Climate Change: The Challenge of Tunisia and Previsions for Renewable Energy Production

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1 Introduction

Climate change relates to global warming, sea level rise, changes in storms and monsoons, drought, and melting permafrost [1, 2]. Climate damage will lead to increased inequality because raised impacts can be expected, especially in warmer regions, which are often linked to poorer countries, including the Middle East and North Africa (MENA) [3].

Based on an analysis carried out by the International Renewable Energy Agency (IRENA), which is an intergovernmental organization supporting countries in their transition to sustainable energy [4], energy-related carbon dioxide (CO_2) emissions would need to be reduced by about 70% by 2050, compared to current levels. The extensive use of electricity from renewable energies could help reduce CO_2 by 60%, or even 75%, if renewable energies are used for heating and transport.

According to the report, the global demand for electrical energy continues to increase. Renewable energies, such as solar and wind, could meet 86% of electricity demand [4].

Aware of these threats, Tunisia has adopted a proactive policy to combat climate change. Tunisia submitted its Intended Nationally Determined Contribution (INDC)

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to the Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) on September 16, 2015. [5]

Tunisia proposes to reduce its greenhouse gas emissions in all sectors (energy, industrial processes, agriculture, forest, and other land uses, and waste) to reduce its carbon intensity by 46% in 2030 compared to the base year 2010. The production of electrical energy represents the largest sector of CO_2 emissions. Consequently, Tunisia has focused primarily on this sector, which alone could contribute 75% of emission reductions.

The energy mix represents the solution. Several studies on the energy mix for electricity production in Tunisia have been carried out. The study by Lechtenböhmer et al. in 2012 focused on modeling and analyzing several scenarios from 2009 to 2030. This study has shown that none of the scenarios studied successfully reduces the demand for non-renewable energy and related greenhouse gas emissions. Renewable energies are the only scenario that can mitigate them [6].

This chapter is divided into seven sections. The following Sect. 2 represents the study area. Section 3 explains the energy situation in Tunisia. Section 4 explains the Tunisian commitments to climate change in the energy sector. Section 5 summarizes the results of the study carried out to establish the inventory of solar photovoltaic (PV) projects currently connected to the Low Voltage (LV), Medium Voltage (MV), and High Voltage (HV) network in self-production mode as well as the evaluation of the potential for PV self-production and forecasts of evolution by 2030. Section 6 proposes a decision support framework for PV energy prediction. A conclusion and discussions are presented at the end of the chapter.

2 Study Area

Tunisia is located in the North of Africa (refer to Fig. 1). It is a bath by the Mediterranean Sea to the north and east, bordered by Libya to the South and most south, and Algeria to the southwest and west.

Tunisia is divided into two large geographical areas:

- A northwestern zone with chaotic reliefs delimiting a series of high plains
- A southeastern zone with a low and hilly appearance extending to the coast.

The relatively high latitude of Tunisia and its stretch geographically from north to the South give it the succession of climatic zones ranging from sub-humid to the north, semi-arid to arid in Tunisia's central, to desert for all the South finally.

With a climate marked by aridity, Tunisia is considered among the Mediterranean countries most exposed to climate change, with the risk of a sharp increase in temperature. This increase would vary by the region, with the best case between 1 and 1.8 °C by 2050 and between 2 °C and 3 °C at the end of the century. In the pessimistic case, the increase could reach 4.1 to 5.2 °C at the end of the century. Projections show a decline in precipitation (−10 to 30% in 2050), a rise in the level of the sea (30–50 cm in 2050), and other phenomena of climatic extremes (floods and droughts) [7].

Fig. 1 Geographic location of Tunisia

These climatic risks would have adverse effects on the social, economic, and ecological, which would manifest themselves in the scarcity of water resources, the weakening of ecosystems land, and sea, the decline in agricultural activities and tourism, and the strengthening of the capitalization of economic activities.

The new Constitution of Tunisia considered the development sustainability and the rights of future generations among the fundamental rights of Tunisians.

