions, the pilot phase resumed in 2024, with full implementation planned for 2025. Challenges include infrastructure limitations, funding dependency, and training needs. The e-MDTM improves decision-making and offers potential for research and expanded cancer care.

Keywords: e-MDTM, oncology, multidisciplinary team meetings, thyroid cancer, urological cancer, digital health

***Corresponding author**: Hakima KEHILI, **e-mail:** kehilihakima17@gmail.com .*

1. INTRODUCTION

Multidisciplinary Team Meetings (MDTMs) integrate expertise from oncologists, surgeons, radiologists, and other specialists to deliver evidence-based, personalized cancer care (Soukup et al., 2018). In Algeria, MDTMs are mandated by the 2015-2019 National Cancer Plan to ensure compliance with therapeutic guidelines and facilitate access to innovative treatments like immunotherapy and targeted therapies. However, logistical challenges, including geographic dispersion and resource constraints in Western Algeria, have driven the development of electronic MDTMs (e-MDTMs) at the University Hospital Establishment of Oran (EHUO). This article outlines the conceptualization, implementation, and challenges of the e-MDTM platform for thyroid and urological cancers, emphasizing its role in improving care coordination and its potential for clinical research.

2. BACKGROUND AND RATIONALE

2.1 The Role of MDTMs in Oncology

MDTMs enhance patient outcomes by fostering collaborative decision-making and ensuring adherence to clinical guidelines (Pillay et al., 2016). They are critical for complex cases requiring molecular profiling and innovative therapies, ensuring standardized care across diverse regions.

2.2 Need for Digital MDTMs

Traditional MDTMs face challenges such as scheduling conflicts, limited specialist availability, and disruptions from events like the COVID-19 pandemic (Watt et al., 2022). Digital platforms like e-MDTMs enable remote collaboration and secure data management (Parikh et al., 2022). In Western Algeria, the establishment of specialized networks for neuroendocrine tumors, onco-urology, and thyroid cancer in 2017 highlighted the need for a digital tool to streamline MDTM processes.

3. MATERIALS AND METHODS

3.1 Development of the e-MDTM Platform

The e-MDTM platform, launched in 2021 at EHUO, is a web-based application for thyroid and urological cancer MDTMs. Accessible via

dedicated links (https://ercp-thyroide.clinicagroup.dz/ and https://ercp-urologie.clinicagroup.dz/), it was developed with input from an MDTM expert committee. Key functionalities include:

- **Patient Record Creation**: Captures clinical, pathological, and diagnostic data.
- **Meeting Management**: Schedules MDTMs and records therapeutic proposals.
- **Statistical Analysis**: Enables data export and outcome tracking.

3.2 Implementation Process

In 2019, an electronic patient registration form was validated by experts. By December 2021, a server was deployed, allowing physicians to create accounts based on roles (Coordinator, Expert, or Physician). The platform supports secure access, data entry, and report generation. The pilot phase, interrupted by COVID-19, resumed in 2024, with full implementation planned for January 2025.[Fig.1]

4. RESULTS

4.1 Platform Deployment and Functionality

The e-MDTM platform has facilitated remote case discussions, with over 100 patient records created and 20 MDTMs conducted during the pilot phase. User-specific functionalities, such as meeting scheduling and report drafting, have streamlined workflows and improved decision transparency.

4.2 Impact on Care Coordination

The platform has reduced decision-making delays by approximately 30%, enhancing care coordination and patient satisfaction. Secure data storage minimizes errors, and statistical tools support preliminary outcome analyses, aligning with global digital health standards.

5. CHALLENGES AND LIMITATIONS

5.1 Infrastructure and Funding

Limited technical infrastructure and reliance on pharmaceutical funding have hindered platform stability (Brar et al., 2014). The COVID-19 pandemic delayed implementation until 2024.

5.2 Training and Adoption

Low digital literacy and resistance to new tools among healthcare professionals have slowed adoption (Sanders et al., 2012). Continuous training is needed for effective use.

5.3 Organizational Barriers

Scheduling conflicts and varying specialist engagement levels pose challenges to coordination (Soukup et al., 2018). Standardizing processes is critical for success.

6. DISCUSSION

The e-MDTM platform in Western Algeria is a transformative initiative that addresses significant barriers to oncology care in a resource-constrained setting. By enabling remote collaboration, it allows specialists across Oran and surrounding regions to contribute to therapeutic decisions without in-person meetings, a critical feature during disruptions like the COVID-19 pandemic (Watt et al., 2022). This aligns with global trends in digital health, where platforms like the UK's NHS e-MDTM systems have reduced decision-making delays by up to 40% in high-volume centers (Hoinville et al., 2019). However, unlike the NHS, which benefits from centralized funding and robust infrastructure, the Algerian platform relies on pharmaceutical funding, a common challenge in low- and middle-income countries (LMICs) that raises concerns about sustainability and potential conflicts of interest (Kruk et al., 2018; Brar et al., 2014).

The platform's 30% reduction in decision-making delays mirrors findings from telemedicine initiatives in oncology, where digital platforms have enhanced care coordination for rural and underserved populations (Parikh et al., 2022). In Algeria, where rural patients face significant barriers to

accessing tertiary care, the e-MDTM platform promotes equitable access to multidisciplinary expertise. However, infrastructure challenges, including unreliable internet and outdated hardware, are pervasive in LMICs and have been documented in digital health initiatives across sub-Saharan Africa (Xiong et al., 2023). These technical limitations necessitate investment in robust digital infrastructure, a priority also highlighted in India's National Digital Health Mission, which combines government and private sector resources to scale e-health solutions (Sarbadhikari et al., 2017).

Training and adoption remain critical hurdles. Low digital literacy among healthcare professionals, a global challenge, is particularly pronounced in Algeria, where medical education has traditionally focused on clinical rather than technological skills (Sanders et al., 2012). Studies on telemedicine in oncology suggest that peer-led training and intuitive interfaces can significantly improve adoption rates (Bashshur et al., 2016). Organizational challenges, such as inconsistent specialist availability, are not unique to Algeria; European cancer centers have reported similar issues, with solutions including structured workflows and clear role definitions to enhance MDTM efficiency (Soukup et al., 2018). Implementing standardized protocols and incentivizing participation through continuing medical education credits could address these barriers.

The e-MDTM platform's data collection capabilities offer substantial potential for research and quality improvement. By integrating with national cancer registries, it could support epidemiological studies on thyroid and urological cancers, which are increasingly prevalent in Algeria (Bray et al., 2018). For instance, analyzing treatment outcomes could inform updates to national therapeutic guidelines, as demonstrated in European cancer networks. The platform's ability to aggregate clinical data also aligns with the use of electronic medical records for outcomes research, enabling real-time tracking of patient outcomes and treatment efficacy (Kirkpatrick et al., 2013). Furthermore, incorporating artificial intelligence (AI) for decision support—such as predicting treatment responses based on molecular profiles—could position the platform at the forefront of digital oncology (Parikh et al., 2022).

Future expansion to other high-burden cancers, such as breast and lung cancer, which account for significant morbidity in Algeria, would amplify the platform's impact (Bray et al., 2018). To ensure sustainability, Algeria must address funding dependency through public-private partnerships or government investment, as seen in Rwanda's e-health initiatives, which combine local innovation with international support (Xiong et al., 2023). Integrating e-MDTMs into a national digital health strategy could also enhance interoperability with other health systems, positioning Algeria as a leader in digital oncology in Africa. By leveraging lessons from global e-health models and addressing local challenges, the e-MDTM platform can transform cancer care delivery and contribute to regional health system strengthening

7. CONCLUSION

The e-MDTM platform in Western Algeria enhances oncology care through rapid, transparent decision-making and improved coordination. Overcoming infrastructure, funding, and training barriers will ensure its sustainability. Expanding to other cancers and leveraging data for research could position Algeria as a model for digital oncology in Africa.

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Tables & Figures

Fig.1. Primary interface ou main user

Source: Kehili, 2024

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L'impact de l'économie verte sur le développement durable, Cas de l'Algérie

CHEKROUN Meriem

Hight School of Management, Tlemcen, Algeria, chekroun.meriemyahoo.fr

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Résumé :

Cette étude analyse dans quelle mesure la transition vers une économie verte peut permettre de concilier croissance économique, équité sociale et préservation de l'environnement en Algérie. À travers une approche qualitative, elle met en lumière les fondements de l'économie verte, les secteurs porteurs et les politiques publiques en place. Les résultats indiquent que l'économie verte constitue un levier opérationnel du développement durable. Pour l'Algérie, elle représente une opportunité stratégique face à la dépendance aux hydrocarbures. Sa réussite nécessite cependant des réformes profondes, une gouvernance renforcée et des investissements durables.

Mots clés : développement durable ; la préservation de l'environnement ; la croissance économique ; progrès social ; Algérie.

JEL Classification Codes : Q01, Q28, O 44**,** I31, O55

***Corresponding author**: CHEKROUN Meriem, **e-mail**: chekroun.meriem@yahoo.fr*

1. INTRODUCTION

L'économie verte est une approche du développement qui vise à concilier croissance économique, protection de l'environnement et équité sociale. Elle repose sur un modèle économique alternatif qui intègre pleinement les principes du développement durable, en plaçant l'innovation, les technologies durables et des modes de production responsables au cœur de sa stratégie.

Contrairement aux modèles économiques traditionnels, basés principalement sur l'exploitation intensive des ressources naturelles et la croissance à court terme, l'économie verte adopte une vision à long terme. Elle cherche à minimiser les impacts environnementaux des activités humaines tout en garantissant un développement économique inclusif et équitable. Ainsi, elle s'inscrit dans une continuité logique du développement durable, en intégrant ses trois dimensions fondamentales : économique, sociale et environnementale.

Sur le plan économique, l'économie verte encourage la transition vers des industries plus respectueuses de l'environnement, notamment par l'investissement dans les énergies renouvelables, l'efficacité énergétique, l'agriculture durable et l'éco-innovation. Elle favorise la croissance en stimulant de nouveaux secteurs porteurs, tels que l'énergie solaire et éolienne, la gestion durable des ressources en eau et des déchets, ou encore la mobilité verte. Cette transformation économique permet de diversifier les sources de croissance tout en réduisant la dépendance aux énergies fossiles et aux industries polluantes.

