Small Wind Power (SWP) as a Renewable Energy Source in Morocco

Lhoussaine Tenghiri (2), Rachid ZAIR (1), Sallem Koubida (2), Anas Bentamy (2)

(1) ONEE - Branche Electricité, 65, rue Othman Ben Affane
20000 Casablanca Maroc

(2) Al Akhawayn University, P.O Box 104, Hassan II Avenue, 53000 Ifrane, Morocco

Author contact email: a.bentamy@aui.ma

Abstract. This paper has two main objectives: (1) to identify the causes behind the low penetration of SWP in Morocco, and (2) to study the design of a horizontal axis wind turbine for domestic applications in the Moroccan context by following the design requirements of the international standard of small wind turbines IEC 61400-2. The three most relevant barriers in Morocco are found to be in this order: a) the regulatory barrier, b) the technical barrier and, c) the financial and market barriers. Further, a proposed design of a 11 kW SWT power that would be the most in demand helps in identifying clearly the technical barrier. Within the list of components of this typical design, locally manufactured components are limited to the rotor, the main shaft, the nacelle cover and frame as well as the tower and the foundation. The total cost associated to these components is very low compared to the other imported components in the wind turbine assembly. The constraint of designing a 11kW SWT's economic viability can therefore only be fully satisfied if all components are locally produced.

1. Introduction

Under the Kyoto Protocol, Morocco has not been bound by any reduction in the emissions of dioxide carbon and other greenhouse gases. Morocco has, however, voluntarily implemented several measures to reduce its dependence on external energy sources as well as to participate in the global climate change mitigation efforts in various economic sectors (energy/electricity; transportation; construction/housing; etc.) [1]. A complete system of organisations has been established to oversee and develop the sector of renewable energies (RE). Although these organisations perform seemingly diverse activities, they share the same goal as to mobilize the national renewable energy potential. The main RE organisations are:

- MEMDD\(^1\) - Morocco’s ministry of energy, mines and sustainable development. The ministry’s main responsibility is to develop the national energy strategy, including the renewable energy sub-strategy. The organisations presented subsequently assume their effective and efficient operational responsibility for the implementation of the national energy strategy.

- ONEE\(^2\) – Morocco’s electricity and water utility public company. Since its creation in 1963, the electricity branch (ONEE-BE) enjoyed monopoly role in the power production and transmission activities. ONEE-BE lost its monopolistic position in the power production business by the end of

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\(^{1}\) MEMDD : Ministère de l’Energie, des Mines et du Développement Durable.

\(^{2}\) ONEE : Office National de l’Electricité et de l’Eau Potable.
the 1990s when Morocco felt the need to open-up the energy sector to other private producers to meet the fast-growing national demand for electricity. Other private organisations also joined the distribution sector which was already shared with other national agencies, especially in the major urban centres. The electricity transport activity remains to this date monopoly of ONEE-BE, who is acting as the electricity grid operator.

- **AMEE** – Morocco’s agency for energy efficiency. Created in 2010, this agency is in charge of developing and implementing national energy efficiency programmes.
- **MASEN** – Morocco’s agency for sustainable energy. Similar to AMEE, this agency was created in 2010 following the announcement of the national energy strategy in 2009 which set aggressive targets for the national RE sector. MASEN’s initial attributes covering only the mobilisation of the national solar energy potential were later extended in 2015 to take over all the RE projects and assets of ONEE-BE, being noted that the later organisation is a 50% shareholder of MASEN.
- **SIE** – Morocco’s energy investments company. Also created in the wake of the announcement of the 2009 national energy strategy. Its role is to assist in structuring and financing the energy projects developed by other organisations (mainly ONEE-BE and MASEN).
- **IRESEN** – Morocco’s renewable and new energies research institute. It was created in 2011 as a research organisation to facilitate the implementation of the 2009 national energy strategy.

In 1997, ONEE-BE began developing major utility-scale wind energy projects starting with the *Abdel khalek Torres* demonstration project with an installed capacity of 50 MW. This project consolidated an existing and mature hydroelectricity generation infrastructure.

The objective of ONEE’s renewable energy programme was, and still, to increase the share of clean energy in Morocco’s electricity mix. In 2018, Morocco produced 35% of its electricity from renewables and is determined to achieve 52% by 2030. To do so, two categories of RE capacities are in place:

- **Centralised RE capacities**

The centralised RE capacities include grid-connected large power generation units using natural renewable energy sources (i.e. water, wind, solar radiation, geothermal heat, ocean waves & currents) as inputs for electricity production. By the end of 2017, the status of the most common types of this category of RE capacities was as shown in the following table.