The joint responsibility of the State and society in the preservation of water resources, the fight against climate change, and the right to a healthy environment for all citizens has been enshrined as a priority in article 45 of the constitution.

Tunisia supports the United Nations Development Program (UNDP) [8], a United Nations agency for international development, working in 170 countries to eradicate poverty, decrease inequalities, and assist countries in developing policies, leadership skills, and partnership capacities. UNDP support to Tunisia focuses on three key areas: democratic governance and consolidation of reforms; inclusive growth and sustainable human development, the environment; and the fight against climate change.

3 The Energy Situation in Tunisia

The energy sector plays a key role in the success of all policies, as do the economic and social sectors. It is also of great strategic importance, especially in light of the climate changes taking place in the world. Tunisia is facing strategic, environmental, societal, and economic challenges.

During 2010–2021, the resources available in primary energy in Tunisia stand at approximately 5.1 million tonnes of oil equivalent (toe). The energy mix is currently dependent on 53% natural gas and 47% petroleum materials, while the contribution of renewable energies does not exceed 0.4% [9].

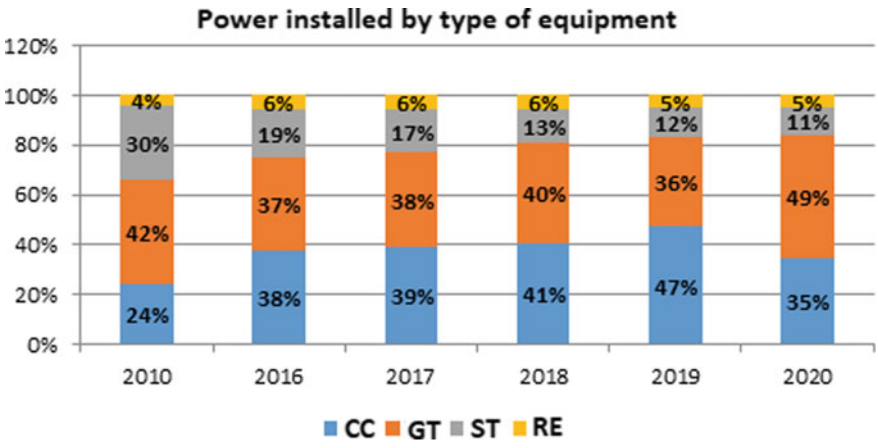

Fig. 2 Electricity production in Tunisia [6]

The electricity production fleet is divided into 27 units, using: Gas Turbines (GT), Steam Turbines (ST), Combined Cycles (CC), and Renewable Energies (RE) between 2010 and 2020. Installed capacities are currently distributed as exposed in Fig. 2.

4 Energy and Climate Change

Tunisia has adopted a proactive policy to fight against climate change both in terms of mitigation and adaptation. The international negotiations on climate change organized within the United Nations Framework Convention on Climate Change [10] led to a historic agreement in December 2015 in Paris called the "Paris Agreement" [11]. This agreement invited all the countries party to the UNFCCC to adopt public policies to contain the increase in temperatures below 2 °C or even 1.5 °C by 2100. To achieve this objective, all the parties are called upon to establish, communicate and update their Nationally Determined Contributions (NDCs) every five years. The NDC represents the political instrument that officially translates the commitments of each country to contribute to the international effort to fight against climate change.

Tunisia submitted its first NDC in September 2015, the objective of which is to reduce the carbon intensity of all sectors of the economy by 40% by 2030 compared to its level in 2010. Energy is placed at the heart of the priority sectors in the mitigation field, with a substantial contribution of 75% to the overall mitigation objective of the Tunisian NDC. Energy efficiency and renewable energies are the two main levers for achieving the objective assigned to the energy sector.