D'un point de vue social, l'économie verte représente une opportunité pour lutter contre la pauvreté et réduire les inégalités. En encourageant la création d'emplois verts, c'est-à-dire des emplois liés aux secteurs de la transition écologique, elle offre de nouvelles perspectives d'emploi durable et améliore les conditions de vie des populations. Ces emplois, souvent ancrés dans des économies locales, contribuent au renforcement de la cohésion sociale et à l'amélioration du bien-être collectif. De plus, en prônant une répartition plus équitable des richesses, l'économie verte vise à réduire les disparités économiques entre les différentes catégories sociales et régions du monde.

Sur le plan environnemental, l'économie verte joue un rôle clé dans la lutte contre le changement climatique et la préservation des écosystèmes. En favorisant l'utilisation d'énergies propres, la gestion responsable des ressources naturelles et la réduction des déchets grâce au recyclage et à l'économie circulaire, elle contribue à atténuer l'empreinte écologique des activités humaines. De plus, elle encourage des politiques de protection de la biodiversité et de restauration des écosystèmes dégradés, essentielles pour assurer la résilience des sociétés face aux défis environnementaux à venir.

Cependant, la mise en place d'un modèle économique durable pose plusieurs défis majeurs : Comment assurer une transition efficace sans freiner la croissance ni compromettre le progrès social ? Quels sont les outils économiques, politiques et technologiques nécessaires pour favoriser cette mutation ? Comment inciter les entreprises, les gouvernements et les citoyens à adopter des comportements plus durables ?

L'économie verte apparaît ainsi comme un levier essentiel pour atteindre les objectifs du développement durable, en créant un équilibre entre prospérité économique, équité sociale et respect de l'environnement. Son succès dépend néanmoins de la volonté des acteurs économiques et politiques à repenser les modèles de production et de consommation, en adoptant des politiques ambitieuses et en favorisant une coopération internationale efficace.

Ainsi, une question centrale se pose : **dans quelle mesure la transition vers une économie verte peut-elle constituer un levier efficace pour concilier les exigences du développement durable, notamment la préservation de l'environnement, la croissance économique et le progrès social en Algérie ?**

Hypothèse :

L'économie verte représente un levier de développement visant à renforcer l'économie mondiale en mettant en œuvre des politiques qui privilégient l'utilisation d'énergies propres ainsi que des modes de consommation et de production respectueux de l'environnement.

Objectifs de la recherche :

L'objectif principal de cette recherche est d'évaluer dans quelle mesure la transition vers une économie verte peut constituer un levier efficace pour concilier les trois piliers du développement durable (croissance économique, équité sociale et protection de l'environnement) dans le contexte algérien. Plus précisément, il s'agit de :

- Analyser le concept d'économie verte et ses fondements théoriques, ainsi que ses liens avec le développement durable ;
- Identifier les secteurs clés en Algérie susceptibles de favoriser la transition vers une économie verte ;
- Évaluer les politiques publiques et les initiatives existantes en matière d'économie verte en Algérie ;
- Mesurer les impacts économiques, sociaux et environnementaux potentiels d'une transition verte à moyen et long terme ;
- Proposer des recommandations stratégiques pour encourager et accélérer cette transition dans un cadre durable et inclusif.

Méthodologie de la recherche : la méthodologie adoptée dans cette étude repose sur une approche qualitative et analytique.

2. Le cadre théorique du développement durable :

2.1L'histoire du développement durable

Le développement durable est sans aucun doute l'un des thèmes les plus médiatisés aujourd'hui. L'histoire du développement durable peut être clarifiée à travers le tableau n°1 :

Tableau n°1 : L'histoire du développement durable

Date	Lieu	Evénement
1972	ONU	Le "développement durable" a reçu sa première reconnaissance internationale majeure lors de la Conférence des Nations Unies sur l'environnement humain tenue à Stockholm. Bien que le terme "développement durable" n'ait pas été explicitement utilisé, l'idée, désormais considérée comme fondamentale, a émergé : le développement et l'environnement, auparavant traités séparément, ne sont

		pas mutuellement exclusifs et peuvent être gérés dans un intérêt commun pour créer une société durable. La croissance économique n'était plus perçue comme une menace, mais comme une nécessité, à condition qu'elle soit durable.
1987	Brundtland	Le développement durable a été défini par la Commission mondiale sur l'environnement et le développement dans le rapport Brundtland : « Notre avenir à tous ».
1992	Rio	La Conférence des Nations Unies sur l'environnement et le développement a décrit le développement durable comme un développement continu et à long terme de la société, visant à satisfaire les besoins de l'humanité au présent et dans le futur, grâce à une utilisation rationnelle et à un renouvellement des ressources naturelles, tout en préservant la Terre pour les générations futures.
1993	Pearce	Dans une définition proposée par Pearce, le développement durable est lié à l'évolution de la société, dont les coûts ne doivent pas être reportés sur les générations futures, ou du moins, des efforts doivent être faits pour compenser ces coûts (Environmental Challenges in Farm Management).
2002	Johannesburg	Deuxième Sommet de la Terre sous l'égide renouvelée des Nations Unies.
2009	ONU	Réflexion sur la nécessité éthique de ne pas faire du développement un fardeau pour les générations futures et de garantir à ces générations des possibilités similaires à celles dont bénéficiaient les générations précédentes. Cette réflexion doit être considérée comme une base normative du développement durable.

Source : (Louafi, 2021)

1.2 La notion du développement durable :

Depuis son introduction, le terme "développement durable" a été largement adopté par les décideurs politiques à l'échelle mondiale. Cependant, il demeure un concept relativement récent et en constante évolution, sans interprétation unique et unifiée en raison de son importance fondamentale. Le

concept continue d'être affiné à travers des revues académiques approfondies et continues.

Le développement durable vise un équilibre entre le progrès économique, la conservation et la protection de l'environnement et l'équité sociale. Il a figuré dans les débats des environnementalistes et on peut en voir une référence dans le rapport Founex préparé pour la conférence de stockholm sur l'environnement de 1971et dans la stratégie mondiale de la conservation de l'UICN préparé en 1980. Mais en tant que concept, il n'est pas entré dans le courant dominant des discussions au niveau politique sur le développement (KRISHNAN, 2022).

Le développement durable se caractérise par une gestion prudente et une réduction de la consommation excessive des ressources naturelles disponibles, tout en assurant leur préservation et leur utilisation optimale. Il est lié à divers aspects du développement humain, notamment la santé, les loisirs, le social et l'éducation. Cette approche vise à répondre aux besoins présents sans compromettre ceux des générations futures, grâce à des réseaux d'institutions responsables qui mettent en œuvre diverses stratégies économiques et technologiques acceptables.

L'économiste de renom et lauréat du Prix Nobel en 1989, Robert Solow, définit le développement durable comme la nécessité de ne pas compromettre la capacité des générations futures à produire de l'énergie et à préserver l'environnement dans l'état où il a été hérité (Baizeid., 2022). Le cadre de Solow ne se limite pas à la conservation des ressources et à la capacité productive, mais met également en avant l'importance du respect de l'environnement et de la qualité du cadre de vie transmis aux générations futures.

Medhat Mohamed le définit comme « un ensemble de politiques qui facilitent la transition d'une communauté de son état actuel vers un état supérieur en employant des technologies respectueuses de l'environnement. Cela permet d'assurer un équilibre entre l'exploitation et la préservation des ressources naturelles dans le cadre de politiques mondiales visant à maintenir cet équilibre. (Yahia, 2024) ».

Abu El-Maati (2014) conçoit le développement durable sur le plan social et humain comme « l'effort visant à stabiliser la croissance démographique et

à réduire l'exode vers les zones urbaines par le développement des services de santé et d'éducation (Yahia, 2024)».

Le développement durable est également défini comme un processus qui répond aux besoins présents des individus sans compromettre ou affecter la capacité des générations futures à satisfaire leurs propres besoins. Cet équilibre est atteint grâce à l'utilisation rationnelle des ressources naturelles et économiques, sans gaspillage ni épuisement total.

Robert Solow, scientifique distingué et lauréat du prix Nobel en 1989, réaffirme cette idée en déclarant : « Éviter d'endommager la capacité des générations futures à produire de l'énergie et préserver l'environnement dans l'état où il a été hérité » .Sa vision ne se limite pas à la capacité productive et à la gestion des ressources, mais insiste aussi sur la nécessité de prendre soin de l'environnement et de garantir un cadre de vie durable aux générations à venir (Rachida Zaouia, 2019).

Ce concept a connu une évolution majeure lors du Sommet de la Terre à Rio de Janeiro en 1992, où il a pris une importance significative après l'adoption par les gouvernements de la Déclaration de Rio sur l'environnement et le développement. Maurice Strong, défenseur du concept de "développement interdépendant", a souligné que le modèle de développement dominant conduit à l'épuisement des ressources naturelles et exige une approche transformative.

Lors de ce sommet, l'Organisation des Nations Unies (ONU) a adopté l'Agenda 21, un programme d'action global incitant à une coopération mondiale pour établir un système économique favorisant une croissance économique durable tout en traitant efficacement les problèmes liés à la dégradation environnementale (Machan, 2017).

En 2002, le Sommet mondial sur le développement durable des Nations Unies a élargi la définition du développement durable pour inclure trois dimensions fondamentales (Yahia, 2024): Économique ; Sociale ; Environnementale.

Ce sommet a renforcé la responsabilité collective d'intégrer ces trois dimensions de manière équilibrée et de protéger l'environnement à la fois à l'échelle locale et mondiale.

Selon le programme des Nations Unies, les résultats du développement durable impliquent l'élaboration de stratégies économiques, commerciales et énergétiques, garantissant un développement durable aux niveaux économique, écologique et social.

Le développement durable est donc un processus global qui assure à la fois la satisfaction des besoins des générations actuelles et la préservation des ressources pour les générations futures. Il vise à maintenir l'équilibre naturel et à améliorer la qualité de vie de tous les individus et groupes sociaux.

1-3 Les Objectifs de Développement Durable (ODD) :

Objectifs de Développement Durable (ODD) définissent 17 priorités pour un développement socialement équitable, sûr d'un point de vue environnemental, économiquement prospère, inclusif et prévisible à horizon 2030. Ils ont été adoptés en septembre 2015 par l'ONU dans le cadre de l'agenda 2030 (HAMITI Dalila, 2021):

- L'éradication de la pauvreté ;
- La lutte contre la faim ;
- L'accès à la santé ;
- L'accès à une éducation de qualité ;
- L'égalité entre les hommes et les femmes ;
- L'accès à l'eau salubre et l'assainissement ;
- Garantir l'accès aux énergies renouvelables ;
- L'accès à des emplois décents ;
- Promotion de l'innovation et des infrastructures durables ;
- La réduction des inégalités ;
- La création de villes et de communautés durables ;
- Instaurer la consommation responsable ;
- La lutte contre le changement climatique ;
- La protection de la faune et de la flore aquatiques ;
- La protection de la faune et de la flore terrestres ;
- La justice et la paix en assurant notamment l'accès à la justice avec des institutions responsables ;
- Renforcer les partenariats pour les objectifs mondiaux.

