Electric Self-Production for LV Subscribers: Is It Better to Have Decentralized or Centralized PV Production?

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Abstract

The Tunisian energy supply system is currently, being restructured to achieve 30% produced electricity from sustainable sources by the year 2030. The objective is to reach 3815 MW of renewable electrical power, with 1755 MW for wind power, 1510 MW for solar PV, 450 MW for CSP and 100 MW for biomass. Photovoltaic solar energy offers great national economic advantages. Grid-connected photovoltaic systems can be as decentralized or centralized production technology. Between decentralized and centralized PV production, the choice is a little difficult. In fact, with decentralized technology, the costs of transporting electricity and losses in transport circuits are eliminated. While for centralized production, the cost of installation is much lower due to the economy of scale. This study is solved using OSeMOSYS tool, which needs certain economic and technical data for each energy technology. Simulation results prove that centralized PV technology is more productive than decentralized one during certain years. Then, decentralized production begins to be more interesting where their cost would be equivalent to that of centralized PV. However, centralized PV technology can be more productive if there is an improvement in the quality of the transmission network.

Keywords: Photovoltaic Systems, decentralized, centralized, OSeMOSYS

1. Introduction

The Tunisian Solar Plan (TSP) is a national program aiming to reach the renewable energy development strategy targets (GIZ.de, 2022) (mrv.tn, 2022). The goal is to increase the total share of renewable energy in the electricity generation mix from 6% today to 30% by 2030, from wind power, solar PV, solar CSP and biomass and the rest of the electricity production coming from gas.

Photovoltaic solar energy offers an economically viable option to bridge the growing gap between supply and demand. According to the Global Atlas of the International Renewable Energy Agency (IRENA) (anme.tn, 2022), the annual production of electricity by solar photovoltaic systems in Tunisia can be between 1450 kWh / kWc in the northwest region and 1830 kWh / kWc in the far southeast.

Between decentralized and centralized PV production, the choice is a little difficult. In fact, with decentralized technology, the costs of transporting electricity and losses in transport circuits are eliminated. While for centralized production, the cost of installation is much lower due to the economy of scale. What are the production constraints that require each type of production for it to be promoted?

2. Methodology

This work consists of developing a comparative study between the two solar energy production technologies: centralized PV and decentralized PV in the Tunisian mix:

- Decentralized PV System: Any establishment, connected to the national electricity grid (STEG) can produce its own electricity from PV. This investment allows to consume the own electricity instantly, and thus save money on the next bills. Indeed, the surplus production is injected into the STEG network, which undertakes to subtract it from the consumption bill as part of a "net metering" billing contract.
- Centralized PV System: Thanks to the economies of scale afforded by a ground-based power plant, the cost is reduced compared to roof panels. Thus, photovoltaic solar power plants can be built on non-

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habitable areas, such as desert areas. This market can be attractive to households that are deprived of access to solar energy for several reasons, whether because they live in an apartment, their roof is not suitable or even for aesthetic reasons.

2.1. Introduction for the OSEMOSYS tool:

The Tunisian energy system is modeled using the Open Source Energy Modelling System (OSeMOSYS), which is a developed linear programming optimization model (Dhakouani, 2017) (Howells, 2011). Linear optimization (also known as LP linear programming) is a method of achieving the best result (such as the lowest cost) whose requirements are represented by linear relationships. In mathematical terms, OSeMOSYS is a framework for long-term modeling, linear and deterministic optimization.
OSeMOSYS calculates the energy mix that meets the demands for energy services each year and at each time step of the case studied, by minimizing the total discounted costs. It can cover all energy sectors or individually, including heat, electricity and transport, and has a user-defined spatial and temporal domain and scale. Energy demands can be met through a range of technologies schematized as a reference energy system (RES). Each technology present certain technical and economic characteristics and rely on a set of resources, defined by certain potentials and certain costs.
In addition, political scenarios may impose certain technical constraints, economic realities or environmental objectives.