The mitigation effort will come more particularly from the energy sector, which accounts for 75% of emission reductions. It is expected that the energy sector will reduce its carbon intensity in 2030 by 46% compared to 2010 (Fig. 3) [7, 12], as part of the energy transition policy recommended by the State. Despite the efforts made

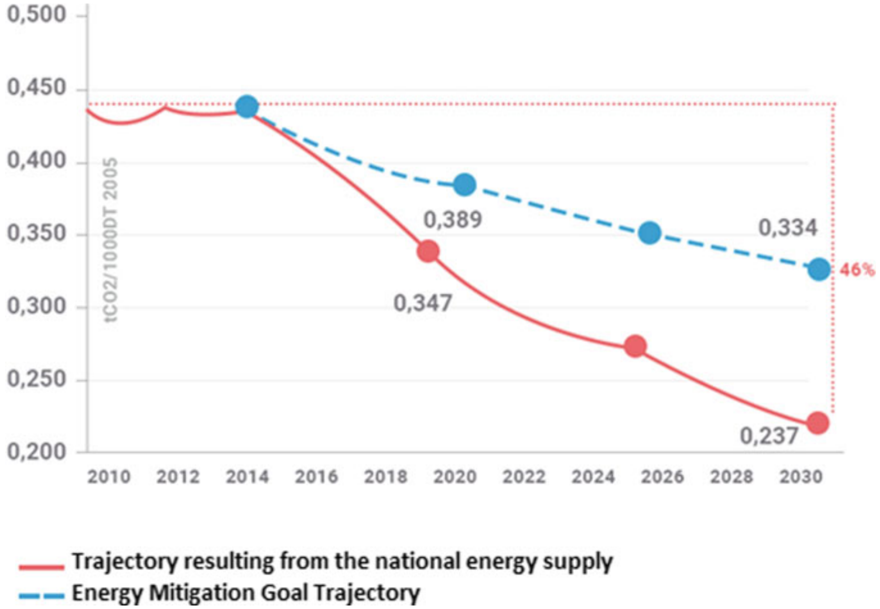

Fig. 3 Decrease of carbon intensity [7]

by Tunisia for three decades in terms of energy control and to meet these challenges, the Tunisian authorities have decided since 2013 to engage in an unprecedented strengthening of the energy control policy. Energy with its two components of energy efficiency and renewable energies. This transition targets, by 2030, a reduction in primary energy demand of 30% compared to the trend scenario and a penetration rate of renewable energies in electricity production of 30%.

However, energy challenges persist; demand remains dominated by hydrocarbons (natural gas and petroleum products) which cover 99% of primary energy consumption, while renewable energies (excluding biomass) do not exceed 1% of this consumption. Because of this increased dependence on conventional energies, coupled with the drop in national hydrocarbon production, the equilibrium of the energy balance was broken from the beginning of 2000. In the future and based on current conventional resources, the energy forecast shows significant challenges regarding the security of the country's energy supply. Indeed, if energy demand evolves according to a trend scenario, the energy balance deficit would reach around 13.3 Mtoe in 2030. In the case of an energy efficiency scenario, this deficit would be 7.9 Mtoe.

5 Renewable Energies in Tunisia

5.1 Current Situation

Tunisia's non-renewable resources are modest compared to international standards and benchmarks; the country. On the other hand, it has strong wind potential and solar resources, which are among the highest in the world. In addition, several resource assessments have already been carried out in Tunisia, which places the country in a good position to accelerate the deployment of renewable energy technologies and translates, concretely, into a real lead over many other countries in the MENA region.

The wind resource has been assessed by the National Agency for Energy Management (Agence Nationale pour la Maitrise de l'Energie: ANME) [13] through the development of a wind atlas for the whole of Tunisia as part of cooperation with Spain [14]. Indeed, the Wind Atlas indicates that the wind conditions are suitable and show a very interesting potential in several regions of Tunisia, particularly in the South.

Tunisia also benefits from a significant rate of sunshine exceeding 3000 h per year. Tunisia is a small country, barely 750 km long (from north to South). However, the sunshine varies significantly depending on the region. The direct irradiation index varies from 1800 kWh/m^2.year in the far north to 2600 kWh/m^2.year in the far South.