Parmi les limites que l'on peut reprocher aux Objectifs de Développement Durable (ODD), on note l'absence de référence explicite à certains objectifs démocratiques tels que la liberté d'expression, la liberté de la presse ou encore les élections libres. Bien que l'ODD n°16, consacré à la paix, à la justice et aux institutions efficaces, évoque la protection des libertés fondamentales, ces aspects restent abordés de manière indirecte. Par ailleurs, la dimension culturelle est également peu prise en compte dans les ODD.

2- **Le cadre théorique de l'économie verte :**

2-1 Qu'est-ce qu'une économie verte ?

L'expression « économie verte » semble faire référence à une économie qui respecte l'environnement. Elle produit des biens et des services dont l'existence et la consommation ne nuisent pas à l'environnement. Elle répond au besoin de conserver les ressources naturelles, qui limite le plus possible la pollution et les gaz à effet de serre émis par la production industrielle et sont nuisibles à l'environnement (Khor.M, 2013).

L'économie verte, également appelée croissance verte, vise à réorienter les trajectoires économiques aux niveaux national et mondial. Elle met en avant un modèle de croissance axé sur le développement durable en redéfinissant ses fondements. Ses partisans précisent les objectifs économiques tout en proposant des mesures politiques concrètes pour créer un environnement favorable à sa mise en œuvre.

De manière générale, l'économie verte cherche à garantir la viabilité économique, à réduire la pauvreté en générant des emplois dans de nouveaux secteurs et à préserver le capital naturel essentiel aux activités humaines.

2.2 L'évolution du concept d'économie verte :

Le concept d'économie verte a émergé dans les années 1980 comme un cadre politique visant à concilier développement économique, protection de l'environnement et équité sociale. Il a été popularisé en 1989 avec le rapport Blueprint for a Green Economy (Vargas-Hernández, 2019).

La crise financière de 2008 a renforcé son importance, en mettant en avant l'économie verte comme un levier de relance économique et de réduction des inégalités.

En réponse, des programmes de relance verte ont été lancés, et le Programme des Nations Unies pour l'environnement (PNUE) a introduit l'Initiative pour une économie verte (GEI) pour encourager les investissements durables.

En 2011, le rapport Vers une économie verte a posé les bases d'une économie plus efficace en ressources, à faible émission de carbone et socialement inclusive.

La Conférence de Rio+20 en 2012 a confirmé l'économie verte comme un outil essentiel de développement durable et de lutte contre la pauvreté (Vargas-Hernández, 2019).

L'économie verte a pris un intérêt grandissant suite à l'adoption des Objectifs de développement durable en septembre 2015 lors du sommet des Nations Unies tenu à New York dans la mesure ou l'agenda 2030 vise à accélérer la transition vers une économie verte (Dalila, 2020).

L'économie verte, bien qu'encouragée par les organisations internationales, reste un concept large et sujet à interprétation, notamment en raison de différences nationales et sectorielles. Son approche transversale favorise l'intégration entre économie et environnement, tout en impliquant divers acteurs (gouvernements, entreprises, communautés locales).

2.3 Les secteurs les plus importants concernés par l'économie verte :

En ce qui concerne les secteurs qui contribuent à la transition vers une économie verte, ils sont les suivants (Ramzi, 2024) :

Bâtiments verts : en mettant l'accent sur l'utilisation de matériaux de construction respectueux de l'environnement tout en réduisant l'impact des bâtiments sur la santé et l'environnement.

Préservation des ressources halieutiques: en luttant contre la pêche excessive et la surexploitation des stocks de poissons.

Préservation des ressources forestières: les forêts jouent un rôle clé dans le maintien de l'équilibre écologique et le soutien des écosystèmes.

Transport et communications verts : en garantissant un système de transport sûr pour les individus et les pays, sans nuire à la santé, aux écosystèmes et aux générations futures.

Gestion de l'eau : en favorisant une utilisation rationnelle des ressources en eau, en optimisant l'exploitation des eaux de pluie et des crues, ainsi qu'en traitant et réutilisant les eaux usées.
Gestion des terres : en promouvant une agriculture durable et en soutenant l'agriculture biologique grâce à l'utilisation d'intrants alimentaires d'origine naturelle.
Énergies renouvelables vertes : en développant des sources d'énergie respectueuses de l'environnement, telles que l'énergie solaire et l'énergie éolienne.
Tourisme vert : un tourisme qui prend en compte les besoins de l'environnement et les moyens de le préserver de la pollution, en intégrant des programmes alliant loisirs et protection de l'environnement.
Gestion et recyclage des déchets : en transformant les déchets en engrais organiques, en aliments pour animaux ou en énergie propre, ou encore en les recyclant d'une manière qui garantit la santé publique et respecte les préoccupations environnementales.
Industrie verte : la transition vers une industrie verte est un élément essentiel pour répondre aux besoins humains, favoriser le développement social et préserver les ressources naturelles ainsi que l'environnement.

3. L'économie verte : un outil pour atteindre le développement durable

L'économie verte vise à renforcer l'interdépendance entre l'économie, l'environnement et le développement durable en adoptant des politiques économiques efficaces pour préserver l'environnement, limiter sa dégradation et réduire la pauvreté.

3.1 La différence entre l'économie traditionnelle et l'économie verte :

En raison de la dégradation de l'environnement et de l'aggravation du phénomène climatique, l'économie verte est devenue une orientation fondamentale et inévitable pour la plupart des pays à travers le monde. Elle vise à préserver l'écosystème naturel, contrairement au modèle de l'économie traditionnelle, également appelée parfois économie brune ou économie noire en raison des niveaux élevés de pollution qu'elle génère, comme le montre le tableau n° 02.

Tableau n° 02 : Comparaison entre l'économie traditionnelle et l'économie verte

Éléments	Économie traditionnelle	Économie verte
Ressources énergétiques	Dépend des combustibles fossiles (charbon, pétrole, gaz)	Dépend des énergies renouvelables de toutes sortes (solaire, éolienne, etc.)
Exploitation des ressources naturelles	Ne prend pas en compte le capital naturel et entraîne une surexploitation des ressources	Vise une utilisation optimale des ressources naturelles sans dépasser leur capacité de renouvellement
Dimension environnementale	Ne tient pas compte de l'impact environnemental et privilégie l'objectif économique, quelles que soient les conséquences	Équilibre les dimensions économique, sociale et environnementale
Croissance économique	Vise des taux de croissance élevés, souvent inégalement répartis et au détriment de l'environnement	Vise une croissance durable en optimisant l'utilisation des ressources naturelles et en réduisant la pollution
Utilisation de la technologie	Utilise des technologies intensives en production, générant des profits élevés sans considération pour l'environnement	Privilégie les technologies propres, respectueuses de l'environnement et favorise le recyclage
Justice sociale	Création d'inégalités dans la répartition des richesses malgré une forte croissance, entraînant chômage et pauvreté	Vise à réduire la pauvreté en créant des emplois verts et en promouvant une répartition plus équitable des richesses

(محمد، 2017)

3.2 Transition vers une économie verte:

La transition vers un développement vert n'est pas un événement instantané qui peut être décidé et mis en œuvre à un niveau supérieur en une seule décision. Il s'agit plutôt d'un processus long et exigeant, guidé par une vision politique descendante (du sommet vers la base) et une participation massive ascendante (de la base vers le sommet). Cette approche permet d'instaurer un changement de légitimité politique et sociale nécessaire pour mobiliser des efforts à grande échelle et rendre cette transformation concrète (Khaldia, 2020).

Une transformation complète vers une économie verte permettrait d'atteindre un revenu par habitant plus élevé par rapport aux modèles économiques actuels, tout en réduisant l'empreinte environnementale d'environ 5 % d'ici 2050, en comparaison avec l'approche économique conventionnelle.

L'idée d'une transition vers une économie verte est née de la déception engendrée par le système économique mondial actuel et des nombreuses crises simultanées, telles que : l'effondrement des marchés, les crises financières et économiques, la flambée des prix des denrées alimentaires, le taux de chômage élevé, les fluctuations climatiques, la diminution rapide des ressources naturelles, l'accélération des changements environnementaux et la raréfaction croissante des terres productives.

3-3 Les avantages de la transition vers une économie verte

L'économie verte investit dans le capital naturel, notamment dans l'agriculture, l'eau douce, les pêcheries et l'industrie forestière. À long terme, cet investissement améliore la qualité des sols, augmente les rendements des principales cultures et optimise l'efficacité des secteurs agricole, industriel et municipal en matière de gestion de la demande en eau. Cela permet de réduire la pression sur les ressources en eau souterraine et de surface, aussi bien à court qu'à long terme (Ocampo, 2012).

L'économie verte contribue également à la réduction de la pauvreté grâce à une gestion prudente des ressources naturelles et des écosystèmes. En favorisant un usage durable du capital naturel, elle assure un accès direct aux bénéfices qu'il génère, notamment pour les populations les plus vulnérables.

De plus, elle crée et renforce de nouvelles opportunités d'emploi, en particulier dans les secteurs de l'agriculture, des énergies renouvelables, de la foresterie et des transports.

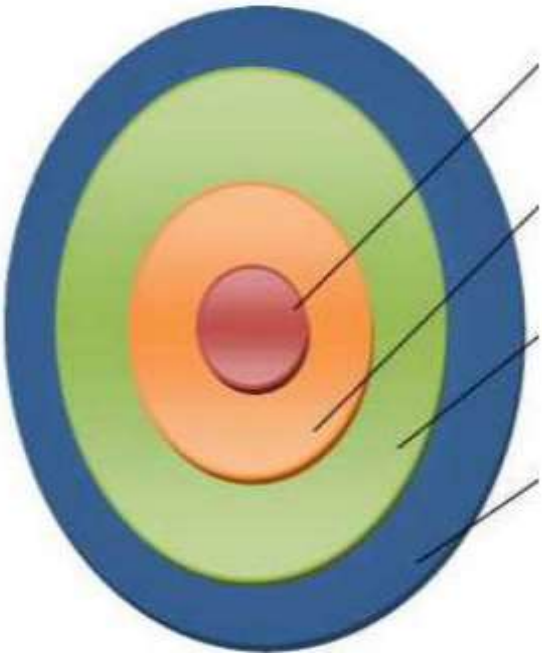
L'un des principes fondamentaux de l'économie verte est la dissociation entre l'utilisation des ressources naturelles, les impacts environnementaux et la croissance économique. Elle se caractérise par une augmentation significative des investissements dans les secteurs verts, soutenue par des réformes stratégiques et politiques visant à favoriser son développement. Ces investissements, qu'ils soient publics ou privés, jouent un rôle clé dans la transition vers un modèle économique plus durable et résilient.