**Table 1. Status of the centralised renewable energies in Morocco.**

| Centralised RE Sources | Installed capacity (MW) | Growth rate |
|------------------------|-------------------------|-------------|
|                        | 1997        | 2017        |              |
| Hydroelectricity       | 1174.6      | 1770        | 50.6%        |
| Wind power             | 0           | 898         | -            |
| Photovoltaic solar     | 0           | 181         | -            |
| Thermo-solar power     | 0           | 20          | -            |

Source: ONEE-BE

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3 AMEE: Agence Marocaine pour l’Efficacité Energétique.

4 MASEN: Agence Marocaine pour l’Energie Durable

5 SIE : Société des Investissements Energétiques.

6 IRESEN: Institut de Recherche en Energie Solaire et Energies Nouvelles.
Decentralised RE capacities

One promising channel that warrants mentioning and lies within the theme discussed in this paper is the decentralized RE capacities which include small-scale power generation systems with a range of 0.1 to 300 kW. These systems, which might be operated either as grid-connected or stand-alone systems, are particularly suitable for on-site electricity generation for isolated customers that are otherwise costly to be reached and served by the national electric grid. Table 2, below, illustrates the types of decentralized renewable energy sources introduced in Morocco and the qualitative assessment of their level of introduction.

Table 2. Introduction status of decentralized renewable energies in Morocco (Sources: ONEE-BE & ADEREE).

| Decentralized RE sources | Implementation status | Introduction level |
|--------------------------|-----------------------|--------------------|
| Micro-hydroelectricity   | The website of the Moroccan agency for renewable energies development (ADEREE\(^1\)) indicates that 7 micro-hydroelectric plants (MHPs) with power varying between 12 kW and 125 kW are already in operation in Morocco as of 2013. ONEE-BE’s data show three more MHPs in operation. They are: - Tabant MHP (68 kW, Azilal); - Askaw MHP (200 kW, Agadir) in operation since 2002; it serves 593 households; - Oum Errabii MHP (220 kW) in operation since 2004; it serves 556 households. | Low\(^2\) |
| Photovoltaic (PV) solar energy | Photovoltaic solar energy is retained by ONEE-BE as a major component of its PERG\(^3\) program. By the end of 2013, ONEE-BE was able to supply electricity to 3,663 villages (corresponding to 51,559 households) by means of PV kits. | Very low\(^4\) |
| Small wind power (SWP)\(^5\) | With respect to this form of RE, the following facts might be stated: - Rare introduction cases of SWP actually exist as one might observe during, for example, a trip in rural Morocco (see illustration photos in the Appendix-1); - None of the competent Moroccan organizations (MEMEE, ONEE-BE, ADEREE) provide official information about these introduction instances (users’ identity, power ratings, usage, etc.); - According to the World Wind Energy Association (WWEA), there are some 200 SWP turbines operating in Morocco totaling an installed capacity of 700 kW (see chapter 1, for more details); Officially, ONEE-BE has never undertaken any structured organizational effort towards a large scale introduction of SWP systems into Morocco. | Extremely low\(^6\) |

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\(^1\) ADEREE : Agence nationale pour le Développement des Energies Renouvelables et de l’Efficacité Énergétique.

\(^2\) This assessment is made relative to the number of potential sites which could be equipped with MHPs (200 sites according to ADEREE (2013)).
PERG: Programme d’électrification rurale global initiated by ONEE-BE in 1994.

This assessment is also made relative to Morocco’s solar power capacity estimated by the Moroccan Agency for Solar Energy (MASEN) at 20,000 MW [2].

This category of RE covers small wind turbines (SWTs) having power rating (or capacity) below 100 kW (or 0.1 MW).

This assessment is made based on the stated facts and the introduction figures provided by the WAWF for Morocco.

Morocco continues to play a minor role in small wind manufacturing. It is obvious that the considerable wind resources in the country, where many regions are ideally suited for small wind application, have not yet lead to the establishment of solid domestic small wind industries.