As part of the solar market strengthening project in Tunisia, the German international development cooperation agency GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) [15] carried out a study in the context of a cooperation project for Strengthening the Solar Market in Tunisia [16]. The Project provides technical support and advice and an exchange of international experiences to develop a relevant, incentive, and operational regulatory framework.

The Tunisian government is successfully implementing the Tunisian Solar Plan (TSP) [17], developing large-scale renewable energies and respecting the country's agreed contributions to climate protection. Figure 4 shows the global objectives of the Tunisian solar plan [17].

To implement these ambitious objectives, a new law on the production of electricity from renewable energies was promulgated in 2015 (n°2015-12 of May 11, 2015) thus determining the different production regimes and authorizing the private sector to play a greater role in achieving the objectives set by the State, through the following production schemes:

- Concession regime for projects whose power exceeds 10 MW for solar energy, 30 MW for wind energy, 15 MW for biomass, and 5 MW for other forms.
- System of authorizations for projects whose power does not exceed the above-indicated thresholds.
- Self-production regime for any type of customer.

Self-production is a major axis of the national energy transition policy contributing to the energy mix's diversification. It is dedicated to playing an important role in achieving objectives in terms of electricity production from renewable energies.

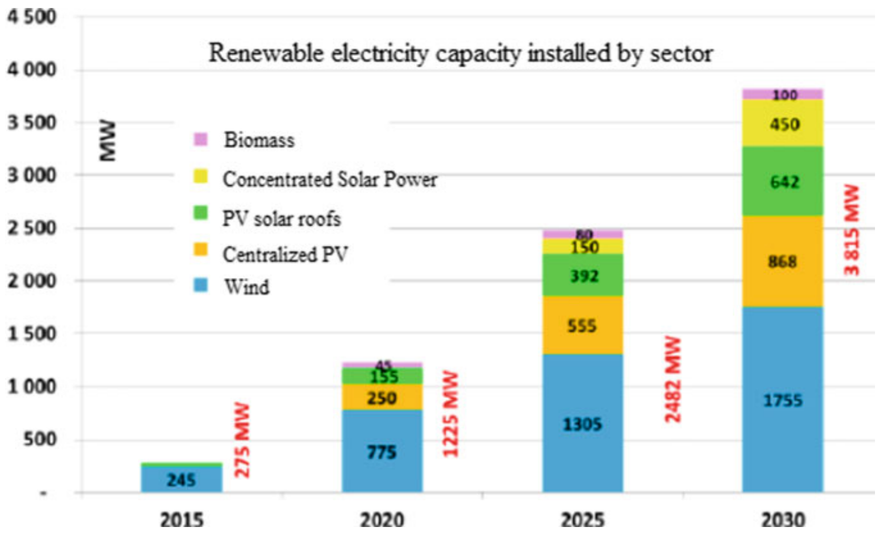

Fig. 4 Objectives of the Tunisian solar plan [17]

5.2 *Self-Production of Photovoltaic Solar Energy*

The self-production of electricity remains possible for any local authority and a public or private establishment, connected to the national electricity grid at Medium or High Voltage (MV-HV). It concerns establishments active in the industrial, agricultural, or tertiary sectors. It is possible to submit a request to the Ministry of Energy, Mines, and Energy Transition [Ministère de l'Energie des Mines et des Energies Renouvelables [18] to install the necessary equipment for the MV/HT self-production of electricity which will be sanctioned by an agreement [19].

The self-production program allows the deployment of two types of projects:

– *On-site projects*, without transmission of electricity on the national network of the Tunisian Electricity and Gas Company (Société Tunisienne de l'Electricité et du Gaz (:STEG) [20].
– *Projects on a remote site*, with the transport of electricity on the STEG network.

The electrical energy transferred by the self-producer to STEG as surplus production from the renewable installation is shifted and then invoiced monthly. The contractual relations between the self-producer and STEG are defined in a contract.