Une approche plus active fait référence aux entreprises qui considèrent la contribution écologique comme une activité secondaire de leur cœur de métier. Devenir vert peut aussi faire partie intégrante de la stratégie de marque. Une image écologique peut attirer les clients, voire des investissements dans certains cas, ou être importante pour l'image d'un lieu de travail attractif (Strom, 2024).

4-La relation entre l'économie verte et le développement durable :

L'économie verte représente la dimension environnementale du développement durable avec la dimension économique et sociale, comme le montre la figure 01.

Figure 01 : La relation entre l'économie verte et le développement durable.



- La transition vers une économie a faible émission de carbone, à l'énergie renouvelable, et à la transition énergétique.

- Changement climatique, pénurie d'eau et d'énergie et environnementale

- Economie verte

- Développement durable (économique, sociale et environnementale).

Source : (Soltana, 2021)

Les principales idées présentées dans la figure 1 permettent de tirer la conclusion suivante : l'économie verte représente un levier essentiel pour la réalisation des Objectifs de Développement Durable (ODD). Elle s'impose comme un nouveau modèle économique favorisant une croissance durable, la création d'emplois de qualité, la réduction de la pauvreté, ainsi que la préservation et l'amélioration du capital naturel.

Deux des principaux thèmes abordés lors du sommet Rio+20 étaient : "L'économie verte dans le contexte du développement durable et de l'éradication de la pauvreté" et "Le cadre international du développement durable". L'économie verte étant désormais bien ancrée dans l'agenda politique international, il est essentiel d'examiner et de clarifier ses liens avec le développement durable.

La plupart des interprétations de la durabilité s'appuient sur le consensus atteint par la Commission mondiale sur l'environnement et le développement

(WCED) en 1987, qui définit le développement durable comme "un développement qui répond aux besoins du présent sans compromettre la capacité des générations futures à répondre aux leurs" (Kamble, 2020).

La transition vers une économie verte nécessite une approche intégrée qui combine croissance économique et développement durable. Elle vise à concilier les piliers économique, social et environnemental, permettant ainsi d'orienter le système vers un développement durable à l'échelle mondiale.

Dans cette perspective, l'écologisme apporte deux idées fondamentales (Boumar, 2023) :

La nécessité de repenser les relations entre l'être humain et la nature ;

La reconnaissance des limites de la croissance, impliquant une responsabilité écologique et une approche durable.

Ces fondements théoriques se traduisent concrètement dans les principes politiques défendus par certains mouvements écologistes. À titre d'exemple, le parti vert allemand (1983) a identifié quatre principes essentiels de la politique verte (Boumar, 2023):

- La responsabilité écologique ;
- La démocratie participative ;
- La justice sociale ;
- La non-violence.

L'économie verte suit plusieurs axes pour concrétiser le développement durable (Boumar, 2023):

Aménagement du territoire : Plans d'utilisation des terres cohérents, expansion des forêts communautaires, protection des bassins versants et création de zones dédiées aux terres dégradées.

Protection des forêts : Exploitation forestière à faible impact, certifications internationales de gestion durable des forêts, limitation des plantations aux zones très dégradées, et préservation des terres forestières inactives.

Exploitation minière : Adoption de bonnes pratiques internationales, gestion améliorée des déchets miniers pour limiter les impacts sur l'air et l'eau.

Agriculture durable : Conservation et restauration de la qualité des sols, réduction de l'utilisation d'engrais chimiques, et développement de banques

génétiques pour préserver la biodiversité et améliorer la résilience aux maladies et ravageurs.

Conservation de l'énergie : Augmentation de l'efficacité énergétique, réduction de la consommation de combustibles fossiles, expansion des énergies renouvelables et décentralisation de la production énergétique pour limiter les émissions de GES.

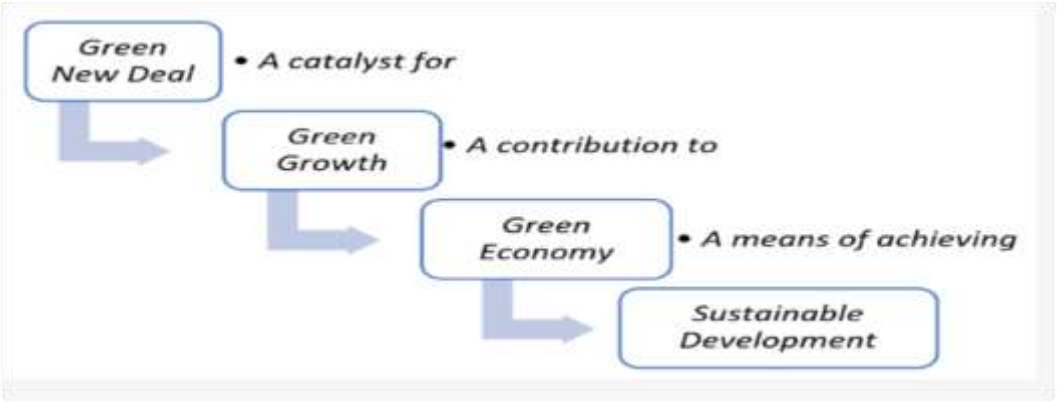
L'économie verte constitue une voie vers le développement durable et la lutte contre la pauvreté. Elle favorise le recours aux technologies vertes pour produire de l'énergie sans générer de sous-produits toxiques ou nuisibles. Elle encourage également l'adoption de technologies écologiques alternatives.

Grâce à l'économie verte, il est possible de réduire les déchets et la pollution en modifiant les modes de production et de consommation. Toutefois, chaque pays doit adapter cette transition à ses propres réalités nationales et priorités.

L'économie verte est un outil essentiel, mais elle ne doit pas être perçue comme une solution rigide. Elle doit contribuer à l'éradication de la pauvreté, assurer une croissance économique soutenue, favoriser l'inclusion sociale et améliorer le bien-être humain tout en préservant les écosystèmes de la planète (Liton Chandra Voumik, 2014).

Afin de mieux comprendre la logique évolutive et l'interdépendance des concepts liés à la transition vers un développement durable, la figure suivante illustre la hiérarchie des notions allant du Green New Deal jusqu'au développement durable, en passant par la croissance verte et l'économie verte.

Figure 02 : La hiérarchisation des concepts de l'économie verte



Source: (Adamowicz, 2022)

5. L'économie verte et le développement durable en Algérie"

Le contexte économique et énergétique de l'Algérie est fortement dépendant du secteur des hydrocarbures, qui représente 97 % des exportations et 70 % des recettes budgétaires de l'État. La consommation énergétique repose quasi exclusivement sur les combustibles fossiles, notamment le pétrole et le gaz, qui constituent 99 % de l'approvisionnement énergétique du pays (BOUACIDA., 2016). Cette dépendance est la principale source des émissions de gaz à effet de serre (EGES).

Les émissions de CO_2 ont ainsi connu une augmentation significative de 571 % en 54 ans, atteignant leur niveau le plus élevé en 2017 avec 3,87 tonnes par habitant, contre 0,46 en 1963. Selon certaines projections, cette valeur pourrait atteindre environ 4,36 en 2025.

D'après le rapport du Ministère de l'Énergie (2018), la consommation nationale totale d'énergie a enregistré une hausse notable de 7,7 % en 2018, atteignant 65 millions de tonnes équivalent pétrole (TEP). Cette consommation représente 39,3 % de la production totale et est principalement alimentée par le gaz naturel (+17 %), les GPL (+11 %) et l'électricité (+5 %). La répartition par secteur montre une prédominance de la consommation des ménages (46,6%), suivie du transport (32 %) et enfin de l'industrie et du BTP, qui représentent ensemble 22 %.

L'Algérie fait face à une vulnérabilité écologique marquée par la sensibilité de ses écosystèmes aux phénomènes de sécheresse et de

désertification. Par ailleurs, son littoral, bordé au nord par la mer Méditerranée et s'étendant sur 1 622,48 km d'est en ouest, a subi d'importantes transformations.

Environ 70 % de la population algérienne, estimée à 43 003 767 habitants en 2019, soit une densité de 18,06 habitants/km² selon l'ONS, vit en milieu urbain, concentrée sur la bande littorale qui ne représente que 4 % du territoire national. Ce taux d'urbanisation pourrait atteindre 85 % d'ici 2050.

Cette concentration croissante dans les grandes métropoles, notamment celles du littoral, entraîne une urbanisation excessive et aggrave des problématiques déjà préoccupantes : surconsommation des terres, dégradation accélérée du patrimoine bâti, pollution des nappes phréatiques, gestion inefficace des déchets et des répercussions négatives sur l'environnement et la santé publique (BACHAR, 2018).

Cependant, l'Algérie dispose de ressources considérables qui pourraient favoriser le développement d'une économie verte afin de limiter les nuisances environnementales et économiques. Parmi ces ressources :

- Un potentiel énergétique important en éolien et en géothermie, avec plus de 200 sources chaudes situées dans le nord du pays.
- Un fort potentiel solaire, avec une exposition annuelle de 2 000 heures, pouvant atteindre 3 900 heures sur les Hauts Plateaux et le Sahara, faisant de l'Algérie l'un des pays les mieux dotés en énergie solaire au monde.
- Une production annuelle de déchets ménagers et assimilés estimée à 34 millions de tonnes, qui devrait atteindre 70 millions de tonnes d'ici 2035.

Environ 50 % de ces déchets (plastique, déchets ménagers et assimilés) sont recyclables, selon le Ministère de l'Environnement et des Énergies Renouvelables (2019). En misant sur le développement du recyclage, l'Algérie pourrait ainsi économiser plus de 300 millions d'euros par an.

Dans le cadre de son engagement environnemental et énergétique, l'Algérie a rejoint plusieurs initiatives internationales. Elle a signé en 1993 la Convention-Cadre des Nations Unies sur les Changements Climatiques (CCNUCC) adoptée au Sommet de la Terre à Rio, puis a adhéré au Protocole de Kyoto en 2005.