2.2. Design of the reference energy system (RES):

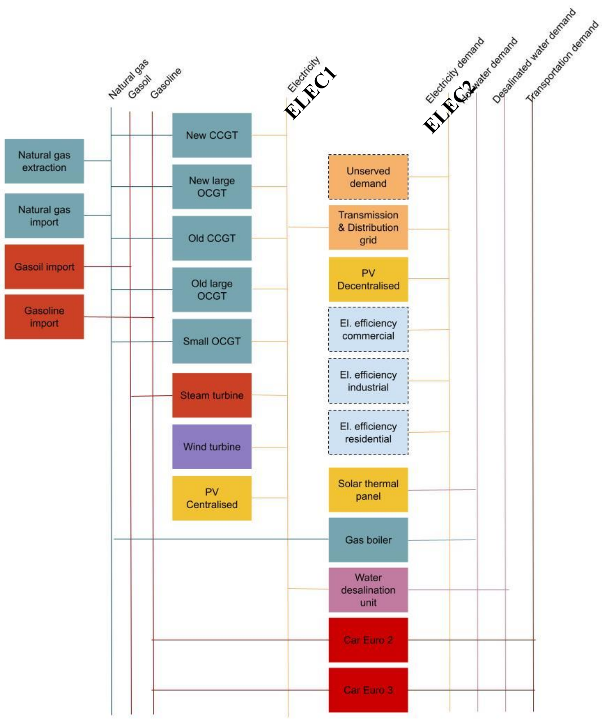


Fig. 1: The RES oft he Tunisian Energy Mix

The Reference Energy System (RES) is a simplified and aggregated graphical representation of the actual energy system to be analyzed.

The RES of the Tunisian energy mix is shown schematically in Fig1. Decentralized PV technology directly produces final electricity ELEC2, while centralized PV technology produces electricity for transmission ELEC1, which is connected to the transmission and distribution technology to produce ELEC2.

2.3. OSeMOSYS Modeling and Data collection:

OSeMOSYS tool needs economic and technical data for each energy technology. The model adopted is originally developed by the GIZ called 'TENEM', on which modifications have been introduced according to the studied scenarios. The different data used for this modeling are collected from STEG, GIZ, ANME and the Ministry of Energy and Mines.

- Electricity demand: Fig 2 represent the electricity demand curve. The estimated electricity needs, are certainly multiplied by more than twice between 2020 and 2046.

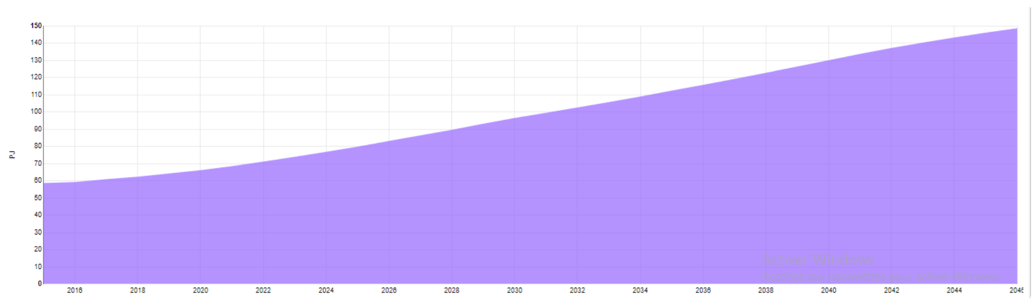


Fig.2: Estimated electricity demand in PJ

- Investment Costs: The investment costs of centralized and decentralized PV technologies, go through increasingly significant falls until the horizon of 2035 from which these costs stabilize at a fixed value. Due to the economy of scale, the investment cost of centralized technology is reduced compared to decentralized technology by 10%. The following graph summarizes the evolution of these costs over the years

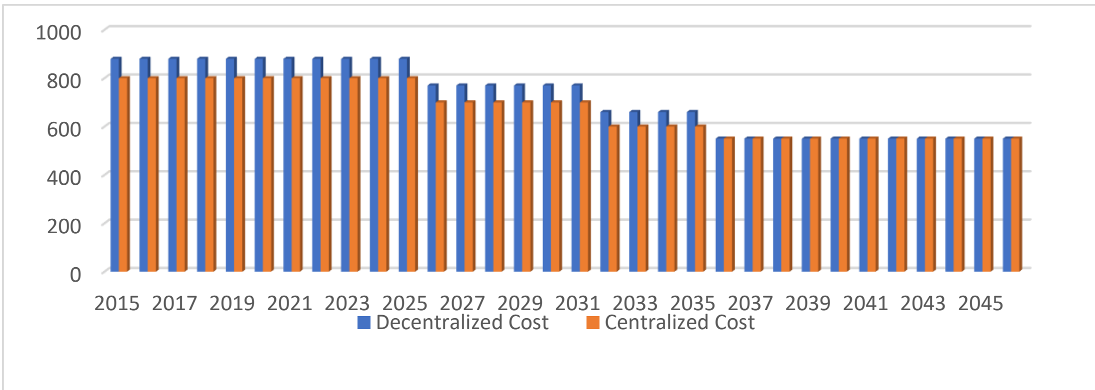


Fig. 3: Centralized and decentralized PV technology investment costs in $

- Capacity Factor: For each PV technologies: centralized and decentralized, capacity factors are given by the following table according to each time slice.

