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A New Approach to Energy Transition in Morocco for Low Carbon and Sustainable Industry (Case of Textile Sector)

Slimane Smouh [1], Fatima Zohra Gargab [2,*], Badr Ouhammou [3], Abdel Ali Mana [2], Rachid Saadani [1] and Abdelmajid Jamil [2]

[1] High School of Technology, Faculty of Sciences, Moulay Ismail University of Meknes, Km 5, Agouray Street P1, Meknes 50040, Morocco; slimane.smouh@gmail.com (S.S.); rachidsaadani@gmail.com (R.S.)
[2] High School of Technology, Sidi Mohamed Ben Abdellah University, Imouzzer Road, Fez 30000, Morocco; abdelali.mana@usmba.ac.ma (A.A.M.); abdelmajid.jamil@usmba.ac.ma (A.J.)
[3] Faculty of Science of Kenitra, Ibn Tofail University, Kenitra 14000, Morocco; badr.ouhammou@uit.ac.ma
* Correspondence: fatimazohra.gargab@gmail.com

Abstract: Morocco has resolutely committed to the green transition of its economy by opting for industry decarbonation, which now imposes itself as an essential access criterion to foreign markets. Intending to include energy efficiency in the leading players in energy-intensive industries, this paper has the main objective of contributing to a better understanding of the decarbonation plans potential impact, taking the example of solar energy integrating opportunities as an action for a thrifty, sustainable, and low carbon Moroccan industry. Indeed, the paper focuses on the industrial textile sector, such as the energy-intensive industry. This sector is the first employer and the most important industrial activity; it is also an icon and the oldest industry in Morocco. This study examines the energy, economic and environmental fallout, evaluating the productions, the investment and the CO_2 emissions limit. Besides, the energy industrial sector is characterized by a strong dependence on fossil imports, which increases the energy factor and price. In this regard, several geographical sites and factories were studied under six climatic regional conditions, proposing the most optimal and sustainable configurations for each location and present models with scopes and levels of energy and environment gains and investments that can inspire the sector actors. Then the present work must install concepts by inspiring local factories, accompanying the national vision, and resizing the industrial ecology. In this paper, a power of 8.88 MW is the total power installed, which provides an annual total of 8484.65 tonnes of CO_2, with an average payback time between 2.6 years and 4.5 years, and attractive economic parameters, with an LCOE of 0.034 $/kWh and $181,863 for the NPC, those outputs shows the importance of environmental gains that the generalization of this strategic vision can achieve.

Keywords: efficiency; energy; sustainability; textile industry; decarbonation; solar energy

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1. Introduction

1.1. Literature Background

Renewable energies are the precious key for industrial and sustainable development. It is the primary axis of decarbonation and reinforcing these sectors structuring and positively impact ecological development and limit energy consumption [1]. Significantly, solar energy is one of the cleanest alternative energy sources as an appropriate and feasible option, and was described as an important action and a logical step to achieve the Sustainable Development Goal. The need to invest in renewable energies and human capital was also underlined to support the national energy transition vision. On the one hand, countries tend to diversify their economies, achieving an economic model capable of improving productivity and capital while having a low carbon footprint. The processes needed to achieve this include proper techniques, green technologies, investment in human capital, and, most importantly, a financial plan that facilitates the integration of renewable energies and a more efficient utilisation of resources. This process will lead to a sustainable transition when sustained and flourishing [2].

In Morocco, the share of value-added in the three sectors remained stagnant at around 15% for agriculture; this depends on fluctuations in rainfall. 27% of the industry, which provided fundamental dynamics to the labour market, accounting for around 12% of the employed labour force, and 51% for the service sector, which accounts for around 40% of jobs (67% of total creation), appears to be expanding; most jobs are concentrated in traditional low-skilled services [3]. Following its commitments at the international level within the framework of the Earth Summits of Rio de Janeiro (1992) and Johannesburg (2002) and the relevant conventions, Morocco has put in place the foundations for sustainable development in the country by legal, political, institutional, and socio-economic new reforms. This process has been accompanied and reinforced by adopting an energy transition and the integration of SMEs (small and medium enterprises), creating more synergies [4], and developing the economic sector integrity in which industry with all its domains presents a primary axis because of the huge consumption and the significant emissions. In Morocco, industry accounts for 30% of CO_2 "energy" emissions, including 50% of direct emissions from the combustion of fossil fuels and 50% of indirect emissions related mainly to electricity use. To these energy emissions, we must add the GHG emissions from PIUP, which represent half of the total GHG emissions of the Moroccan industry. The latter has been roughly stable since 2010 and tends to increase less rapidly than those in building or transportation. Therefore, the deep decarbonization of industry largely depends on the decarbonization of the electricity sector [5]. Industry in Morocco is divided into two main categories, Large Energy Consumer Industry, i.e., the sugar industry, cement, paper, pulp, construction materials, iron and steel, phosphate, acids and fertilizers. For these industries, the energy parameter is determined in the cost of production. Light Energy Consuming Industry, includes the agro-food, textile and leather, other and construction and public works industries, para-chemical chemistry, mechanical, metallurgical and electrical industries, and others. For those industry types, the energy parameter is often determined in the production cost function [6]. Based on a current investigation Morocco has 1600 textile manufacturers headed by world leaders such as Inditex (Spanish company), including the Bershka and ZARA brands. However, local production has not often been destined for the national market mainly because of the informal sector scope [7].

Moreover, the clothing industry is one of the most complex industrial chains. Producing yarn from cotton requires several processing steps [8]; then transforming wire into clothing uses a large amount of electricity and water. With the current growth in prices and the inflation of indicators, this sector consumes more energy unsustainably. In this regard, the current article aims to integrate solar energy and optimal measures for efficiency and energy optimization in the Moroccan textile industries to install more sustainability in national industry. This improvement action is implemented in this case study and is represented as a relevant solution that contributes both to the decarbonization of factories and to the national carbon neutrality project that Morocco currently prioritises. In this optic, several studies have addressed the issue of decarbonization and new sustainable strategies at the heart of the policies adopted by countries. Ali et al. [9] present a new approach for a global decarbonation strategy in the Bangkok metropolitan area, the study was carried out following a sectoral analysis and the bilan carbon method based on several countermeasures and a deep investigation of energy demand and carbon mitigation policy existing plans. The study was based on 2015 data, giving a projection of 2050 plans. The author presented a global assessment of the emissions of the industrial sector with the forecasts for 2050. The author then presented an action plan that will guarantee a reduction in emissions by 50%, based on all the critical indicators and measures towards a successful low-carbon policy. Ali et al. [10] also presented a strategic work that proposes directional paths that helps decision-making for low-carbon policies. The case study is Lahore Metropolitan Area-Pakistan, characterized by an increasing population with significant carbon emissions and energy demand spiked. The work presents a novel multi-criteria decision analysis (MCDA) based on the same previous carbon balance approach examining the possibilities for cost–benefit analysis of carbon reduction actions. The study is based on a three-period analysis; 2010, 2050 normal prevision, and 2050 improved the provision of a low carbon scenario. It found that the industrial sector presents the high emissions with a provision of 14 million tons in 2050 for the conventional prevision, with a reduction of 50% for the low carbon 2050-scenario. Moreover, the findings show that in the current LMA energy mix, there is no relevant evidence of renewable energy use—such as biomass, wind, and solar. Furthermore, F. Lallana et al. [11] studied the case of Argentina with a futuristic vision for a decarbonized country by 2050. The paper explores deep qualitative–quantitative decarbonization pathways breaking and improving the existing national scenarios. The method focused on the complementarity between pathways and storylines and the strong links between economy and energy. Presenting a strategic environmental plan that deals with the economic goals involves brilliant energy sector improvement. The critical indicator in this study is the CO_2 emissions rate, with an emphasis on the supply alternatives for optimal energy sector demand. The main focus of the action plans in this study is natural gas, the replacement of which by hydro-nuclear is recommended; the export of this energy source is an action that is presented as an explicit objective of the energy policy.

Europe is also omnipresent in this type of scientific research study. R. Dominguez et al. [12] exploited stochastics to treat decarbonization problems in Europe. An efficiency analysis study was carried out to achieve a successful energy roadmap by 2050 and the results are presented in the European commission goals. The investment plan models are generated based on fuel costs, growing demand, and variability. CO_2 emissions are the principal indicator resulting from a stochastic dominance constraints model. The numerical study was developed considering the power system case. The results show that for zero CO_2, a power of 290 GW of renewable energy is required, presenting a better approach for acceptable CO_2 distribution and for enforcing strategies. For a strategic decarbonization project, the economic dimension is imposing, especially as the vision of transition is complete and successful once it involves all aspects, directly and indirectly, impacting the proposed plans, relating to economics, law and regulation, technology, and more. G. LeTreut et al. [13] zoomed in on the impact of low-carbon strategic direction on the economic fabric and its issues. The author presents a multi-sector economy-wide model for a new integrated energy pathways approach to study the impact of deep decarbonation strategies on all economic levels. The work presents Argentina as a case study with a complete approach highlighting the favourable conditions and the possible lakes and blocks for a provisional risk study.

The work in the literature concluded that the main action of decarbonization is to converge the energy production towards a clean, renewable and sustainable mode as treated in W. Jing et al. [14] research. The author chose the China Three Gorges Corporation (CTGC) as a case study; a SWOT analysis was established to study the enterprise situation between the current and the development expectations. The results show that to achieve sustainable development and become a first-class clean energy model, companies must adopt an expensive development strategy model instead of a conservative, progressive one. Other works have moved to a sectoral approach, treating the manufacturing sector similar to the case of Lofgren et al. [15], research which studied the industrial decarbonization in Sweden in less than three decades, evaluating the policy context. The decarbonation project is a conceptual framework for a successful climate transition, taking into account the principal market barriers, coordination, technology, and regulations, and which concern the basic material industries. The authors managed to determine the challenges of the decarbonization of the case and subsequently of the whole sector, where the main is the climate agenda of the country, and the capacity of the policy measures and instruments to facilitate the technological shift and, as a result, the low carbon project. By the end they proposed the government first to develop new holistic approaches reducing regulation barriers, and second to support high risk technology development to reduce the technological risk. Besides, P. Singh et al. [16] addressed the issue of industry decarbonization. The paper focused on conceptualising sector decarbonization as a sustainable transition strategy based on the dematerialization aspect. The fuzzy cognitive map is applied to model and simulate the system's issue. The results reveal insufficient technical measures of decarbonation and dematerialization for a profound industrial transition. The approach discussed the necessity of a transition enabling systemic corporate and governance strategies based on the interactions between decarbonization and dematerialization, taking into account regulations and governance policies, technology transfer and financial flows. The paper also highlights the importance of partnerships and private–public co-governance for better results of decarbonation plans, focusing on the necessity of corporate behaviour for transparent collaboration and organisational culture. Many other works based on the same sectoral approach and vision, developing new transitions to integrate in all principal sectors, in order to improve countries and government, present new transition programs of industry [17–19], electricity and energy production [20–22], for better climate mitigation [23].

1.2. Moroccan National Industry Economic Programs and Climate Plan

The Kingdom of Morocco is part of the international effort to operationalize the Paris Agreement and accelerate the Climate Action Agenda while capitalising on the dynamics and mobilisation of key actors and the achievements and progress made in recent years at different levels. In June 2021, a Morocco submitted its updated NDC with a new ambition of 45.5% to reduce GHG emissions by 2030, which is expected to be implemented through 61 projects and actions covering seven (07) economic sectors [24]. In addition, in 2019, Morocco developed its National Climate Plan 2030 (NCP), which forms the basis for coordination and the framework for developing a medium- and long-term climate policy to respond ambitiously and proactively to climate change and the Moroccan context challenges. The NCP is based on the following five pillars:

- Strengthen climate governance;
- Build a resilience to climate risks;
- Converge to a low-carbon economy with an accelerated transition;
- Place territories in a climate dynamic;
- Build human, technological and financial capacity.