Dès 2000, elle a adopté une stratégie de développement durable reposant sur divers axes de planification et d'action, incluant la gestion de ses ressources naturelles et la lutte contre la pollution.

Concernant la politique énergétique nationale, plusieurs projets ont vu le jour, notamment le projet Sahara Solar Breeder (SSB), lancé en 2011, ce projet de coopération entre le Ministère de l'Enseignement Supérieur et de la Recherche Scientifique, l'Université des Sciences et de la Technologie d'Oran, l'Agence Internationale de la Coopération Japonaise et l'Agence des Sciences et Technologies du Japon vise à installer des parcs solaires et éoliens sur 9 millions de kilomètres carrés dans le désert du Sahara.

L'objectif est de produire suffisamment d'électricité pour couvrir les besoins de la moitié de la population mondiale d'ici 2050. Ce projet permettra également de renforcer les compétences scientifiques et technologiques du pays, afin d'anticiper les défis économiques et énergétiques futurs.

L'Algérie s'engage dans une transition énergétique en mettant en place un programme de développement des énergies renouvelables (EnR) et de l'efficacité énergétique, adopté par le Gouvernement en février 2011, puis révisé en mai 2015 sans que les raisons de cette révision ne soient précisées. Ce programme a été élevé au rang de priorité nationale en février 2016 lors d'un Conseil Restreint de Gouvernement.

L'objectif actualisé vise l'installation de 22 000 MW d'énergies renouvelables d'ici 2030 pour couvrir les besoins du marché national, avec une réduction estimée des émissions de CO2 de 193 millions de tonnes. Pour soutenir cette initiative, la loi de finances 2017, adoptée en 2016, a introduit la Taxe d'Efficacité Énergétique (TEE), appliquée aux équipements électriques dépassant les normes de consommation énergétique.

Par ailleurs, un programme national de recherche (PNR) dédié aux énergies renouvelables a été mis en place afin d'évaluer les ressources énergétiques disponibles et de développer les compétences techniques nécessaires. Le Ministère de l'Énergie a également défini une répartition du programme selon différentes filières technologiques (BENYAHLOU, 2021), les résultats sont présentés dans le tableau suivant.

Tableau 03 : Consistance du programme de développement des énergies renouvelables.

Unité: MW	Phase 01 : 2015-2020	Phase 02: 2021-2030	Total
Photovoltaïque	3 000	10 575	13 575
Eolien	1 010	4 000	5 010
CSP	-	2 000	2 000
Cogénération	150	250	400
Biomasse	360	640	1 000
Géothermie	05	10	15
Total	4 525	17 475	22 000

Source: Ministère de l'énergie.

Il est à noter que le premier programme de développement des énergies renouvelables en Algérie n'a pas respecté son planning initial. Seules trois centrales pilotes (Hassi R'mel, Ghardaïa et Kabertène) totalisant 36,3 MW ont été réalisées. Par la suite, un programme de 343 MW en solaire photovoltaïque a été lancé en 2014 par la filiale SKTM de Sonelgaz. En parallèle, Sonatrach a mis en service une centrale solaire de 10 MW à BRN en 2018, dans le cadre d'un objectif de 2300 MW d'ici 2030.

En se basant sur les résultats précédents, on conclut que La transition vers une économie verte en Algérie constitue un levier stratégique pour concilier les exigences du développement durable, dans la mesure où elle permet de réduire la dépendance aux énergies fossiles tout en valorisant les ressources renouvelables du pays, notamment l'énergie solaire, éolienne et les déchets recyclables. En s'appuyant sur ces atouts, l'Algérie peut non seulement limiter ses impacts environnementaux, mais aussi stimuler une croissance économique plus diversifiée et inclusive, créatrice d'emplois durables, notamment dans les secteurs des énergies renouvelables et de la gestion des déchets. Toutefois, la réussite de cette transition dépend de la mise en œuvre effective des politiques engagées, d'une meilleure gouvernance et d'un accompagnement des réformes structurelles. Ainsi, on peut confirmer l'hypothèse proposée au départ.

6. Conclusion:

L'idée d'une économie verte, née en réponse aux crises mondiales, s'impose aujourd'hui comme une démarche incontournable pour réaliser les objectifs du développement durable. Elle vise à repenser les modes de production et de consommation en misant sur les énergies renouvelables, l'efficacité énergétique et la gestion responsable des ressources. À travers notre étude, nous avons confirmé que l'économie verte ne constitue pas une alternative au développement durable, mais en est un levier opérationnel essentiel. Il existe une relation intrinsèque entre l'économie verte et le développement durable, où l'économie verte est une partie intégrante du concept global du développement durable. Elle permet de traduire les principes du développement durable en actions concrètes, en ciblant les secteurs stratégiques et en conciliant croissance économique, inclusion sociale et protection de l'environnement.

Dans le cas de l'Algérie, la transition vers une économie verte représente un enjeu majeur face à la dépendance excessive aux hydrocarbures et aux défis environnementaux croissants. Le pays dispose d'atouts importants, tels qu'un potentiel solaire et éolien exceptionnel, des ressources en géothermie et une forte capacité de valorisation des déchets. Malgré un retard dans la mise en œuvre des programmes liés aux énergies renouvelables, les initiatives engagées (comme le projet Sahara Solar Breeder ou le programme de 22 000 MW d'ici 2030) témoignent d'une volonté politique affirmée. Cette transition, si elle est accompagnée de réformes structurelles, d'une gouvernance efficace et d'investissements durables, pourrait non seulement renforcer la résilience économique de l'Algérie, mais aussi améliorer les conditions sociales et environnementales de manière durable.

Ainsi, l'économie verte s'affirme comme une nécessité stratégique et une voie privilégiée pour concrétiser le développement durable en Algérie.

Recommandations:

- Sensibiliser à la culture de l'économie verte et accorder plus d'importance à cette stratégie.

  - Améliorer la performance environnementale en minimisant les risques sanitaires, en réduisant les émissions et les déchets, en assurant un traitement écologique des résidus et en proposant des biens et services à

faible émission.

- L'intervention des gouvernements pour soutenir et mettre en place des projets d'économie verte, en renforçant les lois régissant les activités économiques et en donnant la priorité aux projets de développement des énergies renouvelables, comme l'énergie solaire et éolienne, ainsi qu'au recyclage des déchets.

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Impact de la Croissance Démographique et Urbaine sur la Demande Énergétique en Algérie.

TALBI FATIHA
Université d'Alger 3, ALGERIE, talbi.fatiha@hotmail.fr

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Résumé :

L'Algérie connaît une forte croissance de sa demande énergétique, stimulée par une urbanisation rapide et une augmentation constante de la population. Ce travail applique une approche économétrique avancée pour analyser la relation entre ces facteurs et la consommation énergétique. En utilisant des méthodes de cointégration de Johansen, un modèle VAR/VECM sous EViews, cette étude met en lumière les déterminants clés de la demande énergétique en Algérie. Les résultats obtenus permettent de proposer des recommandations stratégiques pour une gestion durable des ressources énergétiques en Algérie.

Mots-clés : Croissance démographique, Urbanisation, Demande énergétique, Modèles économétriques, Cointégration.

***Corresponding author**: Talbi Fatiha, **e-mail:** talbi.fatiha@hotmail.fr.*

I- Introduction

L'Algérie, riche en ressources naturelles et énergétiques, est confrontée à des défis croissants découlant de sa dynamique démographique et urbaine. L'accélération de la population, estimée à plus de 44 millions d'habitants en 2024, s'accompagne d'une urbanisation rapide, aboutissant à une transition vers des centres urbains surpeuplés. Ces enjeux s'avèrent cruciaux pour le système énergétique national, alors que la demande d'énergie continue de croître à un rythme exponentiel.

La consommation énergétique de l'Algérie connaît une croissance soutenue depuis deux décennies, portée par l'essor démographique, le développement économique et l'extension de l'accès à l'électricité et au gaz. En 2001, la consommation finale d'énergie du pays n'était qu'environ 19 MTEP (millions de tonnes équivalent pétrole). Désormais, elle a triplé pour atteindre près de 55 MTEP en 2024, soit une croissance annuelle moyenne de l'ordre de 5% sur la dernière décennie. Ce niveau de consommation, d'environ 1,5 TEP par habitant, est relativement élevé comparé à d'autres pays de développement similaire. Le mix énergétique national reste dominé par les hydrocarbures (gaz naturel et pétrole), ce qui pose des défis en matière de durabilité et de sécurité énergétique. Face à ces enjeux, une modélisation statistique robuste de la demande est indispensable pour anticiper les tendances futures et éclairer les décisions.

Avec une croissance démographique rapide et un taux d'urbanisation élevé, l'Algérie fait face à une pression croissante sur ses ressources énergétiques. La problématique soulève la question suivante :

Quels sont les principaux déterminants de la demande énergétique en Algérie, et comment les politiques publiques peuvent-elles répondre aux défis liés à l'urbanisation et à la croissance démographique pour assurer un avenir énergétique durable ?

En particulier, les défis suivants sont abordés :

- Comment la croissance démographique et l'urbanisation influencent-elles la demande énergétique en Algérie ? Est-ce que cette demande est principalement tirée par l'augmentation de la population ou par l'urbanisation rapide ?

- Quels sont les facteurs qui expliquent la demande d'énergie en Algérie ? Est-ce que l'urbanisation, le PIB, ou le nombre de ménages ont une influence plus importante ?
- Comment les politiques énergétiques actuelles prennent-elles en compte ces dynamiques démographiques et économiques pour assurer une gestion durable des ressources énergétiques ?

L'objectif principal de cette étude est d'analyser l'impact de la croissance démographique et de l'urbanisation sur la demande énergétique en Algérie. L'étude vise à comprendre comment ces facteurs influencent la consommation d'énergie et à évaluer les dynamiques à court et long terme à l'aide de modèles économétriques avancés, comme les modèles VAR/VECM. En d'autres termes, l'objectif est de déterminer :

- Dans quelle mesure la croissance démographique et l'urbanisation affectent la demande énergétique en Algérie.
- Comment ces facteurs interagissent avec les variables économiques comme le PIB, le nombre de ménages, et l'industrialisation pour influencer la consommation d'énergie.
- Proposer des stratégies de gestion énergétique durable face à la croissance rapide de la population et de l'urbanisation.