Among all renewable technologies, solar photovoltaic technologies have dominated the renewable energy industry worldwide for many years. Photovoltaic solar installations could multiply by six over the next ten years and reach an annual increase of 9% until 2050. By 2050, the self-production of PV origin will represent 40% of the total capacity projected [21].

The International Energy Agency (IEA) [22] deployed a technology roadmap for PV energy. The roadmap assumes that the costs of electricity from PV in different parts of the world will converge as markets develop, with an average cost reduction of 45% by 2030 and 65% by 2050 [23].

With the metering system based on Net-Metering [24], the Tunisian regulatory framework allows subscribers to the Low Voltage network to cover all of their annual electricity needs through self-production projects from renewable energies. For this voltage level, these energies are represented only by photovoltaic technology.

5.2.1 Potential of PV Self-Production in Low Voltage

According to STEG, at the end of 2019, there were 4,049,047 subscribers with a PV installation, spread over the following sectors:

- Residential, which represents 86.3%.
- The tertiary represents 10.7%.
- Agriculture with 2%.
- The industrial with only 1%.

Currently, the PV market is facing significant growth in demand. This is because STEG has difficulty developing enough capacity to cover national demand. The advantage of developing the LV market is that private households have the opportunity to contribute financially to a long-term energy transition. All the power installed on the PV market in LV would be financed exclusively by private investment.

The study conducted in this context aims to make estimates and show the potential for the years to come. Regarding the development potential of the residential sector, the study focused on the availability of surface, the technical potential of total power to be installed, and the available funding programs:

A—Availability of surface

This involves estimating the surface of the roofs available for the installations, based on studies by GIZ [25] and the National Institute of Statistics on the characteristics of housing [26]. It is estimated that 40% of the total roof surface is available for photovoltaic systems and about 60% of the remaining surface for the use of satellite dishes, and other uses by the inhabitants. Given these estimates, the estimated available surface for the residential sector does not present any problem with the availability of roof surfaces.

B—Technical potential of total power to be installed

At the end of 2018, approximately 62,000 residential subscribers opted for a self-production installation from renewable energies. Based on data from STEG's 2018 annual report [27]. Taking into account the total consumption of this segment at the end of 2019, and with an annual growth of 3%, this potential will increase to around 4000 MWp by the year 2030.

C—Available funding programs

ANME has implemented, since 2018, the social photovoltaic program "Social PV" for households with low electricity consumption (less than 1800 kWh per year), fully financed by the Energy Transition Fund (FTE) up to 15MDT. The program promotes the generalization of the installation of photovoltaic solar panels in households.

Also, an Economic PROSOL Program has been set up for 2019–2023. This program is part of the project "Promotion of renewable energy and energy efficiency in the building sector in Tunisia", funded by the NAMA Facility [28]. With an estimated budget of €5.3 million, this fund was granted as a donation. This NAMA Facility program aims to encourage households whose electricity consumption is less than 1800 KWh per year.

Regarding the development potential of the non-residential sector, it should be noted that non-residential subscribers generally have higher than average monthly electricity bills.

Aiming to involve public establishments in the energy transition and in achieving the objectives of the Tunisian Solar Plan in terms of renewable energies, ANME and the Ministry of Industry and Small and Medium-Sized Enterprises jointly developed the 2017 program to equip public buildings with photovoltaic installations under the self-production scheme in collaboration with the German Development Bank KfW for seven years. This Public program, called PROSOL Public Program, which is scheduled to be implemented in early 2021, will only focus on promoting the use of photovoltaics for producing electricity in the public sector, given the significant potential it offers. It provides for installing a hundred photovoltaic systems with an approximate capacity of 30 Megawatts by 2024.

