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Impact Evaluation of the National Ecological Transition Strategy of Tunisia

MASTER DEGREE IN
ENERGY ENGINEERING – ENERGY FOR DEVELOPMENT

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Abstract

The objective of this thesis is to conduct a comprehensive socio-economic and environmental impact evaluation of the National Ecological Transition Strategy (SNTE) of Tunisia over a ten-year planning horizon from 2025 to 2035. The project initiates with an ex-ante diagnostic analysis of Tunisia's baseline development context, focusing heavily on the indicators of the first eight Sustainable Development Goals (SDGs) from the UN Agenda 2030, alongside an evaluation of past and current energy situation dynamics and power sector regulations. To determine the multi-dimensional effects of the SNTE's proposed measures, an Impact Evaluation Framework (IEF) is deployed. This framework utilizes a qualitative, multi-indicator approach across the sustainable development pillars to track systemic benefits and vulnerabilities. Concurrently, a dedicated quantitative energy system optimization model is constructed specifically for SDG 7 (Affordable and Clean Energy) to assess whether Tunisia's planned power sector expansions can successfully meet its long-term targets of 50% electricity generation from renewable energy sources (RES) and emission reduction of 38% by 2035.

The energy modeling results indicate a profound structural transformation of the national grid, characterized by a "solar explosion" driven by decentralized installations and utility-scale projects. Under the core 2035 Scenario, the national RES generation share expands significantly from a 3.00% baseline to 41.64%. This shift enhances system reliability by reducing annual unmet demand from 10,713 GWh/y to 5,292 GWh/y and substantially improves climate performance, dropping carbon intensity from 0.502 to 0.290 kgCO2/kWh. However, the findings reveal that even with these extensive additions, the planned strategy falls short of the official 50% renewable target and leaves a portion of unmet demand unaddressed. On a broader scale, the qualitative IEF results reveal a widespread outward expansion of development metrics across macro-pillars from 2025 to 2035. The strategic execution of the SNTE acts as a powerful driver for sustainable development, unlocking green job creation, mitigating pollution-related illnesses, modernizing municipal building efficiency, and gradually decoupling Tunisia's vulnerable economy from highly volatile fossil fuels.

Key-words: Energy Modelling, Agenda 2030, SGDs, Socio-Economic analysis, Impact Evaluation, SNTE

Abstract in Italiano

L'obiettivo di questa tesi è condurre una valutazione d'impatto socio-economico e ambientale della Strategia Nazionale per la Transizione Ecologica (SNTE) della Tunisia nel periodo 2025-2035, avviando l'indagine con un'analisi diagnostica ex-ante incentrata sui primi otto Obiettivi di Sviluppo Sostenibile (SDG) dell'ONU e sulle regolamentazioni storiche del settore elettrico. Utilizzando un quadro metodologico qualitativo multi-indicatore (IEF) e un modello quantitativo di ottimizzazione energetica focalizzato sull'SDG 7, la ricerca valuta la capacità del Paese di raggiungere i target del 50% di elettricità da fonti rinnovabili e di una riduzione delle emissioni del 38% entro il 2035.

I risultati della modellazione indicano una profonda trasformazione strutturale della rete guidata da una "esplosione del solare" che innalza la quota di rinnovabili dal 3.00% al 41.64%, dimezzando la domanda insoddisfatta da 10,713 a 5,292 GWh/anno e abbattendo l'intensità di carbonio da 0.502 a 0.290 kgCO2/kWh, pur mancando l'obiettivo ufficiale del 50%. Su più ampia scala, tuttavia, l'attuazione della SNTE si rivela un potente motore di sviluppo sostenibile, sbloccando la creazione di posti di lavoro verdi, mitigando le patologie legate all'inquinamento, modernizzando l'efficienza degli edifici comunali e avviando il progressivo disaccoppiamento della vulnerabile economia tunisina dalla forte volatilità dei combustibili fossili.

Parole chiave: Energy Modelling, Agenda 2030, SGDs, Analisi Socio-Economic, Impact Evaluation, SNTE

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Introduction

Tunisia, the smallest country in the North African region, has a surface area of 163,610 km². It is divided in four physiographic regions: the mountains of the Northwest, the mountains of the South, the coastal plains, and the desert plains. From an administrative perspective, the country is divided into seven regions and 24 governorates, as shown in the Appendix. Tunisia is the 31st country in Africa and 80th in the world with a population of 12 million (green dotted line) of which 30% still living in rural areas and annual growth in the last years of 0.63%, the lowest between neighboring countries, and a density of 79 people/km², as reported in Figure 1. Following the same descending trend of MENA Region countries, Tunisia moved from a peak of annual growth between the 70s and 80s of 2.7% to the lowest today, decreasing every year. The country went through a political transition after the 2011 revolution, which triggered the so-called Arab Spring, with the adoption of a new Constitution in early 2014 followed by orderly elections.

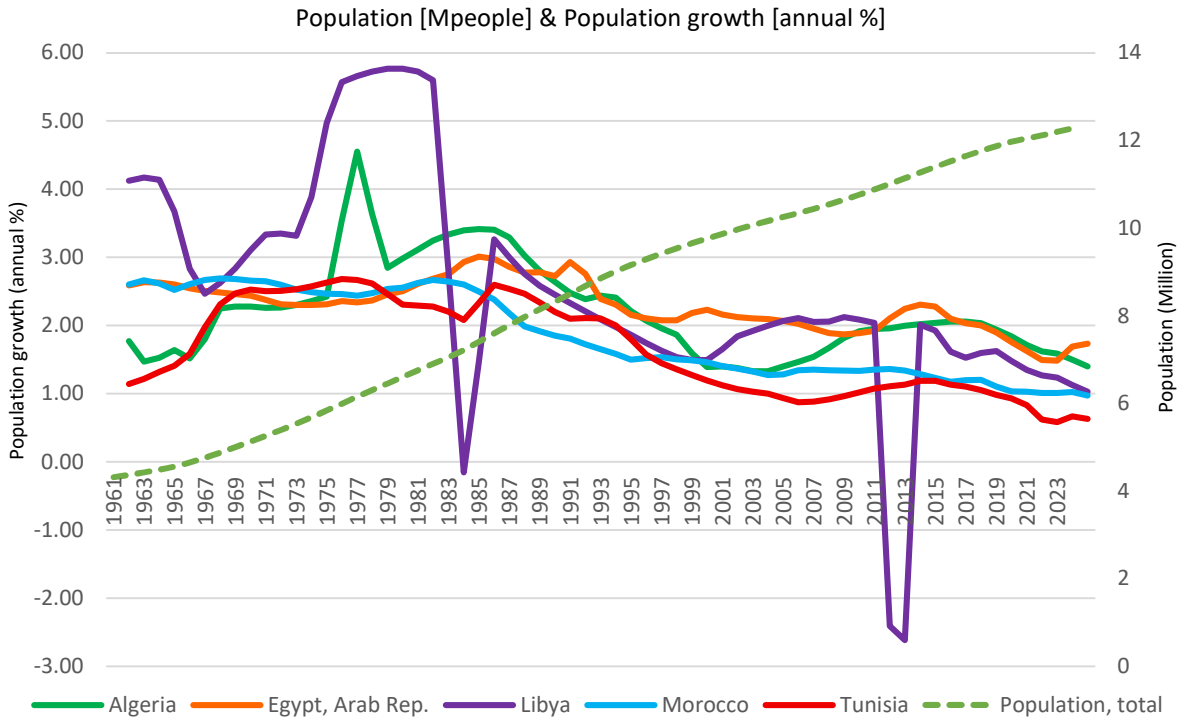


Figure 1: Population MENA region [Mpeople] e annual growth [%]

Demographically, urbanization is high with 70% of people living in urban areas. This value, according to the World Bank based on data from the UN Population Division is going to increase up to 83% in 2050, while total population up to 13 million

maintaining mostly the same population growth of nearly 1%. The capital, Tunis, is the most populated city in the country with 600 thousand inhabitants while the greater metropolitan area (Grand Tunis) holds over 2.6 to 2.9 million inhabitants. While the division between male and female is equally distributed similar to neighboring countries.

The data provided in Figure 2 reveals a profound structural transformation in Tunisia's demographic and economic profile from 1960 to the present day. Over these six decades, as mentioned above, the total population nearly tripled, rising from approximately 4.2 million to over 12 million by 2023. This growth was not uniform across age groups, reflecting a classic demographic transition. In the earlier decades, the chart is dominated by a "youth bulge," with the 0–14 and 15–24 age people expanding rapidly. However, starting in the late 1990s, the base of the population began to narrow as birth rates declined. Total Fertility Rate (TFR) fell under the threshold value of 2.1 children per woman, which is generally considered the replacement-level fertility in developed countries (enough to replace the population without migration). This decline tends to be associated with the decrease in child mortality, which started dropping from 50% in 1860 to 27% in 1950, to 4.3% in 2020, and also associated with the increase of women involvement in the workforce. According to the Five Stages of the Demographic Transition reported in Appendix, Tunisia fall under Stage 4, which is characterized by a low TFR, low death rate (stable around 6 per 1000 people) and population change slowing decreasing. This shift is characteristic of a population pyramid moving from an "expansive" shape (wide base, narrow top) to a "stationary" or "regressive" shape (barrel-like), where the middle-aged and elderly segments represent an increasing share of the total.

The most significant demographic characteristic of recent years is the maturation of this youth bulge into the 25–64 age group, which now forms the largest portion of the population. While this created a demographic dividend of abundant labor, the GDP per capita (in current US$) shows that Tunisia has struggled to capitalize on it. After a period of steady economic growth that saw wealth rise from under $1,000 in the 1970s to a peak of roughly $4,300 in the early 2010s, the trend has become increasingly volatile. The sharp fluctuations visible after 2011 are direct reflections of the Jasmine Revolution and the subsequent period of political transition, which brought both high hopes and significant economic disruption.

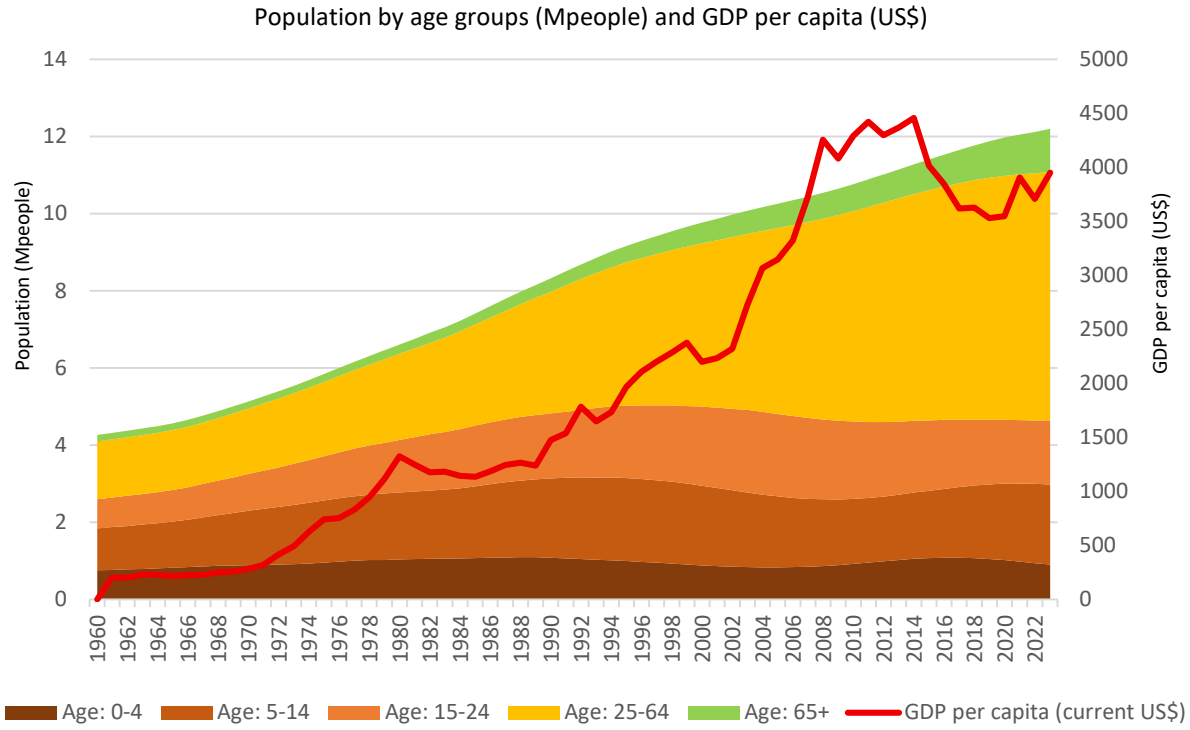


Figure 2: Population by age groups [Mpeople] and GDP per capita [US$]

The economic stagnation observed in the mid-2010s was further exacerbated by specific historical shocks. The visible dip in GDP per capita around 2015 corresponds to the devastating terrorist attacks at the Bardo Museum and Sousse paralyzing the tourism sector, essential for the Tunisian economy. This period also saw the Tunisian Dinar (TND) lose value against the US dollar, which combined with high inflation (peaking at 5.8% in 2013) to erode the purchasing power of the average citizen. By the late 2010s and early 2020s, the GDP line shows a "stalled" recovery, further complicated by the global pandemic in 2020, which pushed the economy into a sharp but temporary contraction.

For the most recent years (2020–2026), the population characteristics have entered a more challenging phase. The median age has risen to approximately 33.5 years, and the fertility rate has fallen below the replacement level at roughly 1.83. This means that while the 15–24 youth is shrinking in relative size, they face a "structural mismatch" in the labor market. Despite being better educated than previous generations, many young Tunisians remain unemployed or underemployed because the economy, represented by the fluctuating GDP trend, has failed to move beyond low-skill industries. Furthermore, the elderly population (65+) is growing at a rate unmatched in North Africa, creating a "fiscal time bomb" for pension and healthcare systems that must be supported by a working-age population that is itself beginning to stabilize and shrink in proportion.

Figure 3 shows the GDP growth in the last 30 years compared to MENA region countries. Tunisia had an average annual Gross Domestic Product (GDP) growth rate

of 4.3% over the period 2000–2010, and was considered the most competitive economy in Africa. Despite political instability, Tunisia has witnessed a rapid recovery of its GDP growth following a recession in 2011, reaching 4.0% in 2012. Since then, however, it has struggled to maintain this level, with a 2.6% growth rate in 2018. Several factors challenge the national economic situation today, including the devaluation of the Tunisian Dinar (TND), thus amplifying the public debt and foreign trade deficit to record highs. As of September 2018, Tunisia has a public debt of 71.4% relative to GDP, with a foreign trade deficit that widened by 16.8% over 2017. Tunisia has undertaken a series of reforms, including a Strategic Development Plan (SDP) that was adopted for the period 2016–2020 to boost economic activity and investment, as well as to reassure stakeholder confidence. The SDP represents a new development model that is based on the promise of a new social contract under which the state is expected to provide a level playing field to ensure inclusion and equal opportunity. The main objective of the SDP was the transformation and modernization of Tunisia's existing economic model, aiming to reduce unemployment to 11.5% and reach an average GDP growth rate of 5% in 2020. [1]

In recent years is facing a very little growth of GDP. Even if in the last two years there was an increase of it, it's still the country of the MENA region with the lowest growth in 2024 with 1.6%. Algeria faced a 3.7% growth rate and it's stable on this value post covid period. Egypt faced a 2.4% growth rate but it's decreasing in the last years. Libya faced a 1.9% growth rate but data for Libya are very liable and not displayed in the graph. Morocco faced a 3.8% growth rate in 2024 and it continue to increase its trend. According to World Bank prevision for year 2040, Tunisia will face a GDP growth of 1.21% between 2025 and 2030, and 1.6% between 2025 and 2040. Economically, Tunisia is classified as Lower-Middle Income Country with national GDP of 51.33 USB$ in 2023 with an annual growth of 1.6% against an average growth between 2.18% and 7.94% in the 90s.

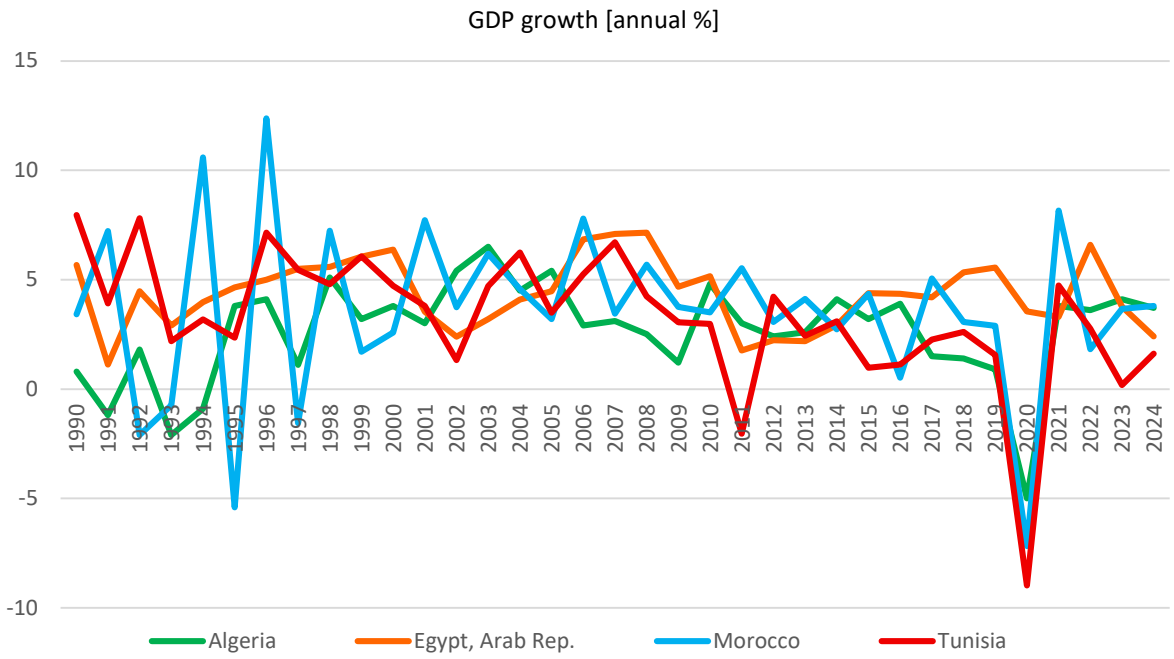


Figure 3: GDP growth [annual %]

Below, in Figure 4 is reported the trend of urban & rural population for MENA region countries, showing big differences between this countries. The biggest different is for Libya where almost 90% of the population living in urban areas. This can be explained due to the geography of the country where around 90% of it is covered by the Libyan Desert. Same consideration can be made for Algeria, even if its and Tunisia data are the most similar with 75% and 70% of population living in urban areas respectively, followed by similar trend by Morocco with 63% of population living in urban areas. Different consideration must be made regarding Egypt, where this indicator is stable in the last 30 years around 43% against 57% of population living in rural areas.

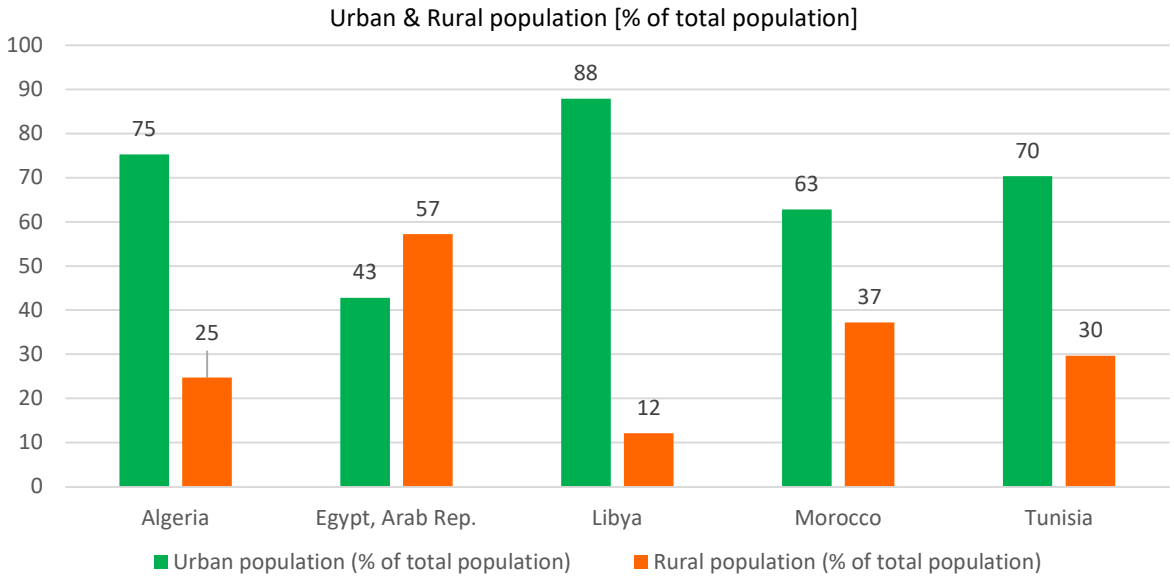


Figure 4: Urban & Rural population [% of total population]

Table 1 summarises the most relevant indicators for social, economic, environmental, and institutional assessment.

Social	
Population, total (Mpeople)	12.28
Population growth (annual %)	0.627
Human Capital Index (HCI) (scale 0-1)	0.52
Human Development Index (HDI) (scale 0-1)	0.746
Life expectancy at birth, total (years)	76.51
Expected years of schooling	14.67
Mean years of schooling	7.59
Gross national income (GNI) per capita	12011
GINI coefficient related to consumption per capita	0.34
Maternal mortality rate (per 100,000 people)	36.60
Infant mortality rate (IMR) (per 1,000 people)	10.60
Death rate (per 1,000 people)	6.00
Adolescent fertility rate (births per 1,000 women ages 15-19)	4.30
Multidimensional Poverty Index (MPI)	0.0034
Share of population living in extreme poverty	0.70%
Economic	
GDP per capita (current US$)	14521
GDP growth (annual %)	1.6
Unemployment, total (% of total labor force)	15.34
Unemployment, youth total (% of total labor force ages 15-24)	38.5
Environment	
Forest area (% of land area)	4.6
Access to electricity (% of population)	100
Electricity production from renewable sources, excluding hydroelectric (% of total)	2.7

Table 1: Key Indicators

1 Define the problem of interest

The purpose of this section is to establish a comprehensive ex-ante diagnostic of Tunisia's current socio-economic and environmental landscape, mapping critical challenges across the United Nations Sustainable Development Goals (SDGs 1, 3–6, 8, and 10) to understand how historical dynamics shape the country's baseline development. Against this backdrop, addressing the national energy sector (SDG 7) emerges as the core imperative of this thesis; Tunisia's economic stability is deeply tied to volatile fossil fuel imports, making a structured transition toward renewable energy not merely an environmental goal, but a vital catalyst for nationwide prosperity, green job creation, and macro-economic resilience. By contextualizing these interconnected challenges, this section sets the stage for the remainder of the study, which evaluates the National Ecological Transition Strategy (SNTE) over a ten-year horizon from 2025 to 2035.

The SNTE is defined as a holistic strategic framework that boldly reframes the ecological transition not as a financial burden, but as a driving force for green job creation, regional development, and the protection of the country's most vulnerable populations by shifting them away from environmentally harmful practices and integrating them into formal, sustainable livelihoods. Its primary objectives involve a structural break from the Business-As-Usual (BaU) trajectory to achieve a 38% net carbon emission reduction by 2035, long-term carbon neutrality by 2050, a 50% share of electricity generation from renewable energy sources (RES), and a continuous reduction in primary energy intensity. Structurally, the strategy is anchored on critical pillars or strategic axes, most notably Axis 1 (Governance and Financing)—which modernizes the state apparatus through the High Authority for Ecological Transition (HAET) and aggregates green financing via the Joint Ecological and Energy Transition Fund (FOCTEE)—and Axis 2 (Climate Change and Energy), which governs the country's decarbonization and renewable expansion. Among other measures, it promotes: development of climate-specific policies and the formation of government entities to oversee their implementation; creation of a national climate early warning system; intensification of reforestation efforts; substantial waste reductions across the economy; enhanced flood protection; sustainable urban mobility.

Specifically, the subsequent chapters deploy a dual methodology: a dedicated quantitative energy system optimization model is constructed using the Hypatia framework to assess whether the planned power sector expansions can successfully meet Tunisia's long-term targets of 50% electricity generation from renewable energy

sources (RES) and a 38% emission reduction by 2035 , while a qualitative Impact Evaluation Framework (IEF) tracks the multi-dimensional systemic benefits and vulnerabilities across the five sustainable development macro-pillars of People, Prosperity, Planet, Peace, and Partnership.

1.1. Poverty (SDG 1) & Inequality (SDG 10)

Tunisia has significantly reduced poverty, which consistently declined between 2000-2019. The national poverty rate fell from 25.4% to 15.2%, about 1.73 million individuals, between 2000 and 2015 and with an increase to 16.6% between 2015 and 2021. Extreme poverty, defined as living below the International Poverty Line of $3 per day [2]), declined from 10.5% of the population to 0.7% during the same period. It is interesting to note that extreme poverty remained fairly high until 2010, reflecting the failure of social programs to reach the poorest. During the 2010-2015 period, and despite low average annual growth of 1.8%, poverty fell sharply from 20 to 15%, then further to 14.2% in 2018 and 13.8% in 2019. [3]

The profile of the poor in Tunisia has not changed significantly between 2000 and 2019. In pre-revolution Tunisia, poverty status was positively correlated with factors such as household size, location, age and level of educational attainment of the household head. In addition, workers living in poor households were often employed in low-quality jobs and in low-productivity sectors. [4] These profiles have remained unchanged in the post-revolution period. Households with higher poverty incidence rates continue to likely be headed by younger men without education, who live in rural areas, and seeking work or working in agriculture or the construction sector. The poor are also likely to concentrate in larger families.

In Figure 5 are reported Poverty trends by region (2000-2019). Grand Tunis region, historically with the lowest levels of poverty, made the most rapid gains in poverty reduction since 2000. Six governorates are concentrated in the North West and Centre West regions: Béja, Jendouba, Kasserine, Kairouan, Le Kef, and Siliana. Data shows that absolute numbers of the extreme poor are generally concentrated in four to five governorates with a high extreme poverty rate mainly in the North West and Centre West regions (in particular, in Kasserine, Kairouan, Le Kef, and Siliana). North and Center-West regions of the country had the slowest pace of poverty reduction and continue to have the highest poverty rate, with Béja and Jendouba to the list of those with the highest poverty rates. Data shows that the absolute numbers of people without a formally provided water service (through SONEDE or GDAs) are concentrated in two to three governorates, and that the single biggest number are concentrated in Kairouan, which is also one of the poorest governorates. For example, the poverty rate of 30.8% in the historically poorest Center-West region was six times higher than the 5.3% in Tunis, and twice the 15.2% national rate in 2015. Overall,

although all regions made poverty reduction progress, their relative positions have remained mostly unchanged.

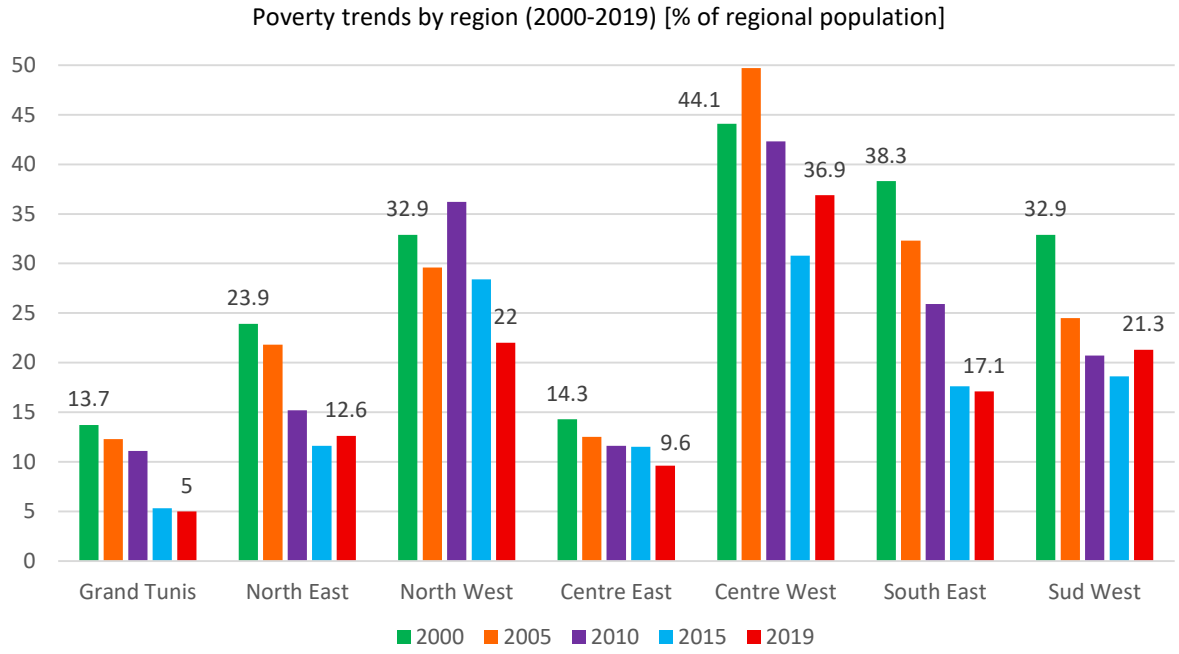


Figure 5: Poverty trends by region (2000-2019) [% of regional population]

The three delegations with the highest poverty rates in Tunisia are all situated in central Tunisia. Hassi Ferid (53.5% of the population lives under the poverty line), Djedeliane (53.1%) and El Ayoun (50.1%) are the poorest delegations in Center-West regions. Despite having an overall lower rate of poverty, some pockets of poverty also exist in certain rural areas in the North-East region, especially in the Governorate of Bizerte where the incidence of the highest poverty is observed in the delegation of Sedjnane (39.9%), followed by Djoumine (36.6%) and Ghezala (34%). [3] [5]

Tunisia has one of the lowest poverty rates compared to other MENA countries. According to the latest estimates from the World Bank, only 0.2% of the population lives on less than $1.90 a day at 2011 international prices. This is lower than other countries such as Egypt where the latest data suggest that about 3.8% of the people live below $1.90 a day, and Morocco and Algeria where 0.9% and 0.4% live below $1.90 a day, respectively. This is consistent when poverty rates are defined as percent of population living on $3 per day. Poverty is primarily a rural phenomenon. This applies both for income-poverty and human development indicators, such as health outcomes. [3]

The World Bank's country poverty assessment confirms that economic growth in Tunisia has contributed to reducing poverty but not to reducing inequality, according also with 2021 report on Poverty & Inequality. It also notes that the socioeconomic profiles of the poor and bottom 40% have not changed in the past decade and that vulnerability remains high—that is, many nonpoor individuals remain at risk of falling

into poverty. In 2010, around 36% of the rural population lived in poverty, and 13.6% lived in extreme poverty. Poverty and extreme poverty rates in rural areas decreased to 23.4% and 4.1% in 2019. While rural poverty remains a significant problem, gaps between rural and urban areas have been closing throughout the last decade. Differences in rural and urban poverty rates between 2010 and 2019 decreased from 23.5% to 14.1%, while differences in extreme poverty rates closed from 11.5% to 3.5%. While poverty declined in Tunisia between 2000 and 2015, many that escaped poverty remain vulnerable to falling back into it. Only 1.8% of the population was considered poor in 2019 but 24% remains vulnerable to falling back into poverty. Despite the population moving out of poverty and vulnerability into more secure subgroups, geographical disparities are important as 42% of rural residents were vulnerable in 2019 compared to 15% of urban residents. In fact, the share of rural residents that are vulnerable did not decline much over time between 2000 and 2019. [3]

Convergence between regions has been weak. Poverty is heavily concentrated in the North-West and Center-West regions as shown in Figure 6, which have the highest poverty rates and the slowest pace of reduction. Households in richer regions such as Grand Tunis have greater access to natural gas and drinking water facilities, in comparison to the lagging North West and Center-West. For example, 72.4% of households have access to natural gas in Grand Tunis in 2019 compared to merely 0.6% in the North West and 1.2% in the Center West regions. Similarly, almost 100% of Grand Tunis households have access to drinking water facilities compared to only 67.6% in the North West and 53.4% in the Center-West regions. Not surprisingly, these disparities are also prevalent in access to sanitation network connection across regions where Grand Tunis area have an access of 97.3% compared to only 54.9% in the North West and 45.3% in the Center-West regions. However, access to all these services improved slightly nationally between 2015 and 2019.