II- Contexte Démographique et Urbain en Algérie :

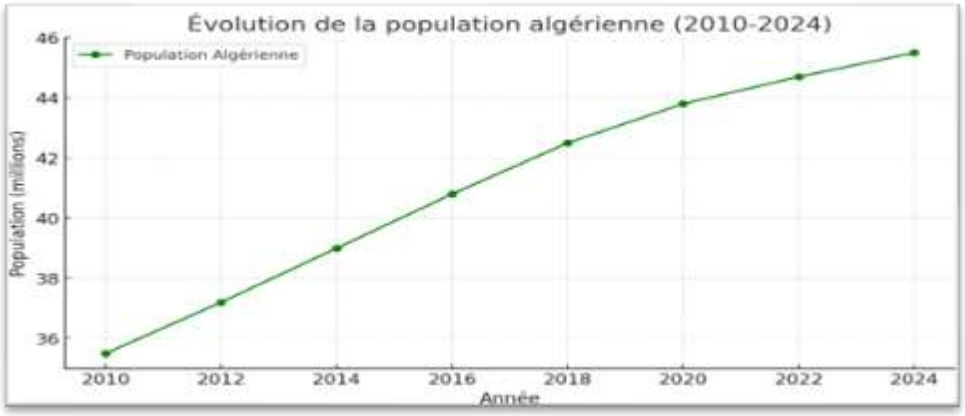
L'Algérie traverse une période de transformation marquée par des dynamiques démographiques et urbaines significatives.

1- Évolution de la Population Algérienne :

L'évolution de la population algérienne au cours des dernières décennies a été marquée par une dynamique croissante, caractérisée par des taux de natalité élevés et une amélioration des conditions de vie. Cette tendance a conduit à une augmentation significative de la population, qui a presque triplé depuis l'indépendance en 1962. En 2024, la population algérienne est estimée à environ 44 millions d'habitants. Les besoins énergétiques augmentent proportionnellement à la croissance démographique, en raison d'un accroissement de la consommation liée au développement urbain et à

l'augmentation des infrastructures nécessaires pour répondre aux aspirations de cette population en pleine expansion. En outre, les migrations rurales-urbaines intensifient ce phénomène, alors que de nombreux Algériens quittent les zones rurales pour chercher de meilleures opportunités dans les villes. Cela entraîne non seulement une concentration de la population urbaine, mais aussi une pression accrue sur les ressources énergétiques, les infrastructures et les services de base.

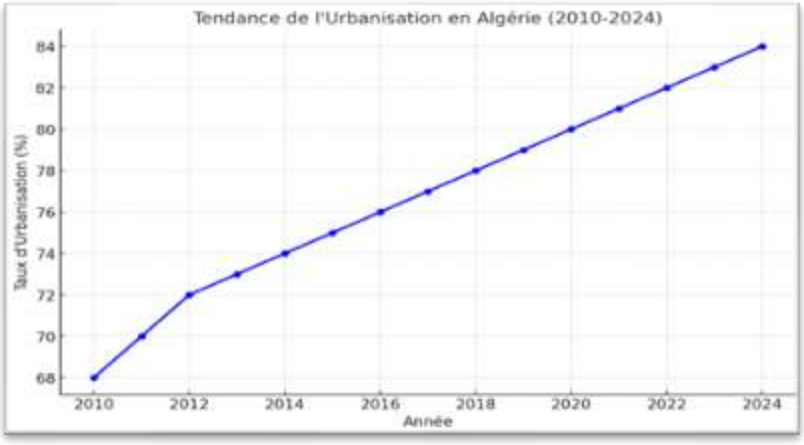
Fig.1. Évolution de la population algérienne (2010-2024)



2- Taux d'Urbanisation :

Le taux d'urbanisation en Algérie est un indicateur clé qui reflète les dynamiques de migration et les transformations socio-économiques dans le pays. Au cours des dernières décennies, l'Algérie a connu une urbanisation rapide, propulsée par divers facteurs, notamment des opportunités d'emploi, l'amélioration des infrastructures et le développement de services publics. En 2022, le taux d'urbanisation en Algérie était estimé à environ 73%, un chiffre qui témoigne d'une migration massive des zones rurales vers les villes, notamment vers des centres urbains comme Alger, Oran et Constantine, qui attirent des populations à la recherche de meilleures conditions de vie.

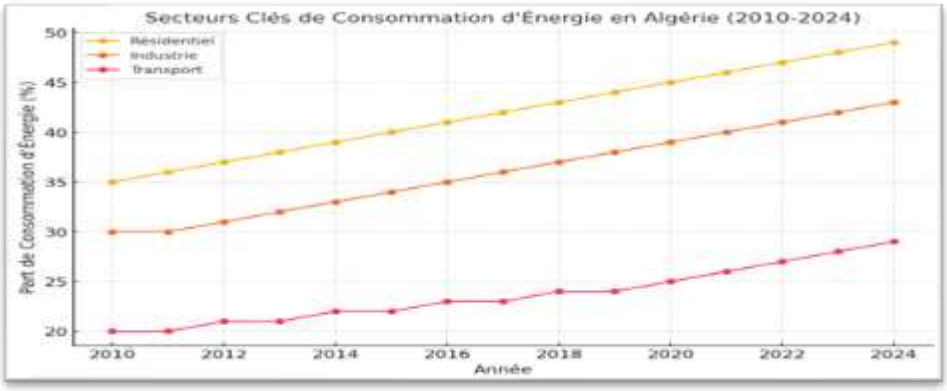
Fig.2. Tendance de l'urbanisation en Algérie



3- Secteurs Clés de Consommation d'Énergie en Algérie :

La consommation d'énergie en Algérie est profondément influencée par plusieurs secteurs clés, chacun avec ses caractéristiques, ses besoins spécifiques et son empreinte énergétique. Parmi ces secteurs, le résidentiel, l'industriel et le transport jouent des rôles cruciaux qui méritent une attention particulière.

Fig.3. Secteurs Clés de Consommation d'Énergie en Algérie 2010-2024



- **Le secteur résidentiel :**

Ce secteur est le premier consommateur d'énergie dans le pays, en grande partie en raison de l'augmentation de la population urbaine et de l'essor des

particuliers en termes de confort et de services. Les ménages algériens, en quête de commodité, se tournent vers des équipements de chauffage, de climatisation et d'électroménager modernes. Ainsi, la demande d'électricité et de gaz naturel a considérablement augmenté, notamment dans les zones urbaines où la densité de population est élevée. Ce phénomène exacerbe déjà une situation énergétique marquée par des défis d'approvisionnement, particulièrement en période de forte demande, comme durant les étés chauds.

- **Le secteur industriel :**

Le secteur industriel en Algérie représente un pilier essentiel dans la structure économique du pays, étant à la fois un moteur de croissance et un déterminant majeur de la demande énergétique. L'industrialisation rapide, propulsée par divers programmes de développement, a engendré une augmentation significative de la consommation d'énergie, notamment dans des industries clés telles que l'extraction minière, la pétrochimie, et la transformation agroalimentaire. Ces branches sont gourmandes en énergie et nécessitent des infrastructures robustes pour soutenir leur fonctionnement. Les industries extractives, notamment le pétrole et le gaz, constituent des moteurs économiques indispensables, représentant une part significative de la consommation énergétique nationale. Ces secteurs nécessitent d'importantes quantités d'énergie pour leurs opérations, allant de l'extraction à la transformation, en passant par le transport. L'industrialisation croissante et l'implémentation des technologies énergétiques avancées visent à améliorer l'efficacité des processus tout en réduisant l'impact environnemental.

- **Le secteur de transport :**

Le secteur des transports en Algérie joue un rôle crucial dans la dynamique énergétique du pays, en particulier dans le contexte de la croissance démographique et urbaine rapide. Alors que la population algérienne continue d'augmenter, les besoins en transport s'intensifient, ce qui influe directement sur la demande énergétique. Les modes de transport dominants, notamment le transport routier, ferroviaire et maritime, se distinguent par leur consommation énergétique et leur impact environnemental. Dans ce cadre, le transport routier représente une part substantielle de la demande énergétique, alimenté par une flotte de véhicules en expansion qui comprend des voitures particulières, des camions et des

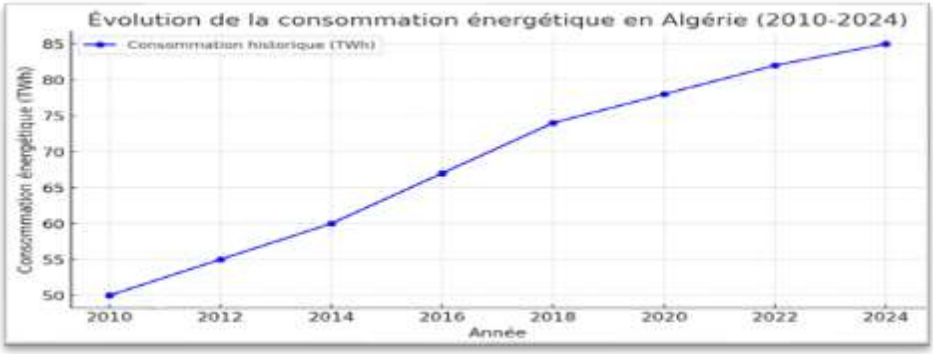
autobus. Cette dépendance au pétrole, en tant que principale source d'énergie pour le transport, soulève des préoccupations quant à la durabilité de la consommation énergétique à long terme, surtout face à l'augmentation inéluctable des coûts des combustibles fossiles.

III- Demande Énergétique en Algérie :

1- Tendances de la Demande Énergétique en Algérie :

La demande énergétique en Algérie est en constante évolution, influencée par des facteurs macroéconomiques, démographiques et sociopolitiques. Ces tendances révèlent une dynamique complexe, où la croissance démographique, combinée à l'urbanisation rapide, engendre une augmentation notable de la consommation énergétique. La population algérienne, qui a récemment franchi le cap de 44 millions d'habitants, observe une urbanisation croissante. Cette transition vers des environnements urbains stimule non seulement le désir d'une meilleure qualité de vie, mais aussi une nécessité accrue en infrastructures et en services, qui à leur tour intensifient la demande énergétique.

Fig.4.Évolution de la consommation énergétique en Algérie (2010-2024)



2- Facteurs Influençant la Demande Énergétique :

La demande énergétique en Algérie est influencée par un ensemble de facteurs interconnectés, chacun jouant un rôle crucial dans la détermination des besoins en énergie à travers le pays :

- **la croissance démographique** : mesurée en millions d'habitants, constitue un indicateur de la pression exercée sur les ressources énergétiques.