In this optic, Morocco developed economic programs for industry benefit. Indeed, in 2023, the European Union plans to tax the imports of foreign companies exporting to its territory. Morocco is concerned by these provisions in perspective despite its low word emissions contribution, which are modest but increasing, the cost of environmental degradation in Morocco, initially estimated at 3.7% of GDP on average, is grossly underestimated [25]. Moreover, the air degradation cost and its impacts are valued at 3.6 billion Dirhams/year, equivalent to 1.03% of GDP [26]. Indeed, Morocco is actively involved in preparing its industrial sector's decarbonation. In Morocco, several industrial sectors are affected by this new measure. These include automotive, electricity and fertilizers. Textiles and the agri-food industry will also be affected. It is also necessary to prevent, from now on, the possible impact that the carbon tax could have on the competitiveness of the business. In this sense, the competent Moroccan entities are already preparing the roadmap. Beyond the constraints that this would create for industry and exports, it could also be an opportunity to strengthen the competitiveness of the Moroccan origin and give an image of a neutral carbon industrial production destination. This is thanks in particular to the carbon-neutral industrial zone projects on the program.

Likewise, it should be noted that the recent «Tatwir Vert» program [27], which is part of the Industrial Recovery Plan, launched with Morocco SME under the aegis of the Ministerial Department of Industry, sets up grants to support enterprise investment. In addition to reducing industrial pollution, «Tatwir green growth» aims to support the emergence of new green industrial sectors and is a tool to support industrials in their process development operations and low-carbon products. This program provides financial support of around one billion MAD for the investment of industrial SMEs in the field of the green economy. In support of decarbonation, other financing lines, such as the Green Value Chain (GVC) and the Green Economy Financial Facility, are set up by European partners with partner financial institutions. It is part of the framework for the development of the green economy encouraging industries to rely on new models of sustainable production and promotion of energy efficiency. Support from the state to companies to offset the additional costs generated by the adoption of new green technologies is undoubtedly also an incentive. Furthermore, to remain competitive, Morocco plans to implement a Moroccan standard recognized at the European level to assess the carbon footprint of national companies.

This work converges in the sense of decarbonization of the Moroccan industry and in accompanying the kingdom's current strategic vision in this area. The paper presents and aims to propose a guideline and pathway for the Moroccan industrial sector decarbonization, adopting the textiles case, which represents an essential component for the Moroccan economic structure. In fact, the Moroccan textile-clothing industry occupies a prominent position in the Moroccan economy. It is the sixth-largest supplier to the European Union, the sector exports mainly to Spain, France, Great Britain, Germany and the Benelux. It is the leading industrial employer in the country with 27% of national industrial jobs, equivalent to 160,000 employees. The sector also contributes to 24% of Moroccan exports, up to 7% of the industrial Value Added, 5% of industrial production, and 5% of industrial turnover [28]. Thus, the textile-clothing industry collides with multiple difficulties necessitating a special support plan. Despite increased international competition (countries in Asia and Central Europe), it retains promising prospects with progress and energy sustainability opportunities, presenting reliable savings [29]. Besides, the textile openness to international markets and the obligation to present impressive environmental indicators, is required to promote Morocco's external economic relations. The paper presents a new approach for decreasing the footprint of the textile industry on the basis of an energy diagnostic of more than 27 company in different zone geographic of Morocco (Casablanca, Meknes, Fez, Settat, Sale; Marrakech, Tangier, Agadir), by the implementation of the Photovoltaics energy as clean technology to reduce factory energy bills and to approach them with carbon neutrality in order to conjoin the kingdom's current strategic vision. This technology is reaching commercial maturity and increasing investment in new generation capacity is expected to reduce prices further and promote greater competitiveness after the pandemic impacts are exceeded. However, this technology remains limited and minor in industrial applications and in industrial manufacturing processes. Therefore, this study tries to cover different regions in Morocco through a general approach applied to several factories proposing PV systems as a better alternative to reduce energy dependence on fossils and grid electricity.

The rest of the paper is structured as follow: Section 2 describes the energy sector of Morocco; Section 3 introduces the methodology, data used, modelling details, equations required, and assumptions for the energy, environmental and economic analysis; Section 3 contains a detailed case as a pilot case; Section 4 presents the main results obtained in this theoretical study; and Section 5 contains the most relevant conclusions.

2. Moroccan Energy Sector

The ambition of Morocco is to make energy a lever of attractiveness and development, with the prospect of triggering a real competitiveness shock around price criteria and low-carbon production modes. Such an approach will also strengthen the country's energy security (in terms of volumes and prices) and establish it as a global player in sustainability and in the field of renewable energies, with a solid impetus to R&D and industrialization of energy production equipment, and new challenging industries to support the ambition energy transition, such as the industrialization of new and efficient technologies (solar water heater [30], photovoltaic panels, etc.)

In fact, in the case of Morocco, electricity production currently accounts for the bulk of the energy transformation sector in the absence of refining activity. The electricity sector alone accounts for 40% of Morocco's energy CO_2 emissions, a share that can be explained by the still-high weight of conventional thermal power plants (natural gas, coal, diesel, and fuel oil) which made up 80% in 2018. The last decade has been marked by the rise of natural gas, renewables, and coal resurgence since 2013. The decarbonation actions imply both the emissions reduction and the optimization of energy consumption, which imposes a situation overview of this sector in figures in Morocco. The national energy context is marked by serious external dependence and a significant increase in energy demand. Up to 93% of energy is imported from petroleum products, coal and electricity. Only hydroelectric, wind and solar energies are produced locally. These figures and the environmental situation of the sector previously discussed shows how the state moves to stimulate investment in renewable energy, provide access to electricity to almost all of its population, and make fossil fuel subsidies a serious part of political discussion.

Moroccan electricity generation is an example of traditional production. The National Grid is responsible for much of the electricity generation. Fossil fuels dominate the energy sector in Morocco; the imports are evaluated to 19.97 Mtoe as shown in Figure 1, presenting almost the entire demand, which covered 88.7% of the country's primary energy consumption in 2018 (oil 60.2%, coal 24%, gas 4.5%), against a contribution of only 9.9% from renewable energies (Figure 2).

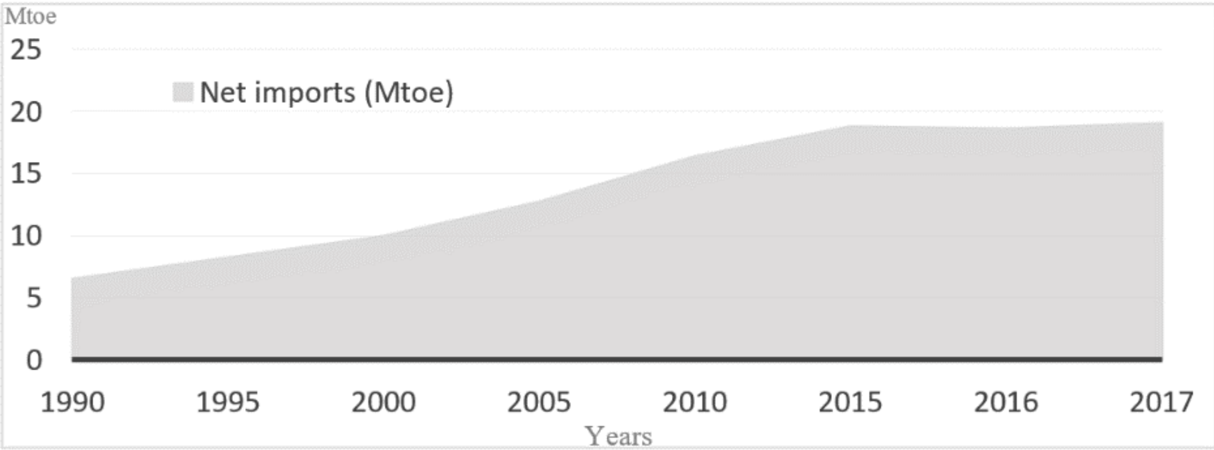

Figure 1. Net energy imports 1990–2018 (Mtoe) in Morocco [31].

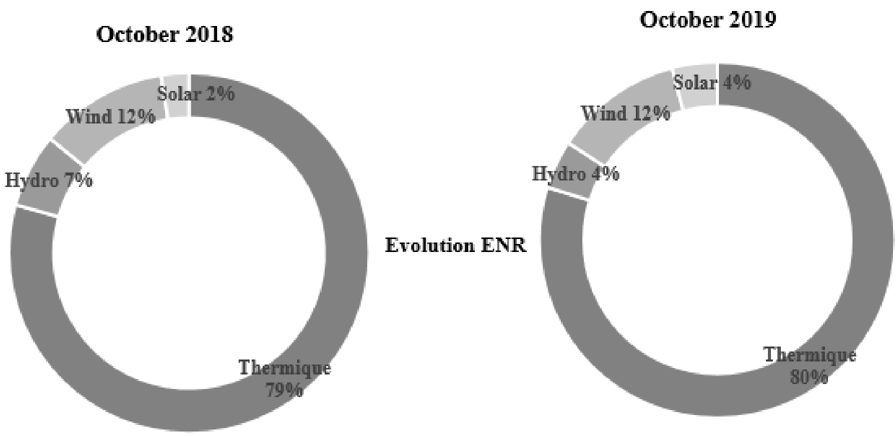

Figure 2. Dynamic share of Renewable energies in Morocco (source: author investigation on national reports).

The Moroccan electricity market is managed by the National Office of Electricity and Drinking Water (ONEE). This state-owned company manages the production, distribution, transmission, and electricity supply in Morocco. However, it recently opened its market to competition for private companies for lower prices, especially for renewables in its new energy transition programs. Thus, Morocco plans to increase renewable energy share to 52% of demand in 2030 against 14% in 2018. In 2018, the installed capacity of solar installations more than tripled to 711 MW. Wind power increased by 36% to 1220 MW; wind power production reached 3.8 TWh, making Morocco the second largest producer of wind power in Africa [32]. Morocco adopted in 2016 a national sustainable development strategy (SNDD) which sets ambitious objectives: 5000 MW of solar by 2030. Moreover, a remarkable increase in wind capacity from 280 MW in 2010 to 2000 MW in 2020 is recorded, equivalent to 14% of the total electrical capacity from RE, and a great development of the waste recovery for energy production [33].

Morocco has set an ambitious program to reduce greenhouse gas emissions by 2050. This strategy is applied in various sectors and is mainly based on a strengthening of renewable energies integration: wind, solar and hydroelectric. Morocco imports approximately 95% of the energy consumption, and the production of hydrocarbons in the kingdom is almost zero. This situation prompted the development of a new energy mix based on a solid energy diversification program to overcome fossil fuel dependency. Indeed, Morocco is closely linked to the climate and its fluctuations. The economy is very dependent on water, agriculture, and industry. Thus, the author renewables speculations in 2030 are about 42%, against 52% fixed in 2030, which is explained by a delay of 10% for 2020. Unfortunately, the structural analysis of the Moroccan context reveals a low sustainability, but pragmatically an optimist transition has been installed to face global warming and to reach a circular economy.

3. Methods

3.1. Data and Hypothesis

3.1.1. Moroccan Textile Factories: Industrial Company

In the framework of this study, a survey has been launched on the textile sector in Morocco. Focusing on the details (energy demands, consumption, production, etc.) of some production units, dispatches were made to different geographical locations to produce a representative sample based on the climatic and economic conditions of the selected regions in order to have a significant diversification of the results and a complete analysis of the national textile sector described as energy-intensive. As mentioned previously in the current study, an energy diagnostic of a several textile companies in different geographic zones of Morocco—Casablanca, Meknes, Fez (detailed case), Settat, Sale, Marrakech, Tangier and Agadir—have adopted the Photovoltaics energy as a clean technology to reduce the energy bill of factories and to help them approach carbon neutrality and to join the kingdom's current strategic vision.