5.2.2 Potential of PV Self-Production in Medium and High Voltage

This market is divided into three types of activity: tertiary, industry, and farming. For this voltage category, Tunisian regulations have limited the excess electricity from renewable energy self-production facilities that could be transferred to STEG. Decree No. 2016-1123 requires that the surpluses sold to STEG do not exceed 30% of the annual production of the self-production facility. Thus, the quantities of electricity exceeding this limit will be transferred free of charge to STEG. The total number of MV/HV customers is 19,701 [27]. The distribution of electricity consumption by sector, based on the STEG annual report for 2018 is presented in the following table (Table 1).

Table 1 Distribution of electricity consumption by branch [27]

	Sector	Consumption (GWh)	% Company
Industry	Extractive industry	308	3.78
	Food industry	687	8.42
	Textile industry	457	5.60
	Paper industry	110	1.35
	Chemical industry	493	6.04
	Construction materials industry	1472	18.04
	Metallurgical industry	284	3.48
	Miscellaneous industry	1159	14.21
Others	Agriculture	606	7.43
	Pumping	766	9.39
	Transportation	305	3.74
	Tourism	540	6.62
	Service & others	971	11.90
	Total	8158	100

6 Decision Support Framework for Photovoltaic Energy Prediction

According to an analysis of the inventory of photovoltaic solar projects under the self-production regime, we have noted a weak adhesion of individuals, institutions, and Tunisian companies connected to the Medium Voltage and High Voltage electricity networks. This is due to various regulatory, institutional, technical, and economic constraints.

It is in this context that we propose a framework taking into account the inventory of PV solar photovoltaic projects connected to the medium voltage network authorized under the self-production regime to monitor and provide the necessary information to decision-makers for the forecasts and decision-making regarding a greater development of achievements under this regime. This framework is a decision-making system based on a data warehouse. To do this, we started with data collection to be able to build the data warehouse.

6.1 Data Collection

In this study, the data is collected from energy consumption databases, and other data is collected in Excel sheets. Also, a self-producer (or self-consumer) survey is performed.

The survey was carried out among all owners of PV projects connected to the authorized MV network and their installers. The objective is to draw up an inventory of the progress of the projects of Medium Voltage (MV) self-consumption to:

- Determine the installed power distribution by region and sector of activity.
- Identify the progress of PV installations (rate of realization of MV projects published in the Journal Officiel de la République Tunisienne (Journal Officiel de la République Tunisienne: JORT), total power installed and connected to the MV network).
- Assess the difficulties encountered in implementing MV projects.
- Identify the rate of satisfaction of the beneficiaries.

As part of this study, the questionnaire developed for the telephone and on-site survey meets the following requirements:

- The questionnaire must be adapted to the type of activity;
- The form of the questions must make it possible to collect the desired information;
- The terms used in the questionnaire must be easily understandable and unambiguous.

The developed questionnaire addresses the descriptive and indicative elements of the status of the MV projects defined in the database, including in particular:

- Customer characteristics (tariff regime before/after installation).
- Installed power.
- Description of the installation (Types, power, number, and origin of modules and inverters as well as the installation method).
- The investment cost, the amount of the subsidy and its payment.
- The method of financing and facilities, the share of self-financing as well as profitability indicators.
- Performance of the facilities (ratios of self-consumption / coverage of needs/surplus).

Also, the questionnaire details the following aspects:

- The deadlines for implementing MV projects (administrative procedures and on-site construction).
- The management of surplus sales and invoicing by the beneficiary of systems (The monitoring and control carried out by the beneficiary and the invoicing method of STEG).
- The equipment guarantees and their receptions, the operation and maintenance of the PV system, and communication with the installing company (Contract, others).

- Energy efficiency measures are envisaged by the beneficiary.
- Comparison between the electricity bill before and after the implementation of the PV installation.
- Customer satisfaction about the savings made and the difficulties/advantages of the assembly process and implementation of an MT project in general.
- A brief visual inspection of the installation and, if necessary, some pictures.
- Self-producer recommendations.

Thus, the telephone survey affected 118 projects out of the 156 authorized. Following the results of the telephone survey, a representative sample of 12 self-consumers and 18 projects representing more than 10% of all authorized projects was chosen to conduct face-to-face interviews with the beneficiaries of these projects.