Tab. 1: Capacity Factor of PV technologies

		Interme-diate	Summer	Winter
Workday	Day	0.4	0.51	0.29
	Night	0	0	0
weekend	Day	0.4	0.51	0.29
	Night	0	0	0

- Transmission losses: Between 2015 and 2046, transmission line losses decrease from 18% to 12% gradually.

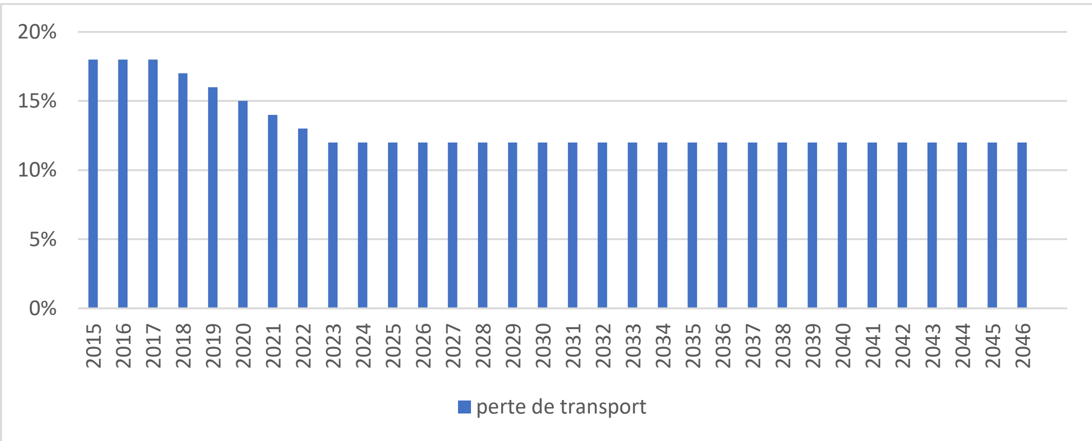


Fig. 4: Transmission line losses.

2.4. Scenarios

The model is tested under two different production scenarios:
Scenarios 1: Reference TENEM model: according to the original TENEM model, the centralized PV technology starts production in 2015 before the decentralized one. This model is tested respectively for:

- Limited solar energy production where annual installed capacity is restricted at most to 300MW.
- Unlimited solar energy production

Each case is studied with and without electricity transmission cost, and with a reduction in transmission losses.

Scenarios 2: Modified TENEM model: represents a case where decentralized and centralized technologies come into production at the same time, and with actualized installed capacity, according to recent statistics from STEG and ANME. In addition, this model is tested respectively for an annual production of limited and unlimited solar energy, taking into account the price of transport of electricity and by acting on transmission losses.

3. Results and discussion

To assess the benefit of integrating renewable energies into the Tunisian mix, the levelized cost of energy (LCOE) is calculated for three initial cases:

- Case1: Energy mix based on conventional energy only.
- Case2: Energy mix based on conventional energy and energy efficiency.
- Case3: Energy mix based on conventional energy, energy efficiency and renewable energy.

The general form of LCOE is written as follows:

$$LCOE = \frac{\sum_{t}^{n}\left(\frac{Operational\cos t}{(1+r)^{t}} + \frac{Invetment\cos t}{(1+r)^{t}}\right)}{\sum_{t}^{n}\frac{Productionannual}{(1+r)^{t}}}$$

Where:
n: years number of the energy project.
t: counter over the years.
r: attenuation rate;

$$r = \frac{i-\gamma}{1+\gamma}$$

i: interest rate = 6.25%.
γ: inflation rate = 5.3%

Tab. 2: Calculated LCOE

Case	1	2	3
LCOE (DT/KWh)	0.222	0.196	0.165

The results in Table 2 confirm that renewable energies as well as energy efficiency reduce the macroeconomic costs of energy production from 0.222DT / KWh to 0.165DT / KWh.