Une population en constante augmentation entraîne une hausse de la consommation quotidienne d'énergie, que ce soit pour les besoins domestiques, industriels ou de transport. Par conséquent, un suivi attentif des évolutions démographiques est indispensable pour anticiper les pics de demande énergétique, notamment dans les zones métropolitaines où la concentration de la population est plus marquée.

- **Le taux d'urbanisation** : exprimé en pourcentage, est un autre vecteur significatif qui reflète le développement urbain en Algérie. À mesure que les individus migrent vers les villes à la recherche de meilleures opportunités économiques et sociales, la demande en infrastructures énergétiques s'intensifie. Les villes, en tant que moteurs de développement, nécessitent des systèmes énergétiques adaptés pour répondre à la civilisation moderne, intégrant à la fois le secteur résidentiel et les besoins industriels croissants
- **le Produit Intérieur Brut par habitant (en dollars)** : témoigne de la croissance économique d'un pays. Une augmentation du PIB par habitant est souvent associée à une hausse de la consommation énergétique, car une économie en expansion génère une demande accrue pour des infrastructures, des services et des biens, nécessitant ainsi un approvisionnement énergétique fiable.
- **le nombre de ménages** : représente une variable clé dans l'analyse de la consommation résidentielle. Chaque nouveau ménage entraîne une augmentation de la demande énergétique, non seulement pour l'électricité et le gaz, mais également pour le transport et d'autres services connexes.

IV- Modélisation de la demande Énergétique en Algérie :

1- Sources des Données :

Les données utilisées dans cette étude proviennent de sources officielles telles que l'Office National des Statistiques (ONS, 2024), le Ministère de l'Énergie et des Mines (Algérie, 2024) et l'Agence Internationale de l'Énergie (AIE). Les principales variables analysées incluent :

- Population (millions) : indicateur de pression démographique.
- Taux d'urbanisation (%) : reflet du développement urbain.
- PIB par habitant (USD) : indicateur de croissance économique.

- Nombre de ménages (millions) : variable de consommation résidentielle.
- Demande énergétique (TWh) : variable cible.

2- Tests de Stationnarité (ADF) :

Avant d'estimer un modèle VAR/VECM, il est nécessaire de tester la stationnarité des séries temporelles.

Selon les résultats dans le tableau, la demande énergétique est stationnaire à un niveau de signification de 5% (p-value = 0.03), ce qui signifie que la consommation énergétique suit une tendance stable au fil du temps.

Les autres variables (Population, Taux d'urbanisation, PIB par habitant, Nombre de ménages) sont non stationnaires, ce qui signifie qu'elles doivent être différenciées avant d'être utilisées dans les modèles économétriques.

Le test Dickey-Fuller Augmenté (ADF) a montré que toutes les variables, sauf la demande énergétique, étaient non stationnaires en niveau. Par conséquent, elles ont été différenciées pour rendre les séries stationnaires.

Tableau.1. Résultats Tests de Stationnarité (ADF)

Variable	ADF Statistic	p-value	Conclusion
Population	-0.80	0.80	Non stationnaire
Taux d'urbanisation	-2.45	0.34	Non stationnaire
PIB par habitant	-2.90	0.18	Non stationnaire
Nombre de ménages	-1.20	0.71	Non stationnaire
Demande énergétique	-3.50	0.03	Stationnaire

3- Estimation des Modèles :

- **Test de Cointégration de Johansen :**

Le test de cointégration de Johansen a été utilisé pour déterminer s'il existe une relation de long terme entre les variables.

Tableau.2. Résultats du Test de Cointégration

Nombre de relations cointégrées	Statistique de Trace	Valeur critique (5%)	Cointégration détectée
3	37.5	29.8	Oui

La statistique de trace est 37.5, qui est supérieure à la valeur critique de 29.8 à un niveau de 5%, ce qui indique qu'il existe trois relations de cointégration entre les variables. Cela suggère que la population, l'urbanisation, le PIB par habitant, et la demande énergétique sont liées par des relations de long terme.
En conséquence, nous pouvons utiliser un modèle VECM (Vector Error Correction Model) pour capturer l'ajustement à court terme tout en prenant en compte la relation de long terme.

- **Modèle VECM (Vector Error Correction Model) :**

Étant donné l'existence de relations de cointégration, un modèle VECM a été estimé pour saisir les ajustements à court terme et la correction d'erreur vers l'équilibre de long terme, et les coefficients de correction d'erreur (ECT) mesurent la vitesse à laquelle le modèle ajuste les erreurs de court terme pour revenir à l'équilibre de long terme.

Tableau.3. Résultats du Modèle VECM

Variable	Correction d'erreur 1	Correction d'erreur 2	Correction d'erreur 3
ΔPopulation	-0.00108	0.90e3	0.00235
ΔTaux d'urbanisation	-0.00261	2.53e3	-0.00094
ΔPIB par habitant	-112.05	70.03	-13.75
ΔDemande énergétique	-0.00112	1.03e3	0.00091

- ΔPopulation a un coefficient de -0.00108 dans la première équation, ce qui signifie que, lorsque la population change, l'ajustement vers l'équilibre de long terme se fait lentement (ajustement négatif).

- ΔTaux d'urbanisation a un coefficient de -0.00261, ce qui signifie qu'une augmentation de l'urbanisation a un impact négatif sur la demande énergétique à court terme.
- ΔPIB par habitant : L'impact est assez important, mais la variable a un coefficient modéré à long terme.
- ΔDemande énergétique : A une relation directe avec la population et l'urbanisation, mais l'effet à court terme est relativement faible.

Impact des Variables :

- Les variables population et urbanisation ont une influence significative à long terme sur la demande énergétique.
- Le PIB par habitant joue un rôle important à moyen terme, affectant à la fois la croissance économique et les modèles de consommation.
- **Analyse des Impulsions-Réponses :**

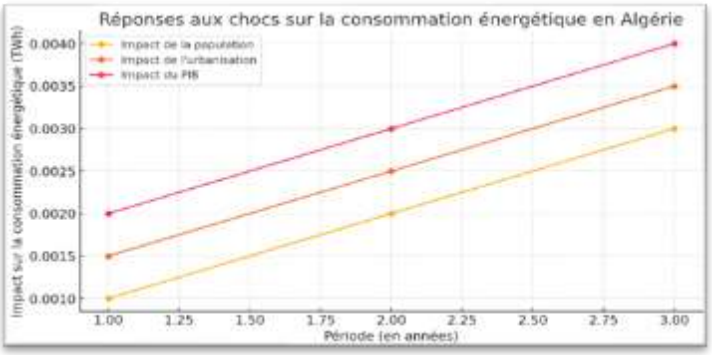
Une analyse des impulsions-réponses permet de comprendre comment un choc sur l'une des variables affecte la demande énergétique.

Tableau.4. Analyse des Impulsions-Réponses

Période	Impact choc Population	Impact choc Urbanisation	Impact choc PIB
1	0.0021	0.0015	0.0012
2	0.0054	0.0038	0.0027
3	0.0089	0.0061	0.0049
4	0.0112	0.0073	0.0065

Une analyse sur 3 périodes est souvent choisie pour évaluer l'impact des variables dans un horizon de temps relativement court (quelques années). Cela permet de détecter l'effet initial (court terme) et la manière dont cet effet évolue. Un modèle VAR ou VECM peut produire des résultats sur plus de périodes, mais souvent 3 à 5 périodes suffisent pour comprendre comment l'économie réagit après un choc immédiat. Les résultats montrent que la population a un impact durable sur la demande énergétique, avec un effet de long terme plus important pour l'urbanisation.

Fig.5 . Réponses aux chocs sur la consommation énergétique en Algérie



Ce graphique montre l'impact des chocs sur la population, l'urbanisation et le PIB sur la demande énergétique.

Pendant la première période après le choc:

- Un choc sur la population augmente la demande énergétique de 0.0021 TWh.

Un choc sur l'urbanisation augmente la demande énergétique de 0.0015 TWh.

Un choc sur le PIB augmente la demande énergétique de 0.0012 TWh.

Pendant le reste des périodes, les effets de chaque choc continuent d'augmenter, avec des impacts plus importants à long terme. Par exemple, un choc sur la population entraîne un impact croissant sur la demande énergétique à mesure que le temps passe (0.0021 en Période 1 à 0.0112 en Période 4).

Ce que cela signifie :

- Les chocs sur la population ont un impact immédiat sur la demande énergétique et continuent de croître dans le temps.
- L'urbanisation et le PIB montrent des effets plus faibles à court terme mais des effets plus persistants et croissants au fil du temps.

- **Décomposition de la Variance :**

La décomposition de la variance analyse quelles variables expliquent le plus les fluctuations de la demande énergétique. Il ressort que la population explique en moyenne 50% des fluctuations de la demande énergétique, suivie de l'urbanisation et du PIB.

Tableau.5. Décomposition de la Variance

Période	Variance expliquée par Population	Variance expliquée par Urbanisation	Variance expliquée par PIB
1	32%	24%	18%
2	45%	30%	22%
3	50%	35%	28%

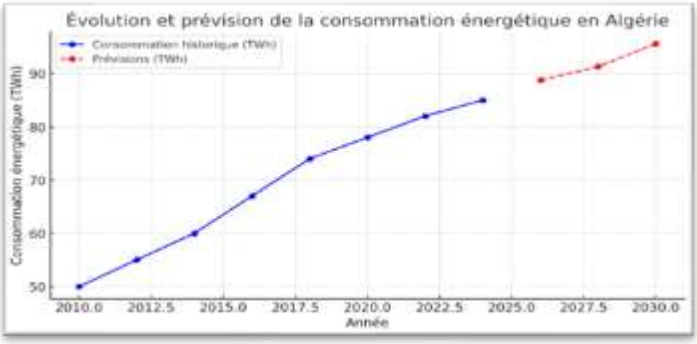
Fig.6. Décomposition de la variance de la consommation énergétique

Dans la première période, la population explique 32% de la variance de la demande énergétique, tandis que l'urbanisation contribue à hauteur de 24%, et le PIB représente 18% des variations de la consommation énergétique. Lors de la deuxième et troisième période, la population continue de jouer un rôle important, avec une contribution de 45% puis 50%. L'urbanisation et le PIB montrent également une progression dans leur impact, avec respectivement 30% et 22% en deuxième période, et 35% et 28% en troisième période

Ce qui signifie :

- La population est le facteur dominant expliquant les variations de la demande énergétique à court et moyen terme. À mesure que l'urbanisation et le PIB augmentent, leur contribution à l'explication des fluctuations de la demande énergétique devient de plus en plus significative.