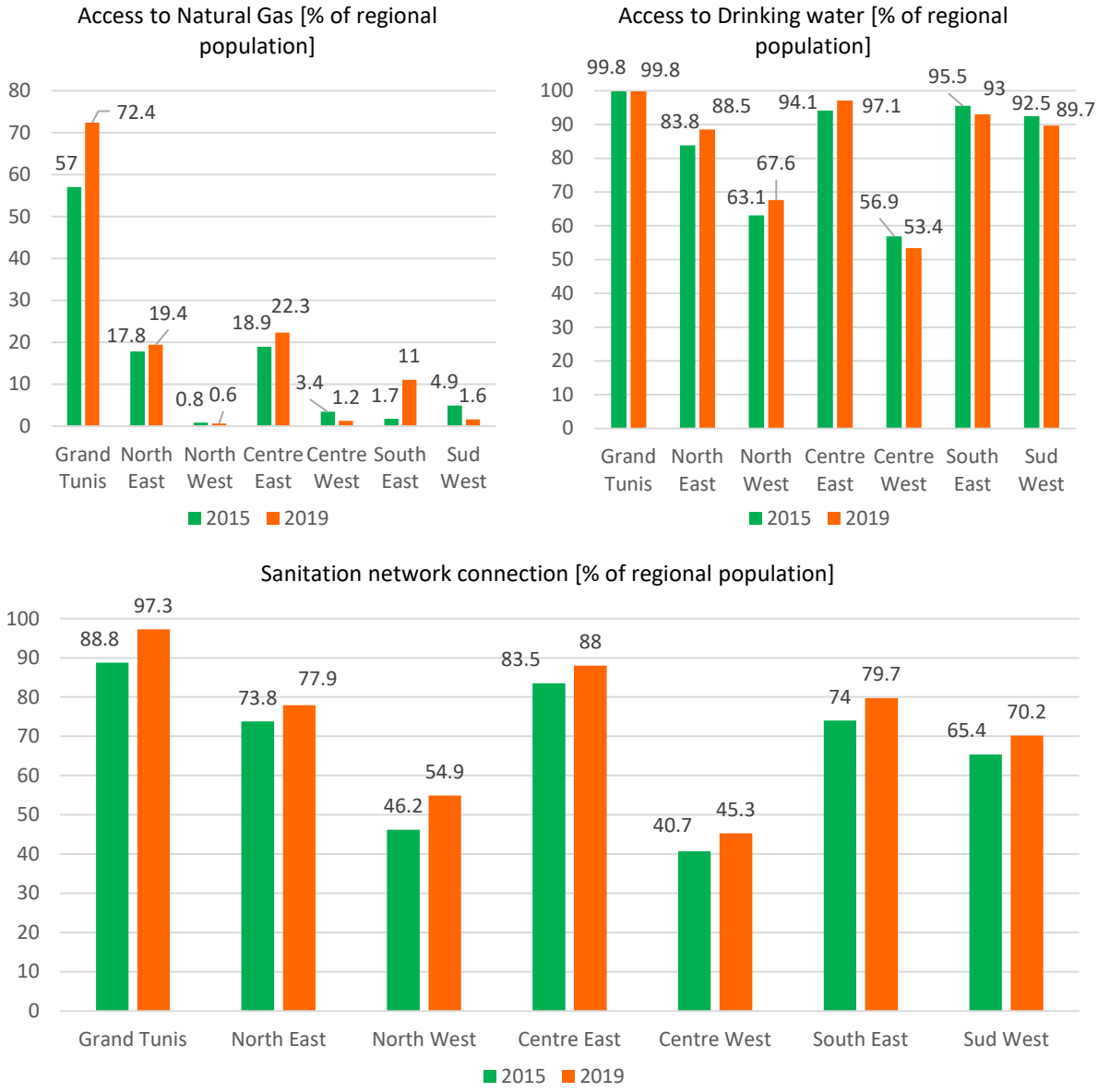


Figure 6: Access to services at household level [% of regional population]

While access to basic services improved over time, access to water, sanitation, gas, and health insurance was still strongly determined by the standard of living. Children living in the poorest households were less likely to attend school. This kind of deprivation decreases human capital accumulation of the youngest and reduces the possibilities of poor households to seize future economic opportunities.

Thorough examination of inequality trends, Tunisia shows slight improvement, particularly from 2005 onwards. The Gini index fell from 40.8 in 2000 to 32.8 in 2015, and further increase to 33.7 in 2021. Considerable disparities exist in both urban and rural areas. Rural areas registered a higher Gini coefficient of 35.0 while those in Urban areas stood at 32 in 2015, while the gap between urban and rural Gini coefficients narrowed between 2015 and 2019 from 3.1 to 1.5 percentage points. Inequality, measured by the Gini index and reported in Figure 7, in Tunisia remains comparable

to other countries in the region. According to the latest estimates from the World Bank, Gini is estimated to be 33.7 in Tunisia in 2021. This is lower than other countries such as Morocco where latest data suggest estimates Gini to be as high as 39.5 in 2013, but higher than other countries such as Egypt and Algeria. [3]

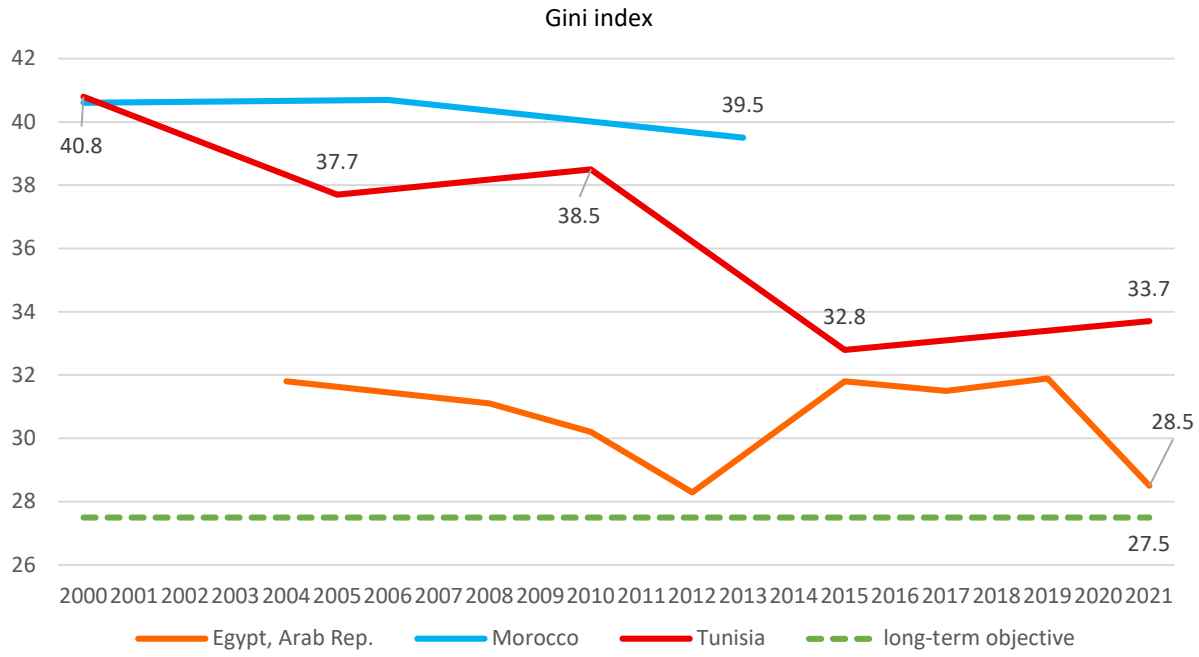


Figure 7: GINI index

Rather than viewing the ecological transition as a financial burden, SNTE boldly reframes it as a powerful engine for job creation, regional development, and the protection of the most vulnerable populations. At its core, it targets poverty eradication by shifting citizens away from informal or environmentally harmful work and integrating them into sustainable, formal livelihoods within the emerging green economy. To power this shift, the strategy heavily invests in human capital through the modernization of university curricula and the launch of certified national training programs designed to equip the workforce with essential green skills, impacting not only SDG 1 (No Poverty) but also SGD 4 (Quality Education). This ambitious vision is anchored by robust new financial and governance structures—notably the accessible FOCTEE (Common Fund for Ecological and Energy Transition) financing fund and the multi-stakeholder Economic, Social and Environmental Council (Axis 5 of SNTE)—which together guarantee that environmental decisions remain deeply socially just. Ultimately, by decentralizing territorial governance beyond the coastlines and fortifying climate resilience in critical sectors like agriculture and health, the strategy ensures that the rural communities most exposed to climate shocks are protected, transforming environmental necessity into a catalyst for inclusive, nation-wide prosperity.

1.2. Health (SDG 3) and Clean Water and Sanitation (SDG6)

Over the last few decades, Tunisia has achieved remarkable results in terms of public health campaigns and programs and health system performance. More specifically, three major reforms have shaped the health system and contributed to these results: the reform of basic health care in 1979, the reform of public health establishments in 1991, and the reform of the National Health Insurance Fund in 2004. [6] However, despite these reforms, there are still major regional imbalances in terms of the distribution of human resources as well as accessibility problems. Furthermore, in 2011, family medicine (FM) was defined as a strategic priority in Tunisia. This orientation resulted in the establishment of a vision aimed at promoting FM, including the integration of a dedicated sector within the framework of health coverage, the creation of a FM college, the reform of medical studies in 2011 as well as the placement of focal points at various levels of the health system. [7]

The current community health landscape in Tunisia is characterized by a transition from traditional public health programs to a more integrated, though not yet fully formalized, national strategy. While the community approach is embedded in the National Health Policy 2030 [8] and various basic health care frameworks, it lacks a dedicated regulatory structure and relies heavily on unpaid volunteers primarily mobilized by civil society organizations and international donors rather than being formal state employees. Furthermore, the system faces significant technical hurdles, as community health data is not currently captured by the national information system, which is still struggling with manual data collection and a lack of unique patient identifiers. [9]

The primary challenges facing the system include a notable decline in basic health care motivation and severe regional imbalances in medical resource distribution. Many rural health centers operate only once a week, and mobile teams are frequently hindered by a lack of transportation and insufficient funding. Additionally, because many community initiatives are financed by external partners, there is a recurring problem with the duplication of projects in some regions while others remain underserved. The lack of a clear strategic framework also makes it difficult to define the role of the private sector in community-based health efforts. To address these gaps, future policy directions focus on revitalizing basic health care and establishing Family Medicine as a central pillar of the community approach. Priority actions include reformulating job profiles and creating promotion incentives to combat professional demotivation. There is also a strong push to accelerate the digitization of health records to ensure comprehensive monitoring and evaluation across both public and private sectors. Finally, the government aims to institutionalize citizen participation by strengthening the role of local municipalities and capitalizing on the experiences of existing local health councils. [9]

Tunisia's progress toward SDG 3 (Good Health and Well-being) is defined by several key indicators that show a generally positive trajectory toward long-term global objectives. The maternal mortality ratio, which measures the deaths of women aged 15 to 49 from pregnancy-related causes per 100,000 live births, has seen significant improvement, dropping from 55.75 in 2000 to 35.71 in 2023; although this remains distant from the long-term target of 3.4 and experienced a temporary peak due to the COVID-19 pandemic, the country is considered on track to achieved the long-term objective as it returns to its descending trend as reported in Figure 8.

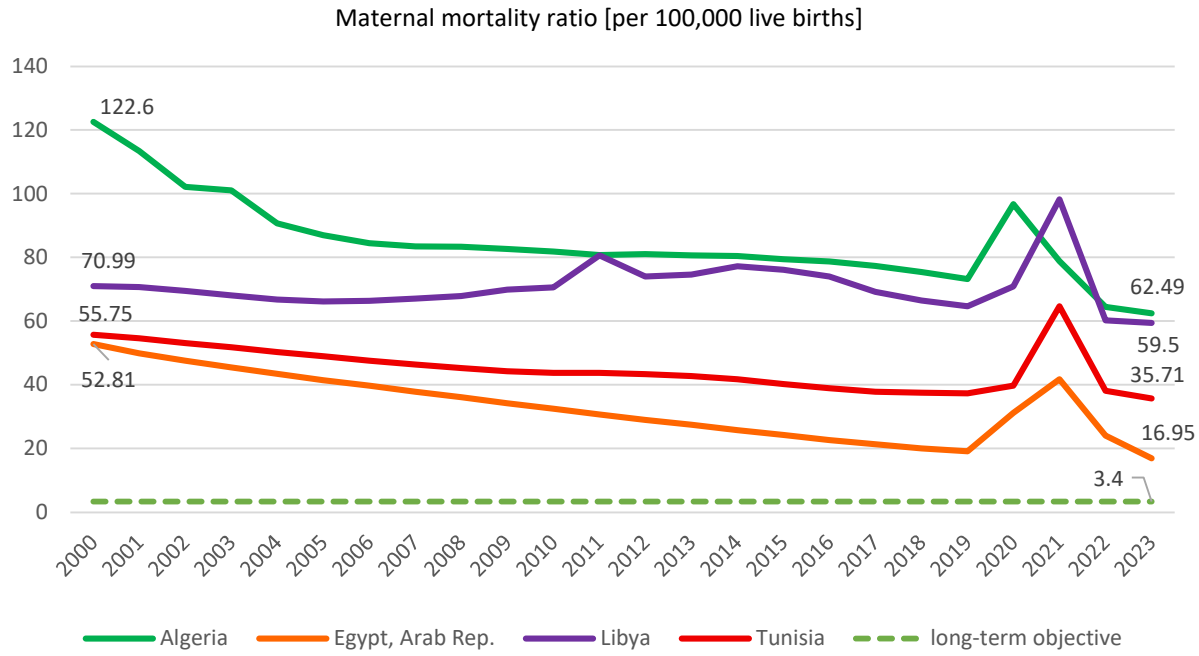


Figure 8: Maternal mortality ratio [per 100,000 live births]

Similarly, the neonatal mortality ratio—the death of infants before 28 days of age per 1,000 live births—decreased from 17.19 in 2000 to 8.36 in 2023 despite a period of stagnation between 2010 and 2016, moving toward a long-term objective of 1.1, while the under-5 mortality rate followed a comparable path by falling from 29.19 in 2000 to 12.91 in 2023 against a target of 2.6. The death rate due to diseases for adults aged 30 to 70 also showed progress, declining linearly from 18.6% in 2000 to 15.1% in 2020 before a sharp drop to 13% in 2021, suggesting that Tunisia will meet its 9.3% objective if current trends are maintained. Conversely, life expectancy at birth has stagnated, remaining stable at approximately 76 years since 2000 against an ultimate goal of 83 years.

The Figure 9 reveals significant disparity in adolescent fertility rates among the featured MENA countries, though the trend over the last decade face a significant decrease. Egypt and Morocco exhibit the highest rates, both experiencing peaks or plateaus around 2009 before beginning a steady downward trajectory through the end of their recorded data. Algeria maintained consistently low and relatively stable rates throughout the two decades, hovering near or below 11 births per 1,000 females while

Tunisia showed marked improvement after 2015, falling from 8.8 to 4.04 in 2021—including a rapid decrease from 5.1 in just one year—positioning Tunisia to successfully reach the long-term objective of 2.5. Despite the notable progress in the countries with historically higher rates, all nations shown still remain above the dashed "long-term objective" line, with Tunisia being the closest to achieving it.

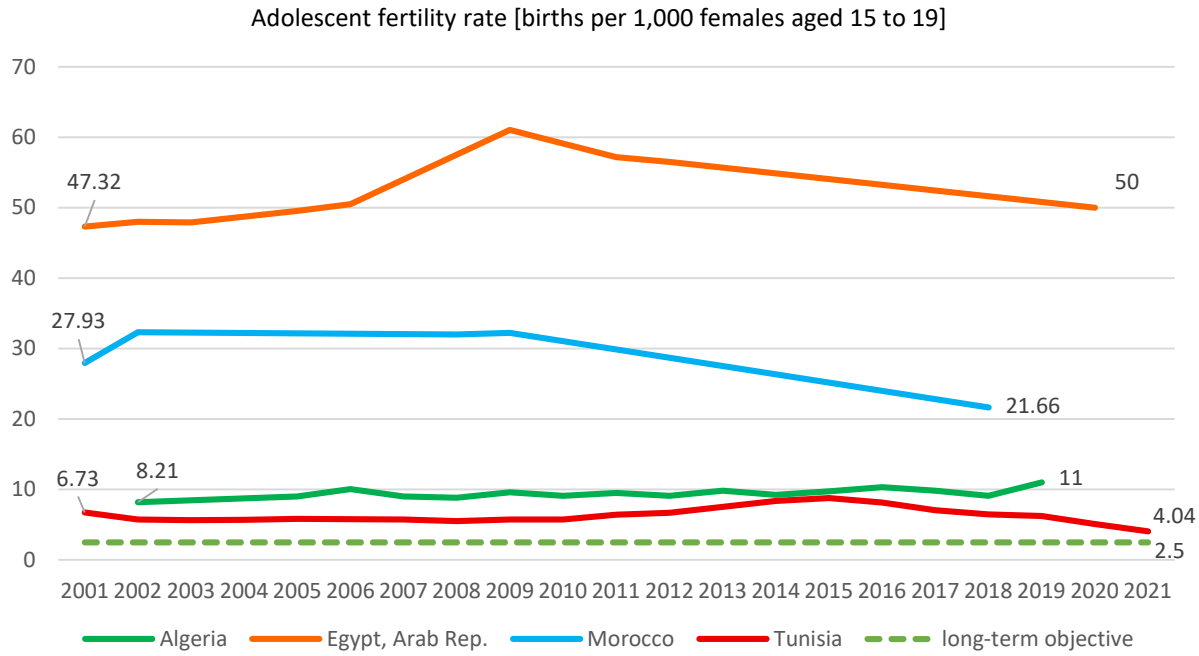


Figure 9: Adolescent fertility rate [births per 1,000 females aged 15 to 19]

Within the SNTE, there are several actions aimed at expanding and upgrading sanitation infrastructure in supported cities, as well as extending these services to non-supported areas, which will significantly improve the aforementioned indicators. In Tunisia, current health expenditure as a percentage of GDP reached 7.99% in 2023, reflecting a continuous upward trend from 5.94% in 2018, highlighted by a notable jump from 6.02% to 7.06% between 2019 and 2020. If Tunisia maintains this positive trajectory, it is well-positioned to reach the global average of 10% by 2030, value that will directly support key objectives of the UN 2030 Agenda. Specifically, these investments are essential for achieving Target 3.7, which ensures universal access to sexual and reproductive healthcare services—including family planning, education, and integration into national strategies—as well as Target 3.8, which guarantees universal health coverage, financial risk protection, and equitable access to safe, high-quality, and affordable essential medicines and vaccines for all. The situation is projected to improve significantly by 2035 through the deployment of Measure 20 (a comprehensive water conservation and loss reduction program) and Measure 21 (the systematic valorization of treated wastewater and unconventional hydraulic resources) to optimize circular water loops.

The World Bank in 2018 funded the present work, referred to as the Tunisia WASH Poverty Diagnostics, to assist the government of Tunisia with exploring the linkages

between poverty and water supply, sanitation, and hygiene (WASH) services. WASH, is commonly used to summarize four types of interventions related to water availability, water quality, excreta disposal, and hygiene promotion (Department for International Development 2013). Tunisia has accomplished remarkable progress in terms of extending access to improved WASH services, particularly in rural areas over the past 25 years. Access to improved WASH services is now almost universal, with 94.15% for water and 92.12% for sanitation at the national level in 2015. Nonetheless, around 250,000 people rely on unimproved drinking water, mostly from unprotected wells and springs. In addition, 900,000 people use unimproved sanitation, about half of whom use shared latrines, and the rest use mostly unimproved latrines. Overall, high access rates show that the SGD 6 (Clean water and sanitation) target should be achievable in Tunisia with both indicators maintaining their increasing trend from the beginning of century, reaching in 2022, 97.18% and 97.44% respectively.

1.3. Quality Education (SGD 4), Gender equality (SDG 5) & Decent Work and Economic Growth (SDG 8)

Figure 10 illustrates the composition of the Multidimensional Poverty Index (MPI) for Tunisia. The MPI is a global metric used to measure acute poverty by identifying overlapping deprivations individuals face in their daily lives. It evaluates poverty across three core dimensions—Health, Education, and Living Standards—which are further broken down into ten specific indicators: nutrition, child mortality, years of schooling, school attendance, cooking fuel, sanitation, drinking water, electricity, housing, and asset ownership.

As shown in Figure 10, the indicators contributing most significantly to Tunisia's MPI are Years of Schooling (36.60%), School Attendance (25.20%), and Nutrition (23.70%). To better understand these primary drivers, here is how they are defined within the MPI framework:

- Years of Schooling: A household is considered deprived if no member has completed at least six years of formal education.
- School Attendance: A household is considered deprived if any school-aged child is not currently attending school.
- Nutrition: A household is considered deprived if any adult or child (for whom nutritional information is available) is undernourished.

Regionally, Tunisia performs relatively well in mitigating severe multidimensional poverty. Its overall MPI score is 0.003, which is notably lower than neighboring countries such as Algeria (0.005), Libya (0.007), Egypt (0.020), and Morocco (0.027).

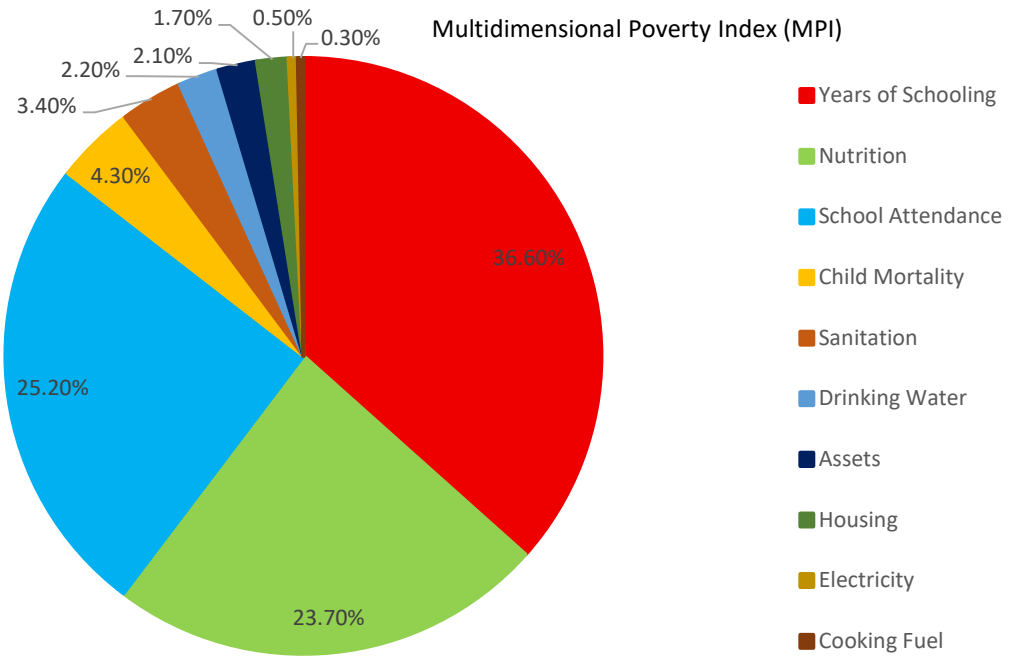


Figure 10: Contribution of deprivation of Multidimensional Poverty Index

There have been several other reforms since independence to further improve the education system at all levels. Following independence, in 1958, the government under Habib Bourguiba nationalized the education system, unifying religious (Zaytuna) and modern school systems. Education was made free for all citizens and compulsory for children. The late 1960s saw the Arabization of primary education, making Arabic the primary language for all disciplines, while French was retained as a second language for technical and scientific communication.

The "New Education Act" of 1990-91 significantly shifted policy by making schooling compulsory for children aged 6 to 16, extending the basic education cycle, and reorganizing school structures.

According to the World Bank, with the 2002 Educational Act (Future Focus), the Ministry of Education established a new strategy focusing on ICT (Information and Communication Technologies) in schools, further emphasizing the 16-year-old compulsory age limit. [10]

In pursuit of SDG 4 (Quality Education), which targets a universal 100% success rate across key educational metrics by 2030, Tunisia and its North African neighbors demonstrate strong foundational progress even as challenges in secondary and tertiary education persist. While the Participation Rate in pre-primary organized learning remains difficult to assess due to data that is outdated—in some cases by over two decades—more recent indicators from 2021–2023 reveal a region nearing universal primary access and literacy.

According to the 2023 data reported in Figure 11 (left), Tunisia maintains a robust net primary enrollment of 98.91%, placing it just behind Morocco (99.16%) and Algeria (99.07%) but ahead of Egypt (95.59%). A more dynamic shift is visible in lower

secondary completion rates; Tunisia's performance surged from 70.41% in 2015 to 80.46% in 2021, and while this outpaces Morocco's (73.88%), it still trails Algeria (84.52%) and Egypt (86.11%). Finally, the region shows near-universal success in literacy for the 15–24 age group, with Morocco leading (98.52%), followed closely by Tunisia (98.16%) and Algeria (97.43%), while Egypt follow in the last place (92.24%). Ultimately, while foundational literacy and primary access are largely established, the regional priority must shift toward improving secondary completion if these nations hope to meet the 2030 Agenda targets.

The Figure 11 (right) illustrates also educational attainment across MENA Region countries, highlighting a significant drop in participation as students' progress through the academic system. Primary education represents the highest level of achievement across the board, led by Egypt at 69% and trailed by Morocco at 53%. Egypt demonstrates the most consistent retention, maintaining 56% across both lower and upper secondary levels before falling to a region-leading 18% in tertiary attainment. In contrast, Algeria and Tunisia experience much sharper declines throughout their academic systems; Algeria's upper secondary attainment falls to 24% and Tunisia's to 19%, eventually culminating in low tertiary attainment rates of 11% and 13%, respectively. Most notably, Morocco exhibits the most significant gap in the dataset, dropping to 31% at the lower secondary level and recording no data at all for upper secondary and tertiary attainment.

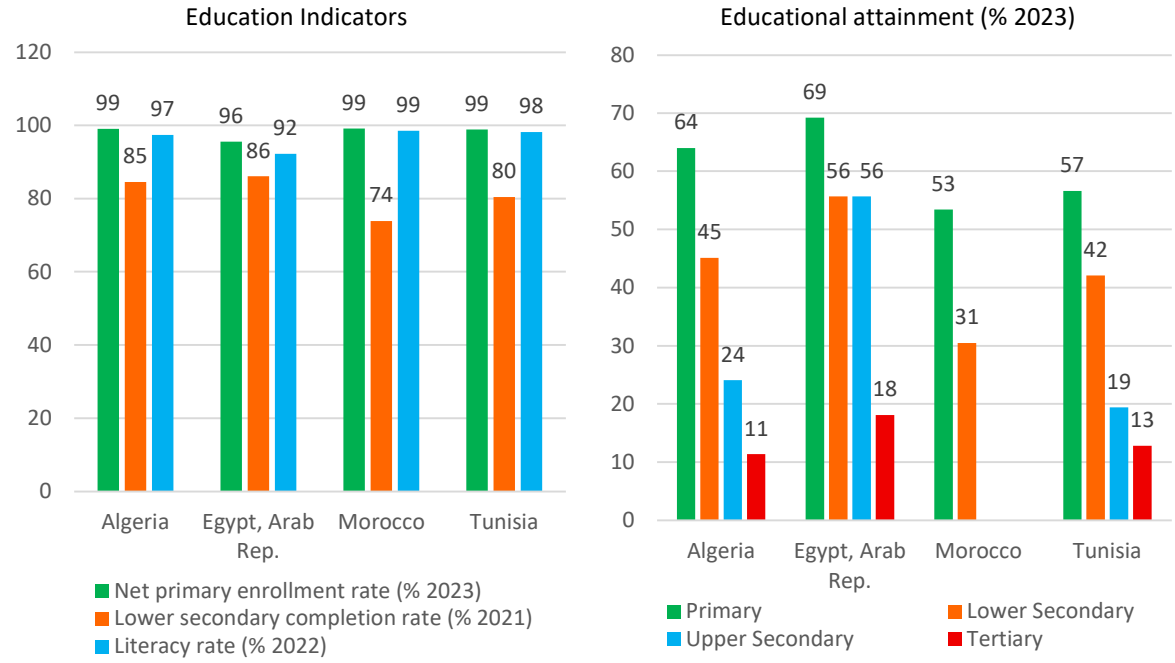


Figure 11: Education indicators & Educational Attainment

The persistent challenge of early school leaving in Tunisia, which reached a rate of 29.5% in 2023, underscores a critical disconnect between national educational expenditure and viable labor market outcomes, severely impeding progress toward

Sustainable Development Goals concerning both quality education (SDG 4) and decent work and economic growth (SDG 8).

Relatively high expenditure (6.7% of GDP) on education does not have a major effect on the quality of outcomes, which show a high unemployment rate among school leavers with medium to high levels of education. The phenomenon of NEETs (Young people not in employment, education or training) in Tunisia is particularly concerning: according to the World Bank, 22.6% of young people for the 15-29 age group (2023) are not in employment, education or training (24.4% among men and 20.8% among women), against a long-term objective for SDG 8.6.1 of 8.1%. The NEET rate for the 15-29 age group has risen sharply between 2010 and 2014 passing from 25.2% to 30.4% respectively. In 2019 (before COVID-19), the NEET rate was 26.8% (27% among men and 26.6% among women), facing some improvements from 2014 and still decreasing with the latest data of 2022 and 2023. According to the latest ILO report (2023), the phenomenon is even more pronounced in some areas, particularly in Kairouan, Sidi Bouzid and Gafsa. The reasons for this situation include a lack of support for school leavers, barriers to employment, and a mismatch between the skills acquired and the needs of the labor market. Women are particularly affected by economic inactivity (72.7%, aged 15+), partly due to cultural barriers and family responsibilities. Although NEET men are more numerous in some regions, women face more obstacles to enter the labor market. [11] [12]

The data highlights structurally high and volatile NEET rates over the past decade also for Tunisia’s neighboring countries. Egypt's NEET share peaked notably at 33.1% in 2010 and, despite a recent downward trajectory toward approximately 23.8% in 2024, remains substantial. Similarly, historical data points for Morocco indicate rates climbing near 35% in 2014, while Algeria consistently record figures hovering between 20% and 25% in recent years, underscoring a persistent regional vulnerability that limits economic potential and risks social instability.

The macroeconomic consequences of this systemic inefficiency are illustrated when comparing Tunisia's youth unemployment rate (ages 15–24) and total unemployment rate to those of neighboring North African countries over the past three decades. As depicted in the comparative ILO estimates in Figure 12, while nations such as Egypt have managed a steady decline in youth unemployment from a 2012 peak down to approximately 15% by 2024, Tunisia’s trajectory has remained chronically severe; following a sharp surge corresponding with the events of 2011, its youth unemployment rate has stagnated at disproportionately high levels, hovering near 38% to 40% into 2024. Consequently, Tunisia not only drastically underperforms against idealized long-term labor objectives of 0.5%, but also consistently exhibits higher youth unemployment levels than regional peers like Morocco—which has seen a gradual rise to just over 30%—and Algeria, highlighting the urgent need for structural reforms that effectively bridge educational frameworks with tangible economic opportunities.