(a) Detailed case: Fez

In Fez city, three typical cases of the textile industry have been studied as detailed and as representative cases. The lead region Sais (Meknes-Fez) has a favorable geographic and economic position. Given the beneficial climatic conditions in most Moroccan regions, the region of Fez-Meknes has great resource diversification and has significant national industry activities. Figures 3–5 represent the electrical profile of three textile factories located in the main selected regions.

(b) Different zone case and company

The survey was carried out in collaboration with the representatives of employers and the two main trade unions and with the support of the Ministry of Employment. This work reflects numerous interviews with various social actors. Twenty seven small and medium firms in the Moroccan textile sector were visited, where 8 are just in Casablanca. As the industrial leader in Morocco, Casablanca holds nearly two-thirds (63%) of the national companies and 10% operate in industry. Table 1 resumes the results on energy diagnostic loads of the investigated industrial park for the year 2019, which represents the normal functioning of the pandemic situation.

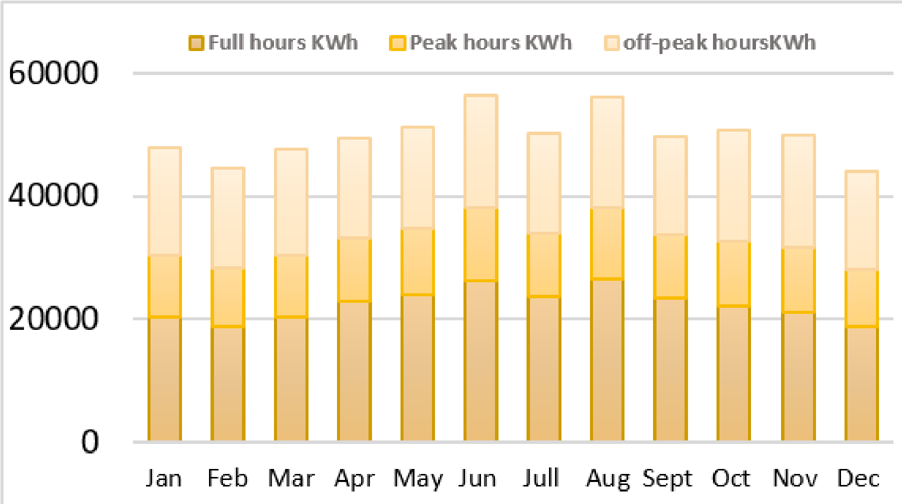

Figure 3. Monthly electrical load of the factory 1—Fez 2021.

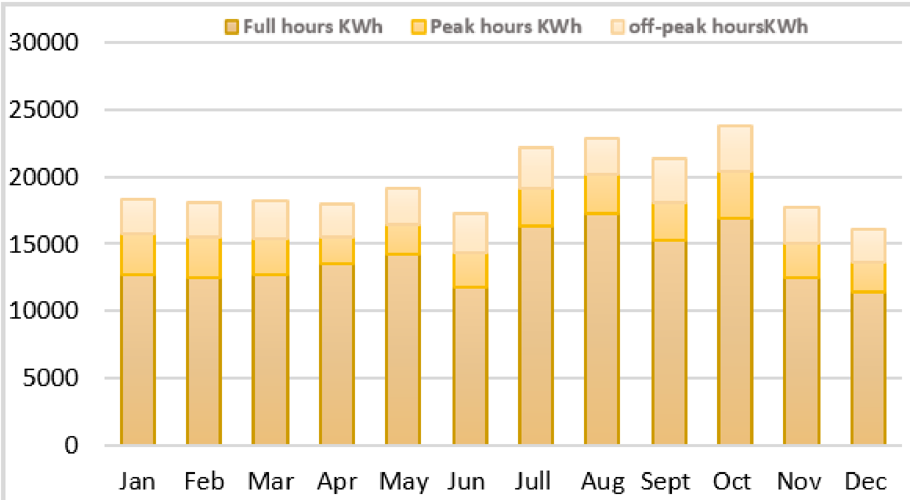

Figure 4. Monthly electrical load of the factory 2—Fez 2021.

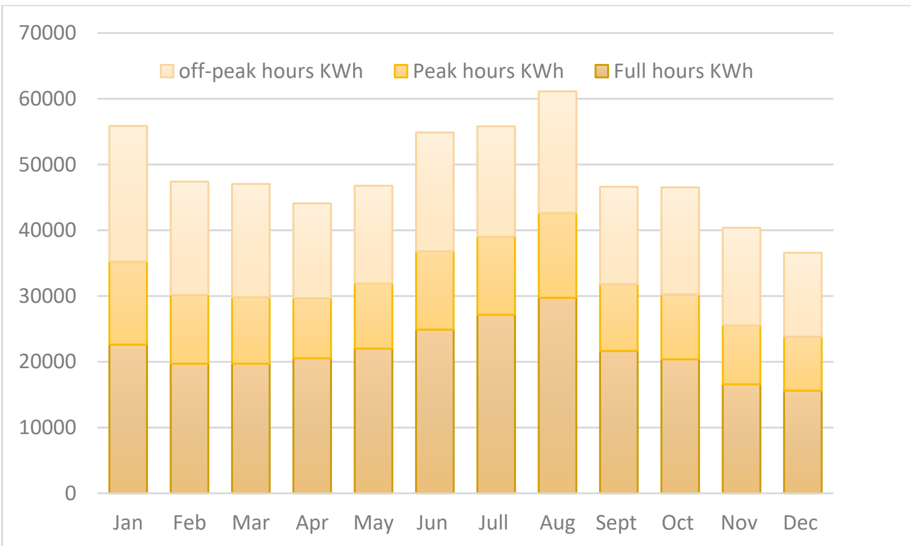

Figure 5. Monthly electrical load of the factory 3—Fez 2021.

Table 1. Survey summary on electric loads.

City	Companies	Total Energy Consumption (kWh/Year)	Daily Electric Profile (kWh/Day)
Casablanca	Company 1	1,813,766	5650
	Company 2	775,823	2424
	Company 3	274,925	864
	Company 4	4,389,956	12,724
	Company 5	215,960	674
	Company 6	67,211	210
	Company 7	102,125	318
	Company 8	113,098	353
Tangier	Company 1	2,305,000	7092
	Company 2	1,146,840	3583
	Company 3	1,649,550	5138
	Company 4	696,985	2178
	Company 5	946,163	2956
	Company 6	8451	27
	Company 7	231,187	720
Meknes	Company 1	45,372	142
	Company 2	289,364	904
	Company 3	95,539	298
Sale	Company 1	338,125	1056
	Company 2	462,075	1439
	Company 3	771,648	2403
Marrakech	Company 1	14,883,639	46,511
Agadir	Company 1	11,115,636	34,736
	Company 2	1,524,782	4750
	Company 3	5,256,697	16,427
Settat	Company 1	30,264,554	94,282
	Company 2	3,990,382	12,431

3.1.2. Solar Potential

Morocco is distinguished by different climate types: sub-humid, humid, arid and semi-arid. In recent years, climate observations in Morocco show that the semi-arid climate is progressing towards the north of the country, which poses a significant threat to socio-economic development and the lives of the population. Indeed, people's lives are very much linked to the climate and its fluctuations. Moreover, the natural vulnerabilities to which Morocco is constrained are water stress, fragility of vegetation cover, desertification and seismicity. Climate data from the country indicate significant warming during the 20th century, estimated at more than 1 °C with a significant intensity and frequency increase of extreme natural phenomena such as floods and droughts. The estimate of the region likely during the 21st century is in the range of 1 to 5 degrees Celsius [34]. Rainfall varies from more than 2 m per year on the northern reliefs of the country to less than 25 mm per year in the southern desert plains (MEMEE). In recent decades, there has been an overall decrease in rainfall, ranging from 3% to 30%, depending on the region. This reduction could reach 60% by the end of the 21st century compared to the 1961–1990 period.

Solar energy is the only secure and viable energy source in Morocco because it is abundant and has a high potential. It is one of the most suitable and feasible renewable energy sources in Morocco. The average incident solar radiation ranges from 4.7 to 5.6 kWh per day (Figure 6) and per square, representing 2800 h of sunshine per year for the least advantaged regions and more than 3400 h per year for the most advantaged regions [35]. Solar technologies are well suited to cope with the high consumption and the limitations of current energy generation patterns and also to complete and optimize existing energy production systems.

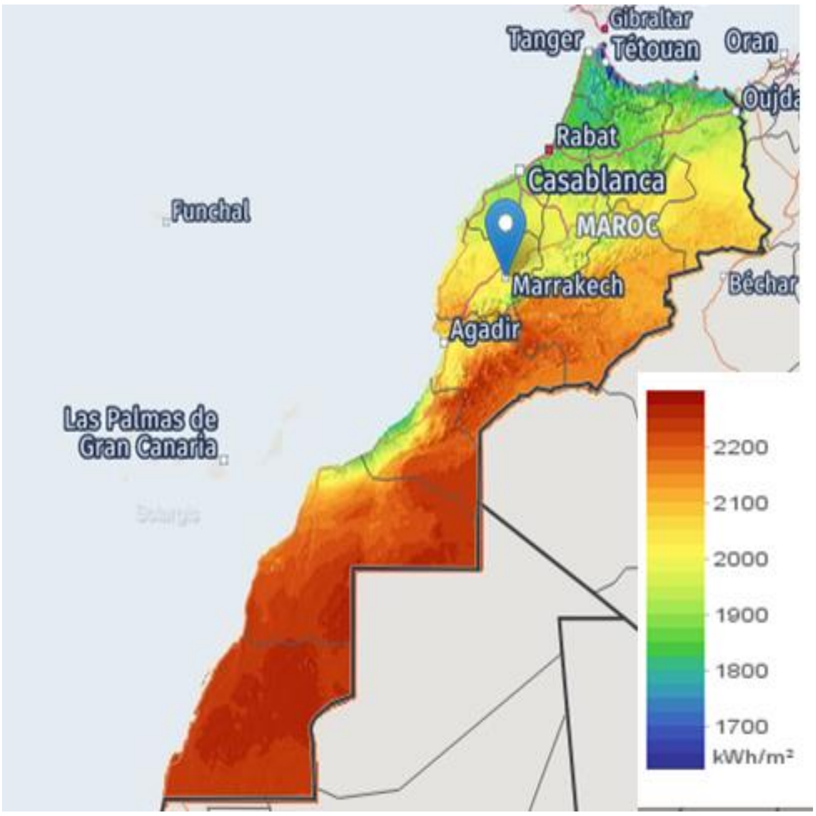

Figure 6. Moroccan solar potential [36].

Solar technologies are the conversion of solar radiations into electrical energy, and they can be classified into several categories, i.e., concentrating solar power (CSP), photovoltaic technology, etc. [37] Photovoltaic technology represents the direct solar energy conversion to electricity (the indirect conversion is, for example, when solar-heated steam is used to drive a turbine). As the cost of PV systems decreases with photovoltaic technology matures, in developing countries the demand for this solar technology increases exponentially [38].

3.2. Proposed Model: Theoretical Model; Methodology Follow

A compilation of qualitative and quantitative studies in the field of textiles was carried out to underline the exact energy profile of the selected industrial sites. The surveys were conducted in collaboration with manufacturers, heads of maintenance departments, and representatives of the Energy Efficiency Agency (AMEE). The variability of climatic conditions was taken into account, by selecting seven different cities in Morocco (Casa, Meknes, Fez, Settat, Salé, Marrakech, Tangier) (Table 2). However, three factories in the Meknes Fez region were carefully studied to generalize our conclusions on the remains of the rest of the selected sites.