3.1. Scenarios 1: Reference TENEM Model:

According to the original TENEM model given by the GIZ, the centralized PV technology starts production in 2015 before the decentralized one. This model is tested respectively for:

- Limited solar energy production where annual installed capacity is restricted at most to 300MW, to achieve the TSP.
- Unlimited solar energy production

Each case is studied with and without electricity transmission cost, and with a reduction in transmission losses.

3.1.1: Limited Solar Energy Production:

- Case1: Without transmission cost:

Fig5.1 and Fig5.2 represents the evolution of the total capacity installed by restricted centralized and decentralized PV technologies without taking into account the transmission costs. The total installed capacity from centralized PV technology, is much larger than that from decentralized PV until 2041. Then, the profiles are reversed, and decentralized technology become dominant because its cost become more reducer over the years.

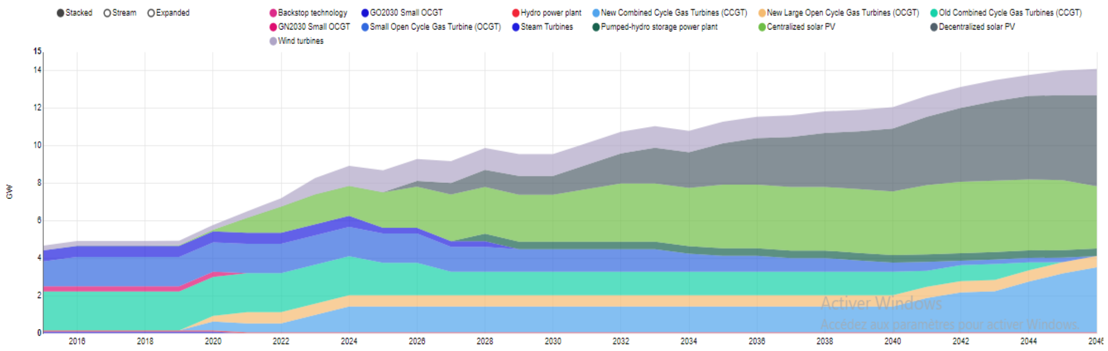


Fig. 5.1: Total installed capacity for all technologies without transmission cost

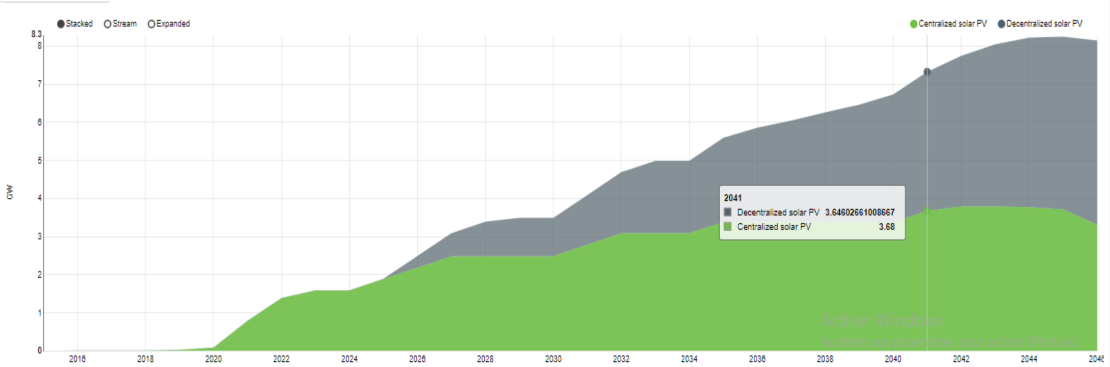


Fig. 5.2: Total installed capacity for centralized and decentralized PV technologies without transmission cost

- Case2: With transmission cost:

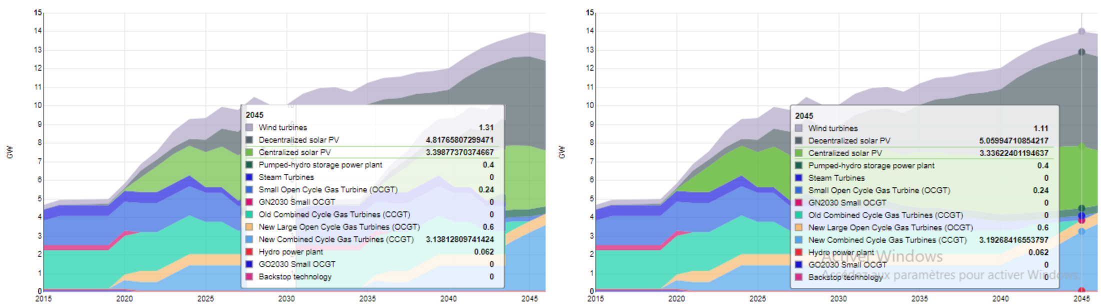


Fig. 6: Total installed capacity for centralized and decentralized PV technologies with transmission cost