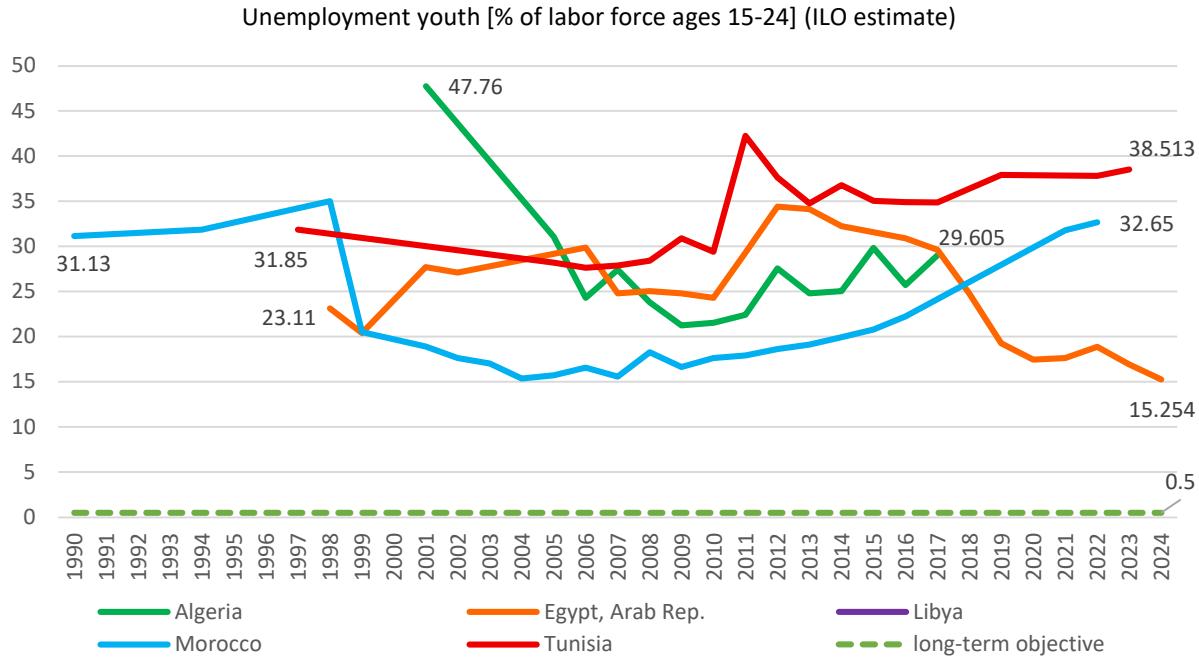


Figure 12: Unemployment youth [% of labor force ages 15-24] (ILO estimate)

The comparative data in Figure 13 shown total unemployment rates across the North African region from 2000 to 2024, reveals distinct national trajectories, with Algeria exhibiting the most significant long-term improvement by reducing its rate from 30% at the start of the millennium to a stabilized range between 10% and 12% after 2010. Conversely, Tunisia has emerged as the country with the most persistent labor market challenges; after maintaining a rate of approximately 15% for a decade, it experienced sharp volatility with a spike exceeding 18% following the 2011 political transition and has since remained a regional outlier with the highest unemployment, fluctuating near 15% to 16% through 2023 against an employment rate of only 38.5%. Male and female unemployment is 12.8% and 20.4% respectively, and an employment rate of 57% and 21%, showing a huge difference also in gender equality. While Morocco has displayed a relatively stagnant profile with rates oscillating narrowly between 9% and 12%, Egypt has demonstrated a successful recent downward trend, pivoting from a 2013 peak of nearly 13% to become the group's best performer with a rate falling below 7% by 2024. Despite these varied outcomes, all four nations remain substantially distanced from the indicated long-term objective of 0.5% of unemployment rate, highlighting a shared regional struggle to achieve full economic absorption of the labor force despite individual periods of national recovery.

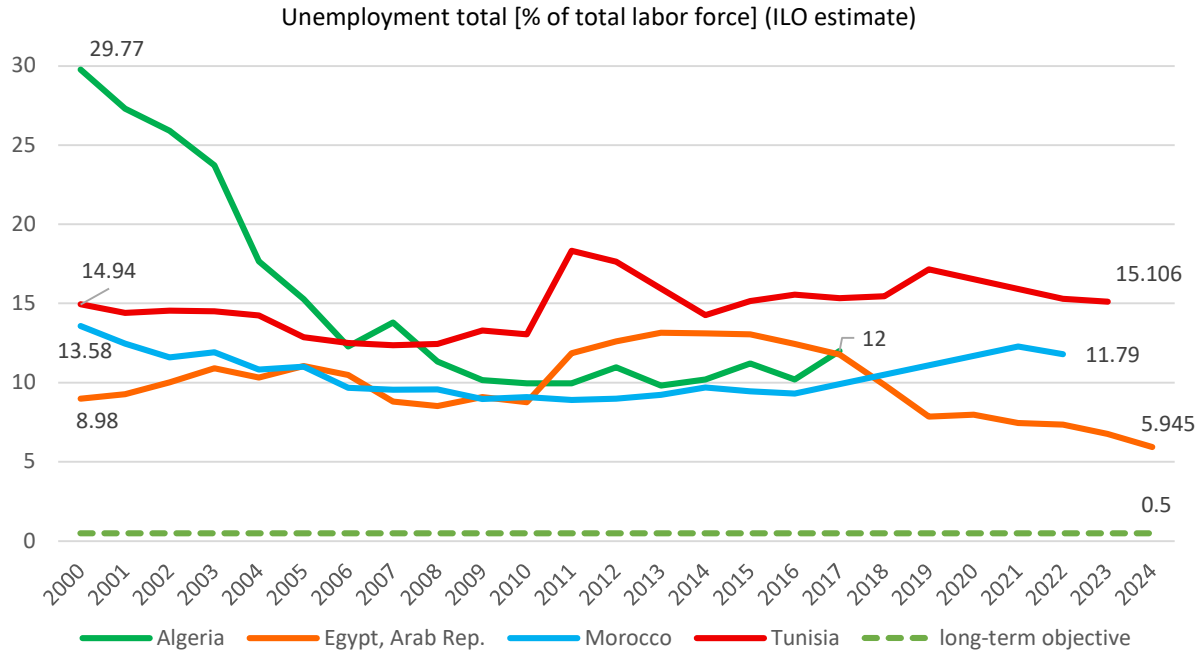


Figure 13: Unemployment total [% of total labor force] (ILO estimate)

Under the action of Tunisia's SNTE, with the implementation of Measures 48 and 49, which mandate biannual synchronization between academics researchers, the private sector and international experts to ensure that Tunisia remains at the forefront of global environmental and energy developments. This collaborative ecosystem is designed to fuel the institutionalization of a "green-collar" workforce specifically by orienting university and vocational training toward innovative high-recruitment sectors and formalizing critical new roles such as energy managers waste and wastewater treatment specialists (green jobs) and QHSE (Quality Health Safety and Environment) managers.

Simultaneously through Measure 50—which aligns with the UN/UNESCO Global Action Programs and the Mediterranean Strategy for Education for Sustainable Development through the 2035–2050 horizon—Tunisia is scaling a robust Network of Sustainable Schools that since 2005 has already grown to include 412 establishments as of 2023 out of a total of over 6000 public institutions. These schools serve as living laboratories where students engage with hybrid photovoltaic-wind energy systems manage selective waste recovery and participate in environmental clubs equipped with modern digital tools and botanical parks featuring nearly 190 plant varieties. By updating preschool and primary pedagogy nationwide the state aims to dismantle the educational divide between urban centers and rural territories ensuring that every child is equipped with the "green literacy" necessary to navigate the national ecological transition and secure future-proof employment in a sustainable economy. [13]

In Tunisia, 88.9% of legal frameworks that promote, enforce and monitor gender equality under the SDG 5 (Gender Equality) indicators, with a focus on violence against women, are in place. 1.5% of women aged 20–24 years old who were married

or in a union before age 18. The adolescent birth rate is 4 per 1,000 women aged 15–19 as of 2021, down from 5.1 per 1,000 in 2020. In 2018, 62.7% of women of reproductive age (15-49 years) had their need for family planning satisfied with modern methods.

However, work still needs to be done in Tunisia to achieve gender equality. As of February 2024, only 15.7% of seats in parliament were held by women. In 2018, 10.1% of women aged 15-49 years reported that they had been subject to physical and/or sexual violence by a current or former intimate partner in the previous 12 months. Also, women and girls aged 15+ spend 21.9% of their time on unpaid care and domestic work, compared to 2.7% spent by men. [14]

As of December 2020, only 44.3% of indicators needed to monitor the SDGs from a gender perspective were available, with gaps in key areas, in particular: key labor market indicators, such as the gender pay gap. In addition, many areas – such as gender and poverty, physical and sexual harassment, women's access to assets (including land), and gender and the environment—lack comparable methodologies for regular monitoring. Closing these gender data gaps is essential for achieving gender-related SDG commitments in Tunisia. [14]

In the following paragraphs, are analyzed some indicators that determine the status of SDG 5. The mean years of education received by women aged 25 and older divided by the mean years of education received by men aged 25 and older. From 2000 the value of this indicators moved from less than 60% to 83.74% in 2022, against a long-term objective of 100%. Even if the score for this indicator face a notable increase, it's not sufficient to obtain the long-term objective of the Agenda 2030, because for the last years, this value remain mostly constant, not showing further improvements. Tunisia's trend is similar to Algeria and Morocco, while Egypt and Libya overcome the Agenda objective in 2018 and 2007 reaching 106.9% and 117.4% respectively, maintaining this positive trend. In Figure 14 are reported the trend for this indicator.

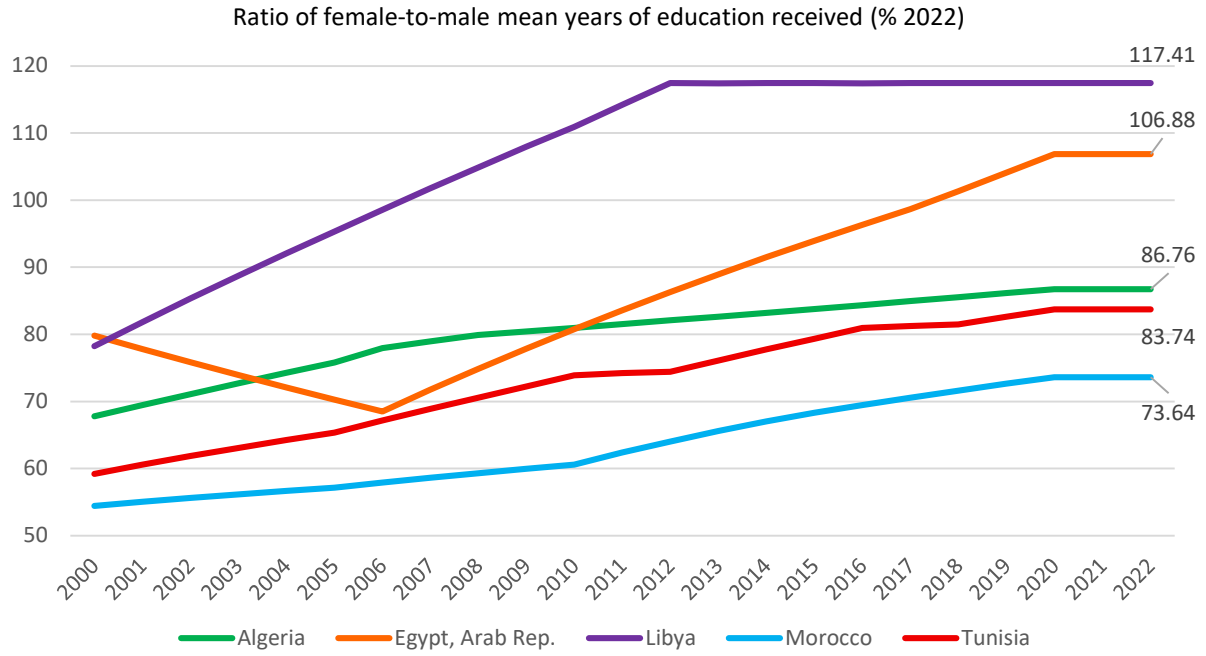


Figure 14: Ratio of female-to-male mean years of education received (% 2022)

Ratio of female-to-male labor force participation rate is a modeled estimate of the proportion of the female population aged 15 years and older that is economically active, divided by the same proportion for men. In 2025 the value for this indicator 40.78% and it's not facing an improvement in recent years. In the last 25 years, this value growth of 32.8%.

In Figure 15 are reported the number of seats held by women in single or lower chambers of national parliaments, expressed as a percentage of all occupied seats, for the MENA Region countries. Seats refer to the number of parliamentary mandates, or the number of members of parliament. The long-term objective for this indicator is a value of 50% and Tunisia is very far from this objective with a value of 15.8% in 2025 after a peak reach in 2019 with a value of 35.9%, a rate higher than that of most nations in Africa and worldwide. Tunisia was also considered one of the most progressive countries in the region regarding gender policies. Yet, Tunisia was not able to keep pace with the new expectations and is even going backward when it comes to gender parity. In September 2022, all temporary measures supporting women's access to parliament were eliminated by Decree No. 55. This shift resulted in a significant drop in female representation in the Assembly of People's Representatives, falling from 26.3% in 2019 to 16.2% after the January 2023 elections. [15]

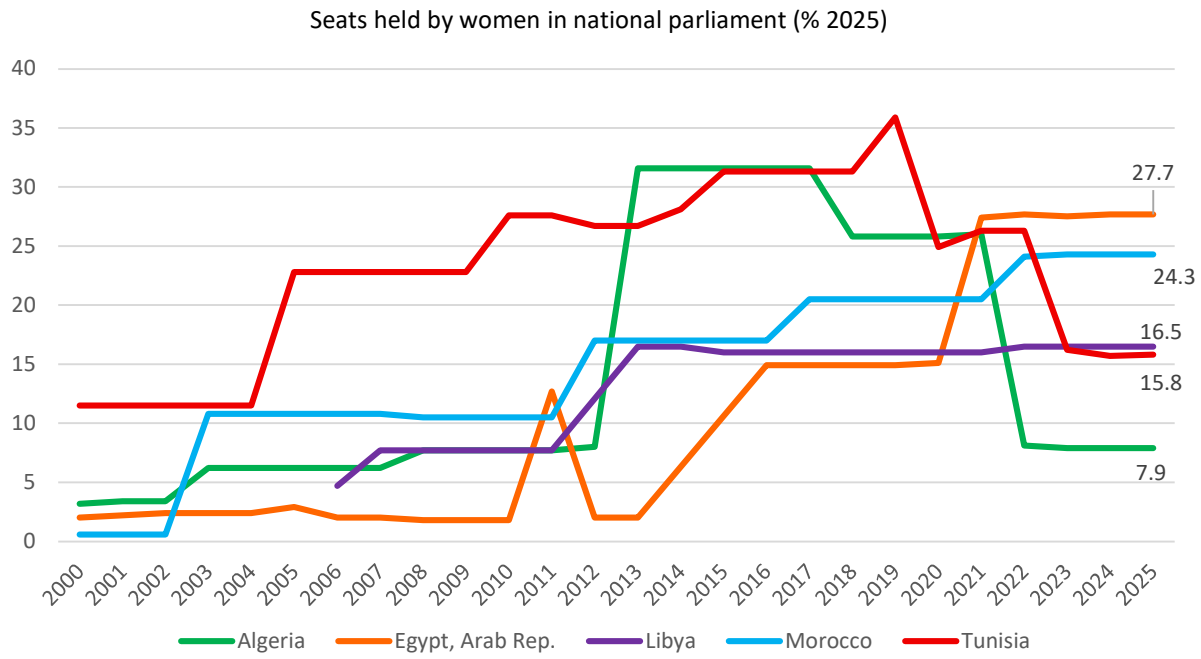


Figure 15: Seats held by women in national parliament (% 2025)

Comparing to the neighboring countries, Tunisia is the worst, second only to Algeria, with the others performing better as value for this indicator, even if none of these countries are facing any improvement in the last few years. Also, there are significant discrepancy between the proportion of women in managerial positions which is just 21.6% and proportion of women in senior and middle management positions which is 26%.

The SIGI 2023 profile for Tunisia shown below in Figure 16 provides a comprehensive overview of the state of gender equality in the country with a focus on violence against women and women's economic empowerment, as measured by the OECD's Social Institutions and Gender Index (SIGI). Overall, Tunisia was among those countries classified as having high levels of gender discrimination based on the SIGI 2023 score (47). For comparison, the average score in the Africa region is 40 while the global average is 29. Across the SIGI's four dimensions, the SIGI score shows lower discrimination in "Restricted physical integrity" (11) and "Restricted access to productive and financial resources" (36) and higher levels of discrimination in "Restricted civil liberties" (47) and "Discrimination in the family" (80). [16]

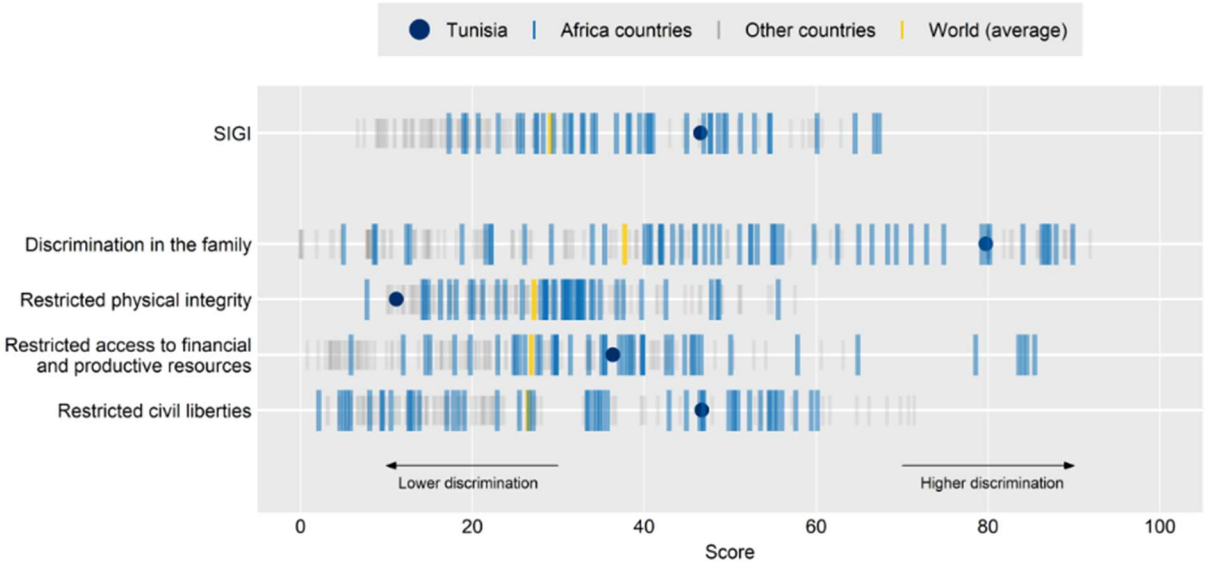


Figure 16: SIGI and dimension scores for Tunisia, 2023

With the exception of Restricted Physical Integrity indicator, the other SIGI profiles are far from the global average (yellow line) and also from the lower levels, similar to most of the African average values.

Even if there's positive highlights regarding gender affairs such as the statutory law in Tunisia protects women's right to bodily autonomy and integrity, guarantees gender equality in access to productive and financial resources, and establishes mechanisms to address discrimination in the public sphere. In 2022, Tunisia launched the second National Action Plan on Women, Peace and Security, aiming to increase women's participation in peacebuilding, strengthening provisions on gender-based violence, and expanding monitoring and evaluation of gender-sensitive commitments. Finally, child marriage rates for girls and boys remain extremely low in Tunisia. [16]

There are significant challenges. In September 2022, the Tunisian government removed the previously established gender-parity provisions for elected officials. In the 2023 elections, women's representation in the national parliament fell by 10%. The Personal Status Law contains discriminatory provisions that restrict women's rights to be legal guardians of their children, to file for divorce, and to inherit on equal grounds as men. Attitudes and norms data reveal that gender inequalities in the workspace remain widely accepted, pressuring women to maintain a reproductive and caring role within the family which can undermine their economic opportunities. For instance, 72% of the population believes that when a mother works for pay, the children suffer. [16]

Overall, SDG 5 is one of the goals in the worst situation for Tunisia. As reported in Measure 48 and 49, SNTE through the 2035–2050 horizon, supports the creation of sustainable jobs, specifically noting that this applies particularly to youth and women. It also supports the emergence of green goods and services companies that integrate social and gender justice. [13]

2 Past and current energy situation

The aim of this section is to assess the country's past and current energy situation, to analyse the main policies shaping the energy sector, and to propose a decision-making framework for future energy planning. The analysis is based on historical data, national energy indicators, and comparisons with neighboring countries.

The energy sector is a key contributor to Tunisia's various economic sectors. In the past two decades, however, the country has witnessed a growing energy balance deficit, largely as a result of relying on fossil fuel sources – oil and natural gas – to meet its energy demand. The decline of its own hydrocarbon resources has led to increased dependence on fossil fuel imports, which rose to record levels in 2019 when the deficit in the balance of primary energy reached 23732 TJ, highlighting that 49% of total energy consumed is imported. In response, Tunisia has begun to leverage its wide array of renewable energy sources to diversify its energy mix. This is coupled with energy efficiency programmes to alleviate its energy balance deficit. [1]

Tunisia has achieved a nearly 100% national electrification rate making it a leader in electricity access in Africa. This near-universal access applies to both urban and rural populations. However, the sector is heavily reliant on fossil fuels (roughly 98% in 2023, IEA), with significant efforts underway to increase renewable energy sources to 35% by 2030. The electricity generation mix is dominated by natural gas at 95%. The strong dependence on natural gas has serious implications for Tunisia's energy security, as domestic production of natural gas has stagnated and even declined during recent years.

According to IEA, between 2000 and 2023, Tunisia's domestic primary energy production showed in Figure 17, experienced a marked structural decline, dropping from a peak of nearly 350,000 TJ in 2010 to just over 200,000 TJ in 2023, driven primarily by the steady depletion and reduced output of its primary oil and natural gas reserves. Conversely, the Total Primary Energy Supply (TPES) in Figure 18 followed a distinct upward trajectory, growing from roughly 300,000 TJ in 2000 to plateau near 480,000 TJ in recent years to meet rising domestic demand, with the national supply mix remaining overwhelmingly dominated by oil products and natural gas. In 2023, TPES for Renewable Energy Sources (RES) was only 1.26% while 50% from Natural Gas and 40% from Oil and Oil products. Renewable Penetration (Electricity generation from RES) instead, is almost 4% and 95% from Natural Gas, both far away from the objective planned in the SNTE.

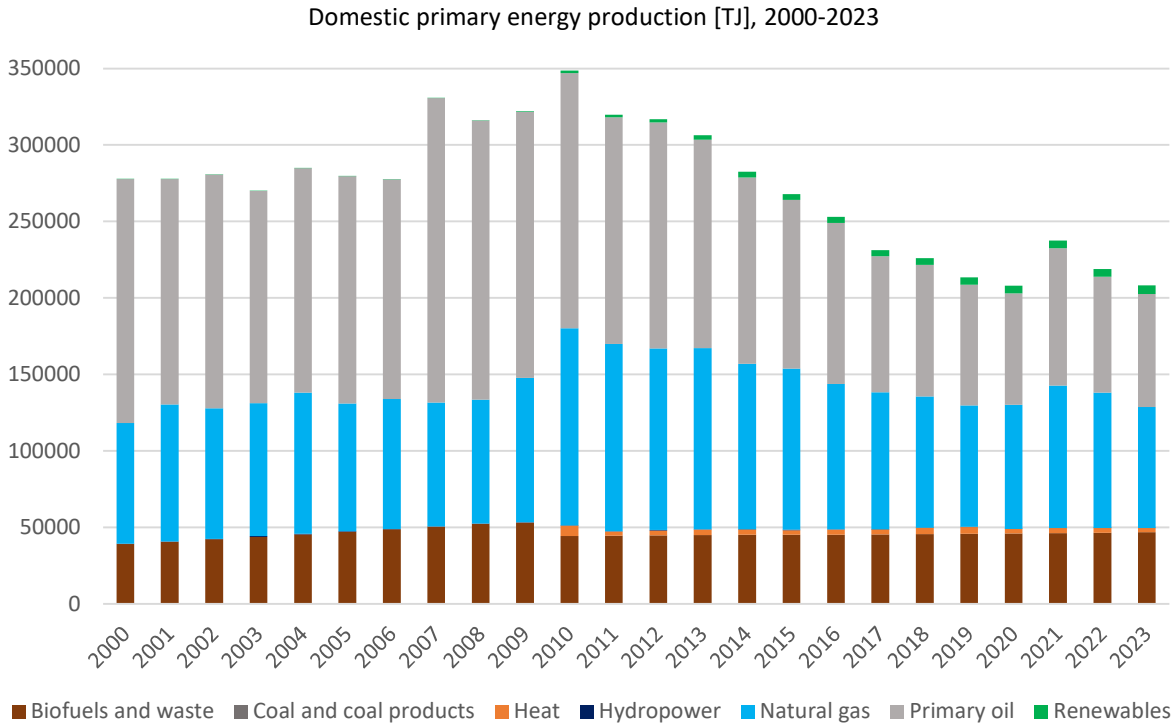


Figure 17: Domestic primary energy production [TJ], 2000-2023

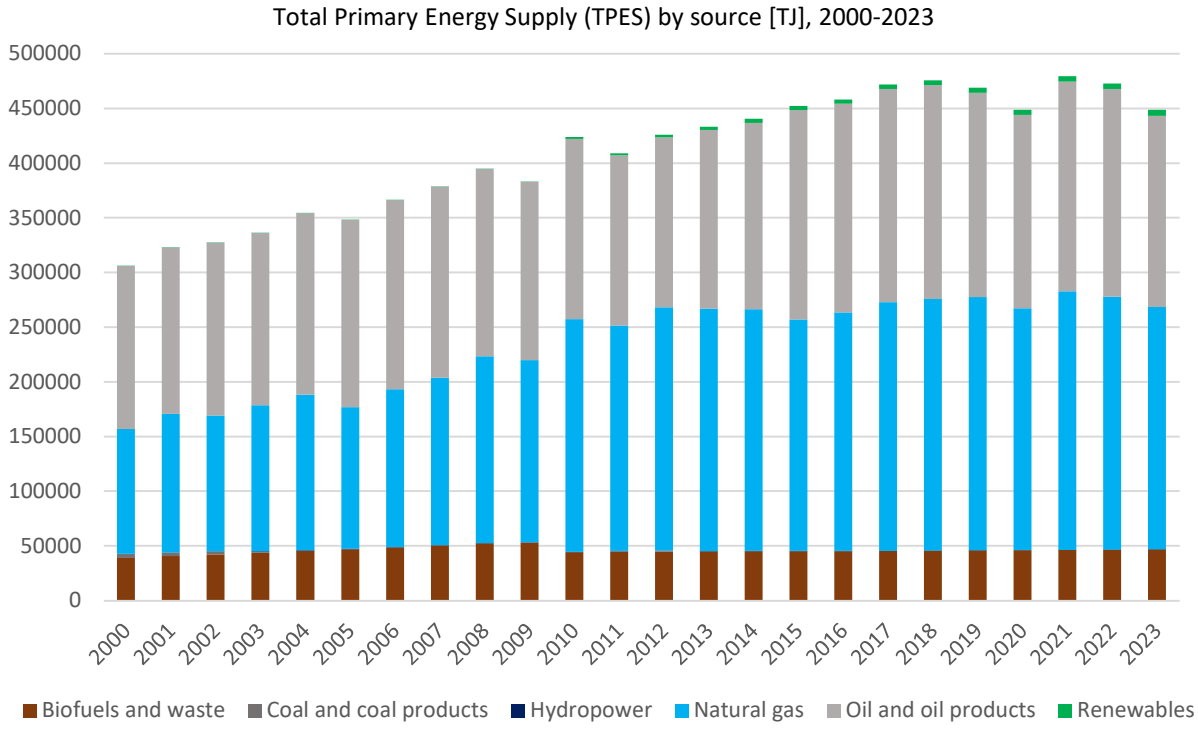


Figure 18: Total Primary Energy Supply (TPES) by source [TJ], 2000-2023

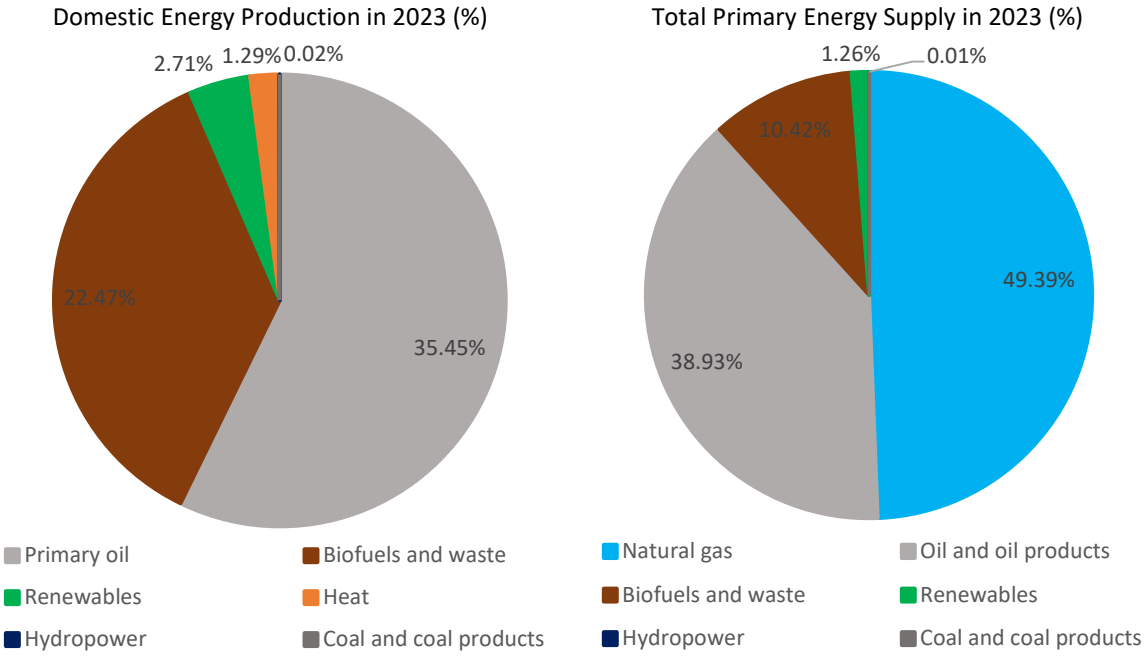


Figure 19: Domestic energy production [%] and Total Energy Supply [%] in 2023

This widening gap between falling domestic extraction and rising consumption has created a precarious energy trade dynamic; as the Figure 20 illustrates, energy imports have steadily surged to approximately 350,000 TJ, while exports have shrunk drastically since their 2007 peak, cementing Tunisia's status as a highly vulnerable net energy importer. Recent context from both the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) underscores the severity of this deficit, noting that despite Tunisia's immense solar and wind potential, the integration of renewables remains minimal, leaving the nation heavily exposed to volatile global fossil fuel markets and making an accelerated clean energy transition a critical macroeconomic necessity.

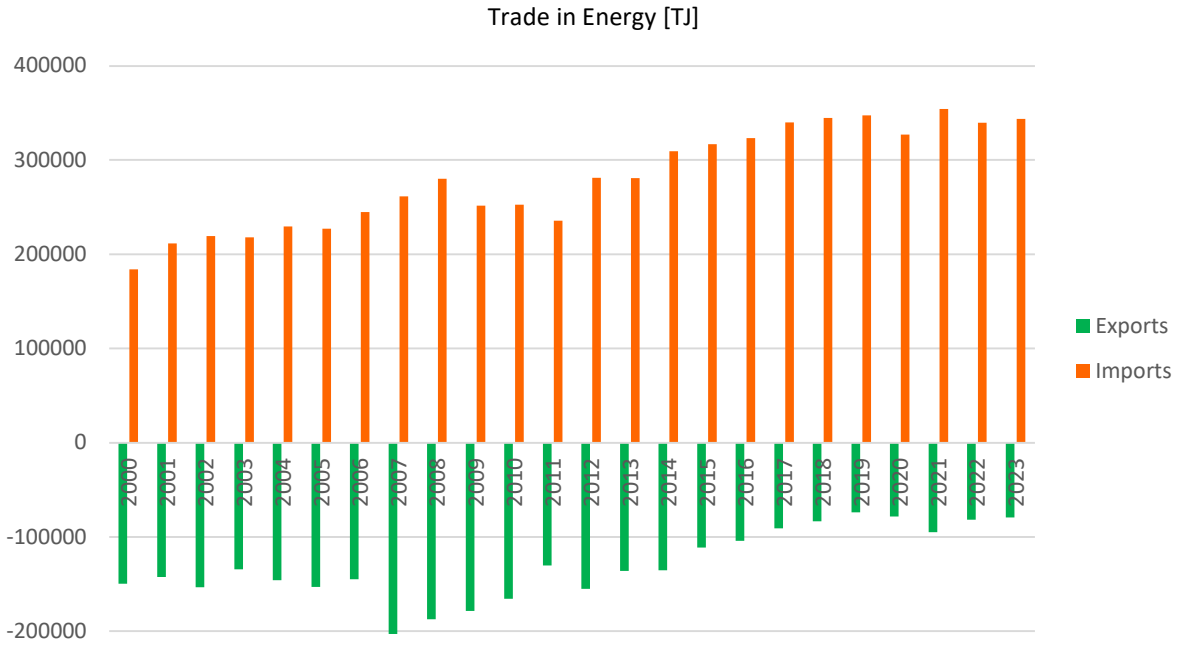


Figure 20: Energy Import & Export [TJ]

Based on Figure 21 data on North African countries in the MENA region, there is a stark contrast between high-energy consumers like Libya and Algeria and more energy-efficient or lower-consuming nations like Morocco, Egypt, and Tunisia. Libya exhibits the highest Total Primary Energy Supply (TPES) per capita at 110 MJ/capita, followed by Algeria at 62 MJ/capita, while Morocco records the lowest at 25 MJ/capita. When evaluating Energy Intensity—which measures energy used relative to economic output [MJ/US$]—Algeria and Libya emerge as the least energy-efficient economies, requiring 5.6 and 5.3 MJ/US$ respectively. Conversely, Egypt and Morocco demonstrate the highest energy efficiency in the group, both utilizing significantly less energy at 3.1 MJ/US$ to generate the same unit of economic value, with Tunisia sitting in the middle at 3.8 MJ/US$.