Table 2. The selected sites.

City	Latitude	Longitude	Altitude
Casablanca	33°35′17″ N	7°36′40″ W	27 m
Meknes	33°53′36″ N	5°32′50″ W	531 m
Fez	34°01′59″ N	5°00′01″ W	406 m
Setat	33°00′03″ N	7°36′59″ W	365 m
Sale	34°01′46″ N	6°50′09″ W	11 m
Marrakech	31°38′02″ N	7°59′59″ W	457 m
Tangier	35°46′02″ N	5°47′59″ W	20 m

The methodology used in this paper was developed as technical, and as a policy approach to help identify the hybrid technology that should be prioritized. The final decision is based on mitigation potential under several conditions, in light the most important critical criteria like technical parameters, financial and economic feasibility, and sustainability considerations. In addition, the identification of variables that may hinder renewable energies integration in the industry was made, suggesting photovoltaics as a solution that deserves greater attention for a fluent energy transition.

The methodology's is organized in five steps (Figure 7), to assess, and answer the principal problematic issues. There are three main points to be considered when analyzing the results. Firstly, the methodology has been developed as a rapid measurement technical process using a mix of data sources depending on the availability in Morocco, with quantification of energy, climate, and environmental inputs in the textile sub-sector. However, the approach can be adapted and applied to any other industrial sub-sector. The study mainly used official national data and industrial sources, territorial investigations, and information. The data were collected by a team of national and local experts in close collaboration with country officials' departments. This work is the reflection of numerous visits and interviews with the various industrial players. We have carefully investigated the annual energy consumption of 27 SMEs in the Moroccan textile sector. The rest of the information from the remote sites was to be completed by e-mail or telephone with industrial partners. The electrical profiles of companies remain confidential, which is the reason why the company names are not revealed. The objective is to develop methodical work to inspire all SMEs in the textile and automotive sector and future academic work.

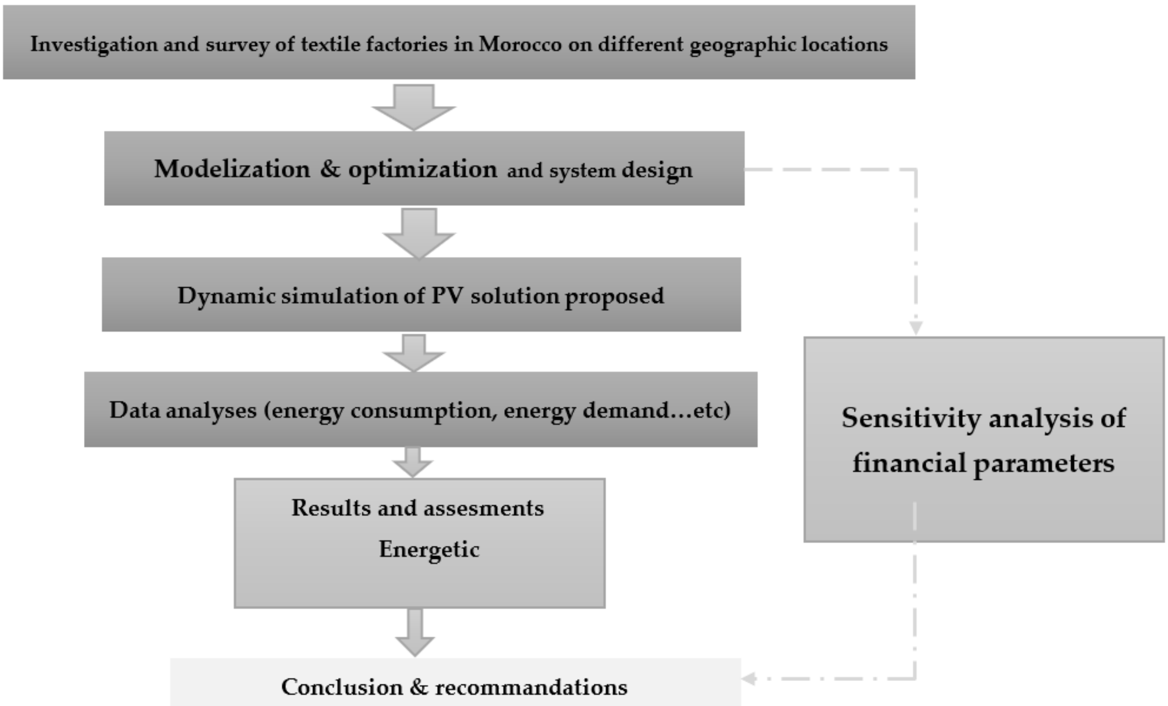

Figure 7. Analytical framework methodology.

In this paper, seven different locations were studied, introducing the photovoltaic technology as an improving action to reduce the energy bill and the environmental impact of fossil fuels. Different factories in each location were studied. For Fes city, three cases were deeply presented with more analysis detailed as a representative case of this study. The other cases in several Moroccan locations were presented in a summary analysis.

3.2.1. Proposed System Analysis

During the last decade, renewable energies systems have undergone significant development. Nevertheless, the integration of renewable solutions seldom varies by country, and even within the same country it varies from one region to another. In this work, the use of photovoltaics connected to the grid was selected as the most suitable to relieve the energy bill of textile factories and to reduce their carbon footprint.

However, as mentioned previously, hybrid systems combining multiple sources, such as renewable energy systems and the national distribution network or conventional sources, can be promoted for future works. These systems' main challenge is ensuring flexible energy management. Indeed, the energy management strategy implementation must match demand with supply. These systems must guarantee financial viability and environmental sustainability, allowing energy efficiency and reduced electricity bills. Consequently, limiting the systematic use of the national electricity grid, typically using non-renewable sources, thus supporting the sustainable and social development of the population in the rural areas. In fact, several works have used the techno-economic feasibility of solar PV systems [39] for offshore energy [40,41], or those connected to the grid [42–44]. Isolated systems with batteries are often used for remote sites [45–47] and agricultural practices [48,49], but their large-scale integration remains limited. However, grid-connected systems are intended to provide clean electricity to the power grid. These final selections find several uses for private customers linked to the grid, distribution centers, and especially to the territorial and industrial sectors. Several solutions can be proposed by hybridizing with diesel engines [50,51], CHP machines [52], biogas and wind power [53,54].

Using Hybrid Multiple Energy Resource Optimization (HOMER) software, the applied loads were the annual consumption of the textile factories taking into account the consumption in peak hours, while the climatic data for the different regions are collected and processed by triangulation. The grid-connected system turned out to be the most reliable option for the industrial sector in Morocco. The network link can provide storage. Therefore, the batteries are added to the selected configuration and can be deleted in the optimal solution. The general configuration of the proposed system is described in Figure 8.

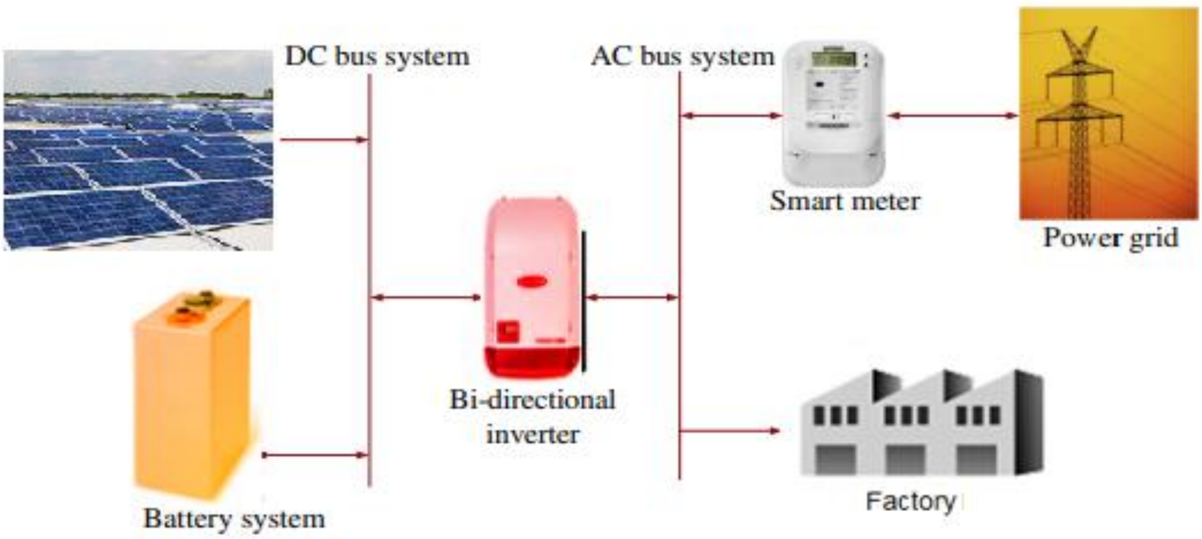

Figure 8. PV on-grid system with storage.

3.2.2. Mathematical Model

PV systems are one of the most suitable next-generation renewable sources. Batteries can offer a better solution for stand-alone systems to compensate for the mismatch between the system power production with the load demand. Exceptionally for hybrid systems connected to the grid, the electrical storage can be optional, as in the case optimized in the current study.

The Photovoltaic energy can be expressed as follows:

$$P_{pv} = P_{stc} \cdot Y_r \cdot \frac{G_{pv}}{G_{stc}} \tag{1}$$

Under standard test conditions (STC), P_{pv} is the power generated, Y_r is the rated capacity factor; G_{pv} the incident solar radiation per the PV collector surface unit (W/m^2), and G_{stc} is the incident radiation at STC (kW/m^2). The PV module efficiency/yield is evaluated under standard test conditions, representing the conversion of the received radiation into electricity at its maximum power point, calculated as follows:

$$\eta_{pv} = \frac{P_{pv}}{A_{pv}\ Irr_{STC}} \tag{2}$$

where, A_{pv} is the surface of a solar PV panel (m^2) and Irr_{STC} is the irradiance under STC.

The battery state of charge (B_c) at a specific time of load is given by Equation (3):

$$B_c = B_c(t=0) + \eta_c \sum_0^t B_{cb}(k) + \eta_d \sum_0^t B_{db}(k)s \tag{3}$$

where B_c (t = 0) is the battery initial state of charge, B_{cb} is the battery electrical power charged, and the power discharge is expressed as B_{db}, η_c and η_d are the charging and discharging efficiencies.

The inverter is a critical element in the system. Connected between the DC and AC busses, the inverter converts the DC power output generated to the AC load, with a supposed constant inverter efficiency (ηInv) of 98%. The AC power output is calculated as follows:

$$P_{out} = \eta_{Inv}\ P_{pv} \tag{4}$$

The performance ratio is a critical parameter, which depends on the system's final yield Y_f on Equation (5) and reference yield Y_r expressed by Equation (6).

$$Y_f = \frac{E_{net}}{P_o} \tag{5}$$

Po is the Installed PV system power on kW, and Enet is the net energy output expressed on kWh.

$$Y_r = \frac{H_i}{G_r} \tag{6}$$

The PV reference irradiation on the studied location is expressed as G_r on kW/m^2, and the Total plane irradiance H_i is expressed on kWh/m^2.

To evaluate the PV system performance an important factor must be calculated. It is expressed as a ratio in Equation (7) [55].

$$PR\ \% = \frac{Y_f}{Y_r}\ 100 \tag{7}$$

3.3. Economic Analysis Model

The metrical economics used in the conducted study are the net present cost (NPC) and the simple payback period (SPBP). Therefore, the cost of electricity (COE) and the capital cost of the selected system are essential to elaborate a sensitivity analysis on the NPC. The CEO uncertainty is also verified, considering the variation of the financial indexes (inflation, discount rate). The NPC and the COE are two very significant indicators; the categorization of the possible configurations is made by comparing the NPC. Therefore, the most optimal configuration is with the minimum NPC. This Financial Index contains the investment (setting up costs, maintenance costs, replacing cost) the system revenues realized during the project's life cycle. The NPC and the COE negative values explain that the income generated by electricity injection to the grid is more important than the total costs and the purchase of electricity.