The KWh transmission rate is set at 0.025DT. This tariff is introduced in the "variable cost" parameter of the transmission and distribution technology. As a result, the capacity produced by technologies that use transport has decreased such as centralized PV and wind turbines. As an example, in Fig6, the total power produced by centralized PV technology for the year 2045 drops almost by 60MW in return, the power produced by decentralized PV technology increases by 200MW.

Following these two previous cases, we can only deduce that decentralized PV technology have a tendency to be favored over centralized one, regardless of with or without transmission cost. So, if we want to increase the interest of centralized PV technology, all that remains is to reduce transmission losses.

- Case3: With transmission cost and reduced transmission losses:

Fig7, represents the total installed capacity, where the transmission cost is included and the transmission losses are reduced from 18% in Fig7.1 to 11% in Fig7.2.
Therefore, a simple improvement in the quality of the transmission network increases centralized PV production and decreases decentralized one.
This scenario recommends the Tunisian state to invest more in the quality of the STEG network and this can be achieved using the smart grid policy which help to reduce the economic losses of electricity transmission caused by fraudsters.

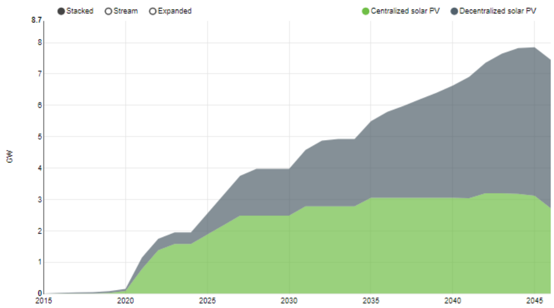


Fig. 7.1: Transmission losses 18%

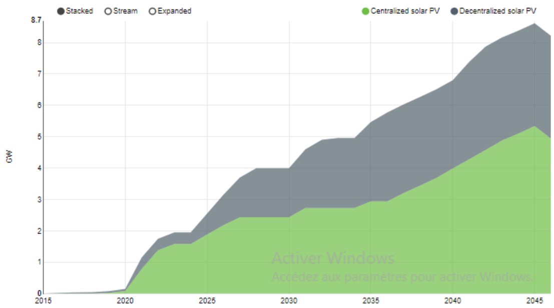


Fig. 7.2: Transmission losses 11%

3.1.2: Illimited solar production:

By eliminating the restriction on solar technologies, only the decentralized technology participates in the production, Fig8. This is convincing since this technology does not pass throw the technology of transport. So, whatever the case tested, without or with transport cost, decentralized PV technology is always favored. Centralized PV technology may be lucky if transmission losses are smaller.