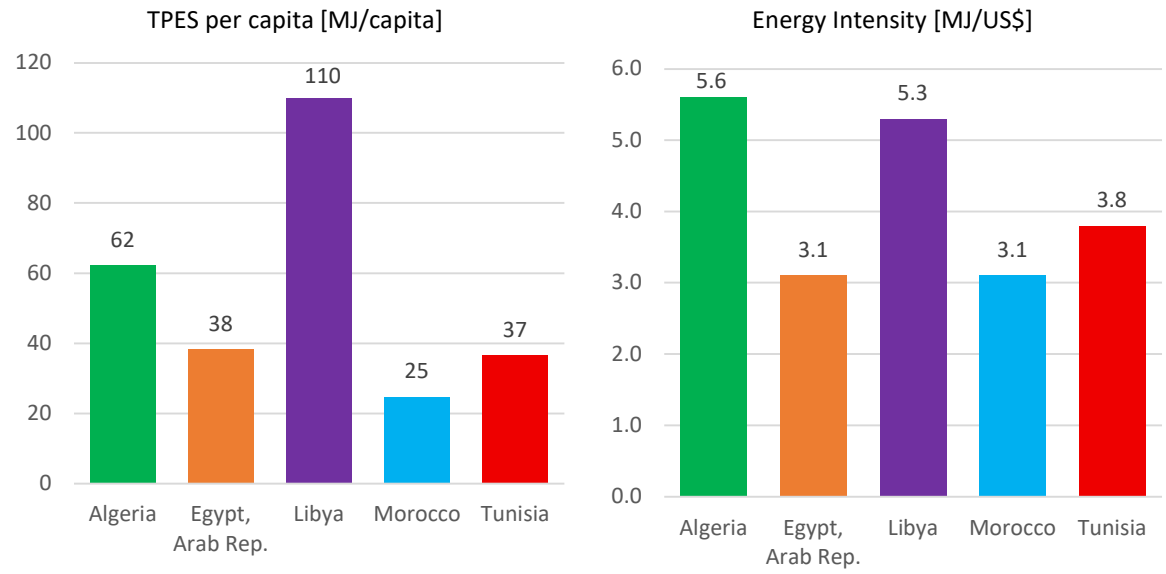


Figure 21: TPES per capita [MJ/capita] and Energy Intensity [MJ/US$] in 2023

According to IEA, Total Final Consumption (TFC) data in Figure 22 and Figure 24 highlights the domination by oil products, which account for 51.22% for Tunisia and serve as the primary energy source for every individual nation, peaking in Morocco (nearly 73%). Natural gas acts as the second major pillar for the region, heavily driving consumption in Algeria (around 46%) and Tunisia (18%) but remaining virtually absent in Morocco's energy mix, while electricity maintains a balanced share of roughly 14% to 22% across all five nations. Notably, Tunisia stands out with the highest regional reliance on biofuels and waste at 10%.

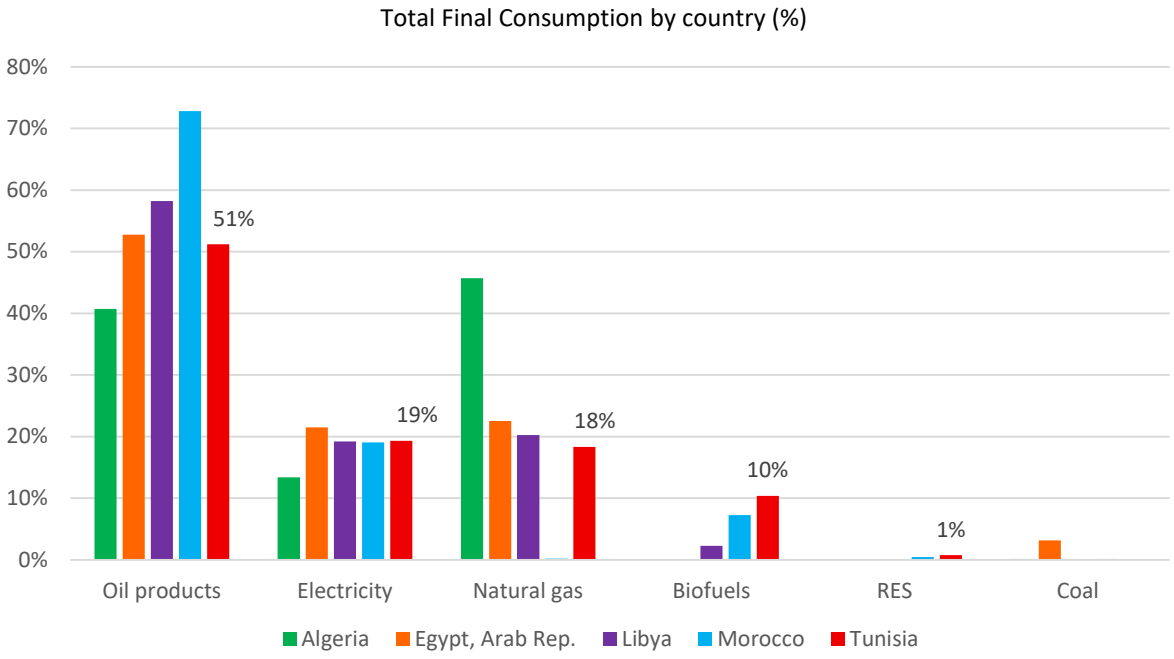


Figure 22: TFC by country [%]

When breaking down consumption by sector in Figure 23 and Figure 24, transport is the definitive leading driver of energy demand, consuming 31.51% regionally and ranking as the top sector for Libya (where it exceeds 50%), Algeria, Morocco, and Tunisia (around 32%). The remaining consumption is primarily split between the residential and industrial sectors depending on the nation's specific economic structure; residential energy use is highly prominent in Algeria, Tunisia, and Morocco (all nearing the 27–30% mark), whereas Egypt uniquely relies on its industrial sector as the primary consumer of its total final energy.

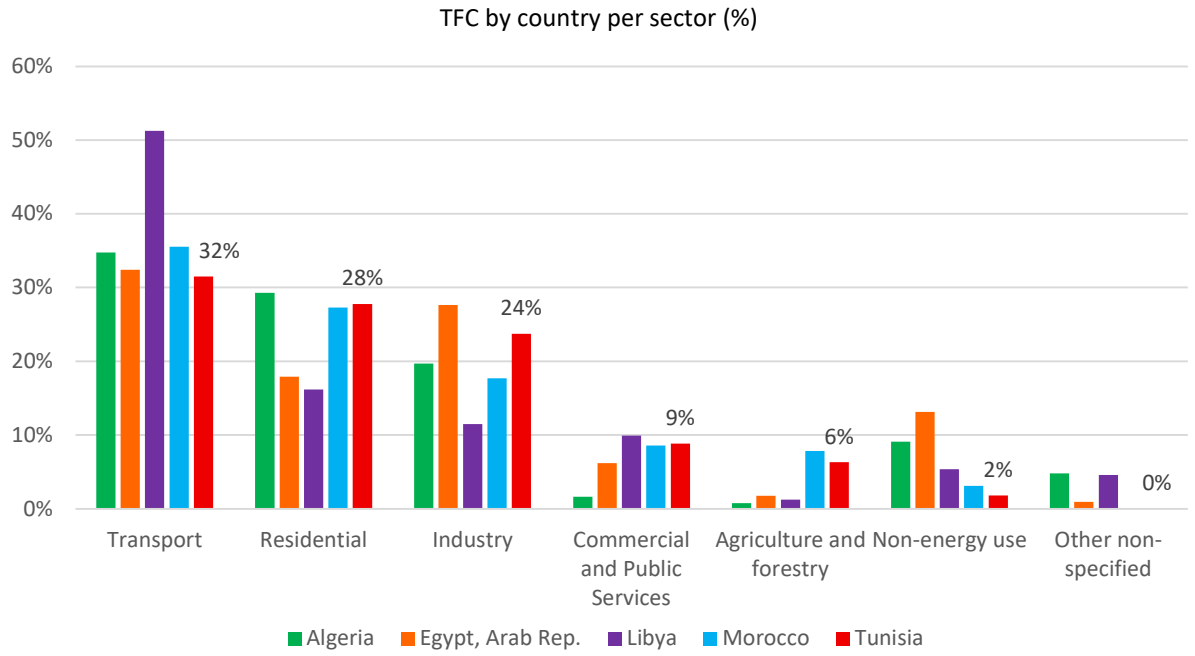


Figure 23: TFC by country per sector [%] in 2023

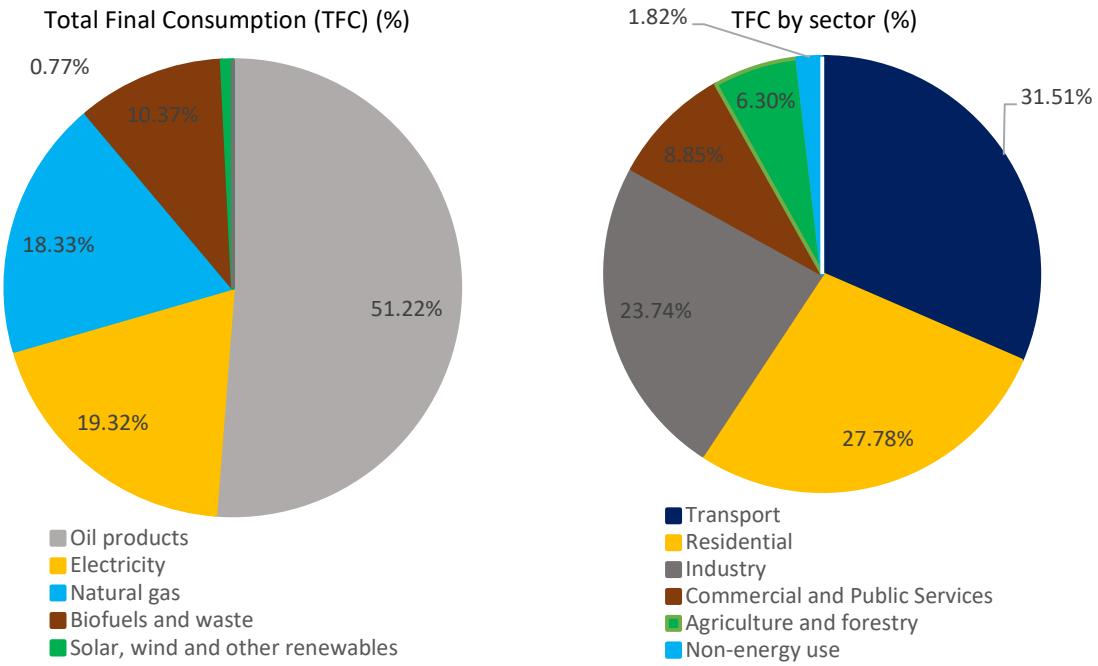


Figure 24: TFC (%) and TFC by sector (%) in 2023

2.1. Renewable Energy Sources (RES)

Figure 25 shows the percentage of renewable energy in total final energy consumption (TFEC) for MENA Region countries from 1990 to 2021 according to the World Bank, revealing distinct regional trends and an overall decline in proportional usage. Morocco and Tunisia consistently maintained the highest shares, though both saw significant reductions over time; Morocco started at approximately 22.5% and, despite a notable peak in 2004, ended the period near 11%, while Tunisia fluctuated between 12% and 16% before settling at roughly 11.6%. Egypt followed a similar downward trajectory, decreasing from an initial 9% to about 6% by 2021. In contrast, Libya and Algeria exhibited minimal and stagnant reliance on renewables, with Libya remaining below 3.5% and Algeria consistently hovering just above 0% for the duration of the three decades. However, this is largely due to traditional biomass rather than modern renewable technologies, which is a crucial distinction when analysing the country's energy transition potential. Biomass which climate impact varies considerably depending on where biomass feedstocks come from and how they are grown.

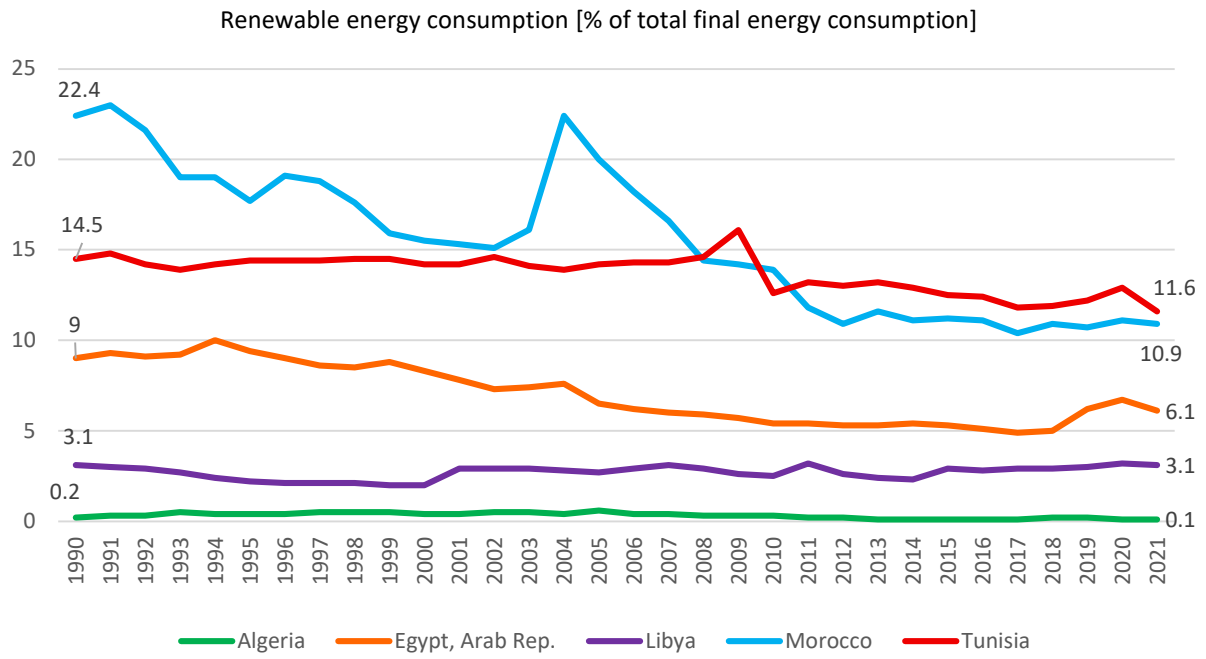


Figure 25: Renewable energy consumption (% of total final energy consumption)

Figure 26 shows the trend of Electricity Generation from 2000 until 2023 with focus on the production from RES. Electricity generation comes mostly from Natural Gas shows that natural gas is the overwhelmingly dominant energy source, steadily rising from approximately 9,000 GWh in 2000 to over 20,000 GWh by the early 2020s corresponding to 95% of electricity generation. Focus on renewable energy sources, reveal a dynamic shift where wind power peaked at about 500 GWh around 2014 and 2019 before declining reaching 338 GWh in 2022, while solar PV experienced rapid exponential growth starting in 2010 to reach nearly 500 GWh by 2022. Conversely, hydropower exhibits a volatile and generally downward trajectory in the RES chart, starting near 70 GWh and falling to minimal levels by the end of the timeline. Electricity from Hydroelectric, Wind and Solar correspond to, 0.04%, 1.59% and 2.28% respectively.

This contraction in green energy is directly driven by the progressive physical degradation and gradual shutdown of aging wind power plants and turbines, which are phased out of operation without sufficient new renewable installations to replace them.

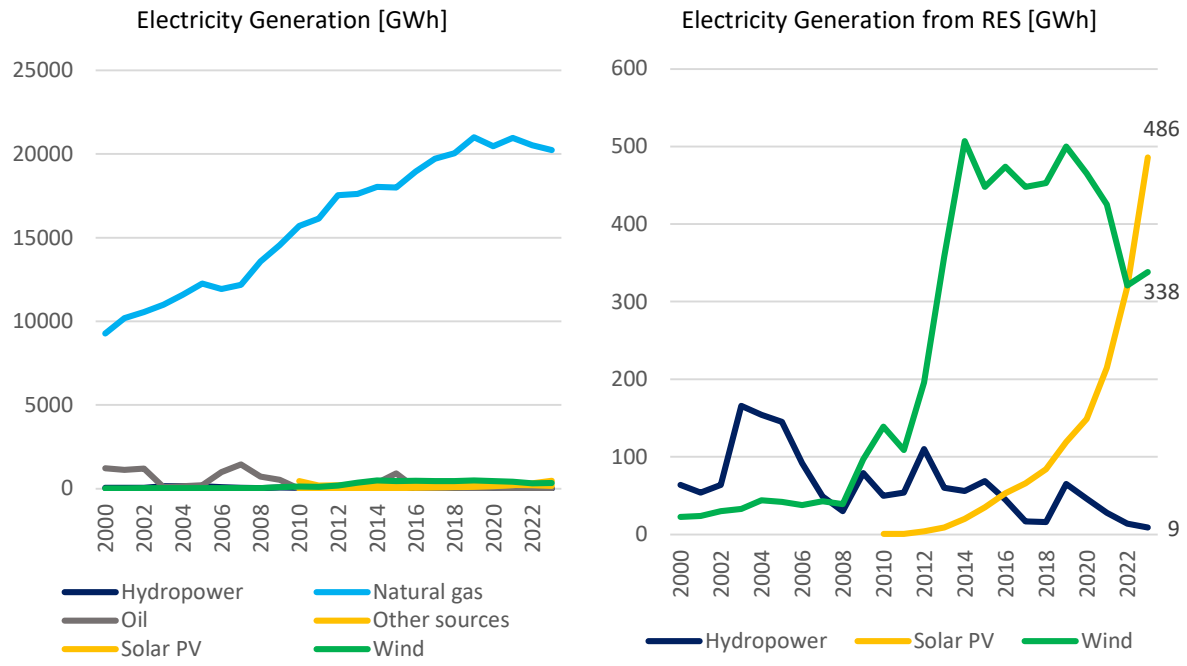


Figure 26: Electricity Generation total [GWh] (left) and from RES [GWh] (right)

The energy landscape across these North African nations remains heavily dominated by fossil fuels, yet a clear divide exists in their adoption of renewables, with Morocco leading the region through a diverse portfolio that derives over 21% of its power from clean sources—most notably its 15% wind contribution. Egypt follows as a significant secondary player with a 12.8% renewable share, uniquely anchored by its 7.2% hydropower usage. In contrast, Tunisia and Algeria maintain very minor renewable footprints (under 4% and 1% respectively) primarily focused on solar, while Libya shows a total absence of renewable integration, remaining entirely dependent on natural gas and oil. In the following Table 2 are reported data about Electricity Generation in the neighboring countries of Tunisia.

	Natural gas	Oil	Coal	Hydropower	Solar	Wind
Algeria	99.00%	0.30%			0.70%	
Egypt	75.80%	11.40%		7.20%	2.50%	3.10%
Libya	73.80%	26.20%				
Morocco	9.70%	4.20%	62.10%	1.20%	4.84%	15.00%
Tunisia	95.11%			0.04%	2.28%	1.59%

Table 2: Electricity Generation in the MENA Region

Tunisia's climate is affected by various types of wind due to its geographical location: the northern coast is exposed to moderate and humid sea winds blowing from southern France, resulting in a significant decrease in temperatures and an increase in rainfall. In the south of the country, there are hot and dry continental winds, such as the Chergui wind, which blows over large desert areas causing a sudden rise in temperatures and a clear dry atmosphere. The country also benefits from a high

amount of sunshine, exceeding 3000 hours per year, which reaches its peak in the southern desert, on the Algerian and Libyan borders. [1]

Temperatures vary according to latitude, longitude, and proximity to the Mediterranean Sea. While temperatures can drop below 0 degrees Celsius in the winter in the Khemer Mountains (Kroumirie), the maximum temperature often rises to around 45 degrees Celsius in the desert regions in the summer. Average annual rainfall also varies by region, from about 1000 mm in the north to about 380 mm in the center and down to less than 50 mm in the far south. [1]

Tunisia has experienced a significant increase in temperatures over the 20th and early 21st centuries, with the average temperature rising by approximately 1.2°C from 1901 to 2020. This trend of rising temperatures is expected to continue, leading to numerous impacts on the country's ecosystems, agriculture, and human health. The Mediterranean is one of the regions of the world most affected by the effects of climate change. Mediterranean temperatures are increasing 20% faster than the global average. The country faces high vulnerability to climate change, anticipating adverse impacts from heightened temperatures, increased aridity, reduced precipitation, and rising sea levels. These changes are expected to significantly affect water resources, agriculture, ecosystems, coastal areas, health, and the tourism sector. [1]

The limited water resources available in Tunisia means that the country is very susceptible to small changes in ambient temperature that result in the even further reduced water availability. This makes the agricultural activities more vulnerable to the effects of climate change. As a result of rising temperatures, sea level rise, and change in precipitation patterns, potential risks to agriculture in Tunisia include decrease in crop yields, shifts in growing seasons, degradation of soil quality and productivity, increased salinization of aquifers and decreased availability of water for irrigation. These changes are likely to affect an increase in food prices and food shortages as well as economic losses, both national and household incomes. [1]

Climate change affects cities more as the ventures in the urban areas are massive contributors to climate change. According to the UN Habitat 2021, city areas account for about 70% of CO_2 emissions and as already mentioned, urban population in Tunisia is increasing every year. The climate in Tunisia in the north reflect the precipitation and temperature patterns of Mediterranean climate. The climate becomes hotter and drier further moving to the South. [1]

The coastal regions of Tunisia have a Mediterranean climate, which allows the production and cultivation of fruits, like grapes and vineyards, and olives. However, the country of Tunisia is large and also has zones of desert where farming techniques have adapted to flourish among low rainfall and extreme heat. Because of Tunisia’s diverse climate and seaside attractions, tourism has been an important source of revenue for the country. However, seaside tourism and urban sprawl along the coasts have had negatively affected coastal landscapes and natural resources. [1]

Tunisia is endowed with abundant renewable energy resources, particularly solar and wind energy; however, renewable energy currently plays a minor role in the country's energy supply. [1]

2.1.1. Biofuels and waste-to-energy

There is minimal use of traditional biomass fuels in Tunisia as almost the entire country has access to electricity and to non-solid fuels for cooking. The production of charcoal has remained almost stable over the last decade, averaging 150 ktoe/year, and wood is frequently used in traditional ovens.
The National Waste Management Agency (ANGED—Agence Nationale de Gestion des Déchets) estimates that the country produces approximately 6 Mt of organic waste annually (2.2 Mt of household waste, 2.2 t from farms and agri-industry, 1 Mt from olive oil processing, 400 000 ton from poultry droppings and 200 000 ton from waste water treatment). According to ANGED, the potential for generating electricity through waste is estimated at 1,000 GWh/year. Various challenges currently exist to exploit this potential, including initial investment cost constraints, a lack of technical knowledge, limited knowledge on biomass resources, lack of clarity on the long-term supply of power plants from low-cost waste, and overlapping roles between ANGED and municipalities, both responsible for waste collection.
One pilot biogas plant capable of generating 2.4 GWh/year of electricity was developed in 2010. The plant was set up to use waste from the wholesale market of Bir El Kassaa; however, it remains offline due to technical problems (ANME, 2017). [1]

2.1.2. Geothermal energy

The southern part of the country, specifically the Kebili, Gabes and Tozeur regions, is rich in hot springs which is good indicator of geothermal activity. These geothermal resources originate from the extensive Continental Intercalary aquifer, covering an area of 1 Mkm^2 and spreading into the neighboring countries of Libya and Algeria. The aquifer is about 2.8 km deep and has temperatures ranging from 30°C to 80°C (UN, 2008). Use of geothermal energy in the power sector, however, is underdeveloped due to the low enthalpy of geothermal resources. Therefore, many geothermal applications are based on direct use of geothermal heat in agriculture (e.g. for heating greenhouses, powering irrigation pumps) and recreational thermal baths. [1]

2.1.3. Hydropower

Hydropower was the first renewable resource exploited in Tunisia through the installation of two hydropower stations in Arroussia and Nebeur (northwest region) in 1956, with a total capacity of 18 MW. Its installed hydro capacity by 2018 stood at 66 MW, spread over seven stations, as shown. Tunisia does not have large dams and its hydraulic energy potential is limited. The production of hydropower is variable,

and its share of total electricity production is very limited. Electricity produced from hydropower in 2018 totaled approximately 18 GWh, which represented 0.12% of STEG electricity production. [1]

As 2026 the only hydropower plant still operative are Sidi Salem Dam, built in 1983 with 33 MW of capacity and Bouherthma, built in 2003 with 1.2 MW of capacity.

2.1.4. Wind

Tunisia's wind map in Figure 27 illustrates the existence of several suitable sites for wind farms. The most interesting sites (speed exceeding 7 (m/s) at 80 m height) are found in the north regions (Bizerte and Nabeul), in the central region (Kasserine) and in the southern regions (Tataouine, Western Cape, Gabes and Kebili). By comparison, sites with less attractive wind conditions (speed between 6.5 m/s and 7 m/s) can be found in the eastern areas of Tozeur, the east coast of Medenine and the Monastir region. The total area available for wind power development is estimated to be about 32,200 km². The gross wind energy potential in Tunisia is estimated at more than 8,000 MW according to GIZ. This potential does not consider potential development opportunities in offshore wind.

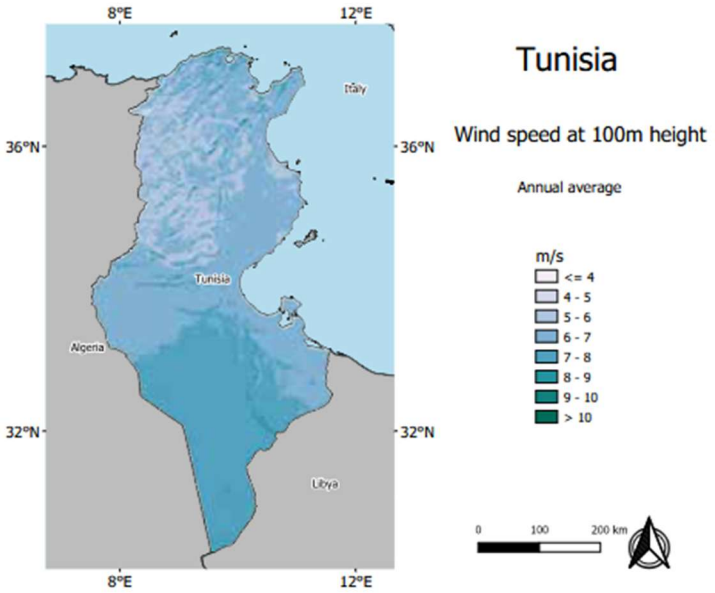


Figure 27: Tunisia's Wind Map

Tunisia's wind generation development began in 2001, when STEG brought online a wind farm at the Sidi Daoud site in the northeast, with an initial capacity of 10 MW and later expanding to 55 MW in 2008. STEG launched two other wind farms in 2012 at the sites of Metline and Kchabta (Bizerte region). Together they account for a total of 143 wind turbines with a total capacity of 190 MW. The total electricity production of the three wind farms installed in 2019 was of 500 GWh while peak production was recorded in 2014 at 507 GWh. [1]

In Figure 28 illustrates the annual average hourly wind capacity factor trends for Bizerte, the northern region hosting all of Tunisia's wind power installations. Utilizing data sourced from Renewables Ninja, the analysis compares the Wet season (October to May) with the Dry season (June to September) for the year 2019. These figures were derived by calculating the mean capacity factor for every hour of the day across all dates within their respective seasonal windows. Made AE-61 is the model of the turbine of Tunisia wind farm. Gamesa G52/58 is the turbine chosen to compute capacity factor on Renewable Ninja because Made turbines were not available on the dataset. Due to the fact that Gamesa took over Made and their early 2000s models like the G52 and G58 (850 kW-1 MW) are considered closely related in technology and design philosophy.

The provided Figure 28 illustrates the daily fluctuation of wind capacity across two distinct seasons over a 24-hour period in Bizerte region (37° 9' 20.52"N 10° 8' 41.28"E). The data reveals that the Wet Season maintains a consistently higher and more stable capacity factor throughout the day, hovering mostly between 0.34 and 0.39. In contrast, the Dry Season experiences overall lower capacity factors with a pronounced duck curve; it dips to a minimum of roughly 0.21 around hours 7AM and 12AM before climbing to a peak of approximately 0.33 in the late afternoon between hours 4PM and 6PM.

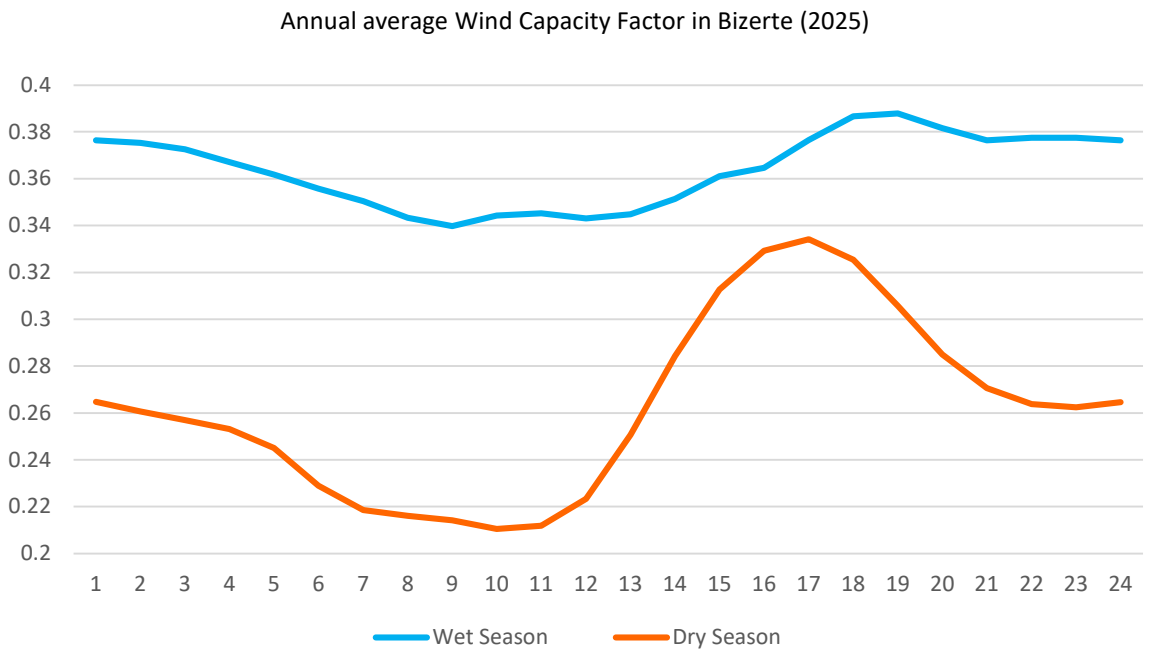


Figure 28: Annual average Wind Capacity Factor in Bizerte (2025)

With a total area available for potential wind development estimated to be 32,200 m^2, Tunisia's gross land-based wind resource potential is approximately 8,000 MW. This is largely relegated to the north coast, center, and southern regions of the country.