(a) Net present cost (NPC)

Over 25 years, which represents the total project lifetime, NPC is an assessment made of the costs incurred by the HRES minus the revenues reported by the system. NPC includes the capital/investment, replacing, operation and maintenance cost. NPC is an important economic factor of renewable systems [56]. This parameter must be calculated for each system component and the system as a whole as presented in Equation (8).

$$NPC = \sum_{0}^{25} \frac{AA_{TC}}{(1 + i_r)^n} + I_{cc} \quad (8)$$

AA_{TC} is the adjusted annual total costs, i_r is the discount rate, n is the project lifetime and I_{cc} is the initial capital cost.

(b) Simple payback period

The simple payback period (SPBP) is worn out to define the time intended to attain the break-even point and recover the equities expended in an investment. Practically, a SPBP of 5 years is accepted for renewable solutions [57]. The SPBP can be calculated as follows:

$$SPBP = \frac{I_{cc}}{\text{Annual saving}} \quad (9)$$

(c) Cost of Energy (COE)

Based on the electrical energy production of the PV system, the necessary average cost per kWh represents the levelized cost of energy (COE), the ratio between divides the electricity production annualised cost of producing electricity (the total annualised cost minus the serving the thermal load cost) and the total electric load served, represent the calculation formula of COE as shown in Equation (10) [58].

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (10)$$

where $C_{ann,tot}$ is the system total annualised costs, and E_{served} is the served total electric load expressed in kWh/year.

3.4. Environmental Assessment and Sustainability Management

In the present section, an environmental assessment of the system proposed is carried out using ABC Carbon method and HOMER platform under the Moroccan clima condition. ABC Method is used to calculate fundamental metrics: Total annual GHG emissions and the equivalent of costs.

The aim is to compare the selected configuration with different optimized systems. The environmental assessment represents the annual CO_2 emission and is determined by multiplication of the electrical demand and the emission factors and respecting this, the result contains a margin of uncertainty depending on the collected data and the emission factor used. The emission factors of electricity by using Morocco's Environment and Energy Management Agency (ADEME) factor is about 0.682 kg CO_2/kWh [59].

In a general approach, the sum of GHG emissions avoided by solar systems (EMAV.Grid) is developed considering that 1 kWh generated by PV systems is equivalent to 1 kWh obtained from the Moroccan electricity grid. The CO_2 emissions avoided are expressed by Equation (11). The on-grid system emission factor was estimated under local estimation with 50 g CO_2/kWh for PV systems [60].

$$EM_{AV.Grid} = \frac{E_{Pv}\left(F_{grid} - F_{PV}\right)}{10^6} \quad (11)$$

where F_{PV} is the emission factor related to PV technologies.

In the present section, the sustainability assessment is also carried out together with the GHG quantification. It is agreed that swelling the percentage of renewables penetration in the system reduces GHG emanations. It is necessary to calculate the total renewable production. To calculate renewable fraction (RF), the following equation is used:

$$FR = 1 - \frac{E_{nnR}}{E_{serv}} \quad (12)$$

where E_{nnR} and E_{serv} are the nonrenewable electricity, and the energy served, respectively in (kWh/year).

4. Results and Discussion

HOMER is an optimization tool for RE hybrid systems developed by the National Renewable Energy Laboratory in the United States. The optimal model has been developed following thousands of simulations based on the variability of critical technical and economic inputs (radius, price fluctuations, energy fraction, system cost, etc.)

The proposed systems are favoured and sorted according to the lowest COE and NCP values. However, the possible configurations are compared according to the costs, the electricity production, the sizing and the renewable energy fraction. The performance and sensitivity results are detailed for the most optimal configuration for the three plants in the Fes region to be carried and generalised to all the national plants.

The potential energy savings percentage in the vast majority of textile companies can range from 15 to 70%; this justifies the adoption of these systems, because of their economic impact, and their environmental contributions. After the whole simulation process, different configurations were checked. In this study, among many configured energy systems, three photovoltaic scenarios are evaluated, PV/biogas hybridization is excluded from our proposals for the textile sector, considering technical and economic limits of this industrial sector.

4.1. Detailed Case: Fez Region

(a) Scenario 1: grid-only system

The connection to the grid-only is the conventional solution adopted to ensure electricity to the textile industries, the same in Morocco and several countries. The Figure 9 shows the monthly energy consumption profile for the three plants located in 3 different locations (industrial districts).

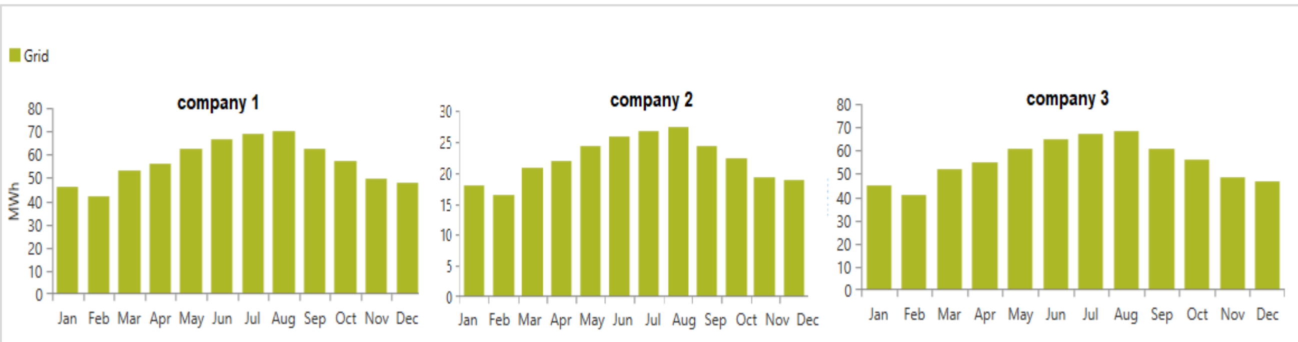

Figure 9. Monthly electric load for the three companies (Fez region), 2021.

The consumption profile is the same for the three factories, the consumption increases during the summer against a fall in the winter. The maximum consumption is recorded in August with a value of 70, 27 and 68 MWh, respectively, for companies 1, 2 and 3. The minimum for the three cases is visualized in February between 18, 48 and 45 MWh in the same order. The consumption increase in the summer is explained by the air-conditioning system's demand necessary for the workspaces. It is also generated by the fall in the efficiency of the machines used due to the excessive heat.

The difference in results is between plants and is explained by their size, where the most extensive plant records the most significant consumption. However, the present study reveals the limits of this classic solution. Even if its initial cost is negligible, the network configuration presents the situation with the highest COE (Table 3). Furthermore, as seen in the Table 3, CO_2 emissions are very critical for the three factories.

Table 3. On-grid system for the lead companies (Fez Region).

Architecture	Electric Load	Grid	NPC	COE	Operating Costs	Initial Capital	Energy Purchased	CO_2
Hybrid On-Grid	**(kWh/Day)**	**(kW)**	**($)**	**($)**	**($)**	**($)**	**(kWh)**	**kg/Year**
Company 1	1868	999,999	871,394	0.1	68,166	0	681,663	430,811
Company 2	728	999,999	339,709	0.1	26,574	0	265,743	167,949
Company 3	1822	999,999	850,292	0.1	66,516	0	665,156	420,378

(b) Scenario 2: PV grid-connected system

The use of photovoltaic systems connected to the grid on the roofs of industrial sites has started to spread in several countries, in various production subsidiaries. The continual fall in the price of PV, and the installation of regulations and synergies supporting the use of renewable energies, have also supported industrial ecology and SMEs to invest in these sustainable solutions.

Three of these industrial companies, which operate different regions, were selected for a technical and economic evaluation. Each of these PVs was evaluated according to the roof surfaces availability, and the results of carbon balances (ABC) developed within the framework of the "Tatwir" national program.

The systems measurements analysis aims to evaluate the performance of grid-connected PV systems, obtained to calculate the main parameters as annual energy produced. Table 4 presents the PV systems proposed for the three cases of the factories in the Fez region, the capacity installed and the systems production.

Table 4. PV systems capacities and productions (for the three factories).

Company	PV Installed (Kw)	Energy Production (kWh/Year)
Company 1	250	425,033
Company 2	165	280,522
Company 3	250	425,669

In the optic of detailed each case for each company, Figure 10 shows that the system can produce up to 425,033 kWh of electricity per year for the company 1, and a photovoltaic generator produces 50.5% of it. 49.5% of balanced electricity is purchased from the grid to provide electricity when needed. Considering 83.2% of the total electricity consumption used by ensuring the AC load, against a percentage of 16.8% that is sold to the grid.

Accordingly, energy purchases occur during peak hours, where the prices are maximums. The use of batteries can remedy this limitation but will add additional costs and increase the COE and the inverter's capacity. The COE for the PV-grid only system is 0.054 dollars for 1 kWh. However, the NPC of the grid for this system is $572,940. Furthermore, the Table 5 represents the cost summary of components during the project lifetime. Thus, according to our comparison studies, the proposed system is the least tenacious in greenhouse effect emissions, with 263,475 kg CO_2/year.

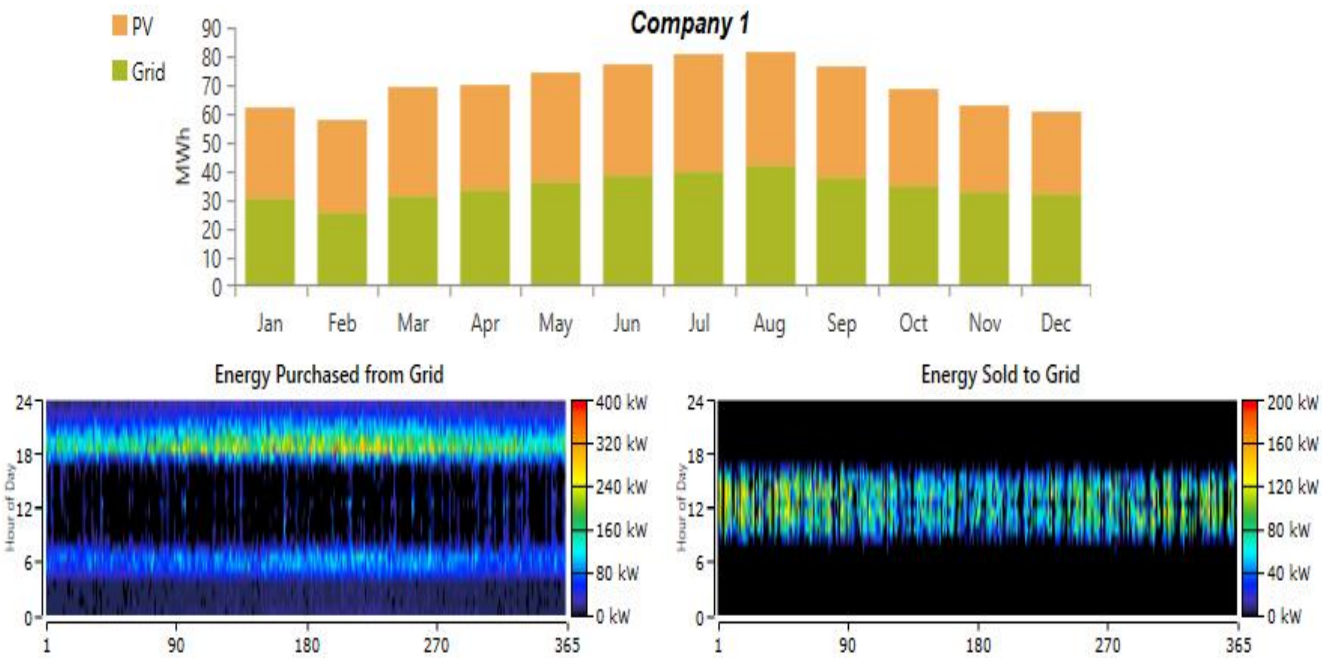

Figure 10. Company 1 system production, 2021.