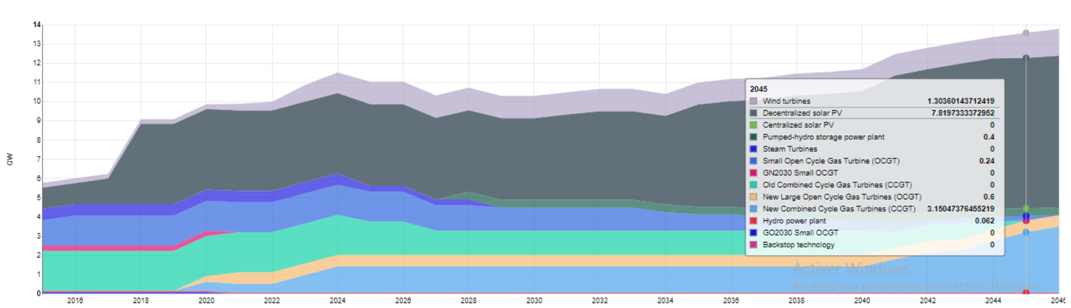


Fig. 8.1: Total installed capacity for all technologies, without restriction

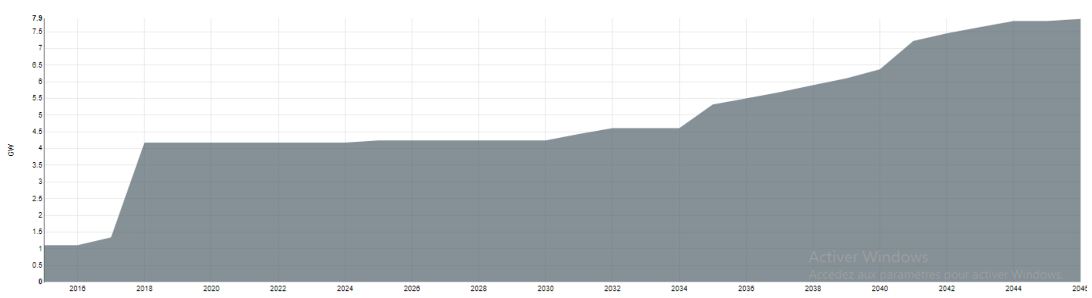


Fig. 8.2: Total installed capacity for centralized and decentralized technologies, without restriction

3.2. Scenarios 2: Modified TENEM model:

According to actualized data from STEG and ANME, decentralized PV technology starts production from 2015, with centralized technology, by introducing at least 10MW every year until now. This scenario is tested too, under 3 cases:

- Case1: Without transport cost:

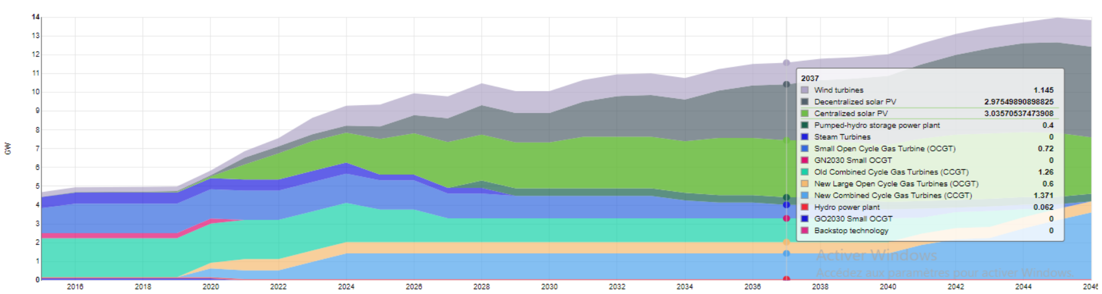


Fig. 9.1: Total installed capacity for all technologies without transmission cost

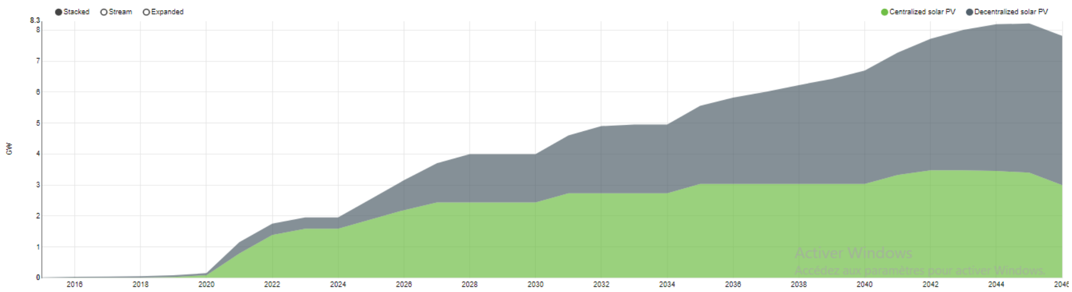


Fig. 9.2: Total installed capacity for centralized and decentralized PV technologies without transmission cost

Similar to the first scenarios, centralized technology is more productive but this time until it reaches 2037. Then, decentralized solar technology begins to be more favored because its cost become more reducer over the years.

- Case2: with transmission cost:

The addition of the transport cost, in Fig10, can only further decrease the chance of centralized PV technology production. Indeed, decentralized PV technology exceeds centralized PV technology in production from 2036.