2.1.5. Solar

Tunisia has solar resources exceeding 3,000 hours/year, although hours of sunshine vary throughout the different regions. Most of the southern provinces have a solar exposure time of more than 3,200 hours/year, with peaks of 3,400 hours/year on the south coast (Gulf of Gabes), while the minimum period of insolation in the northern provinces is between 2,500 and 3,000 full-sun hours equivalent (Renewable and Sustainable Energy Reviews, April 2016). Solar irradiation ranges from 1,800 kWh/m²/year in the north to 2,600 kWh/m²/year in the south. [1]

Global horizontal irradiance is a reliable resource measure for solar PV installations. The daily average global solar irradiance is between 4.2 kWh/m²/day in the northwest of Tunisia and 5.8 kWh/m²/day in its far south. With these favorable conditions, the productivity of PV solar systems in Tunisia is very high. According to IRENA's Global Atlas, annual electricity production by PV solar systems varies between 1,450 kWh/kWp in the northwest region and 1,830 kWh/kWp for systems installed in the extreme southeast region.
Direct normal irradiance (DNI) is the main parameter for evaluating the potential for concentrated solar power (CSP) technology. Generally, the DNI should be at least 2,000 kWh/m²/year to provide a viable energy yield, according to IRENA. In Tunisia, as shown in Figure 29, direct solar irradiation in the south and in most of the central region exceeds this typical DNI value. The DNI in some regions of the extreme southeast of Tunisia can reach a value of 2,300 kWh/m²/year. [1]

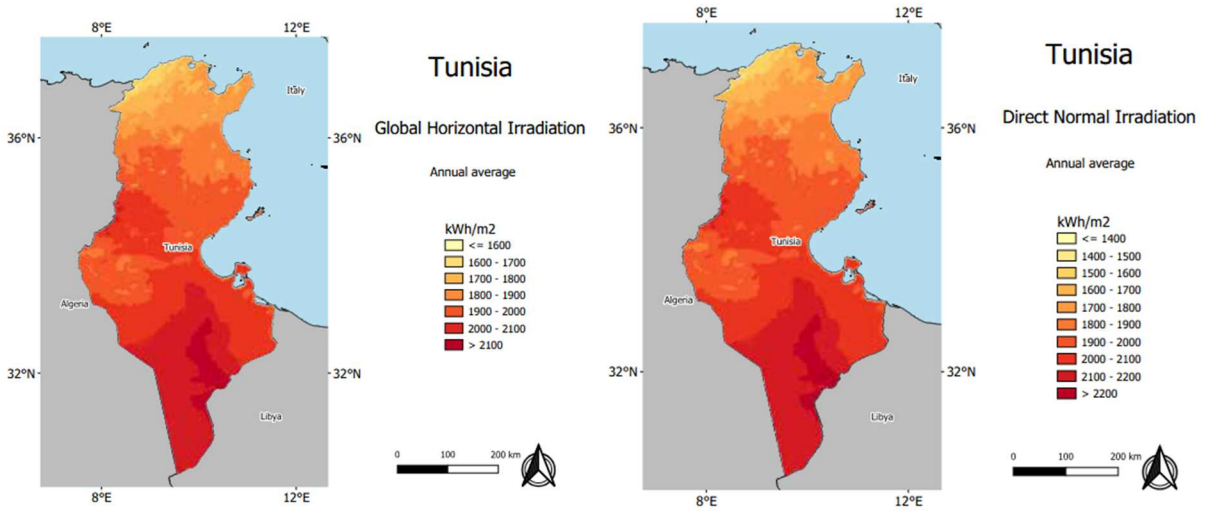


Figure 29: Global Horizontal and Direct Normal Irradiation

Tunisia has significant solar potential given the country's high irradiance, ranging from 1800 kWh/m²/year in the North to 2600 kWh/m²/year in the South. This equals approximately 1,980 sunshine hours per year.

Similar to annual Wind capacity factor, the same considerations were made also for Solar capacity factor. Figure 30 illustrates the hourly solar capacity factor for the Tataouine region in 2025 (Elgordhab solar farm 33°03'01.4"N 10°27'49.7"E), revealing a

distinct bell-shaped production curve that peaks at midday regardless of the season. During the Dry Season (typically extending from June to September), the region benefits from higher solar intensity and clearer skies, resulting in a slightly broader and higher production profile compared to the Wet Season. While both seasons reach a near-identical peak capacity factor of approximately 0.7 at 12:00 PM, the dry season exhibits consistently higher yields during the early morning (6:00 AM – 10:00 AM) and late afternoon (3:00 PM – 6:00 PM) hours. This divergence is likely due to the increased presence of cloud cover and atmospheric dust during the wet months, which reduces overall solar radiation and narrows the effective window for high-efficiency energy generation.

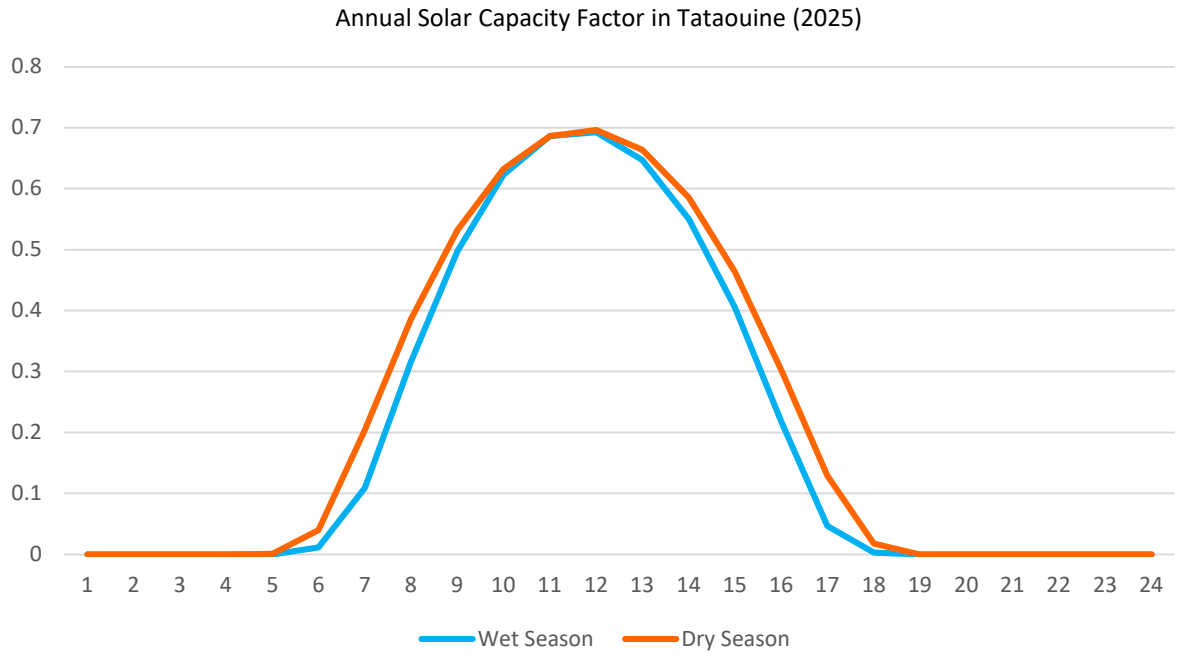


Figure 30: Annual Solar Capacity Factor in Tataouine (2025)

2.2. Main Policies in the Power Sector

According to the SNTE, Axis 2 – Climate Change, Measures 13 and 19, the macro-objective is a complete break with the Business as Usual (BaU) scenario, leading to a 38% reduction in net emissions by 2030, a 77% reduction by 2040 and carbon neutrality by 2050. [13] Tunisia has planned 4 key programs:

- Energy efficiency
- Renewable energies
- Electrification of uses
- Energy Sobriety

The plan propose some activities with the following objectives:

- 3-fold reduction in primary energy intensity between 2020 and 2050

- 2-fold reduction in primary energy consumption in 2050 compared to BaU
- Electrification rate: 43% by 2050
- Renewable Energy penetration: 40% of primary energy balance in 2050
- Renewable Energy penetration: 80% of electricity production in 2050

Measure 14 demand to achieve the measures delineated in the Energy Strategy up to 2035. Tunisia's Renewable Energy Strategy 2035 is a national plan designed to accelerate the country's energy transition, to strengthen energy security and significantly reduce carbon emissions., reduce fossil fuel imports, combat energy poverty, and contribute to carbon neutrality by 2050. At the heart of this strategy is a massive expansion of solar and wind power, with the ultimate goal of having renewables account for 50% of all electricity generation needs by 2035 and renewable energy capacity installed of 8,350 MW by 2035. Additionally, the strategy includes a vital efficiency component, seeking to reduce primary energy intensity by an average of at least 3.6% annually between 2021 and 2035. This transition aims to reduce CO2 emissions from the energy sector by 46% compared to the Business as Usual (BaU) scenario by 2035, while increasing the share of renewables to 18% of the total primary energy consumption. Economically, this strategy is projected to boost the GDP by approximately 2% by 2035 and create over 70,000 jobs. The strategy expect to generate roughly 112 billion TND in gains against an investment over cost of 55 billion TND corresponding to around 40 USB$ and 19 USB$ respectively.

Furthermore, the SNTE's Axis 4, which governs Sustainable Consumption and Production, reinforces these targets through Measure 30. This measure emphasizes the implementation of the Energy Transition Strategy by 2035 by prioritizing energy efficiency and renewable energy, collaborating with the National Energy Control Agency (ANME) to reduce national energy intensity and secure strong coverage of primary energy demand through renewables. To guarantee the financial viability of this massive shift, Measure 9 of the SNTE proposes the creation of a joint ecological and energy transition fund (FOCTEE). This would be achieved by restructuring existing financial mechanisms, including the Energy Transition Fund (FTE), to streamline and optimize funding for these critical ecological and energy transition programs.

2.3. Regulatory framework and Electricity stakeholders

Tunisia's energy sector is governed by a comprehensive legislative framework that has transitioned from a state monopoly toward an open market for Independent Power Producers (IPPs) and renewable energy development. Key milestones include Law N°96-27, which ended the generation monopoly to allow private production for sale to the state utility (STEG), and the pivotal Law N°2015-12, which solidified the legal basis for scaling renewable energy projects alongside the 2011 Grid Code. The regulatory environment also incentivizes energy efficiency and cogeneration through

financial mechanisms like the Fund for Energy Transition (FTE), though it maintains strict technical requirements regarding efficiency thresholds and surplus energy sales. Furthermore, project implementation is regulated by a multi-ministerial permitting process that mandates environmental impact studies, technical grid connection approvals by STEG, and complex land-use concessions involving the ministries of Agriculture, Transport, and Defense [17]

Few entities manage energy deployment in Tunisia, thus shaping a simple and coherent market structure, but limiting the liberties of Independent Power Producers (IPPs). The three main stakeholders are the Tunisian Ministry of Industry, Energy and Mines, the Tunisian company of Electricity and Gas (STEG), and the National Agency for Energy Conservation (ANME) [17]

STEG was founded in 1962, by the Law N°62-8 aiming to harmonize the energy sector in Tunisia, gave to the STEG. The primary objectives of the STEG are the electrification of the country, the development of the Natural Gas network, and the development of installation for electricity and gas. STEG, under the supervision of the Ministry of Industry, is the leading actor in the Tunisian electricity market, performing production, transmission and distribution of energy. Such framework has simplified the energy market, that is currently composed of few key stakeholders. In any case, it is relevant to point out how STEG's monopoly status in electricity generation ended with the opening of the market to IPPs in 1996.
STEG-ER is the renewable part of the STEG. The main activities of the STEG-ER are to study, realize, operate and assure the maintenance of renewable (wind and solar) and cogeneration installations. [17]

ANME was created in 1985; it is an entity under the administration supervision of the Ministry of Energy. Its primary missions are to apply Tunisian policies regarding energy management by studying and promoting energy efficiency, renewable and energy transition. The ANME is composed of two section one focus on Renewable projects and the other one on Energy Efficiency. The branch working on energy efficiency is divided into three sectors: Industrial, Building, and Transport. [17]

3 Energy Modelling

The reason for conducting a dedicated energy modelling analysis within this research lies in the critical need to quantitatively evaluate whether Tunisia's planned power sector expansions can successfully achieve the ambitious targets set by the National Ecological Transition Strategy (SNTE), specifically focusing on Sustainable Development Goal 7 (Affordable and Clean Energy). In an era marked by growing energy deficits and a heavy reliance on fossil fuel imports, such a quantitative framework is indispensable for testing the technical and economic feasibility of long-term energy pathways up to 2035. To achieve this, the analysis deploys *Hypatia*, an advanced open-source energy system modelling tool developed in Python, which operates as a function optimization code utilizing *Gurobi* as its primary mathematical solver to minimize the system's Net Present Cost (NPC) under real-world technical and policy constraints. The expected outcomes of this modelling effort include comprehensive, data-driven insights into the future structure of the national grid—such as quantified production shares, required new capacity installations, and specific emissions trajectories—thereby providing an analytical scoreboard to evaluate energy security, environmental sustainability, and affordability during the ecological transition.

The set of equations and balances used in the software suits the purpose either in the operation and planning mode; below the main equations are reported.

$$\mathrm{E}_{\mathrm{demand}} = \mathrm{E}_{\mathrm{supply}}^{\mathrm{tot}}$$

$$\mathrm{E}_{\mathrm{supply}} \leq \mathrm{Capacity(y)}_{\mathrm{tot}} * \mathrm{CF}$$

Decision variables, such as $\mathrm{E}_{\mathrm{supply}}$ or $\mathrm{Capacity(y)}$ in planning mode, allow to quantify production shares and costs or new capacity installed during the years. To fit the model to the case in analysis, some parameters were modified, among which technology availability, used to calibrate the model in the operation mode and to account for the "aging" of power plants, resource capacity factor, that accounts for the actual renewables availability, or min/max new capacity addition, used to implement policies or technological limitations. A complete technology and economical characterization passed also through other parameters like residual capacity, fix and variables O&M costs or specific emissions.

The Reference Energy System reported in Figure 31 represents the base-case implemented in the software Hypatia and it is valid for all the scenarios except for the addiction of new technologies or resources:

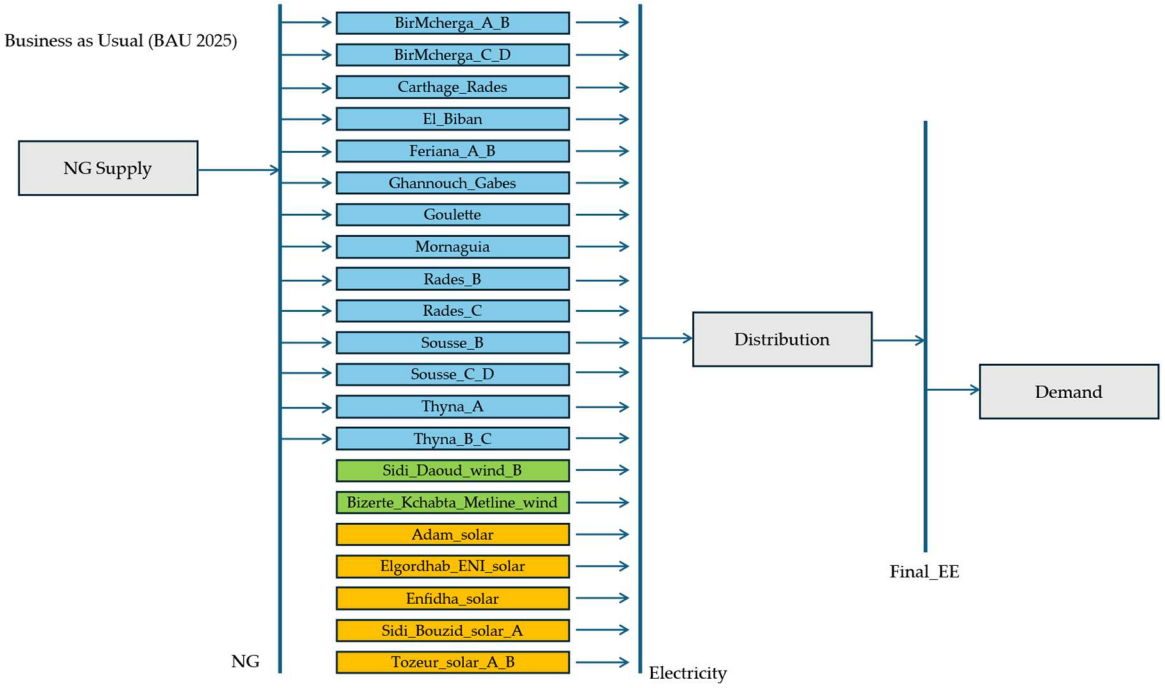


Figure 31: Business as Usual (BaU 2025)

The system considers only electricity as the subject of the study and as final demand. Non-renewable electricity production plants use natural gas supply (for gas-cycle). There are currently nine renewable plants of which five are solar farm, one is the aggregation of all residential and industrial self-consumption solar PV and the remaining three are wind farm.

The total power sector is composed by 22 power plants:

- 10 Natural Gas Power Plants complex for a total of 14 Power Plants
- 5 Solar Power Plants of which one is a complex of two solar plants, and 1 Prosol & Self-Consumption for a total of 6 Power Plants
- 2 Wind Power Plants complex for a total of 3 Power Plants

In the Table 3 are reported the data for the corresponding power plants introduced above:

Project	Technology	Year	Closing	Coordinates		Generation	Capacity [MW]
Bir Mcherga A&B	OCGT	1997	2028	36.462	10.054	Gas	240
Bir Mcherga C&D	OCGT	2013	2043	36.462	10.054	Gas	256
Carthage Rades	CCGT	2002	2027	36.799	10.287	Gas	470
El Biban	OCGT	2003	2033	33.479	11.110	Gas	27
Feriana A&B	OCGT	2005-2009	2035-2039	34.905	8.541	Gas	240
Ghannouch Gabes	CCGT	2011	2041	33.889	10.101	Gas	400
Goulette	OCGT	2005	2035	36.815	10.289	Gas	120
Mornaguia	OCGT	2021	2051	36.677	9.921	Gas	624
Rades B	Steam Turb	1998	2033	36.797	10.283	Gas	360
Rades C	CCGT	2022	2050	36.800	10.285	Gas	450
Sousse B	CCGT	1994	2030	35.786	10.678	Gas	357
Sousse C&D	CCGT	2014-2015	2044-2045	35.786	10.678	Gas	848
Thyna A	OCGT	2004	2034	34.687	10.642	Gas	120
Thyna B&C	OCGT	2007-2010	2037-2040	34.687	10.642	Gas	246
Prosol &Self-Consumption	PV	2015	2040	35.0388	9.4908	Solar	240
Adam	PV	2019	2044	31.399	10.0309	Solar	4.8
Elgordhab ENI	PV	2020	2045	33.0504	10.4638	Solar	10
Enfidha	PV	2019	2044	36.0826	10.3512	Solar	1.4
Sidi Bouzid A	PV	2019	2044	35.0388	9.4908	Solar	10
Tozeur A&B	PV	2022	2047	33.9081	8.0467	Solar	10
Bizerte Kchabta & Metline	Wind	2012-2013	2037-2038	37.195	10.061	Wind	188
Sidi Daoud B	Wind	2009	2034	37.1946	10.061	Wind	55

Table 3: Power Plants operating in 2026

Bir Mcherga power station is an operating power station of 496 MW divided in a complex of four power plants in Sminja, Zaghouan, owned by STEG. Due to the fact that two of this four power plants started their operation in 1997 while the others two in 2013 and their retirement is planned in 2028 and 2043 respectively, it has been decided to model two distinct power plant that unite characteristics of the first two and the second two for a total capacity of 240 and 256 respectively for the 10 years Scenario model starting from year 2025 (Scenario 2035). Rades II power station is an operating power station of 470 MW in Rades, Ben Arous, owned by STEG. It is also known as Carthage Rades. New El Biban Power Plant is an operating power station of 27 MW in Zarzis, owned by Caterpillar Inc. It has started its operativity in 2003 and expected retirement in 2033, according to Global Energy Monitor. Feriana power station is an operating power station of 240 MW in Firyanah, Kasserine, owned by STEG. Similar to Bir Mcherga power station, Feriana is a complex of two power stations with the same capacity of 120 MW, but in this case it has been considered as just one plant because their operation started in 2005 and 2009 and their retirement is planned in 2035 and 2039 respectively, where is not required a distinction for the Scenario 2035. To simplify the analysis Feriana A and B are united in just one plant. Ghannouch power station is an operating power station of 400 MW in Ghannouch,

Gabès, owned by STEG. It has started its operativity in 2011 and expected retirement in 2041, according to Global Energy Monitor. Goulette power station is an operating power station of 120 MW in La Goulette, Tunis, owned by STEG. It has started its operativity in 2005 and expected retirement in 2035, according to Global Energy Monitor. Mornaguia power station is an operating power station of 624 MW in Borj El Amri, Manouba, owned by STEG. It is also known as Bourj El Amiri power station. It has started its operativity in 2021 and expected retirement in 2051, according to Global Energy Monitor. Rades B and C power station are an operating power stations of 360 MW and 450 MW in Rades, Ben Arous, owned by STEG. They have started their operativity in 1998 and 2022 and expected retirement in 2033 and 2050 respectively, according to Global Energy Monitor. Rades A power station is an operating power station from 1985 and its expected retirement was planned for 2025. For this reason is not considered in the model. Sousse B and C-D power stations are operating power stations of 357 MW and 848 MW divided in two plants, in Sousse, owned by STEG. Similar to Bir Mcherga case, the choice to divide in two distinct plant for the model, is due to the fact that Sousse B started its operativity in 1994 and its planned retirement is 2030. Sousse C and D instead, started their operativity in 2014 and 2015 and their retirement is planned for 2044 and 2045 respectively. Sousse A power station is not considered because retired in 2017. To simplify the analysis Sousse C and D are united in just one plant. Thyna power station is an operating power station of 366 MW in Thyna, Sfax, owned by STEG. For the purposes of this project, similar to the previous plants, because Thyna is a complex composed by three power plants with different starting year of activity, it has been decided to separate in two different plants: Thyna A and Thyna B-C. The first one has started its operativity in 2004 and expected retirement in 2034, while Thyna B-C started their operativity in 2007 and 2010 and expected retirement in 2037 and 2040 respectively. To simplify the analysis Thyna B and C are united in just one plant.

Adam solar farm is an operating solar photovoltaic (PV) farm of 4.8 MW, located in the Tataouine Governorate in Tunisia, owned by ENI and lies in close proximity to the hydrocarbon production plant and contributes to its power supply. It has started its operativity in 2019. Elgordhab solar farm is an operating solar photovoltaic (PV) farm of 10 MW in Tataouine. It has started its operativity in 2020. Enfidha solar farm is an operating solar photovoltaic (PV) farm of 1.4 MW in Sousse. It has started its operativity in 2019. Sidi Bouzid Solar Plant A is an operating solar photovoltaic (PV) farm of 10 MW in Sidi Bouzid, owned by Scatec. It has started its operativity in 2019. Tozeur solar farm is an operating solar photovoltaic (PV) farm composed by two solar plants both of 10 MW in Tozeur, half owned by STEG and the other half owned by both STEG and KfW (Kreditanstalt für Wiederaufbau) and operate by Scatec. They have started its operativity in 2019 and 2022 respectively.

Bizerte Métline and Kchabta wind farm are an operating wind farms of 94 MW each in Ghar El Melh and Menzel Bourguiba, Bizerte, owned by STEG. They have started

its operativity in 2012 and 2013 respectively. For the purpose of this project they are considered as one unique power plant of 188 MW for simplicity. Sidi Daoud B wind farm is an operating wind farm of 55 MW in Beni Atta, Ras Jebel, Bizerte, owned by STEG. It has started its operativity in 2009 and its retirement is planned in 2034. For this reason, a part of the plant that started in 2000, it has not been considered in the analysis because its retirement was planned for 2025.

For Solar and Wind power plants, lifetime is chosen arbitrarily equal to 25 years.

The energy carriers that have been considered for the model are:

- Natural Gas
- Electricity
- Final Electricity (net of distribution-related losses)

The distribution and the hourly demand profile are considered unique and regions or territorial subdivisions within the country weren't considered.

3.1. Validation test for the RES

RES verification has been done comparing the data obtained running the Business As Usual (BAU) scenario in operation mode and the ones provided by IEA for 2023.

IEA database doesn't provide data divided by power plant, as it's done in operation, but aggregate data based on supply source. To make a significative analysis, data obtained from the BAU operation scenario have been aggregated like IEA's one.

3.1.1. Technology production share

For the comparison between model results and IEA, the year chosen is 2023 because the most recent available. In first analysis, Residential and Self-Consumption PV were not considered and as is shown in the Table 4, the electricity production share is quite different in respect to IEA values. This is because in the model have not been considered both Oil, Hydro and Other Sources production that according to IEA, in the year 2023 their production correspond to 0.12%, 0.04% and 0.86% respectively, which summed to Natural Gas production give around 96.13%, closing the gap between the results from the model and IEA. Regarding Wind and Solar they face the biggest differences. The model prefer to choose Wind plants against Solar ones due to the low capacity of Solar plants. Total renewable production is 3.57% in the model against 3.87% of IEA, resulting a relative error of 6%.

For this reason, the comparison shows an important difference between the real value provided by the International Energy Agency and the one obtained by the optimization with negative relative error of about 83% for Solar and 105% for Wind.

[kWh]	Model		IEA (2023)		err rel
Natural Gas	$2.09*10^{10}$	96.43%	$2.02*10^{10}$	95.11%	-3.45%
Solar	$8.28*10^{7}$	0.38%	$4.86*10^{8}$	2.28%	82.96%
Wind	$6.92*10^{8}$	3.19%	$3.38*10^{8}$	1.59%	-104.83%

Table 4: Technology production (Model vs. IEA)

The discrepancy between the model and RES data stems from approximately 200 MW of decentralized solar PV capacity, primarily driven by Tunisia's successful PROSOL ELEC residential initiative and robust industrial self-consumption. PROSOL ELEC has empowered tens of thousands of households to adopt rooftop solar through low-interest loans repaid via STEG utility bills, while high electricity prices have incentivized hundreds of industrial and commercial entities—including factories, hotels, and large farms—to install systems ranging from 100 kW to 5 MW since 2015. When accounting for both these decentralized programs and utility-scale projects, total installed solar capacity reached an estimated 200 MW by the end of 2023, according to figures from IRENA and the ANME.

In the model it has been added a new plant for this purpose with a 240 MW capacity in 2025 under the hypothesis of a slight increase of Residential and Self-Consumption from 200 MW in 2023 to 240 MW in 2025. Also, due to the reduction of electricity produced from Wind Energy from 500 GW in 2018 to 338 GW in 2023, it has been considered the degradation and inactivity of some wind turbine due to the age of the wind farms. The data in Table 5 shows a completely different scenario in respect of the precedent, very similar to IEA data where every source exceeded IEA's values, with positive relative errors under 5% for every source of electricity production.

[kWh]	Model		IEA (2023)		err rel
Natural Gas	$2.09*10^{10}$	96.07%	$2.02*10^{10}$	95.11%	3.47%
Solar	$5.07*10^{8}$	2.34%	$4.86*10^{8}$	2.28%	4.32%
Wind	$3.46*10^{8}$	1.59%	$3.38*10^{8}$	1.59%	2.37%

Table 5: Technology production with PROSOL and self-consumption tech (Model vs. IEA)

3.1.2. Emissions

Total emissions of Tunisia in year 2023 are 25.448 MtCO2 and electricity sector correspond to around 33.6% of total emissions, resulting in 8.551 MtCO2.

Emission quantity obtained with operation model is slightly higher compared with the real one, resulting in almost 8.616 MtCO2 giving a relative error of 0.765%. The difference between the values can also be associated to the fact that these plants are more pollutants according to the model respect to the real ones, the value used in the model is an average of power plants emissions and the different year of the IEA data respect to the model.

However, looking at the share emissions values they're quite similar, differences can be related to inaccuracies in energy production share.

	Model	IEA (2023)	err rel
Emissions [MtCO2]	8.616	8.551	0.765%

Table 6: Emissions (Model vs. IEA)

The Figure 32 below shows the disaggregated data for emissions of every Natural Gas plants operating in Tunisia at the starting year of the model.

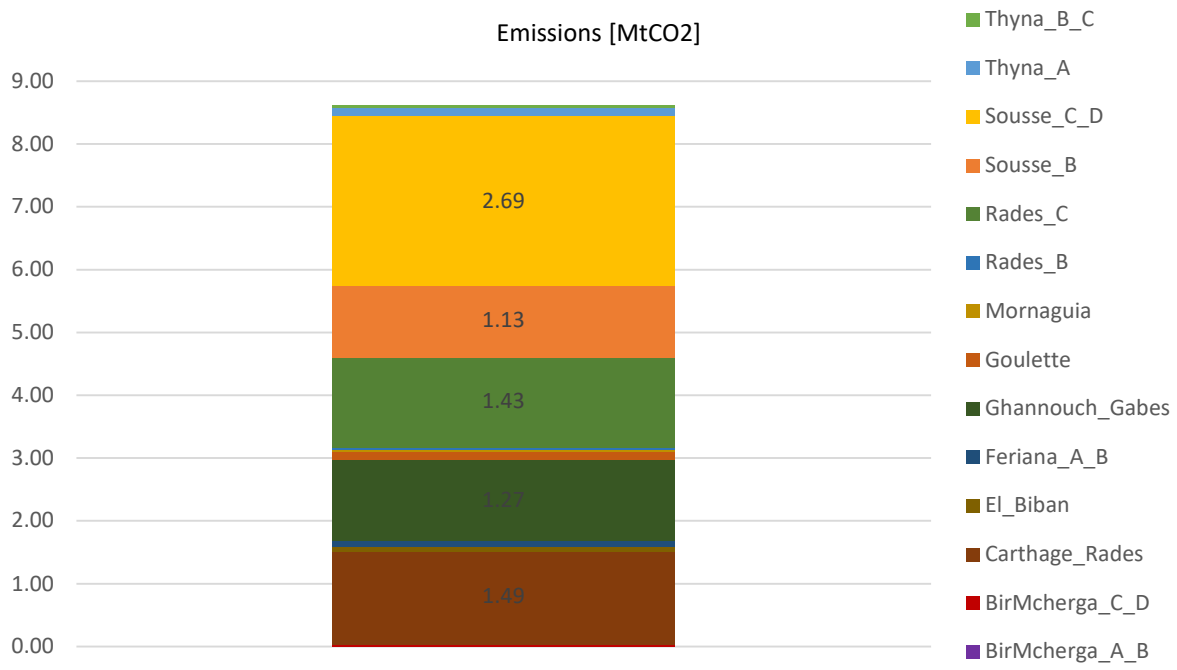


Figure 32: Emissions [MtCO2] in BaU Scenario

3.2. Planned Scenario

The first scenario assumes that by 2035, new solar and wind power plants would be installed, for a total of 6.4 GW. Prosol & Self-Consumption will increase in a linear way reaching seven time the actual value, reaching more than 1.7 GW installed in 2035. In Figure 33 is reported the Reference Energy System according to Scenario 2035. It's important to say that in the RES are reported only the power plants that will be installed in the new scenario to simplify the reading. As yet anticipated previously, not all power plants that will enter in the starting year of the model will be operative in 2035 and not considered in the Scenario 2035 only after their retirement year.