Table 5. The cost summary of the project in the lifetime.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic/flat plate PV	75,000.00	0	31,958.39	0	0	106,958.39
Grid	4500.00	0	445,014.95	0	0	449,514.95
System Converter	12,292.50	5129.23	0	0	954.71	16,467.02
System	91,792.50	5129.23	476,973.34	0	954.71	572,940.36

Accordingly, energy purchases occur during peak hours, where the prices are maximums. The use of batteries can remedy this limitation but will add additional costs and increase the COE and the inverter's capacity. The COE for the PV-grid only system is 0.054 dollars for 1 kWh. However, the NPC of the grid for this system is $572,940. Furthermore, Table 5 represents the cost summary of components during the project lifetime. Thus, according to our comparison studies, the proposed system is the least tenacious in greenhouse effect emissions, with 263,475 kg CO_2/year.

For company 2, an optimal system with a PV array of 165 kWp capacity has been installed for this company. The PV array has been interfaced with the grid via an inverter of 135 kW. During 4382 h, this PV-installed capacity can produce annually 280,522 kWh, with a significant renewable fraction of 65.2% (Figure 11a,b).

The generated electricity is utilized as follows: 63.9% (265,720 kWh/year) is consumed by the users, 36.1% (149,875 kWh/year) is sold back to the grid, and 5% was considered for transmission losses. Thus, Figure 12 represents the net energy purchased monthly by the installed model. As perceived, the system is more profitable during the hot month, with total net energy purchased of 76 kwh. Therefore, the total initial cost of the model is taken as USD $49,500. The system lifetime is taken as 25 years with an average efficiency of 90%.

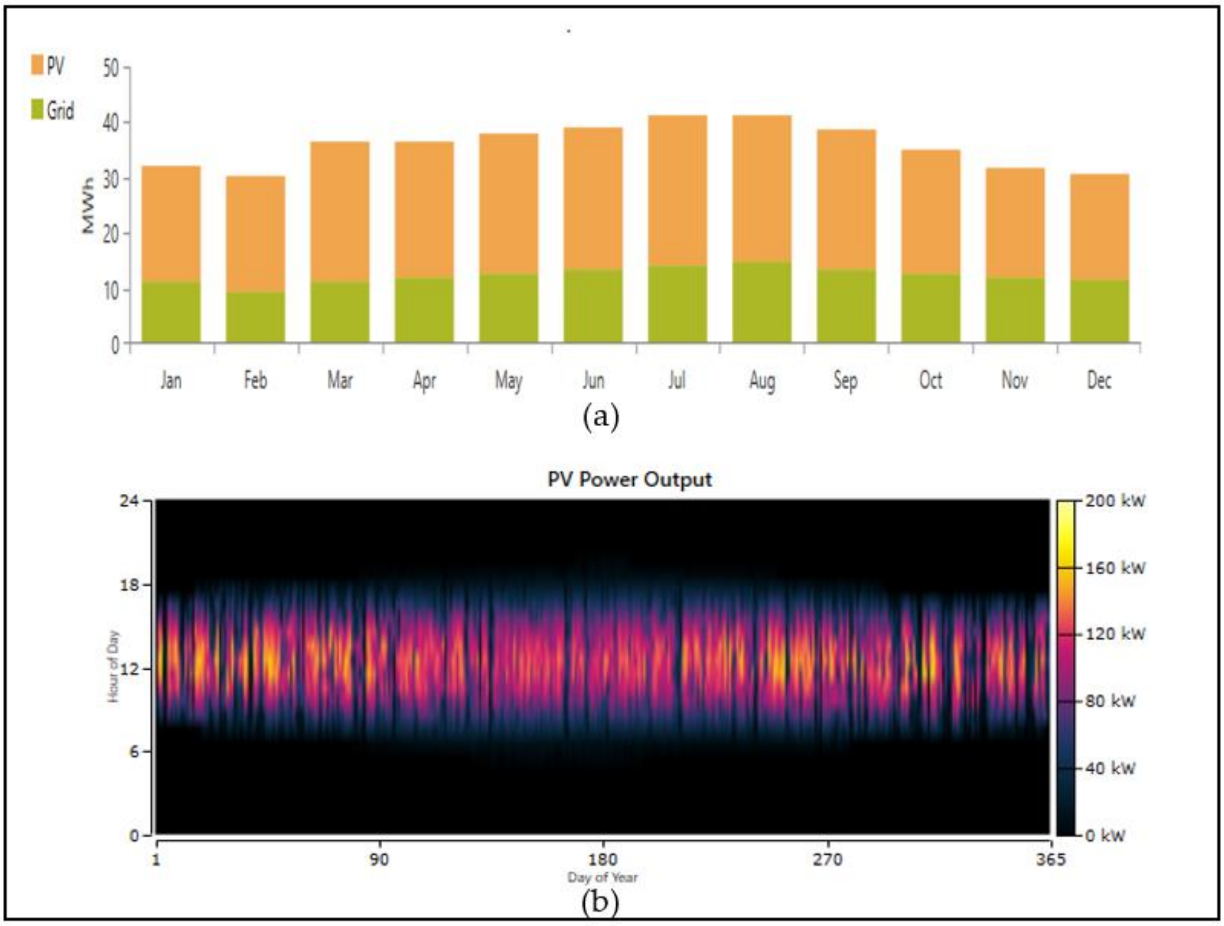

Figure 11. Company 2 production profiles. (**a**) monthly PV production, (**b**) the PV hourly production.

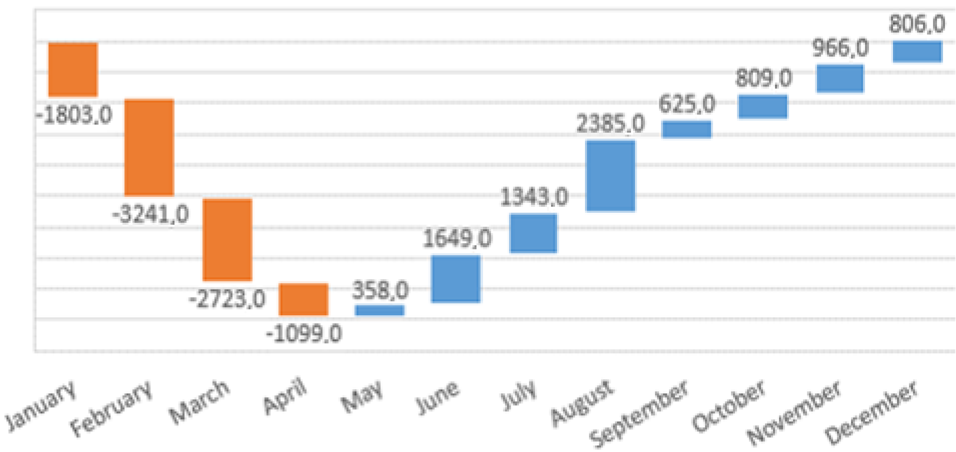

Figure 12. Annual production purchases profile.

The simulation results show attractive economic parameters, with an LCOE of 0.034 \$/kWh and \$181,863 for the NPC parameter. As shown in Figure 13, the total NPC can be justified by the high capital PV investment and the O&M costs of the grid connection. Generally, the model proposed is a friendly and optimal solution, with the lowest carbon emission of 94,769 CO_2 kg/year.

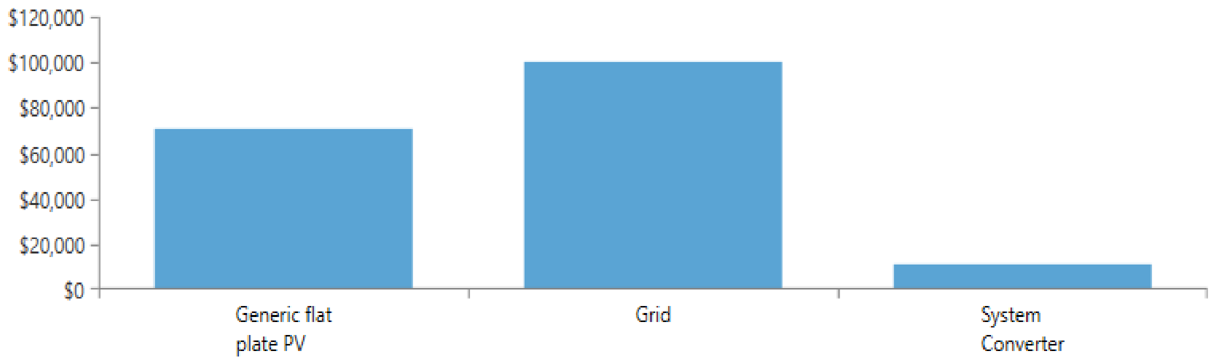

Figure 13. Summary on investment costs.

Moreover, in order to demonstrate the influence of climatic variations and solar radiation, we have agreed to install the same photovoltaic capacity (250 kW), for sites 1 (company 1) and (company 3), seeing that their energy needs are close and almost identical (1868; 1.822 kWh, respectively). The distance which separates the two sites is 26 km. The monthly production profile of the proposed system is illustrated in Figure 14 and the renewable penetration is about 49.9%. In contrast, the amount of carbon generated is 255.670 kg/year.

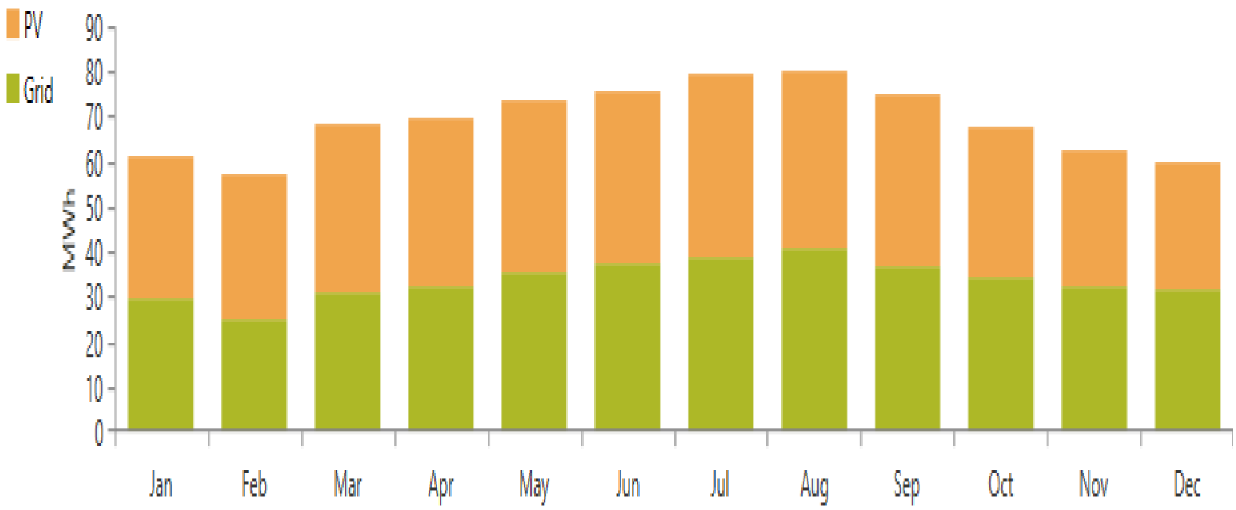

Figure 14. Monthly renewable production for company 3.