Finally, the data collected from the various sources relate in particular to:

- Company name or name of the self-consumer, as well as their contact details.
- Contact person.
- Site coordinates.
- Governorate and Delegation.
- Sector and sub-sector of activity.
- STEG reference, type of tariff, and district concerned by the reception and connection of the PV installation.
- Installing company, as well as its contact details.
- System size (Unit power in kilowatt peak (kWp)).
- Percentage of consumption coverage.
- JORT number, and the date of allocation of the authorization.
- Installation date.
- Date of approval of the detailed study, the signature of the STEG contract, date of commissioning.
- Information concerning the funding.
- The producible of the last 3 years, etc.

6.2 The Proposed Data Warehouse

We propose an approach based on Data Warehouse (DW) technology to address the issues related to PV energy provisions. The latter will support the analysis of PV electricity data to deliver reports and useful information for decision-makers. Therefore, the DW-based approach is introduced to manage and analyze PV energy consumption and production data, delivering valued information for decision-making.

A data warehouse is a copy of transactional data specifically structured for querying and analysis [29]. A DW is a decision support database that is maintained separately from the organization's operational databases. A data warehouse is a Subject-oriented, integrated, time-varying, non-volatile, collection of data used primarily in organizational decision-making [30].

A data warehouse is constructed by integrating data from multiple heterogeneous sources that support analytical reporting, structured and/or ad hoc queries and decision making [31].

DW includes 4 main components: data sources, ETL, data warehouse, and data Access and Analysis [32]:

– Data Sources, gathering the input data as raw material for the data warehouse, including operational databases, and data files (excel, CSV…).
– ETL (Extract, Transform, Load) process, is needed to extract data from data sources, transform the data for integration needs, and load the transformed data into the DW. Several ETL tools exist, such as TALEND, PENTAHO, CLOVERETL, etc. Selecting the right ETL tool is a crucial task for any DW. Each tool has its advantages and disadvantages [33].
– Data warehouse, which can be composed of data marts to store the loaded data in an organized way. Before choosing the final tool to implement the DW (SQL Server, Informix, Hyperion, …), ensure that the tool is capable of meeting the growth and overall requirements of the organization in the present and the future [34].
– Data Access and Analysis, this component is used by decision-makers to access the DW for analysis target. It helps to derive insights from data to be able to make strategic decisions. Several Business Intelligence tools, such as Oracle BI, Microsoft Power BI, SAS Business Intelligence, etc., make it possible to achieve these objectives [35].

Three models are used to design a Data warehouse: the star, snowflake, and galaxy model. The star and snowflake models are the most used in companies. The difference between star and snowflake models is that the star model does not use normalization, whereas the snowflake model uses normalization to eliminate data redundancy. The two main components of these models are dimensions and facts.

– The dimensions are the axes we want to carry out the analysis. There may be dimension hierarchies to split dimension tables when they are too large. A dimension is a table with a primary key and a list of attributes. A dimension table must be linked to a fact table.
– The fact tables are those on which the analysis will focus. These tables contain operational information and relate to the life of a company. The fact table helps the user analyze the business dimensions, which helps in making decisions to improve their business. The fact table contains a primary key which is a concatenation of primary keys of all dimension tables, and numerical variables called measures which can be aggregated (SUM, AVG, COUNT…) using the attributes of the dimension tables.

In this study, the data warehouse incorporates data from the data found in energy consumption databases, the questionnaire, and the data saved in Excel sheets. Table 2 convenes these data.

The conceptual model of the proposed data warehouse according to the snowflake model is described in Fig. 5.