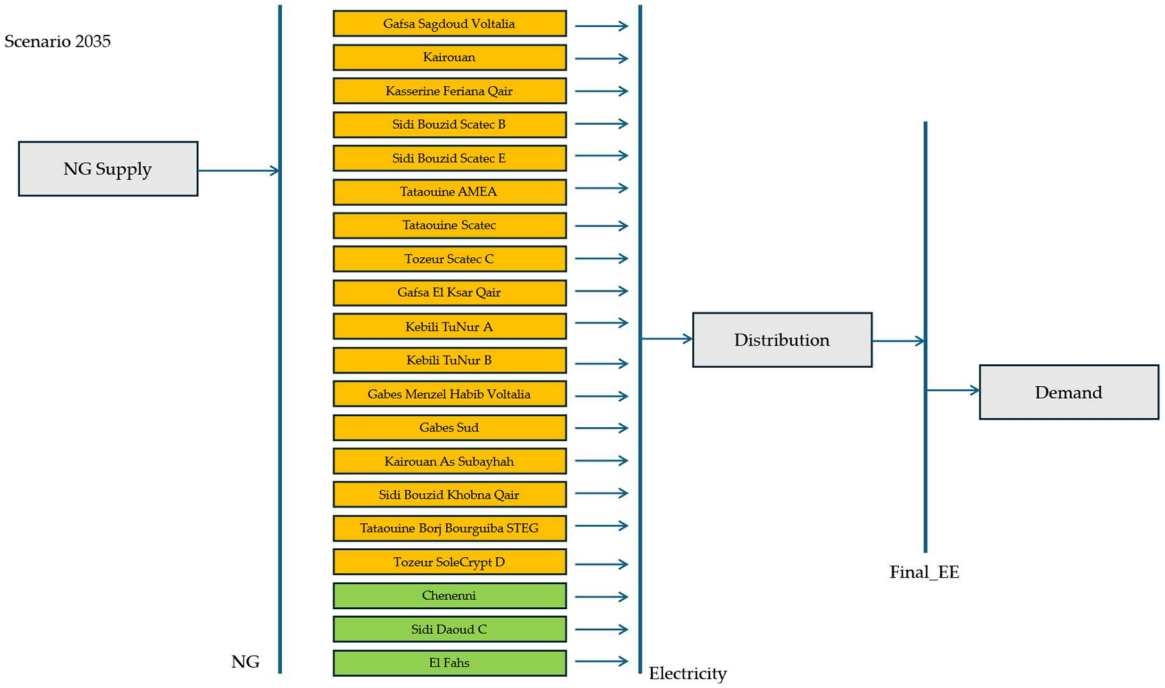


Figure 33: Scenario 2035

The country is advancing a multi-phased strategy to increase its renewable energy capacity through two major calls for tenders. Under the 2018 tender (500 MW), several projects are nearing completion: the 100 MW Kairouan plant is slated for commissioning in December 2025, followed by the 60 MW Sidi Bouzid and 60 MW Tozeur projects (the latter being complete) in early 2026 both owned by Scatec and Aeolus, and the 130 MW Gafsa project in 2027. Kairouan Solar Plant is owned by TBEA Xinjiang New Energy and AMEA Power and due to the fact that it has started its operativity in December 2025, for the purpose of this project it will be active starting from the second year of the model. [18]

Simultaneously, the 2022 tender (AO-01-2022) has successfully reached its first round, attributing three 100 MW projects to international firms—Qair International SAS in El Ksar (Gafsa), Scatec in Mezzouna (Sidi Bouzid), and Voltalia in Menzel Habib (Gabes). With project agreements for this second wave signed on March 24, 2025, these additional MW are expected to enter service by 2027, significantly expanding the national grid's solar footprint over the next two years. For simplify the model, the two solar farm in Sidi Bouzid are aggregated in one plant of total capacity of 160 MW. [18]

By 2026, the country expects several solar plants to go operative, Qair Feriana solar farm is a solar photovoltaic (PV) farm complex composed by two solar farm each of 10 MW in Feriana, half owned entirely by Qair Group and the other half owned by Qair Group and Mazarine Energy in equal shares. According to Qair Group website, they have been commissioned in 2025 and will be operative in 2026. For this project purposes they will be considered as just one plant of 20 MW. Tataouine Solar Plant is a solar photovoltaic (PV) farm in pre-construction of 200 MW in Tataouine, owned by AMEA and it's planned to be operative in 2027. In the same region, another two solar

plant are planned to be operative in 2026 and 2028 respectively, the first owned by Scatec and the second one by STEG, with a capacity of 120 MW and 200 MW respectively. TuNur solar farm is a solar photovoltaic (PV) and solar thermal farm of a total of 4.5 GW equally shared between PV and Solar Thermal under construction in El Abadla, Douz Nord, Kébili, owned by TuNur. It's planned to be operative in 2027.

There are six solar plant under construction and pre-construction, for a total capacity of 1.5 GW. In the model are considered only three of those due to availability of the starting year of construction and operation, and investment costs for a total capacity of 440 MW. These plant are Gafsa Sud of 10 MW, As-Subayhah in Kairouan governorate of 230 MW, and Khobna in Sidi Bouzid, owned by Qair Group, of 200 MW. The other three plants are in Gabes, financed by the World Bank and a complex of four power plants each of 100 MW for a total of 400 MW, in Kebili, owned by STEG of 400 MW and finally Al-Mazzunah in Sidi Bouzid of 262 MW. These project will not be considered in the model due to the lack of data regarding the real existence of these project, starting year of construction and operation and investment costs, but it will be verified if with the new total capacity installed by RES, it will reach the long-term objective of 50% production from renewable sources.

Sidi Daoud wind farm new project of 21.5 MW in the same location of the previous ones over citated and it's planned to be commissioned in 2027 and be operative in 2028. Chenenni wind farm is a wind farm of 75 MW in pre-construction in Chenenni, Tataouine, owned by Swicorp and Acciona. It's planned to be commissioned in 2027 and be operative in 2028. El Fahs wind farm is a wind farm of 75 MW in pre-construction in El Fahs, in the Zaghouan Governorate. It's planned to be commissioned in 2027 and be operative in 2028.

Wind power capacity expansions will be implemented at the Djebel Abderrahmen sites in Nabeul (increasing from 200 MW to 400 MW) and the Djebel Tbaga sites in Kébili (increasing from 100 MW to 600 MW), alongside the addition of four new sites: El Guetar in Gafsa at 200 MW, Zaghouan at 200 MW, Fériana in Kasserine at 100 MW and Beni Khedache in Medenine at 500 MW. However these projects will start at the beginning of 2026 the wind measurement campaign. The total time from starting a wind measurement campaign to the final installation of a wind farm usually takes between 4 and 9 years for onshore projects. With no further information, these projects will not be considered in the Scenario 2035, but can surely help the country reaching it 2035 objective of 50% of electricity from renewable sources. [18]

Finally, it has been made the hypothesis that PROSOL residential PV and Industrial self-consumption faced every year a linear increase from 240 MW in 2025 to 1740 MW in 2035.

Thanks to the addition of these power plants, in 2035, Tunisia will have installed 7.5 GW new solar and wind capacity plus around 1.5 GW of Residential and Self-Consumption solar PV, for a total of 9 GW installed.

For every renewable plant, it has been extracted capacity factor values from Renewable Ninja based on the location of the plants. These values were derived by calculating the mean capacity factor for every hour of the day across all dates within their respective seasonal windows (Wet and Dry).

The carriers remain the same as those listed in the RES (NG, electricity and final electricity).

In the Table 7 are reported some data regarding the new power plan projects for Tunisia in the next years.

Project	Technology	Year	Coordinates		Generation	Capacity (MW)
Gafsa Sagdoud Voltalia	PV	2026	34.4311	8.7757	Solar	130
Kairouan	PV	2026	35.8159	10.1340	Solar	120
Kasserine Feriana Qair	PV	2026	34.8891	8.5529	Solar	20
Sidi Bouzid Scatec	PV	2026	35.0394	9.4851	Solar	160
Tataouine AMEA	PV	2026	32.9211	10.4509	Solar	200
Tataouine Scatec	PV	2026	32.9211	10.4509	Solar	120
Tozeur Scatec C	PV	2026	33.9211	8.1253	Solar	60
Gafsa El Ksar Qair	PV	2027	34.39	8.8	Solar	100
Kebili TuNurA	PV	2027	33.4574	9.0253	Solar	2250
Kebili TuNurB	Solar Thermal	2027	33.4574	9.0253	Solar	2250
Gabes Menzel Habib Voltalia	PV	2028	34.2382	9.6095	Solar	139
Gabes Sud	PV	2028	35.8159	10.1340	Solar	10
Kairouan As-Subayhah	PV	2028	33.0504	10.4638	Solar	230
Sidi Bouzid Qair Khobna	PV	2028	35.0394	9.4851	Solar	200
Tataouine STEG Borj Bourguiba	PV	2028	32.9211	10.4509	Solar	200
Tozeur SoleCrypt D	PV	2028	33.9211	8.1253	Solar	60
Sidi Daoud wind C	Wind	2028	37.1946	10.0610	Wind	21.5
Chenenni wind	Wind	2027	32.9144	10.2772	Wind	75
El Fahs wind	Wind	2028	36.3742	9.90651	Wind	75

Table 7: New Projects plans for Scenario 2035

3.3. Results

The Energy System Decision Scoreboard was employed to evaluate and compare the outcomes of the Baseline and Scenario 2035 with the objective of assessing each scenario's performance across the three key dimensions of the energy trilemma: energy security, environmental sustainability, and energy access.

Criteria	Sub criteria	Indicators	Unit of measure	Baseline	Scenario 2035
Energy Security	Energy Mix	Share of FF	%	97.00%	58.36%
		Share of RES	%	3.00%	41.64%
	Reliability	Annual Unmet Demand	GWh/y	10713	5292
Energy	Climate Change	CO2/EE	kgCO2/kWh	0.502	0.290
Enviromental Sustainability	Land Use	Land Use	m2/MW	0	25000-50000
Energy Affordability	Access to Energy	EE/capita	kWh/capita/y	2096	2490
	System Productivity	EE/GDP	kWh/USD	0.44	0.43
	System Costs	fixed costs	USD/y	183 M	314 M
		variable costs	USD/y	2017 M	1455 M

Table 8: Energy System Decision Scoreboard

3.3.1. Energy Security

Under Tunisia's Business as Usual (BaU) scenario, the energy production mix remains heavily locked into natural gas—which expands its dominance from 96.38% in 2025 to 97.00% by 2035—while the renewable energy (RES) share steadily shrinks from 3.62% down to 3.00%. This contraction in green energy is directly driven by the progressive physical degradation and gradual shutdown of aging wind power plants and turbines, which are phased out of operation without sufficient new renewable installations to replace them. As these legacy wind assets lose efficiency or go offline entirely, natural gas inevitably steps in to fill the deficit trying to meet the demand, further cementing the country's fossil fuel dependency over the ten-year period.

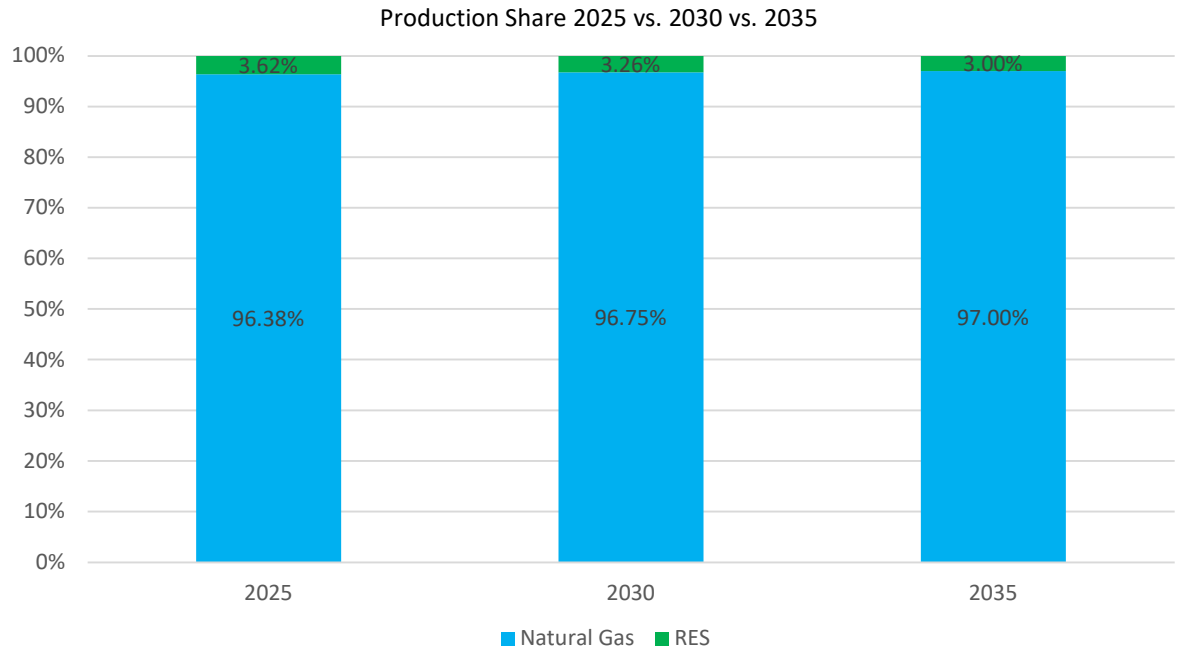


Figure 34: Production Share 2025 vs. 2030 vs. 2035 for BaU

Scenario 2035 indicates a decisive shift towards renewables, with renewables accounting for 41.72% of the supply mix in 2030 and 41.64% in 2035. The downgrade in renewable production share between 2030 and 2035 is caused by the shutdown of Sidi Bouzid Wind farm in the year 2034.

Between 2025 and 2035, Tunisia's energy sector is projected to undergo a profound structural transformation characterized by a decisive shift from traditional thermal gas power to large-scale renewable energy. The most significant trend is the phased retirement of major natural gas plants like Carthage Rades, while production is consolidated into newer, more efficient gas facilities such as Mornaguia, which surges from 0.61% in 2025 to nearly 8% in 2035. Simultaneously, the country will experience a "solar explosion" led by mega-projects like TuNur solar plants in Kebili and a massive rise in decentralized Self-Consumption and Industrial solar PVs, which collectively transition from near-zero levels in 2025 to becoming the primary drivers of the national grid by 2035. While wind power remains a stable secondary contributor, the overarching trend is a strategic replacement of aging fossil fuel infrastructure with a diverse mix of utility-scale solar farms and regional renewable clusters, fundamentally diversifying Tunisia's energy portfolio over the decade.

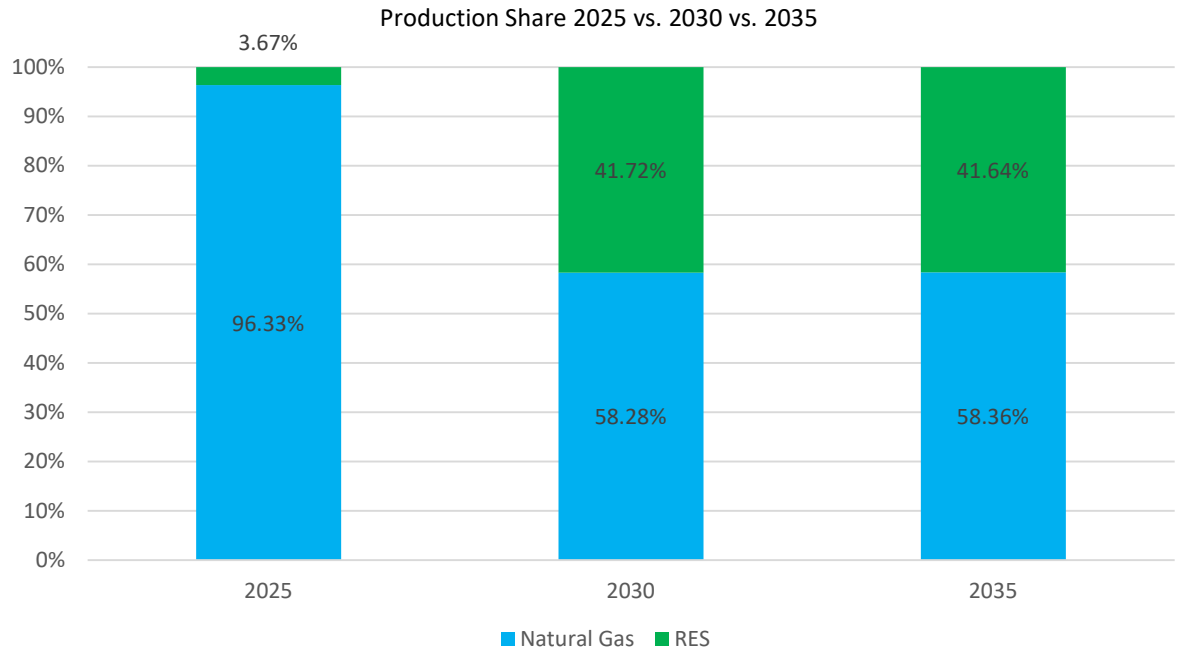


Figure 35: Production Share 2025 vs. 2030 vs. 2035 for Scenario 2035

However, Scenario 2035 doesn't succeed in eliminating unmet demand, representing an improvement in the reliability of the energy system compared to the baseline scenario passing from 10,713 GWh/y to 5,292 GWh/y, but this means that Tunisia needs to continue in promoting the installation of new capacity to replace old plants and the retired ones with newer ones more efficient and also to reduce dependences from energy imports, which is a big part of the Total Electricity Final Consumption (13.4% in 2023).

If it will be considered also World Bank solar plant in Gabes, Kebili STEG solar plant and Al Mazzunah solar plant in Sidi Bouzid, the total electricity production from RES even if it faced an increase to 45.68% and reduction of unmet demand but not eliminating it, it's still less than the long-term objective of 50%.

3.3.2. Energy Environmental Sustainability

Scenario 2035 substantially reduces carbon intensity and significantly improves climate performance, largely due to the increased integration of and solar energy in the mix.

Under the BaU scenario from 2025 to 2035, Tunisia's greenhouse gas emissions showed in Figure 36 exhibit a steady upward trajectory for the majority of the decade before experiencing a minor decline towards the end of the period. Total emissions start at approximately 10 MtCO2 in 2025 and climb consistently year-over-year, driven by sustained heavy contributions from sites like Sousse and the emergence of Mornaguia around 2027, which quickly compensates for the rapid phase-out of Carthage Rades plant after 2026. This upward climb culminates in a peak of 14 MtCO2 in 2033. Following this peak, the trend reverses slightly during the final two years due to the retirement of Bir Mcherga A&B, Carthage Rades, El Biban, Rades B, Sousse B and Thyna A, with overall emissions dipping down to around 13 MtCO2 by 2035, yet still concluding the observed period significantly higher than the 2025 baseline.

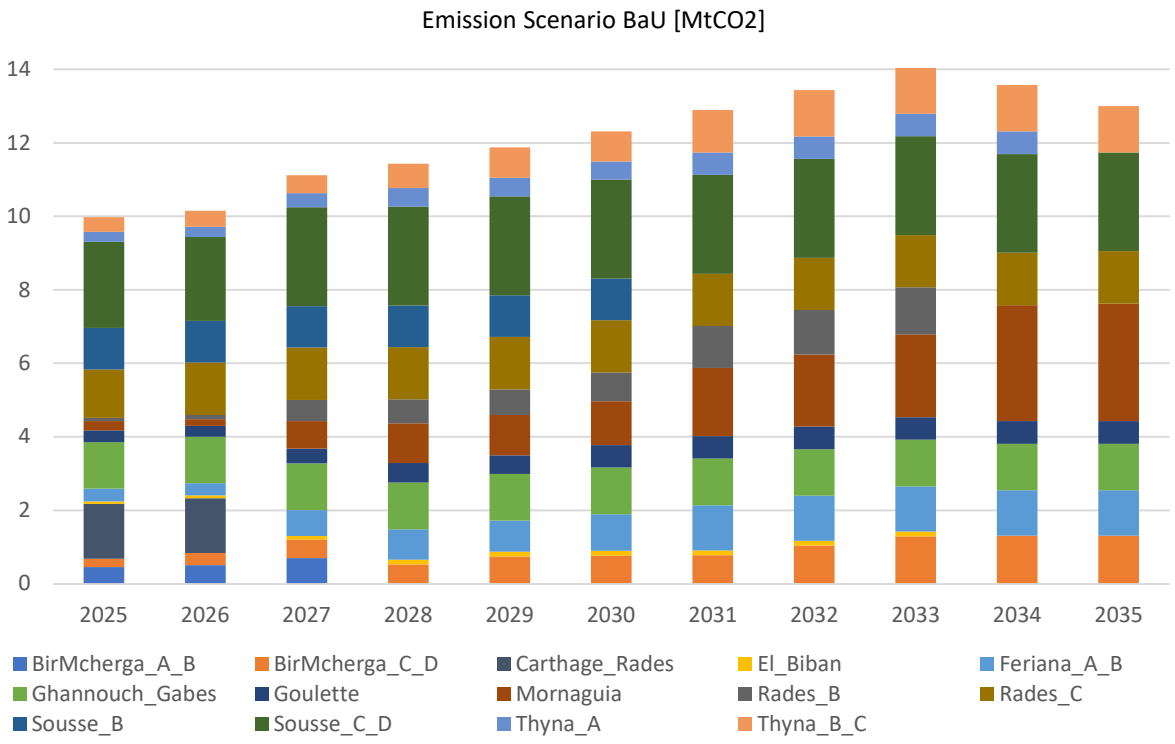


Figure 36: Emissions Scenario BaU [MtCO2]

To eliminate completely the unmet demand, Tunisia, starting from the fourth year, must install new capacity for a total of 3.5 GW in 2035, increasing a lot the emissions.

Total greenhouse gas emissions exhibit a continuous and accelerating upward trend, expanding from 10 $MtCO_2$ in 2025 to over 20 $MtCO_2$ by 2035. This doubling of carbon output is primarily driven by the massive scaling up of specific power generation facilities which reduce the Energy Environmental Sustainability.

Most notably, emissions from Feriana A&B power plant, which in this scenario is free to install new capacity to verify how much capacity is needed to cover the unmet demand, explode in the latter half of the decade—becoming the dominant source of emissions by 2035—while contributions from Sousse C&D and Mornaguia also maintain a heavy, consistent presence throughout the period. Conversely, older or less utilized sources like Carthage Rades phase out early on, and several other stations (such as Ghannouch Gabes and Rades C) maintain relatively stable, minor footprints, illustrating that the race to meet unmet demand under a BaU framework relies heavily on intensifying a few massive, carbon-intensive energy assets.

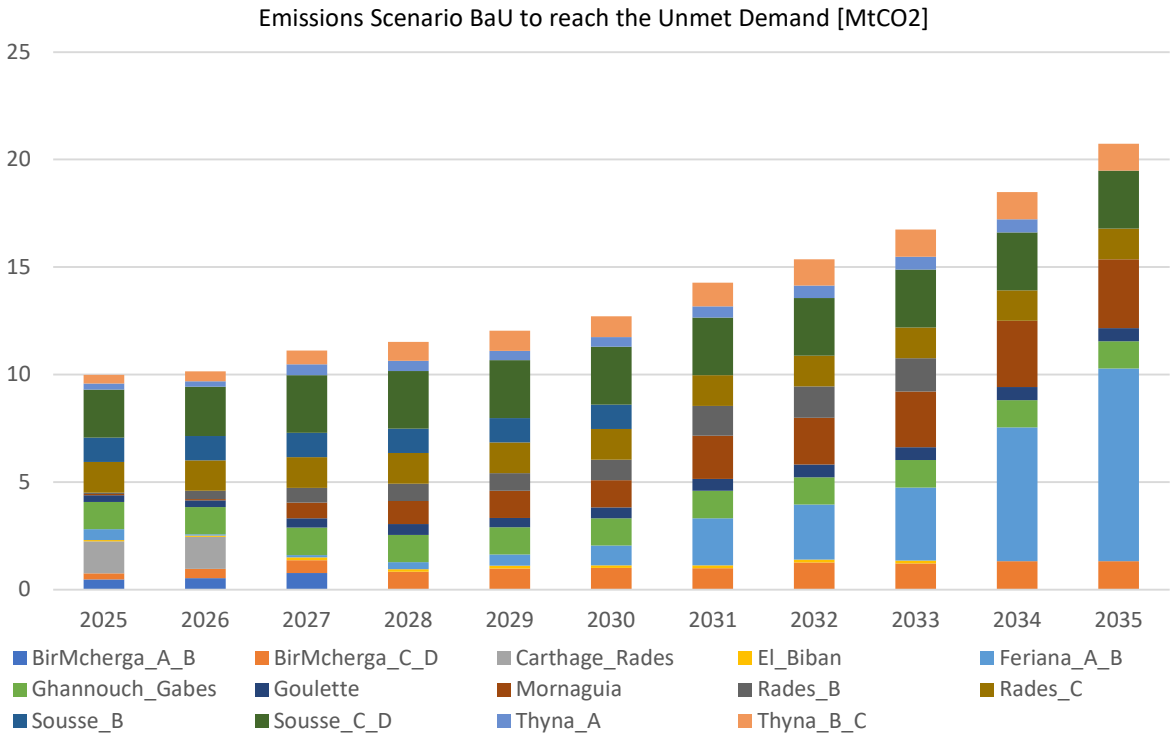


Figure 37: Emissions Scenario BaU to reach the Unmet Demand [MtCO2]

Tunisia's total emissions in Scenario 2035 showed in Figure 38 faced a sharp initial decline followed by a gradual, long-term recovery. Total emissions start at approximately 10 MtCO2 in 2025, dip slightly in 2026, and then plunge to a low of about 6.6 MtCO2 in 2027, a benchmark that holds steady into 2028. This dramatic drop is primarily driven by the rapid phase-out of the Carthage Rades facility and the retirement of Bir Mcherga A&B and huge installation of new capacity from renewable sources. However, from 2029 onward, the trend reverses into a steady, year-over-year increase driven by the introduction and growth of the Mornaguia plant alongside consistently high contributions from Sousse C&D. This gradual upward trajectory

continues through the end of the decade, ultimately bringing total emissions up to roughly 9.3 MtCO2 by 2035—marking a clear rebound from the 2027 trough, yet successfully keeping overall emissions just below the original 2025 baseline, with a negative relative error between 2025 and 2035 total emissions of 7.1%.

This scenario shows how the country's objective of reducing emission by 2030 of 38% is reached, obtaining a total reduction of 40% from BaU Scenario.

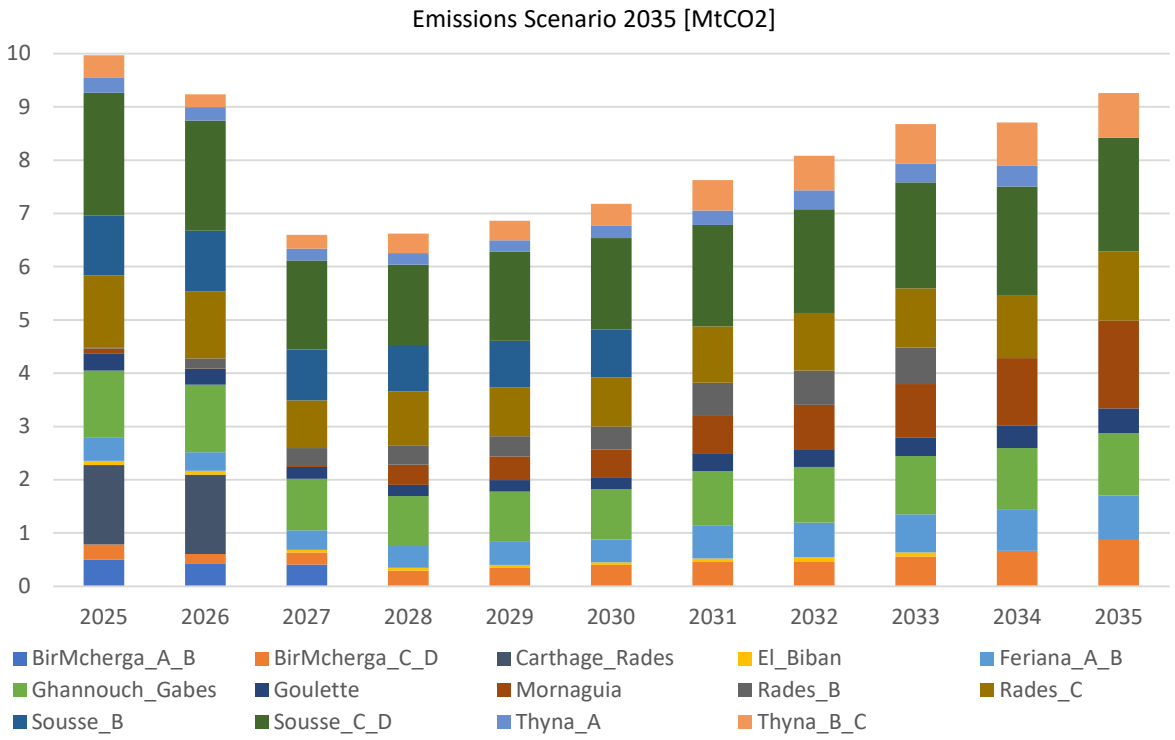


Figure 38: Emissions Scenario 2035 [MtCO2]

However, because Scenario 2035 doesn't eliminate completely the unmet demand, it has been made an analysis similar to BaU Scenario to eliminate it. Both scenarios kick off at an identical 10.0 $MtCO_2$ in 2025 and follow a parallel downward path to a local minimum in 2027 (~6.2 $MtCO_2$ in the unmet demand scenario vs. ~6.6 $MtCO_2$ in the standard scenario), their trajectories drastically diverge over the subsequent decade. In the standard scenario displayed in Figure 38, total emissions recover moderately to cap out at 9.25 $MtCO_2$ by 2035. Conversely, the unmet demand scenario illustrated in experiences an aggressive escalation, culminating in a peak of 13.0 $MtCO_2$ in 2035. The fundamental structural driver of this 3.75 $MtCO_2$ difference is the Feriana A&B power plant, which in this scenario is free to install new capacity to verify how much capacity is needed to cover the unmet demand.

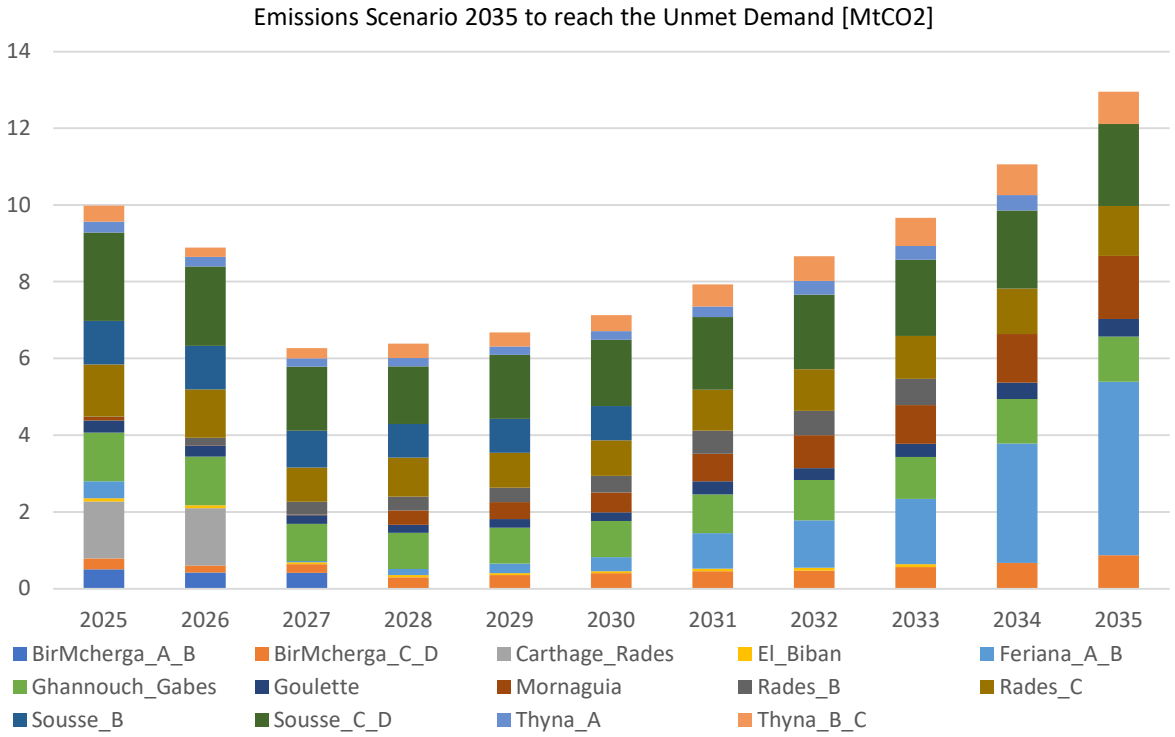


Figure 39: Emissions Scenario 2035 to reach the Unmet Demand [MtCO2]

Another way to eliminate unmet demand in the Scenario 2035 is to install only energy from renewable sources. The capacity to install in a ten year span is 20.5 GW of which 16 GW are from Wind, reducing almost completely the emissions. Obviously, this would require a huge investment and a significant increase in variable costs, but at the same time would reduce considerably the natural gas supply costs.