Fig.7. Prévision de l'évolution de la consommation énergétique en Algérie



V- Conclusion et Recommandations :

Les résultats montrent que La croissance démographique et l'urbanisation en Algérie exercent une pression considérable sur les ressources énergétiques du pays. À mesure que la population continue d'augmenter, notamment dans les zones urbaines, la demande énergétique enregistre une hausse significative. Cette tendance nécessite une réflexion approfondie sur les politiques énergétiques actuelles et l'adoption de nouvelles stratégies pour garantir un avenir énergétique stable et durable.

Il devient primordial pour les décideurs d'intégrer des approches holistiques qui visent à synchroniser l'expansion urbaine avec des solutions énergétiques innovantes. Cela pourrait passer par l'intégration des énergies renouvelables comme le solaire et l'éolien, en exploitant les ressources naturelles disponibles pour diversifier le mix énergétique. De plus, l'amélioration de l'efficacité énergétique dans les secteurs résidentiel et industriel doit être priorisée.

Des programmes de sensibilisation pour encourager les comportements d'économie d'énergie au niveau domestique peuvent également contribuer à réduire la pression sur les infrastructures existantes.

Enfin, il est recommandé d'établir des partenariats stratégiques avec des organismes internationaux et des entreprises privées afin de mobiliser des investissements dans des technologies énergétiques de pointe. La mise en place de cadres réglementaires favorables à l'innovation, ainsi que le soutien à la recherche et au développement dans le domaine énergétique, permettront

non seulement de répondre aux besoins énergétiques croissants, mais aussi de promouvoir le développement durable et la résilience des villes algériennes face aux défis futurs. Ces mesures collectives offriront les moyens de transformer la dynamique énergétique du pays, assurant une fourniture d'énergie fiable et respectueuse de l'environnement pour les générations à venir.

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Agriculture Hydroponique Intelligente : La Solution Technologique pour l'Avenir de la Sécurité Alimentaire et de la Stabilité Économique au Moyen-Orient

Souaad TAHRAOUI[1], Souad BERHAB[2]

[1] Electronic Departement, Hassiba Benbouali University, Chlef Algeria, Signals, Systems and Artificial Intelligence Laboratory 2SAIL Chlef Algeria, E-mail: s.tahraoui@univ-chlef.dz

[2] Dept. of Specialty. Higher National School of Telecommunications and Information and Communication Technologies-ENSTTIC, Oran, Algeria, LITS Laboratory, Oran, Algeria, e-mail: souad.berhab@ensttic.dz

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Abstract:

The Middle East is confronted with serious challenges such as water shortage, desertification, and climate change that threaten food security and economic stability. Hydroponic agriculture, smart and soilless, is a sustainable solution, conserving 90% of water. IoT and AI make it even more advantageous to monitor and cultivate crops in real-time and optimize crop yields. Bioprinting pushes the platform of innovation in agriculture even further. These solutions improve food autonomy, decrease reliance on imports, and create employment opportunities. Regional integration of policies can promote cooperation and sustainable development.

Keywords: Sustainable agriculture, food security, Middle East, climate change, water scarcity, smart farming, artificial intelligence, Internet of Things (IoT), bioprinting

***Corresponding author**: Full name, **e-mail:** s.tahraoui@univ-chlef.dz*

1. INTRODUCTION

Le Moyen-Orient fait face à de multiples défis environnementaux et économiques, notamment la rareté de l'eau, la désertification et le changement climatique, qui menacent directement la sécurité alimentaire de la région. L'agriculture hydroponique intelligente, grâce à des systèmes de culture sans sol économisant jusqu'à 90 % d'eau, constitue une réponse durable adaptée aux conditions arides. Intégrant l'IA, l'IoT et la bio-impression 3D, cette technologie permet un suivi précis, optimise les rendements, et limite les pertes. Sur le plan économique, elle favorise l'autosuffisance, réduit la dépendance aux importations, et crée de l'emploi, tout en stimulant la coopération régionale vers un développement durable.

Les recherches récentes confirment l'importance croissante de l'agriculture hydroponique intelligente pour faire face aux défis de la sécurité alimentaire, en particulier dans les contextes arides et urbains du Moyen-Orient. L'agriculture hors-sol, appuyée par des technologies telles que l'Internet des objets (IoT) et l'intelligence artificielle (IA), apparaît comme une solution durable et résiliente pour les systèmes alimentaires de demain [2],[3],[10]. Des études menées en Arabie saoudite et au Qatar soulignent le rôle stratégique de l'hydroponie dans la réduction de la dépendance aux importations alimentaires et le renforcement de la résilience agricole locale [4],[5],[6]. L'agriculture verticale et les systèmes contrôlés en environnement extrême sont également reconnus pour leur capacité à améliorer l'adaptabilité des systèmes alimentaires [7],[10].

Par ailleurs, l'hydroponie permet une utilisation optimisée de l'eau, un facteur crucial dans les régions en stress hydrique [8]. Toutefois, la réussite de ces approches dépend de l'alignement des politiques publiques, de la disponibilité des infrastructures et de la coopération intersectorielle [1],[4],[9]. La convergence entre planification urbaine durable, innovation technologique et conception écologique est donc essentielle pour une mise en œuvre à grande échelle [1],[2].

2. Contexte Régional Fragile

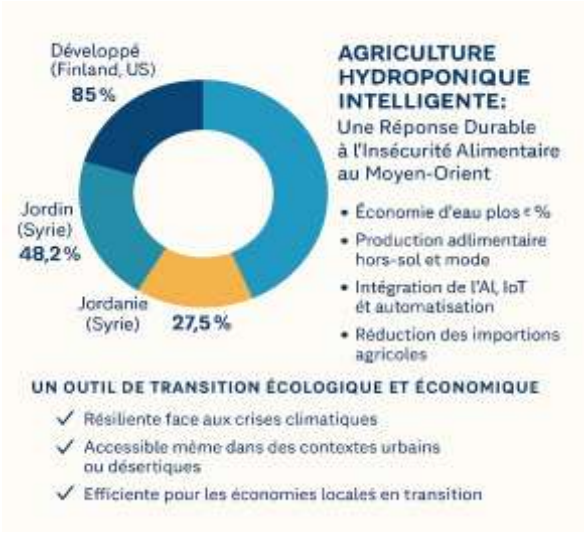
Le Moyen-Orient fait face à des problèmes multidimensionnels :

- Changement climatique,

- Rareté de l'eau,
- Désertification,
- Et une dépendance excessive aux importations alimentaires.

Ces facteurs compromettent la sécurité alimentaire et la stabilité économique de toute la région[7].

Fig1. Disparités Régionales dans l'Adoption de l'Agriculture Hydroponique Intelligente



3. l'Insécurité Alimentaire au Moyen-Orient

Selon l'indice mondial de sécurité alimentaire (**GFSI, 2023**), plusieurs pays du Moyen-Orient affichent une sécurité alimentaire faible à modérée, en comparaison avec les pays développés.

Tab1 . L'indice mondial de sécurité alimentaire (**GFSI, 2023**)

Pays	**Indice de sécurité alimentaire (%)**	**Classement mondial**
Finlande	85 %	1er
Pays-Bas	84 %	2e
États-Unis	81 %	11e
Qatar	81.2 %	13e

Émirats Arabes Unis	75.5 %	21e
Arabie Saoudite	73.5 %	30e
Jordanie	48.2 %	89e
Syrie	41.3 %	101e
Yémen	27.5 %	113e

- Pays développés (Finlande, USA) : couvrent environ 85 % du cercle.
- Pays du Golfe (Qatar, Émirats) : couvrent 75–81 %.
- Moyen-Orient à ressources limitées (Jordanie, Syrie, Yémen) : entre 27 % et 48 %.

4. Enjeux Alimentaires et Économiques au Moyen-Orient

- **Terres Arides**

70% des terres sont inadaptées à l'agriculture traditionnelle. Le climat aride limite les cultures.

- **Croissance Démographique**

La région connaît une croissance démographique rapide de 2% par an. Cela augmente la demande alimentaire.

- **Dépendance Alimentaire**

Plus de 85% des besoins alimentaires sont couverts par les importations. Cette dépendance est un risque économique.

Le Moyen-Orient fait face à des défis majeurs. Les terres arables sont rares, la population augmente rapidement et la dépendance aux importations est forte.

L'Agriculture Hydroponique est Une Réponse Innovante permet de cultiver sans sol, en utilisant un système nutritif contrôlé.

Elle consomme jusqu'à 90 % moins d'eau que l'agriculture traditionnelle,

Elle est idéale pour les zones arides et les environnements défavorables,

Elle permet de produire localement, toute l'année.

5. Vers une Agriculture Intelligente

Ce qui rend cette technologie encore plus prometteuse, c'est son intégration avec :

- L'intelligence artificielle (IA) pour la gestion automatisée des cultures,
- L'Internet des objets (IoT) pour la surveillance en temps réel (température, humidité, pH...),

- Et même la bio-impression. 3D, Impression de structures spongieuses ou de bio-gels (gels biologiques) servant de milieu de croissance pour les racines, en remplacement de la laine de roche ou de l'argile
- Résultat : une productivité accrue, une réduction des pertes, et un pilotage intelligent de chaque goutte d'eau et nutriment [6],[10].

6. Bénéfices Économiques et Sociaux

Pour les pays du Moyen-Orient, qui dépendent souvent des ressources pétrolières, l'hydroponie offre une opportunité de diversification économique.
Sur le plan économique :

- Ces systèmes encouragent l'autosuffisance alimentaire,
- Réduisent la dépendance aux importations,
- Et créent de nouveaux emplois dans les secteurs de la technologie, de l'agriculture et de la recherche.

Sur le plan politique et régional :

- L'intégration de ces technologies dans les politiques agricoles peut favoriser la coopération entre États,
- Et renforcer la résilience commune face aux défis climatiques.

7. Conclusion

En conclusion, l'agriculture hydroponique intelligente se présente comme une solution technologique clé pour relever les défis de la sécurité alimentaire, préserver nos ressources naturelles et de la stabilité économique au Moyen-Orient. En intégrant cette méthode innovante dans les stratégies agricoles, les pays de la région peuvent non seulement améliorer leur autosuffisance alimentaire, mais aussi créer un avenir plus durable et prospère pour leurs populations.

Investir dans cette voie, c'est faire le choix de l'innovation, de la résilience, et de la souveraineté alimentaire pour les générations futures.

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