The LCOE generated by the system install is $0.05 compared to $0.03 for site 2, despite the climatic conditions and the maximum production of site 3. This is explained by the purchase price of electricity, which is relatively low in Morocco, and likewise, the quantity sold is injected during the full hours. In this case, 82% (665.030 kWh/year) of the generated energy is consumed by the users while 17.7% (142.684 kWh/year) is sold back to the grid. Respectively, Figures 15 and 16 represent the profile of the energy exchanges with the network and the summary of the system's cash flow. Generally, the critical analysis of the results shows that the PV grid systems are more efficient, beneficial and friendly to the environment, if we compare them with the traditional system (only-grid) most used. Furthermore, it is observed that by reducing the initial installation costs (which include the capital cost of PV, connection cost and other associated costs), the cost of electricity (COE) can be drastically reduced. In addition, it has been observed that radiation plays a significant role in the economic viability of this system.

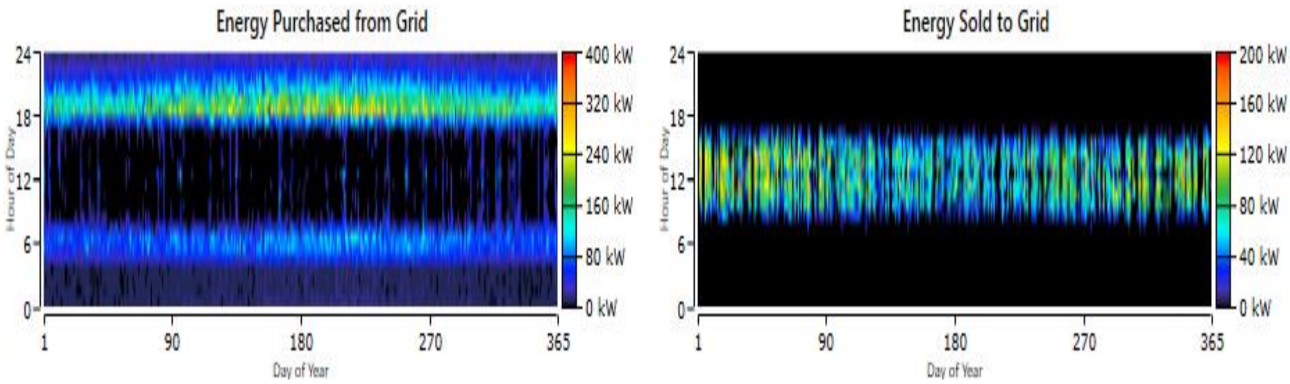

Figure 15. Energy exchange with the grid for company 3.

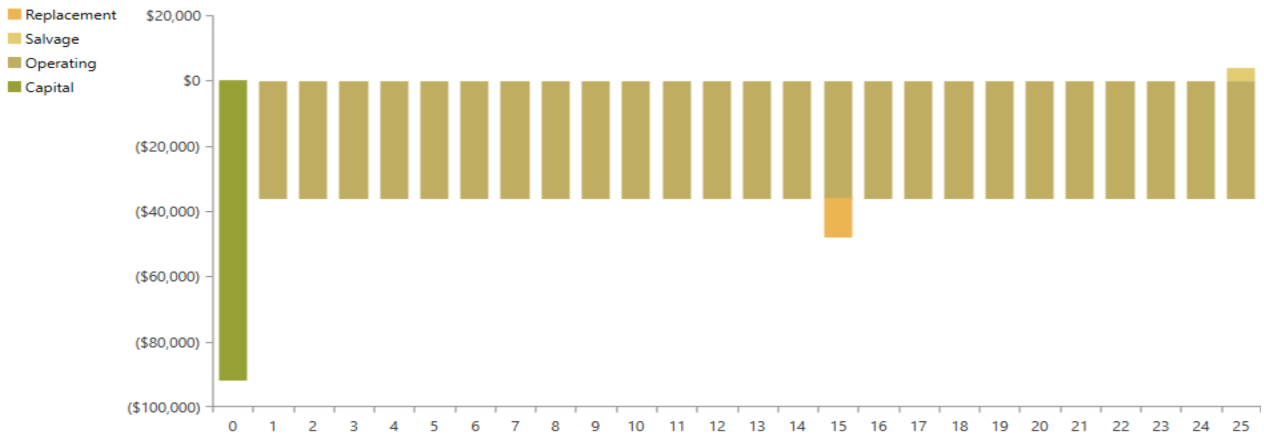

Figure 16. Summary of the system's cash flow.

4.2. Optimal Decisions for Other Zone Company

The optimal sizing approach used for the representative case study of Fez is applied to the various industrial sites studied, taking into account the technology and the type/number of inverters and the inclination of the photovoltaic modules. The main objective is to compare the performance parameters obtained from the previous three main sites in Fez city with those reported at various climatic conditions and geographic locations, and also to present a complete study of the majority textile industrial locations in Morocco. For each location, we presented different cases studying various factories sizes and demands to cover all climatic and functional influencer conditions. A summary is presented in Table 6.

A power of 8.88 MW is the total power installed in seven Moroccan cities, represented by 27 various existing textile factories. This study converges on the new Moroccan strategic vision of the industrial sector decarbonization, where an annual total of 8484.65 tonnes of CO_2 can be provided. Moreover, the energetic results show that the dry regions generally have an appropriate solar radiation, which allows an efficient performance factor for photovoltaic power plants, increasing the renewable fraction. This explains the attractive LCOEs for these regions. The payback time is reasonable and optimal for all the sites studied and does not exceed 4, with an average of 2.6 years and 4.5 years in the case step. This indicator depends on several parameters, as shown in Table 6. It depends on the size of the site, the initial investment, and the solar fraction (renewable) depending on the climatic conditions of the site and the operating costs. The monthly distribution of photovoltaic production is uniform for all plants (casa example). The same look is reproduced for all of the plants. It is explained by the same climatic conditions as the geographical area where they are located. The difference is in the power output, which varies according to the plant size and the proposed installation, but they all remain of the same form (pick and fall).

Table 6. Summary results for different factories.

Cities and Main COMPANIES		Pv (kW)	Converter (kW)	Production (kW/Year)	COE ($)	NPC ($)	Simple Payback (Year)	Operating Cost ($)	Initial Cost ($)	RF %	Saved CO_2 (kg/Year)
Casablanca	1	554	750	938,907	0.069	1.91 M	2.88	132,541	215,625	39.9	469,232
	2	300	246	508,739	0.057	761,546	2.93	51,028	109,235	46.7	211,753
	3	120	97.7	203,496	0.053	264,823	3.18	17,089	46,365	50	78,000
	4	604	507	1,024,262	0.084	5.01M	2.39	374,756	216,105	21	606,241
	5	75	62	127,185	0.062	221,564	3.14	14,931	30,695	43.6	56,821
	6	40	32.5	67,832	0.043	60,573	2.17	3295	3295	59.1	20,372
	7	50	40.4	84,790	0.05	96,304	3.75	5819	21,932	53.7	43,755
	8	65	53	110,227	0.043	100,185	3.74	5711	27,178	58.2	34,009
Tanger	1	650	514	1,068,053	0.069	2.44 M	2.67	172,929	231,988	36.8	539,373
	2	320	262	525,811	0.07	1.24 M	3.01	88,228	116,203	36.1	268,872
	3	520	426	854,443	0.066	1.74 M	2.75	120,578	186,078	39.7	409,229
	4	350	282	575,106	0.049	642,671	2.84	40,385	126,416	53.2	200,435
	5	350	285	575,100	0.06	955,512	2.91	64,845	126,845	44.3	250,038
	6	65	52.6	106,514	0.035	70,613	3.02	3400	27,154	64.4	26,994
	7	75	60	123,237	0.066	244,172	3.16	16,707	30,954	40.5	58,046
Meknes	1	45	37	76,477	0.024	31,455	4.63	26,200	20,214	72	15,060
	2	45	39	76,470	0.084	356,677	4.75	26,310	20,346	22	45,112
	3	50	40	84,974	0.047	88,269	4.67	5189	21,934	55.6	28,211
Salé	1	120	98	206,210	0.06	340,123	2.95	22,977	46,398	44.6	90,502
	2	150	124	257,762	0.063	473,073	2.82	32,551	56,959	42.1	119,551
	3	175	144	300,722	0.075	863,102	2.35	62,385	65,618	31.6	165,125
Marrakech	1	920	787	1,556,028	0.093	20.3 M	2.37	1.56 M	327,736	8.7	1,476,360
Agadir	1	650	553	1,195,707	0.093	15.1 M	2.18	1.16 M	232,704	10	716,795
	2	460	379	846193	0.063	1.53 M	2.46	106,910	165,210	42.1	369,420
	3	560	474	1,030,148	0.087	6.7 M	2.09	508,371	200,960	16.3	615,858
Settat	1	920	751	1,549,333	0.096	42.6 M	2.37	3.30 M	325,559	5%	927,136
	2	650	536	1,094,637	0.082	4.81 M	2.41	358,412	231,683	22.8	642,354

4.3. Sensitivity Analysis

To better provide the feasibility of PV grid systems, this section aims to study the dynamic of performance and financial model results. Thus, sensitivity analysis is performed to investigate the viability of the third system proposed to supply an average daily need of 1868 kWh.

The sensitivity analysis involves assigning multiple values to one or more input variables in order to explore the relationship between the input variables and resulting metrics. In the developed simulations and sensitivity analysis, several parameters were subject to dynamic variability and the radiation varies from [4: 4.5: 5: 5.5] kWh/m^2/day, to verify the viability of the system in different locations in Morocco. As perceived in Figure 17, solar variation strongly affects financial results.

The conducted sensitivity study considers the variability of economic variables (inflation, discount rate). As an example, for a fixed inflation of 5%, an increase in the discount rate from 8% to 12% will increase the COE from 0.053 to 0.055 $/kWh. Consequently, the NPC is reduced from 689,664 to $543,837.

Inflation also impacts the COE and NPC. As viewed in Figure 18, moving from a rate of 0% to 10% will reduce COE with 0.06 $/kWh and increase the NCP from $572,940 to $1,670,000. Note that these economic parameters also impact the technical performance and capacity of the components.

Otherwise, the current study carried out the flexibility of the system design, as shown in Figure 19. Thus, growing the capacity of installed PV plants can ensure low LCOE and a high renewable fraction, but it will add financial charges due to the increased inverter capacity. Thus, it can be found that PV/grid systems are flexible and efficient and can be applied to the industrial textile sector and can reach a low COE (0.02 $/kWh).

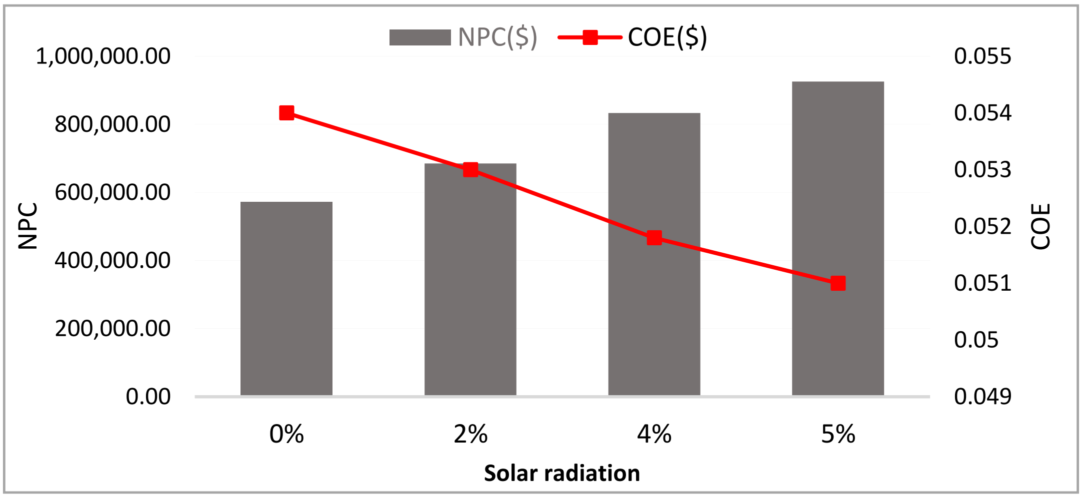

Figure 17. Solar radiation effects on COE and NPC.