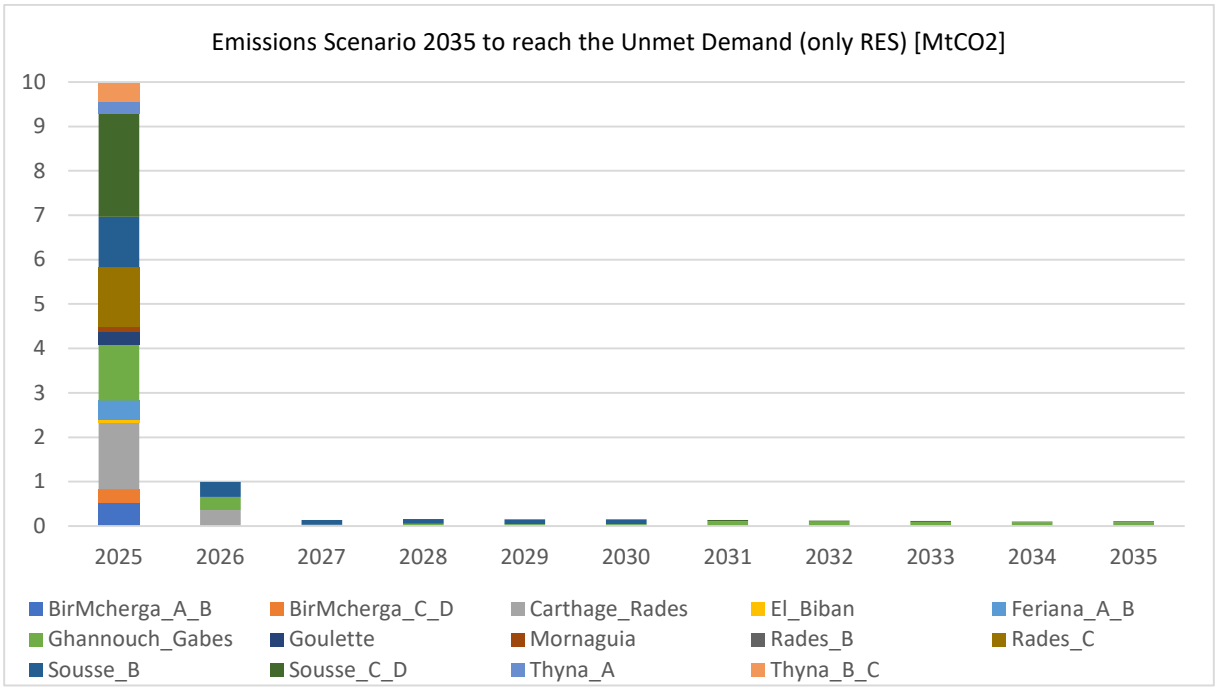


Figure 40: Emissions Scenario 2035 to reach the Unmet Demand (only RES) [MtCO2]

3.3.3. Energy Affordability

In the BaU scenario represented in Figure 41 for Tunisia between 2025 and 2035, fixed costs remain virtually stagnant with a minor decline from approximately 0.22 B$ to just under 0.20 B$, consisting entirely of plant expenses, because a complete lack of new capital investments means no new infrastructure or capacity is being added to the system. In contrast, variable costs—which are heavily dominated by the Natural Gas Supply—exhibit a steady upward trend from around 1.54 B$ in 2025 to a peak of nearly 2.18 B$ in 2033, followed by a slight contraction to 2.01 B$ by 2035 due to the retirement of some plants. This overall escalation in variable expenses occurs because, without strategic investments into cleaner alternative energy sources or efficiency upgrades, the existing infrastructure is forced to burn increasingly higher volumes of expensive natural gas to keep up with growing baseline demand, creating a heavy financial reliance on fuel supply.

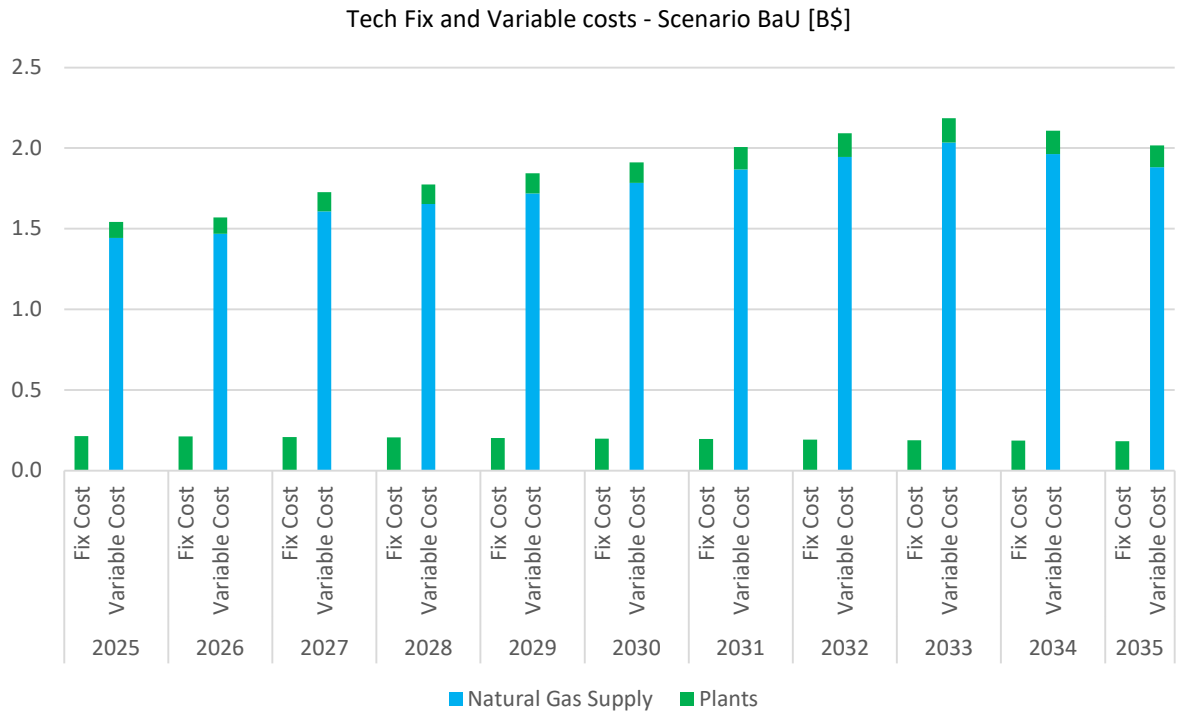


Figure 41: Tech Fix and Variable costs - Scenario BaU [B$]

Figure 42 highlights the Scenario BaU to reach unmet demand, where total tech costs escalate significantly from around $1.75 billion in 2025 to over $3.3 billion by 2035. This steady climb is entirely driven by a massive surge in Variable Costs—specifically Natural Gas Supply, which skyrockets from roughly $1.45 billion to a peak of $3.0 billion—while Fix Costs remain consistently low and flat across the decade at around $0.2 billion. When confronted with the baseline Scenario BaU in Figure 41, which represents the model with unmet demand, the core divergence becomes clear: while both scenarios share identical, flat fixed costs, the baseline BaU scenario peaks at roughly $2.2 billion in 2033 before dipping down to $2.0 billion by 2035. This reveals

that eliminating unmet demand requires a massive, unmitigated acceleration in natural gas consumption after 2030, widening the spending gap between the two scenarios to over $1.1 billion annually by 2035.

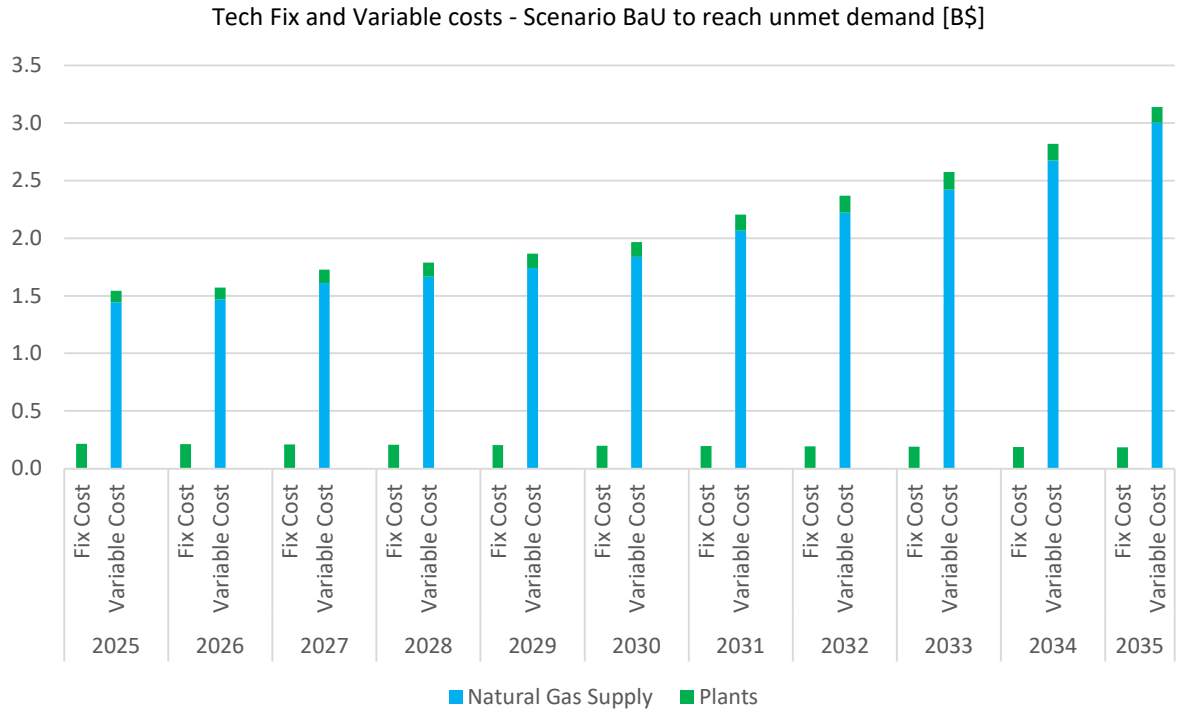


Figure 42: Tech Fix and Variable costs - Scenario BaU to reach unmet demand [B$]

In the Scenario 2035 represented in Figure 43, fixed costs start similar the BaU baseline at approximately 0.21 B$ in 2025 and after a rapid increase to 0.35 B$, they undergo a gradual, minor decline down to 0.31 B$ by 2035, a trend driven by the upfront capital and fixed operation costs associated with newly introduced energy assets and plant modernizations. In contrast, variable costs decrease drastically from 1.54 B$ in 2025 to a low of 1.04 B$ in 2028, before steadily climbing back up to 1.45 B$ by 2035. This dynamic occurs because the initial investments successfully substitute and displace a massive chunk of expensive Natural Gas Supply in the medium term; however, as overall national energy demand inevitably scales up after 2028, the system is forced to progressively ramp gas consumption back up to cover the widening demand gap. When confronted with the BaU scenario, Scenario 2035 represents a classic strategic trade-off: it absorbs higher fixed asset costs to unlock massive macroeconomic savings on fuel, capping the maximum variable cost at just 1.45 B$ in 2035, which safely undercuts the BaU scenario's unmitigated, gas-driven variable cost peak of nearly 2.18 B$.

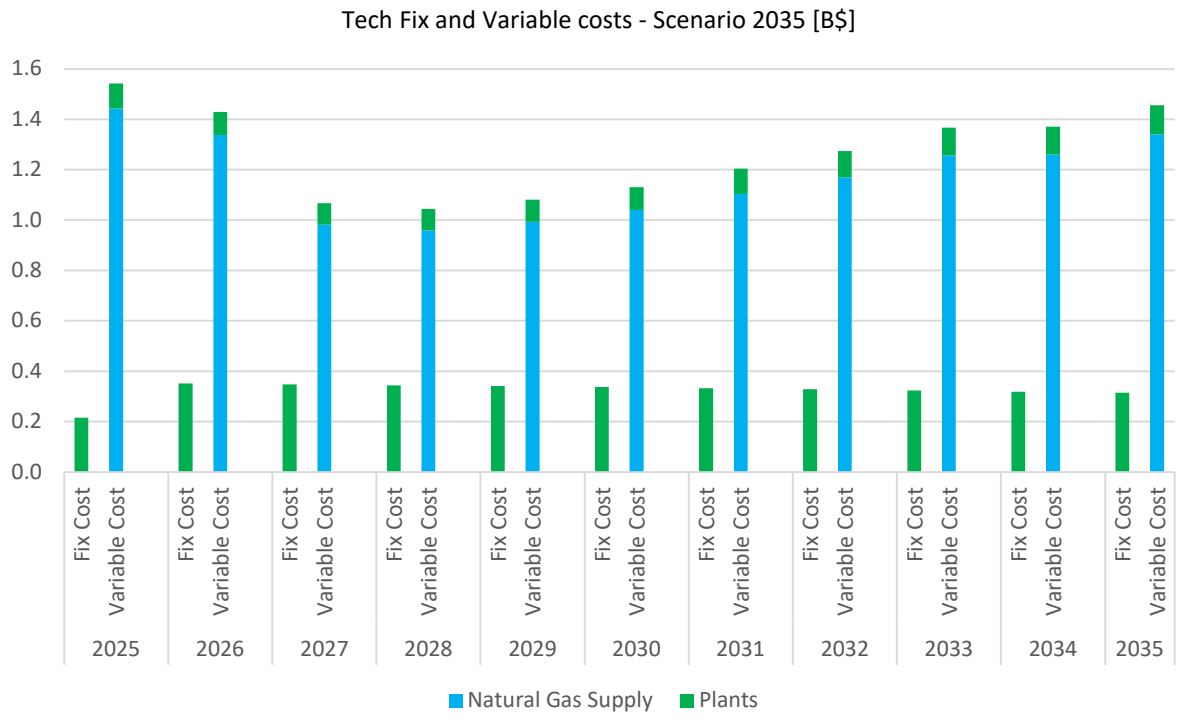


Figure 43: Tech Fix and Variable costs - Scenario 2035 [B$]

In the Scenario 2035 to reach unmet demand, tech expenditures follow a distinct U-shaped trajectory where standalone Fix Costs remain highly stable at approximately $0.35 billion from 2026 onward, while Variable Costs drop from an initial $1.55 billion in 2025 to a low of ~$1.05 billion in 2028 before embarking on a sharp, continuous climb up to a peak of $2.12 billion by 2035. This late-period escalation is overwhelmingly driven by Natural Gas Supply costs, which alone reach $2.0 billion by the final year. When confronted with the baseline Scenario 2035 with unmet demand, the Fix Costs profiles remain completely identical across both charts, but a massive divergence occurs in the Variable Costs after 2032.

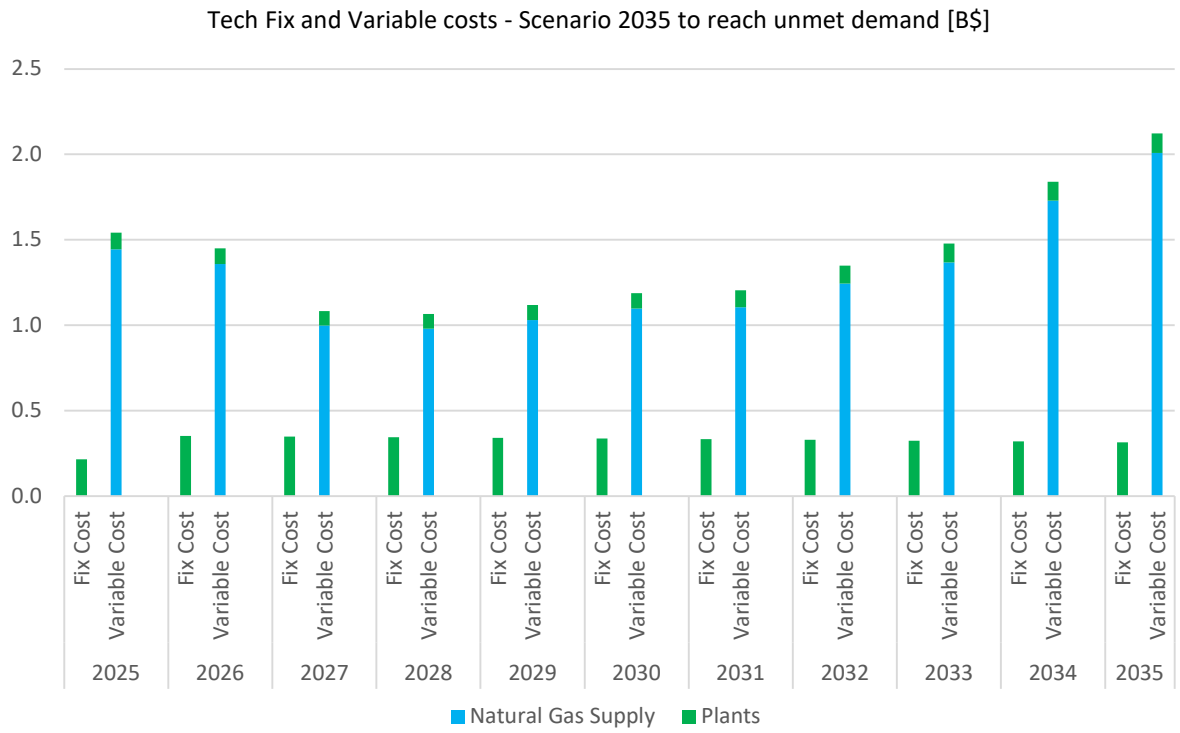


Figure 44: Tech Fix and Variable costs - Scenario 2035 to reach unmet demand [B$]

As previously introduced, to reach unmet demand with only RES it's needed a huge increase of variable costs but at the same time, this is compensated but a significant decrease of natural gas costs.

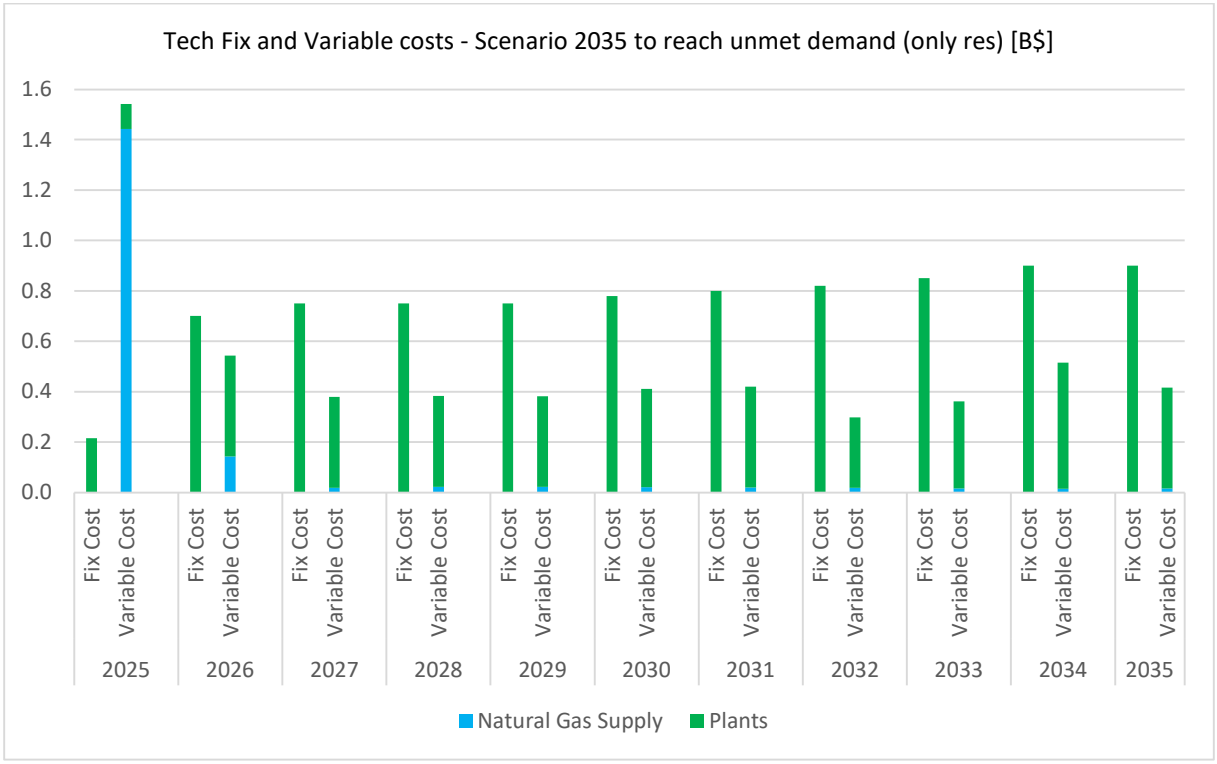


Figure 45: Tech Fix and Variable costs - Scenario 2035 to reach unmet demand (only RES) [B$]

4 Impact Evaluation

The primary objective of this project is to evaluate the impact that can have the National Ecological Transition Strategy on the 17 SDGs of the Agenda 2030 in a 10 years span, from 2025 to 2035.

The Evaluation Hierarchy represents the skeleton of the Impact Evaluation Framework (IEF), namely a multi-dimensional, people-oriented and context-specific structure. IEF allows to evaluate the long-term project impact as changes (positive or negative) of the five Pillars of Agenda 2030: People, Prosperity, Planet, Peace, Partnership reported the Figure 46. Pillars are broken down into the SDGs, which represent the second level of the hierarchy. Pillars and SDGs represent only the first two levels of the hierarchy: an appropriate set of indicators within each SDG should be defined through a participatory process, accordingly to the relevant context factors, available data and projects' features. In these terms, while the Evaluation Hierarchy is designed with a top-down approach, its customization follows a bottom-up path, since users can adapt the general structure to their own case in a participatory way by defining the project-specific indicators.

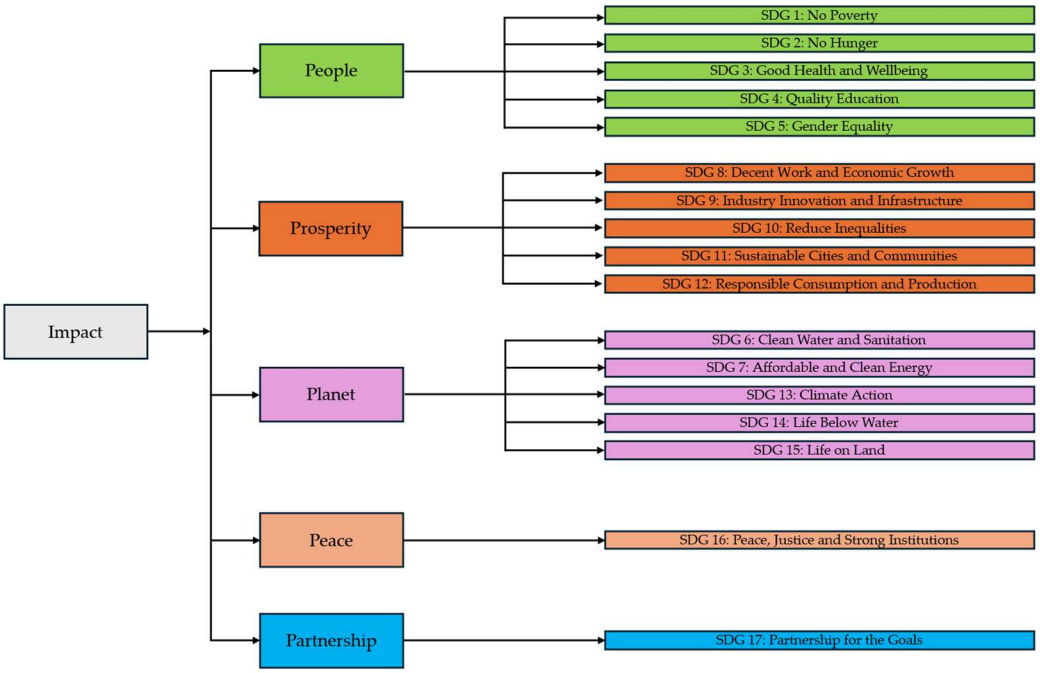


Figure 46: Evaluation Hierarchy

4.1. Indicators

Under SDG 2 and SDG 3, traditional vulnerabilities like undernourishment (3.2% in 2022), child stunting (8.4%), child wasting (2.1%), maternal mortality (35.7 per 100,000), and under-five mortality (12.9 per 1,000) are relatively low and on track for Agenda 2030 targets; however, domestic progress is heavily undermined by chronic, non-communicable challenges, including a 26.83% adult obesity rate, a 13.0% premature NCD death rate, high pollution-related mortality (56.0 per 100,000), traffic fatalities, and a low subjective well-being score of 4.6 out of 10.

This internal strain extends directly into the economic and urban spheres; while manufacturing remains an economic cornerstone accounting for 23.3% of GDP and employing 34% of the workforce under SDG 9, a tight fiscal environment with public debt near 83% of GDP restricts public investments into high-tech Research and Development (R&D), trapping industrial output in low-to-medium-value assembly lines.

Consequently, the nation's 70% urbanized population faces escalating utility and consumption strains across SDGs 11 and 12. Access to improved water source is achieved but still there is urban population living in slums (7.64%). Also it’s characterized by a near-collapse of solid waste management, significant levels of unrecycled electronic waste (6.9 kg per capita), severe air pollution in industrial hubs like Greater Tunis, Sfax, and Gabès, and market-distorting fossil fuel subsidies that delay a transition to a circular economy.

Most critically, these vulnerabilities are magnified by a profound, climate-driven resource emergency spanning SDGs 6, 14, and 15; despite a deceptive 98% basic water access rate, Tunisia's freshwater withdrawals exceed 130% of natural availability and aquifers suffer from a 140% overexploitation rate. This water crisis, worsened by consecutive years of severe drought and tracking inefficiencies in nitrogen management, directly threatens long-term agricultural stability, drives rampant land degradation, and destabilizes marine and terrestrial ecosystems already suffering from overfished stocks (22%), severe coastal erosion (71%) of the shoreline, and structural gaps that leave more than 60% of key biodiversity sites completely unprotected.

By projecting Tunisia's development trajectory from today to 2035, the systematic implementation of the National Ecological Transition Strategy (SNTE) offers a comprehensive operational framework to reverse stagnation and drive significant improvements across the first five Sustainable Development Goals (SDGs). This economic restructuring directly reinforces SDG 2; by focusing heavily on green growth that is resilient to climate change, risks, and crises, and by prioritizing the preservation of the country's natural capital and ecosystems, the strategy directly mitigates the agricultural vulnerabilities, soil degradation, and water scarcity that threaten food security. SDG 3 will see a direct and measurable improvement over the next decade through aggressive pollution-mitigation policies, most notably Measure 42, which

outlines a definitive roadmap for the decontamination and environmental reconversion of heavily polluted industrial hot spots—including Gabès, Gafsa, Kasserine, Sfax, Ben Arous, and Hammam-Lif—thereby directly lowering the incidence of pollution-related illnesses and improving community health indicators.

Currently, the IMF World Economic Outlook projects a modest GDP growth rate of 2.1% for 2026, which is forecast to slow down further due to a high vulnerability to global energy price shocks and constrained fiscal buffers. Measures 48 and 49 (introducing certified green job training) and Measure 39 (establishing a dedicated investment support unit for the ecological transition) can directly revitalize the sluggish labor market, transforming the IMF's subdued growth outlook into high-value employment and driving SDG 9 forward by building a climate-resilient economy decoupled from volatile fossil fuels. Furthermore, the targeted execution of Measure 43's National Action Plan for Sustainable Consumption and Production will directly reverse the negative environmental impacts holding back SDG 12, while Measure 44's national program for eco-friendly buildings will modernize municipal infrastructure to address the urban inefficiencies dragging down SDG 11. Ultimately, if these green initiatives are fully funded and integrated over the next decade, they will not only shield Tunisia against external energy shocks but also distribute green economic opportunities across underdeveloped regions to mitigate the inequalities of SDG 10, turning today's stagnating indicators into a story of successful sustainable transformation by 2035.

The ongoing degradation affecting SDG 14 along the industrial coastline can be systematically reversed over the next decade through Measure 42 directly reducing toxic marine discharges and protecting marine biodiversity. Finally, the negative trajectories threatening SDG 15 due to rapid soil degradation and habitat loss can be actively corrected by 2035 through the combined execution of Measure 24 (National Biodiversity Protection Strategy), Measure 26 (National Plan to Combat Desertification), and Measure 29 (Sustainable Development Action Plan for Oases), ensuring that Tunisia's fragile terrestrial ecosystems, soils, and vital oasis biomes are ecologically restored and legally shielded against climate degradation.

Currently, latest dashboard trends indicate that Tunisia faces significant challenges under SDG 16, characterized by administrative fragmentation and regulatory gaps, alongside a strained resource ecosystem under SDG 17, driven by a widening climate-finance deficit and constrained global mobilization. However, looking toward 2035, the situation regarding SDG 16 is poised for substantial improvement through Axis 1 (Governance and Financing) policy actions: Measure 2 establishes a centralized High Authority for Ecological Transition (HAET) under the Presidency of Government to eliminate bureaucratic silos, while Measure 8 sets up the Economic, Social, and Environmental Council (ESEC) to promote inclusive, transparent civic dialogue and robust multi-stakeholder accountability. This institutional transformation is legally fortified by Measure 3's long-awaited adoption of a comprehensive Environmental

Code and Measure 4's sweeping restructuring of specialized organizations, which together will strengthen the rule of law, counter administrative corruption, and stabilize domestic indicators. Simultaneously, Tunisia's capacity to satisfy SDG 17 targets can drastically improve over the next decade by operationalizing Measure 9, which creates the Joint Ecological and Energy Transition Fund (FOCTEE) as yet mentioned, to aggressively aggregate international green grants, domestic public funding, and private investments. When backed by Measure 34's mandatory application of Corporate Social and Environmental Responsibility (CSR) laws, Measure 39's dedicated assistance unit for green investors, and the high-level digital data tracking mandated by attaching the Tunisian Observatory for the Environment and Sustainable Development (TOESD) directly to the executive branch via Measures 1 and 5, Tunisia will possess the unified institutional transparency and innovative funding pipelines necessary to turn its current partnership constraints into a highly credible, well-financed sustainable economy by 2035.

To determine the results of the Impact Evaluation for every set of indicators chosen for every SGDs, it has been indicated if the indicator is considered "benefit" of "damage" in the analysis and it has been assigned a value between 0 and 4. In the next paragraph it is described how the values have been assigned in the framework.

According to the SDR, if the indicator at the starting point of the analysis in 2025 has achieved its objective of the Agenda 2030, it has been assigned a value of 4 out 4 in the case of "benefit" indicator. On the contrary, if the indicator is considered "damage", it has been assigned a value of 0 out 4.

If the indicator is performing well according to the latest data, its recent trend is decreasing constantly with the results of achieving its long-term objective but not yet achieved, it has been assigned a value of 3 out 4 in the case of "benefit" indicator. For the ex-post value in 2035 for the purpose of the analysis it has been assigned a value of 4, meaning that the objective of the indicator will be achieved at the end of this analysis. On the contrary, if the indicator is considered "damage", it has been assigned a value of 1 out 4.

If the indicator is mostly stagnating in the 21st century but showing a slight improvements according to the latest data changing its trend in the last years but not enough to achieve its long-term objective, it has been assigned a value of 2 out 4 in the case of "benefit" indicator. On the contrary, if the indicator is considered "damage", it has been assigned a value of 2 out 4.

If the indicator is stagnating along all the 21st century not showing any kind of improvements according to the latest data, it has been assigned a value of 1 out 4 in the case of "benefit" indicator. On the contrary, if the indicator is mostly stagnating in the 21st century, showing a very low improvement in the recent trend reducing the gap but not enough to achieve the long-term objective, it has been assigned a value of 3 out 4 for the "damage" indicator.

If the indicator's trend is increasing/decreasing against its long-term objective, not showing any kind of changing trend, it has been assigned a value of 0 out 4 in the case of "benefit" indicator. On the contrary, if the indicator is stagnating in the 21st century, not showing any kind of improvement in the recent trend, and if goes on with the latest trend with the result cannot achieve its objective, it has been assigned a value of 4 out 4 for the "damage" indicator.