Table 2 Dimension and fact tables

	Tables	Attributes
Dimensions	Self-producer	IdSP (primary key), name, address, energy consumption
	Region	IdR (primary key), name
	Governorate	IdG (primary key), name, IdR (foreign key)
	Delegation	IdDel (primary key), name, IdG (foreign key)
	Installation company	IdIS (primary key), name
	STEG reference	IdSR (primary key), district name
	Tariff type	IdTT (primary key), tariff type
	Installation site	IdIS (primary key), name
	Main activity sector	IdMA (primary key), name
	Secondary activity sector	IdSA (primary key), name, IdMA (foreign key)
	Date	IdD (primary key), day, month, year
	Financing type	IdFT (primary key), financing type
Fact	Production PV	IdSP, IdG, IdDel, IdIS, IdSR, IdTT, IdIS, IdMA, IdSA, IdD, IdFT (foreing keys)
		Satisfaction rate
		Advancement rate
		Number of installations
		Installed power
		Energy produced
		Energy injected into the steg network

Once implemented, the DW allows managers to:

- Display the number of installations by date of commissioning.
- Have the coverage percentage (PV consumption/production).
- Select data relating to such period, production, sef-producer sector, etc.
- Sort group, or distribute this data according to the criteria of their choice.
- Perform calculations (totals, averages, differences, comparisons from one period to another, etc.).
- Present the results in a synthetic or detailed way, with a graph according to their needs or the expectations of the decision-makers.

7 Conclusions and Recommendations

Tunisia's energy situation is marked by limited energy resources, a decline in energy production, and a strong increase in demand. To follow the path of sustainable development in Tunisia, it is imperative to develop renewable energies and massively accelerate of energy efficiency projects.

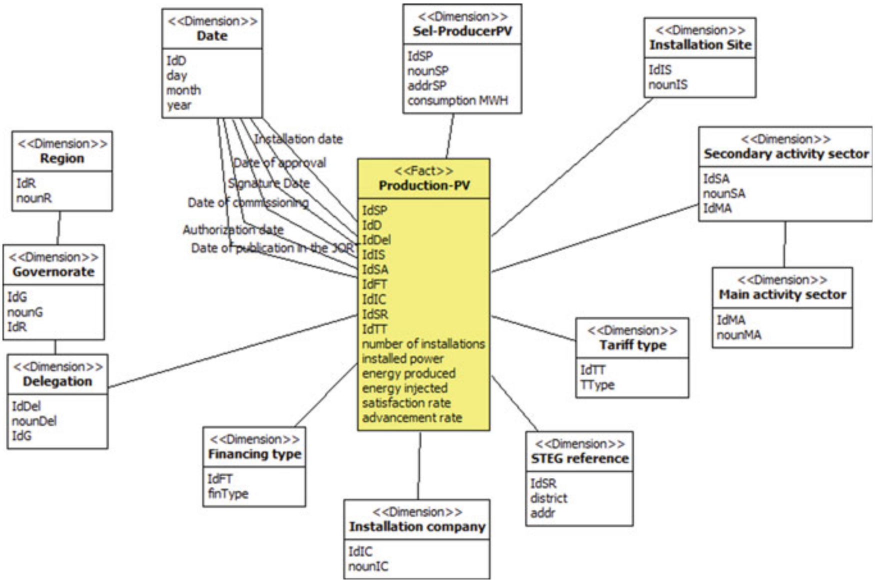

Fig. 5 Proposed Data Warehouse

For sustainable development and to mitigate the impact of global climate change, Tunisia is committed to reducing greenhouse gases. The effort has focused on introducing renewable energies to partly replace conventional energy production, the main emitter of CO_2. In this work, a study is carried out to establish the inventory of renewable energy projects, particularly the solar photovoltaic currently connected in self-production mode. An evaluation of the potential for PV self-production and forecasts of evolution by 2030 is also performed.

For the achievement of the objectives established by the government and to accelerate the implementation of renewable energy installations such as PV self-production projects, we recommend a new strategy based on four main elements:

– Respect regulatory deadlines.
– Change the regulations to simplify the procedure as much as possible.
– Allow some flexibility (like reprogramming counters).
– Change the counting mode: from the instantaneous to the hourly post with a monthly balance sheet (change at the level of the contract).

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