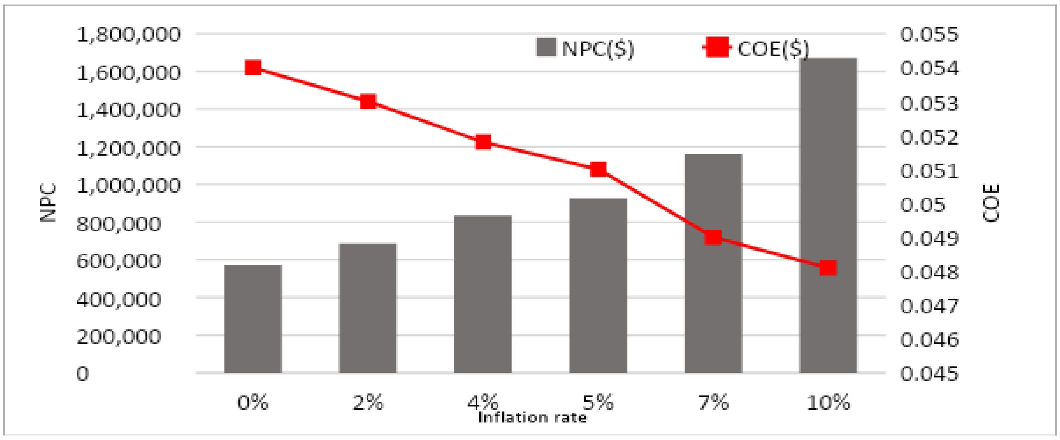

Figure 18. Inflation effects on COE and NPC.

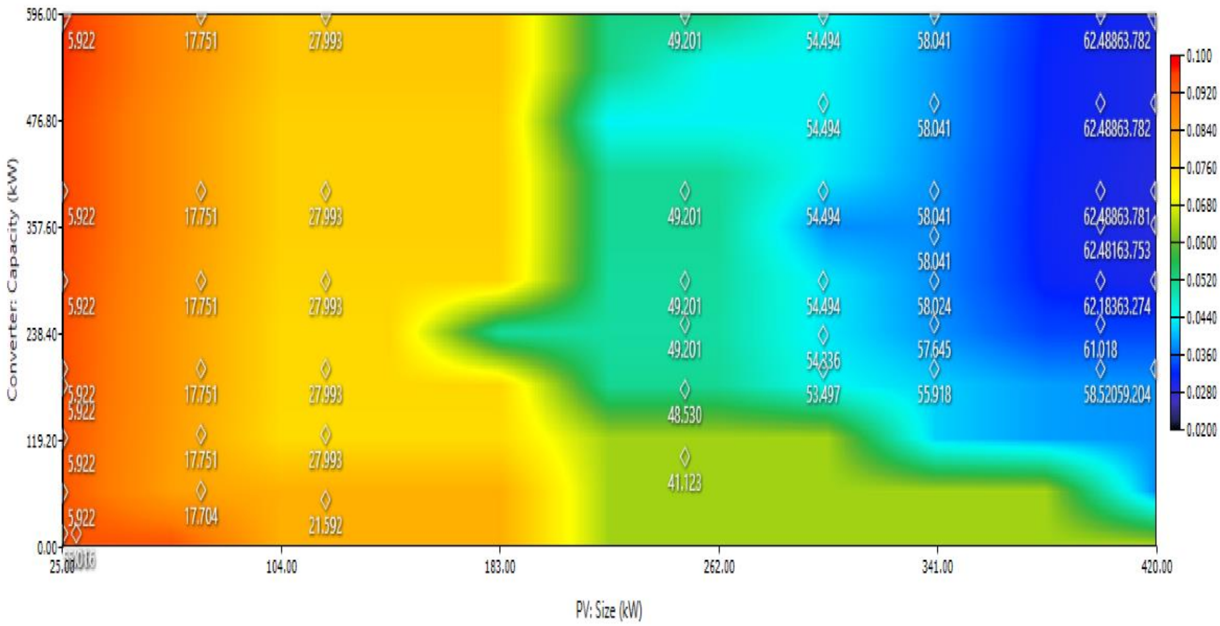

Figure 19. Effects of design parameters on COE and Renewable Fraction.

As calculated previously, the daily load of the selected company is considered to be 1868 kWh/day. To better consider the dynamic nature of the loads and by generalizing the proposed solution for the rest of studied companies, the energy demands are varied from 850 kWh/day to 2500 kWh/day. The performance of total NPC and COE has been measured accordingly. As shown in Figure 20, the COE and NPC of the proposed model increased with increasing loads and decreased for low energy needs.

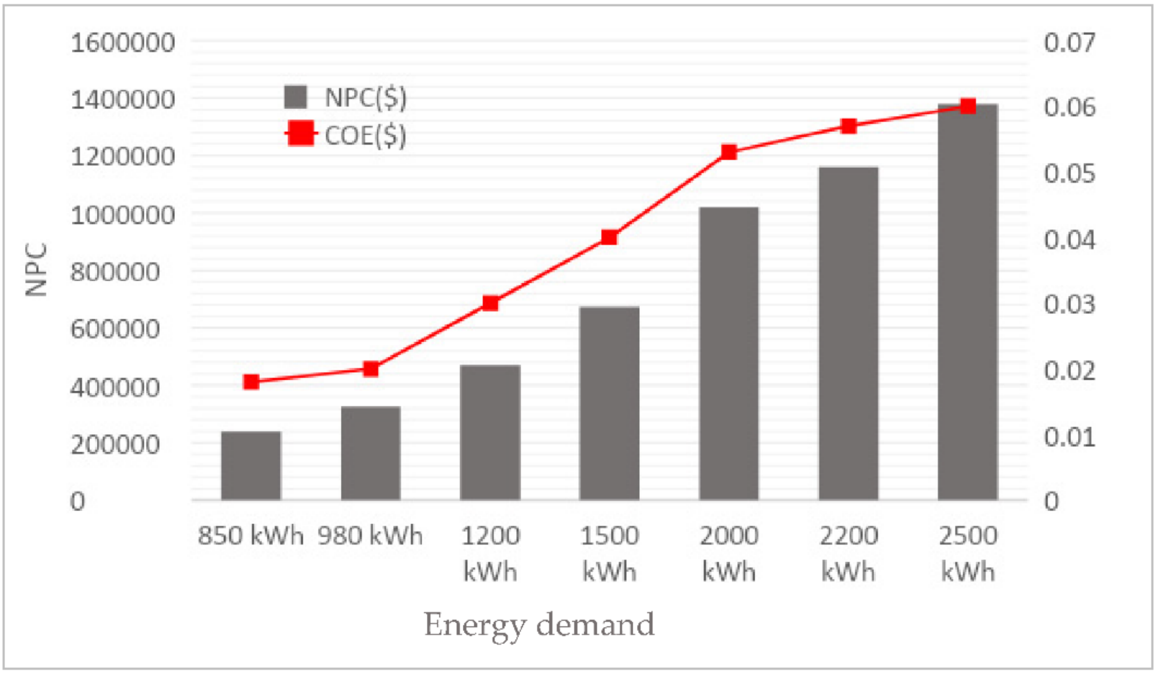

Figure 20. Effects of variability of loads on COE and NPC.

5. Conclusions and Recommendations

The paper highlights the importance of decarbonization in the industrial sector (taking textiles as a case study). We have used the textile industry sector in Morocco as a case study. It is reasonable to believe that our findings are valid and applicable to other sectors where barriers for deep decarbonation and emissions reduction tend to be high. It aims to shade the lights on the positive impact in terms of the coverage of electricity needs and the reduction of greenhouse gas emissions. It features a low-carbon industry capable of integration into the international market. Moreover, the work comes with the strategic orientation of today's Morocco eight in order to inspire academics, manufacturers, and SMEs to adopt PV grid-connected plants and hybrid systems, in their strategic, energetic, and environmental policies.

The techno-economic feasibility analysis of grid-connected PV for the industrial textile sector in eight different Moroccan locations was carried out. The Main Variables NPC, COE, and emissions were carefully measured as basic parameters to underline the feasibility of the proposed systems. The results quantify the importance of system integration in the industrial sector, which can exceed 600 kg/year in the case of a medium-sized plant, and can exceed 400 kg/year. The multiplication of this use on all the factories in the kingdom will succeed in presenting very significant figures in reducing harmful emissions. The avoided emissions exceeded 1500 kg/year only in the plants studied in Casablanca and exceeded 1483.16 tones/year for the total of plants treated in this paper. Moreover, the integration of these systems may be successful in all Morocco industrial localizations because of the favorable climate in the country and this is most beneficial in central and semi-arid regions, due to the high PV potential and radiation.

In this context, Morocco has already taken the lead in the Subsidies Directive for this kind of decarbonization project of the industrial sector to encourage them to participate in the low-carbon national vision. Despite all this, there is still a lot of work to do with the launch of more support and investment programs for the industry, which is now demotivated following the impact of the COVID-19 pandemic. However, the essential point that will complement the plan is the awareness of the actors of this sector by the importance of decarbonization and the ample energy and economic gains it can bring. This requires, before the financial support of the industrialists, investment in large-scale campaigns to raise awareness of all those involved in the Moroccan industry; that is, to clarify and introduce the importance of the decarbonation projects and their environmental, economic, and energetic benefits for the firm and the nation. Next, financial support as subsidies must be involved to motivate industrialists to invest in their first decarbonization projects. In this part of subsidies, a call for the collaboration of the banks is necessary to manage and facilitate the implementation of this national project properly.

The advanced decarbonization of the electricity sector and renewable energies deployment provide a favorable environment for industrial activities. Deep decarbonization of the electricity mix in 2040 and 2050 of 70% or 80% respectively is an essential and entirely conceivable first step. However, a significant reduction in industrial emissions requires going beyond the greening of the electricity mix and involves a range of measures, including energy efficiency, low-carbon electricity, increased electrification of uses, energy substitution, reduction of materials at source, reuse and recycling of materials and the digitization of industrial technologies and methods (automation and digitization of processes, internet of things, machine to machine communication, etc.) The rapid and continuous decline in the cost of renewable energy and storage validates the direction taken by Morocco. It allows the adoption of very ambitious decarbonization strategies focused on producing green electricity and hydrogen. A share of renewable energies of 70% by 2040 and 80% by 2050 in the electricity mix in energy and capacity is conceivable with the technologies and current cost outlook. Going beyond these rates could entail high additional costs, but the situation may change with the technological advances expected in the coming decades, allowing countries to successfully achieve their decarbonation and energy transition plans.

This work highlights the importance of mobilising industrialists and winning their support for the transition project; however, the techno-economic trajectories for the decarbonization of the industry still present uncertainties which must be considered carefully.

To process this kind of study, the limiting constraint is the availability of data on the entities to be studied to come out with realistic, applicable, feasible and reliable results adapted to the conditions of the studied contexts. This project is one among many prospects to treat all the welcoming sectors of the decarbonation project in Morocco with a zero-carbon strategy.

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