Pillars	SDGs	Indicators	Type of Indicator	Ex-ante Value	Ex-post Value	Effect
PEOPLE	SDG1 – No poverty	Poverty headcount ratio at $3.00 per person per day at 2021 PPP (% total population)	benefit	4	4	Neutral
		MPI	benefit	4	4	Neutral
	SDG2 – Zero hunger (& sustainable agriculture)	Prevalence of undernourishment & of stunting and wasting in children under 5 years of age (% total population)	benefit	3	4	Slightly Positive
		Prevalence of obesity, BMI≥ 30 (% of adult population), Human Trophic Level, Cereal yield (tonnes per hectare of harvested land) & Sustainable Nitrogen Management Index	damage	3	1	Positive
	SDG3 – Good Health and wellbeing	Mortality rate (Maternal per 100,000 live births, Neonatal & Under-5 per 1,000 live births), Life Expectancy at birth & Adolescent Fertility rate	damage	1	0	Slightly Positive
		NCDs	damage	1	0	Slightly Positive
	SDG4 – Quality education	Net primary enrollment rate & Literacy rate (% of population aged 15 to 24)	benefit	3	4	Slightly Positive
		Lower secondary & Tertiary completion and enrollment rate	damage	2	0	Positive
	SDG5 – Gender equality	Ratio of female-to-male mean years of education received & labor force participation rate (% total population)	benefit	3	4	Slightly Positive
		Seats held by women in national parliament (%)	damage	4	2	Positive
PROSPERITY	SDG8 – Decent work and economic growth	Annual GDP & GDP per capita growth (US$)	benefit	3	4	Slightly Positive
		Unemployment rate (% of total labor force, ages 15+) & Fundamental labor rights are effectively guaranteed	damage	4	2	Positive
	SDG9 – Industry innovation and infrastructure	Manufacturing, value added (annual % growth & % GDP) & population access (internet, roads)	benefit	3	4	Slightly Positive
		Carbon intensity of manufacturing	damage	3	1	Positive
	SDG10 – Reduced inequalities	Palma ratio	benefit	2	3	Slightly Positive
		GINI coefficient	damage	2	1	Slightly Positive
	SDG11 – Sustainable cities and communities	Access to improved water source, piped (% of urban population)	benefit	4	4	Neutral
		Proportion of urban population living in slums & Annual mean concentration of PM2.5 (μg/m³)	damage	2	1	Slightly Positive
	SDG12 – Responsible consumption and production	Production-based air pollution & Air pollution associated with imports (DALYs per 1,000 population)	damage	1	0	Slightly Positive
		Production-based nitrogen emissions, Nitrogen emissions associated with imports & Exports of plastic waste (kg/capita)	damage	1	0	Slightly Positive
PLANET	SDG6 – Clean water and sanitation	Population using at least basic drinking water & sanitation services	benefit	4	4	Neutral
		Freshwater withdrawal (% of available freshwater resources) & Scarce water consumption embodied in imports (m^3 H_2Oeq/capita)	damage	2	0	Positive
	SDG7 – Affordable and clean energy	Population with access to electricity & clean fuels and technology for cooking (% total population)	benefit	4	4	Neutral
		Renewable energy share in total final energy consumption & CO_2 emissions from fuel combustion per total electricity output (Energy Intensity) (MtCO2/TWh)	damage	4	1	Highly Positive
	SDG13 – Climate action	Climate Disaster Resilience Index	benefit	3	4	Slightly Positive

		GHG emissions embodied in imports and exports & CO_2 emissions from fossil fuel combustion and cement production (tCO_2/capita)	damage	1	0	Slightly Positive
	SDG14 – Life below water	Fish caught	benefit	2	3	Slightly Positive
		Mean area that is protected in marine sites important to biodiversity (m2), Ocean Health Index (%)	damage	2	1	Slightly Positive
	SDG15 – Life on land	Deforestation (permanent and imported) (% of forest area and m²/capita) & Red List Index of species survival (0-1)	benefit	2	3	Slightly Positive
		Mean area that is protected in terrestrial (m2) & freshwater sites important to biodiversity	damage	2	1	Slightly Positive
PEACE	**SDG16 – Peace, justice and strong institutions**	Governance and Financing policy actions: HAET, ESEC and Environmental Code	benefit	3	4	Slightly Positive
		Homicides (per 100,000 population), Corruption Perceptions Index, Proportion of youngster victims of abuse and/or violence & Unsentenced detainees (% prison population)	damage	2	0	Positive
PARTNERSHIP	**SDG17 – Partnership for the goals**	Government spending on health and education (% of GDP)	benefit	3	4	Slightly Positive
		FOCTEE, CSR and TOESD implementation	benefit	3	4	Slightly Positive

Figure 47: Impact Evaluation Framework

4.2. Results

The radar diagram in Figure 48 illustrates illustrate a widespread, outward expansion of development metrics for Tunisia from the ex-ante baseline (2025) to the ex-post projections (2035) across both macro-pillars and individual Sustainable Development Goals (SDGs). In the Radar Diagram of Pillars, all five core dimensions—People, Prosperity, Planet, Peace, and Partnership—experience substantial growth. The ex-ante values for 2025 are extracted from the Sustainable Development Report (SDR) for Tunisia —reflecting the country's baseline metrics, such as its overall country score of 72.0., against a regional average value of 65.6, and its performance across various SDG dashboards. In the model the ex-ante value is 64.1, lower in respect to SDR, due to approximation and conservative approach in assigning for each indicator a weight between 0 and 4, as mentioned in the previous chapter.

In contrast, the ex-post values demonstrate a substantial and uniform advancement across all five dimensions, with scores expanding significantly outward toward the maximum target rating of 1.0. This distinct visual shift highlights a trajectory of major improvement from the initial data recorded in the Tunisian national report to a highly optimized level of achievement across every sustainable development pillar.

The results obtained from the IEF show a qualitative approach along all the 17 SDGs with the only exception of the SDG 7 (Affordable and Clean Energy) where it has been performed a quantitative analysis using an energy model to determine if Tunisia will be able to reach its RES objective, as explained in the previous chapter 3.

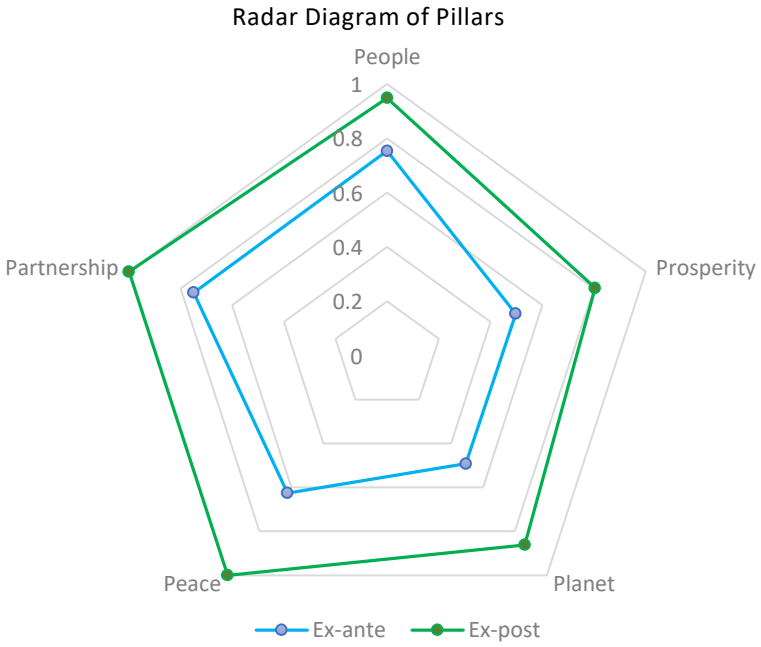


Figure 48: Radar Diagram of Pillars

The radar diagram in Figure 49 illustrates a transformative shift for Tunisia across all measured Sustainable Development Goals (SDGs), contrasting the current baseline (Ex-ante, represented by the blue line) with the projected outcomes following the implementation of the SNTE actions (Ex-post, represented by the green line). Currently, Tunisia exhibits a highly uneven developmental profile; while it achieves a perfect score in No Poverty (SDG1) and maintains solid baselines in Quality Education (SDG4) and Partnerships (SDG17), it severely lags behind with low scores between 0.2 and 0.4 in critical areas such as Gender Equality (SDG5), Affordable and Clean Energy (SDG7), Decent Work (SDG8), and Climate Action (SDG13). Following the SNTE implementation, the country experiences a massive, comprehensive expansion across nearly every single metric, indicating widespread progress. Notably, Climate Action (SDG13) rise near the maximum, while Responsible Consumption (SDG12), Quality Education (SDG4), Peace, Justice and Strong Institutions (SDG16), and Partnerships (SDG17) expand to near-maximum capacity. Even previously stagnant areas like clean energy, gender equity, and economic growth see their values double or significantly improve, reflecting a far more balanced, sustainable, and resilient national framework.

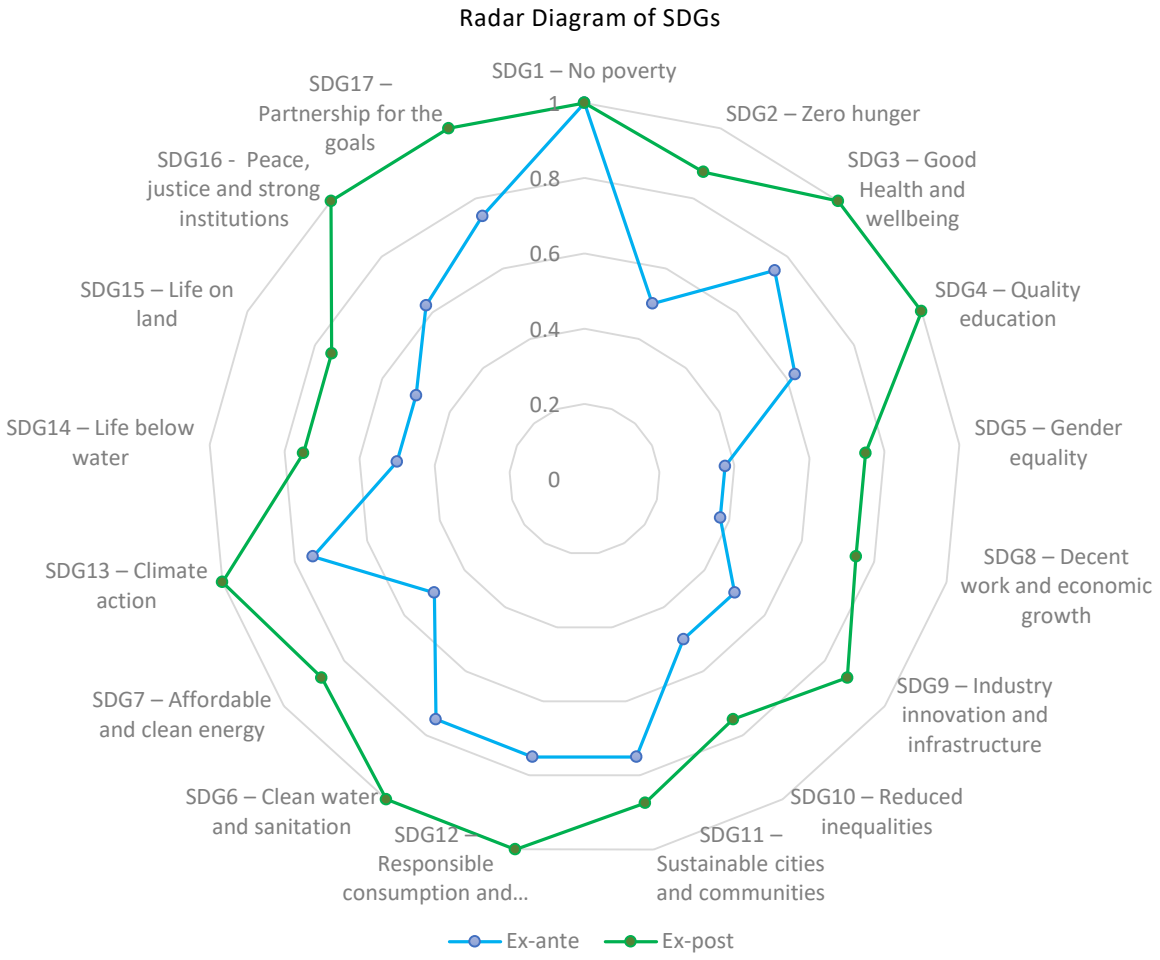


Figure 49: Radar Diagram of SDGs

The provided data in Figure 50 illustrates a comprehensive increase in sustainable development impact scores from the ex-ante baseline to the ex-post projection across all five core pillars, with the total general impact score expanding from 0.641 to 0.935. This overall growth is led by the People and Prosperity pillars, reaching ex-post values of 0.19 and 0.17 respectively (rising from 0.14 and 0.11, respectively), while Planet increases from 0.12 to 0.18, and Peace and Partnership climb to 0.20 from 0.13 and 0.15 respectively.

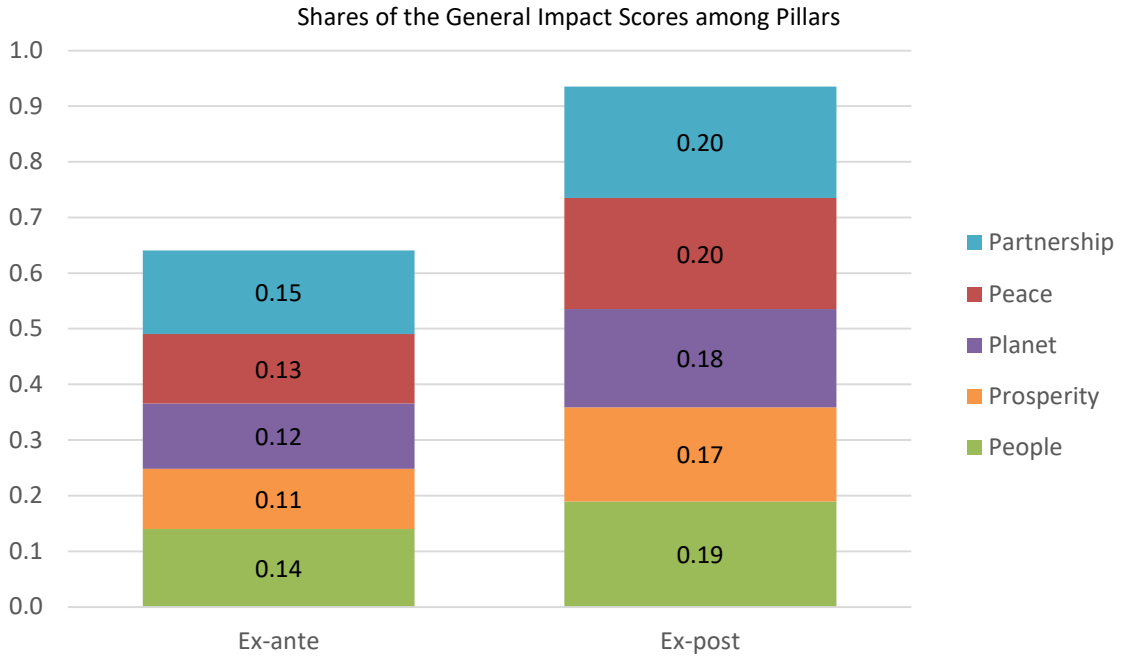
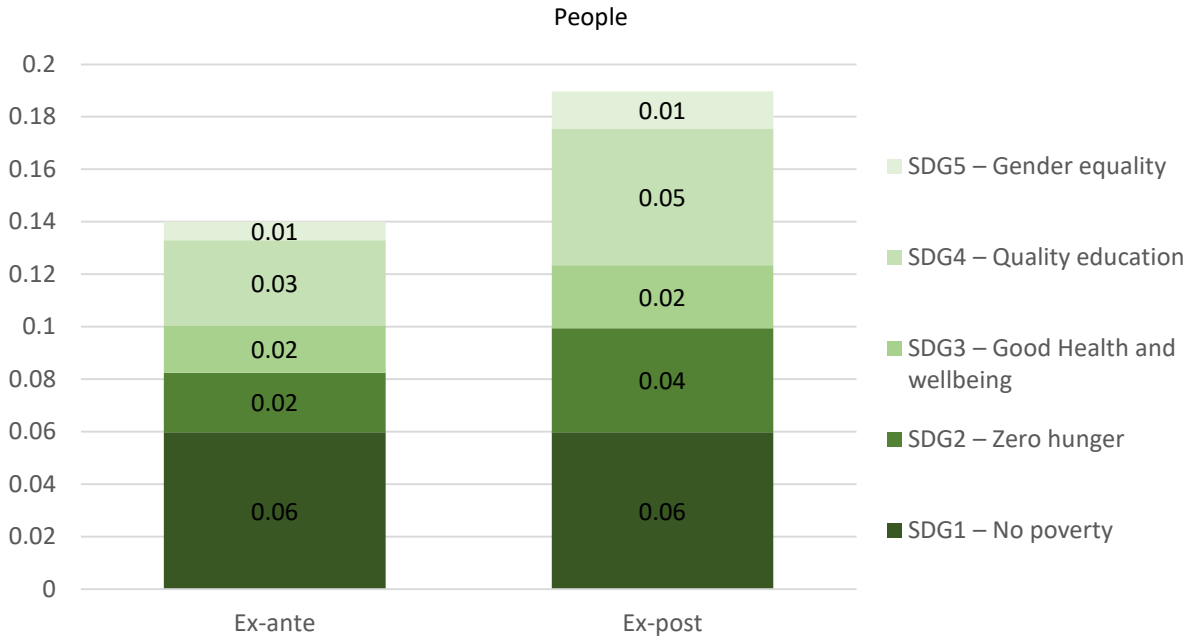


Figure 50: Shares of the General Impact Scores among Pillars

The following paragraph illustrates the data reported in Figure 51 with the objective to understand the Impact Scores for every Pillar among their relative SDGs.

Across all five sustainable development pillars for Tunisia, the data showed in Figure 51, reveals a projected increase from the 2025 ex-ante baseline to the 2035 ex-post impact scores. People pillar, its growth from 0.14 to 0.19 is primarily driven by significant advancements in quality education (SDG4 increasing from 0.03 to 0.05) and zero hunger (SDG2 from 0.02 to 0.04), good health and wellbeing and gender equality remain stable (SDG3 0.02 and SDG5 0.01), while the contribution for no poverty (SDG1) remains completely stable at almost 0.06. In the Prosperity pillar, the total score rises from an ex-ante baseline of 0.11 to an ex-post value of 0.17, primarily driven by gains in decent work and economic growth (SDG8 increasing from 0.02 to 0.04) and industry innovation and infrastructure (SDG9 increasing from 0.03 to 0.05), while sustainable cities (SDG11) and responsible consumption (SDG12) increase a little bit reaching 0.03 each. The Planet pillar demonstrates the most substantial overall growth, jumping from an ex-ante value of 0.12 to an ex-post value of 0.18; this surge is heavily anchored by advancements in affordable and clean energy (SDG7 rising from 0.04 to 0.06) and climate action (SDG13 increasing from 0.03 to 0.04). Finally, both institutional and collaborative frameworks show positive trajectories: the Peace pillar (SDG16) climbs from an ex-ante score of 0.09 to an ex-post score of 0.14, and the Partnership pillar (SDG17) similarly advances from an ex-ante score of 0.11 to achieve an ex-post score of 0.14.


People
0.2
0.18
0.16
0.14
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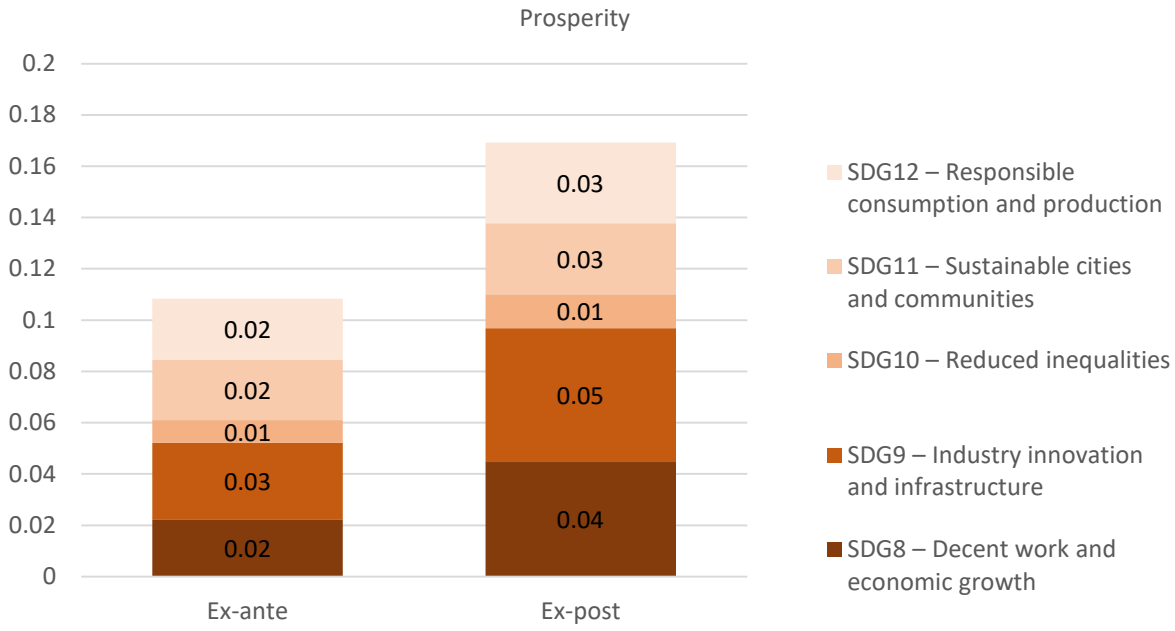
0.1
0.08
0.06
0.04
0.02
0
0.01
0.03
0.02
0.02
0.06
0.01
0.05
0.02
0.04
0.06
Ex-ante
Ex-post
SDG5 – Gender equality
SDG4 – Quality education
SDG3 – Good Health and wellbeing
SDG2 – Zero hunger
SDG1 – No poverty


Prosperity
0.2
0.18
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0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.02
0.02
0.01
0.03
0.02
0.03
0.03
0.01
0.05
0.04
Ex-ante
Ex-post
SDG12 – Responsible consumption and production
SDG11 – Sustainable cities and communities
SDG10 – Reduced inequalities
SDG9 – Industry innovation and infrastructure
SDG8 – Decent work and economic growth

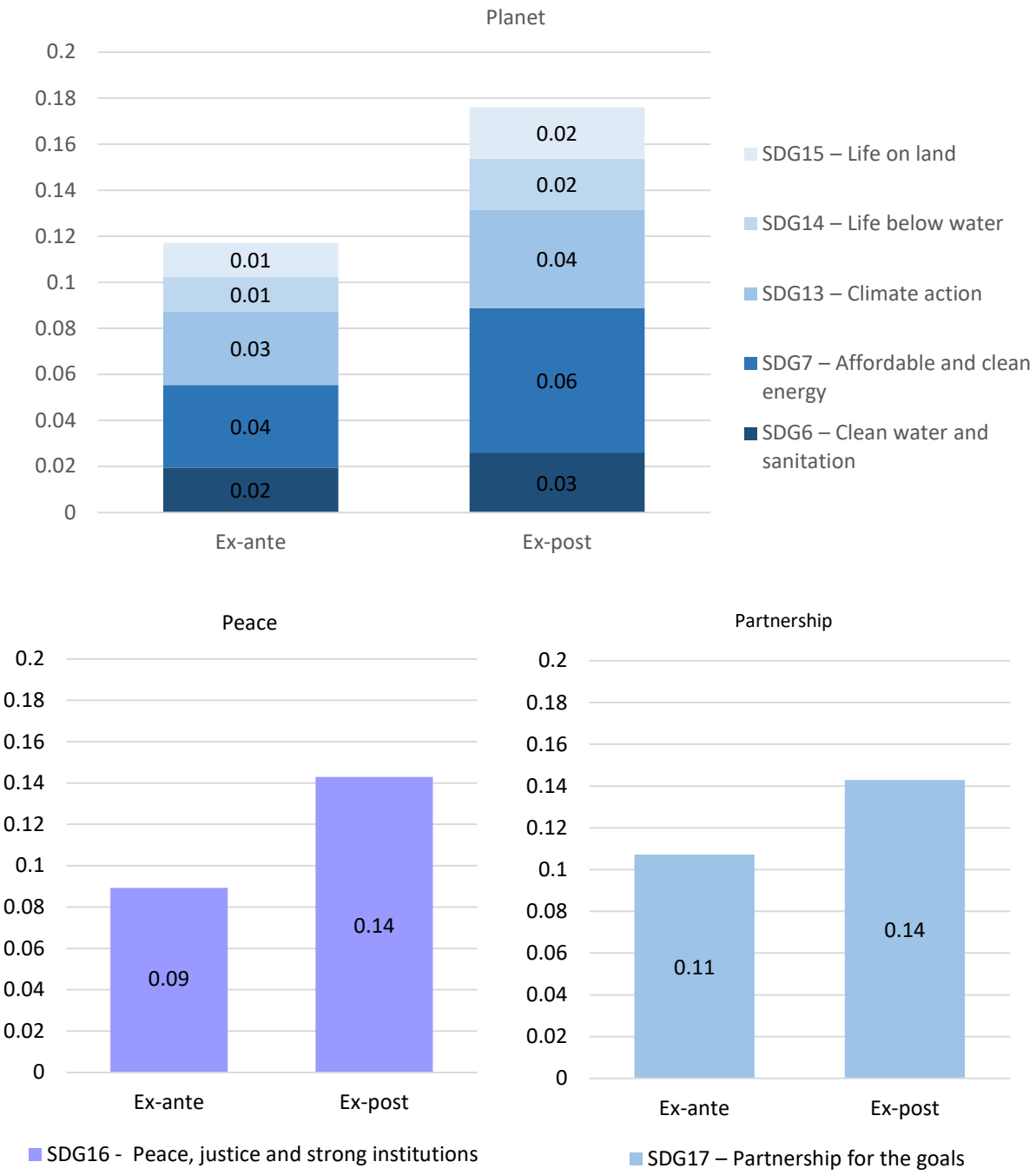

Figure 51: Shares of the Impact Scores for every Pillar among their relative SDGs

5 Conclusion

In conclusion, this study highlights the critical importance of the ecological transition in Tunisia, a context characterized by uneven socio-economic development and significant energy vulnerability stemming from dependence on volatile fossil fuels, factors that make the integration of the United Nations 2030 Agenda Sustainable Development Goals (SDGs) particularly urgent. To address this complex multidimensional challenge, the methodological approach adopted introduces a highly innovative contribution to the current scientific landscape by synergistically combining a qualitative multi-indicator framework (Impact Evaluation Framework – IEF), applied to all 17 SDGs, with a quantitative energy system optimization model specifically focused on SDG 7 for the 2025–2035 period.

This dual approach reveals, from a quantitative perspective, a profound structural transformation of the national electricity system driven by a large-scale expansion of solar energy, increasing the share of renewable electricity generation from 3.00% to 41.64% and successfully drops grid carbon intensity to 0.290 kgCO2/kWh. However, the currently planned capacity expansions remain structurally insufficient to achieve the nation's 50% renewable energy target by 2035, leaving a critical deficit of 5,292 GWh/year in unmet electricity demand, remaining energy net importer. Concurrently, the qualitative analysis conducted through the IEF demonstrates the effectiveness of the National Ecological Transition Strategy as a systemic driver capable of unlocking widespread socio-economic and environmental benefits, including the creation of green jobs, improvements in building energy efficiency, and pollution mitigation. Together, these results provide an essential holistic perspective for decoupling the Tunisian economy from the fluctuations of fossil fuel markets.

To bridge these persistent gaps and prevent the country from lagging behind, Tunisia must urgently accelerate institutional and regulatory reforms by fully unbundling its power sector, establishing an autonomous energy regulatory authority to build private investor confidence, and easing the financial bottlenecks surrounding the state utility (STEG) to unlock decentralized self-consumption routes-to-market. Furthermore, managing the technical volatility of the projected "solar explosion" and completely eliminating unmet demand will require the strategic integration of public-private partnerships tailored for utility-scale Battery Energy Storage Systems (BESS), coupled with the maximization of cross-border grid transmission infrastructure—such as the ELMED interconnector with Europe—thereby stabilizing the national grid, capturing

surplus clean generation, and securing a fully self-sufficient, equitable ecological transition.

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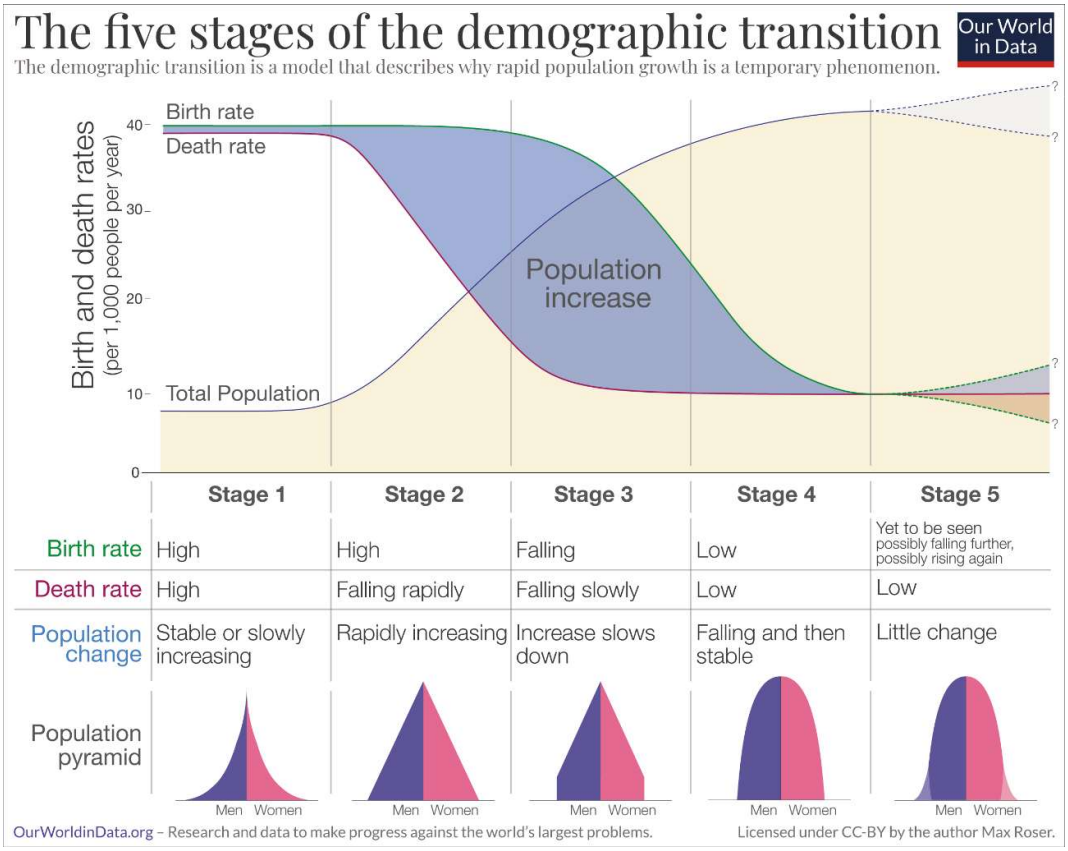
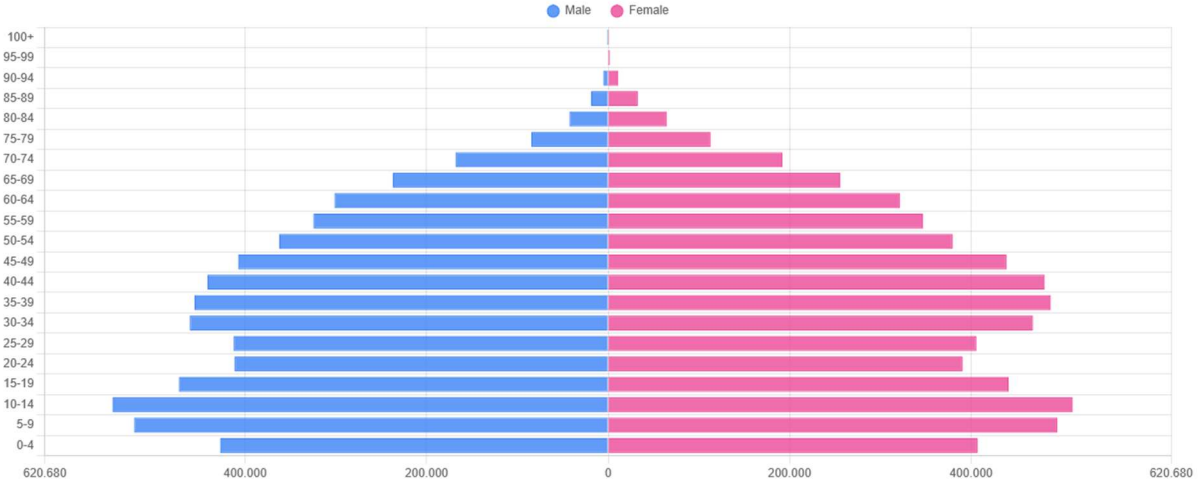
A Appendix


Mittelmeer
Bizerte
Tunis
Nabeul
Jendouba
Beja
Zaghouan
Kef
Siliana
Sousse
Monastir
Kairouan
Mahdia
Kasserine
Sidi Bouzid
Sfax
Gafsa
Libysches Meer
Tozeur
Gabès
Medenine
Kebili
Tataouine
ALGERIEN
LIBYEN


The five stages of the demographic transition
Our World in Data
The demographic transition is a model that describes why rapid population growth is a temporary phenomenon.
Birth and death rates (per 1,000 people per year)
Birth rate
Death rate
Population increase
Total Population
Stage 1
Stage 2
Stage 3
Stage 4
Stage 5
Birth rate
High
High
Falling
Low
Yet to be seen possibly falling further, possibly rising again
Death rate
High
Falling rapidly
Falling slowly
Low
Low
Population change
Stable or slowly increasing
Rapidly increasing
Increase slows down
Falling and then stable
Little change
Population pyramid
Men Women
OurWorldinData.org – Research and data to make progress against the world's largest problems.
Licensed under CC-BY by the author Max Roser.


Male
Female
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60-64
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20-24
15-19
10-14
5-9
0-4
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200.000
0
200.000
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Acknowledgments

Here you might want to acknowledge someone.