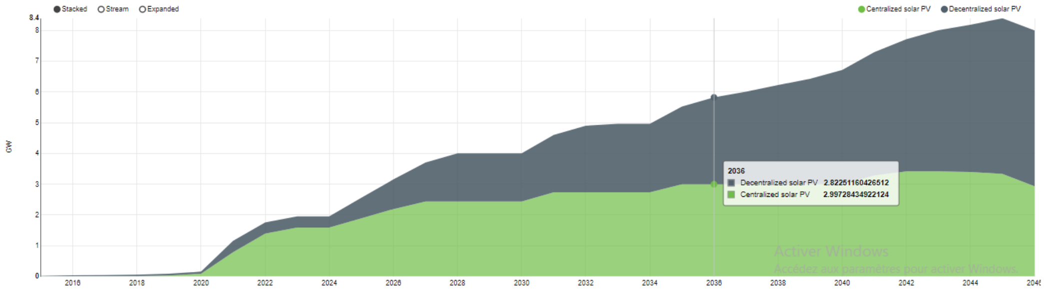
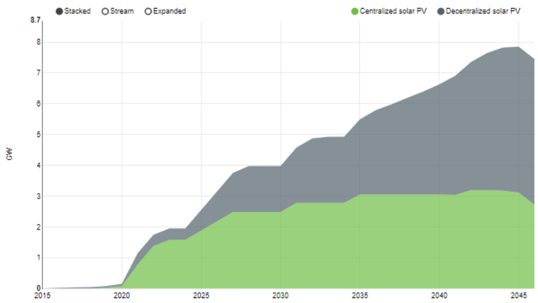


Fig. 10: Total installed capacity for centralized and decentralized PV technologies with transmission cost

Case3: With transmission cost and reduced transmission losses.



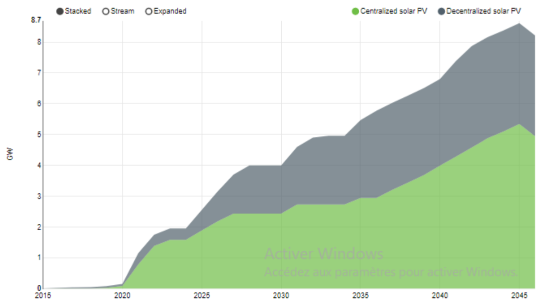


Fig. 11.1: Transmission losses 18%

Fig. 11.2: Transmission losses 11%

Fig11, represents the total installed capacity for the second scenario, where the transmission cost is included and the transmission losses are reduced from 18% to 11% .

Therefore, a simple improvement in the quality of the transmission network increases centralized PV production and decreases decentralized one.

3.3. Discussion:

To compare between those two scenarios, a calculation LCOE is developed in the following table:

Tab. 3: Calculated LCOE for different scenarios

	Limited solar generation + transmission losses 18%-12%		**Unlimited solar generation + transmission losses 18%-12%**	
	without transport cost	with transport cost	without transport cost	with transport cost
LCOE(DT/KWh): Scenarios 1	0.1654	0.1658	0.15158	0.15187
LCOE(DT/KWh): Scenarios 2	0.1635	0.1639	0.15158	0.15187

The lowest calculated LCOE (Levelized Cost of Electricity) values, presented in Tab. 3, are that relating to the unlimited solar production scenarios, which promotes the integration of renewable energy in the Tunisian mix. Respecting this optimistic scenario, the Tunisian state can increase the share of PV technologies in national energy production from 6% in 2022 to 37% in 2030 which exceeds the objective of the Tunisian solar plan.
Also, in terms of Greenhouse Gaz (GHG) emission, this scenario can contribute to reduce this emission from 6.35 Kton in 2022 to 3.054 Kton in 2030, that means a GHG emission reduction that can reach 48% between 2022 and 2030. These results, despite being optimistic, but they are a bit further from the new European Commission plans which aims to raise the greenhouse gas (GHG) emissions reduction target from 40% towards 55% by 2030 (Jager-Waldau, 2022).

4. Conclusion

Generally, because of its lower investment cost, the energy produced by centralized PV technology is more important than that produced by decentralized for the short run. Then, decentralized production begins to be more interesting where their cost would be equivalent to that of centralized PV, also by the transmission losses, which reduce the productivity of centralized PV technology. For another scenario, centralized PV technology can be favored if there is an improvement in the quality of the transmission network such that transmission losses are reduced to 11%. Adding up the cost of transport for all scenarios can only decrease centralized PV production and increase LCOE. The lowest calculated LCOE values are that relating to the unrestricted production scenario, which promotes the integration of renewable energy in the Tunisian mix and contribute to reduce the GHG emission.

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