This paper has two main goals. The first, a list of potential causes was identified from a review of the literature dealing with the issue of SWP barriers in developing countries. These potential causes were submitted via an electronic survey to the opinion of a selection of Moroccan professionals working in the field of renewable energies to identify those barriers most relevant to Morocco. The second, the power output of the wind turbine was determined based on the needs of a typical household in rural areas in Morocco. Throughout the design process, three fundamental constraints were considered. These are the potential economic viability of the system, the reliability of the assembly and the efficiency of the overall wind energy conversion mechanism. The remainder of this paper is organized as follow: section 2 reviews the literature and discusses of the methodology used. Section 3 presents the results of the surveys used and identified the main challenges in the development of SWP in Morocco. Section 2 & 3 are related to the first goal while section 4 proposes the design of a horizontal axis wind turbine for domestic applications in the Moroccan context by following the design requirements of the international standard of small wind turbines IEC 61400-2. The last section concludes.

2. Literature Review and Methodology

The limited introduction of SWP is not unique to Morocco. It has been noted in the literature that not only developing countries (DCs) that are facing challenges to develop SWP systems but also developed countries which share the same dissatisfaction with their national levels of SWP deployment [3]:

Several institutions and researchers have attempted to determine the factors behind the low global diffusion of SWP, particularly in developing countries (DCs). Although these factors are country-specific, they invariably fall within four ‘barrier categories’, briefly summarised as follows:

2.1. Awareness & information barriers

There is little information available on the subject of SWP to energy decision-makers and potential developers of SWTs in DCs. This is basically a knowledge barrier commonly attributed to the fragmented nature of the SWP international market that provides little contact opportunities but also to insufficient ‘marketing efforts’ on the part of international manufacturers and local importers/distributers.

2.2. Technical & technological barriers

Feasibility studies (FSs) of a SWP project require, among other data, a complete & reliable dataset characterizing the wind resource available at the site proposed for hosting the project. Unfortunately, collecting site-specific wind data is often too expensive and the study’s duration is just too long for developing countries to invest in, especially for such a small-scale project. Also, the national wind data (made available in maps or atlases by counter-part organizations of IRESEN) are usually unsuitable for use in FSs of SWP projects as they are often elaborated to serve the development of utility-scale wind power projects (that is, ‘big’ wind power projects).
As the international SWP industry is still in its infancy stage, certain SWT technologies offered in the market lack the operating experience needed to demonstrate their reliability (performance, safety, longevity, etc.). At this stage, the SWP industry is still in the process of developing its own standards to comprehensively address its reliability issues. Completing this ‘standardization process’ by the SWP industry is essential for adequately responding to the expectations of potential customers and for protecting them from unscrupulous suppliers.

2.3. Market, economic & financial barriers

As for all RE sources with lower fuel and operating costs, initial investment costs for SWP system acquisition and installation are relatively high. The American Wind Energy Association (AWEA) estimates the purchase and installation cost of a SWT large enough to power an entire home between 10 and 70,000 USD depending on the exact turbine size, height and installation expenses; the average cost being around 3 kUSD/kW \(^4\).

The 2013-2014 average installation costs given by the WWEA in its 2016 annual report \(^5\) vary depending on the power capacity of the SWT as follow: 8200 USD/kW (\(\leq 2.5\) kW); 7200 USD/kW (2.5-10 kW) and 6000 USD/kW (\(\geq 100\) kW). The Chinese average cost is significantly lower: 1900 USD/kW.

Another type of costs associated with the initial investment need also to be considered. This category of costs, known as transaction costs (TCs), relate to such activities as: consulting (siting and techno-economic studies); permitting; contracts negotiation (purchase contract with the SWT supplier; power purchase agreement (PPA) negotiation with the power off-taker; etc.). Generally, TCs are typically higher for small projects than for large projects which makes SWP projects less attractive.

Research has shown that TCs for RE technologies vary widely according to several factors such as the scope of TCs and their definitions, the evaluation methodology, the type and size of the RE technology considered and the complexities involved in the transactions. However, a rough estimate of total TCs is given as 13.5% of total investment costs \(^6\).

Depending on the SWP project specific conditions, the financial market might factor-in a risk premium in the interest rates applicable for lending the totality or a portion of the required project total investment costs (TIC). This is because more capital is being risked up-front in comparison with a conventional energy project with the same capacity. This fact clearly adds to the financial burden of SWP projects developers, particularly in DCs where equity capital is scarce.

Two additional barriers that distort the competition between REs (including SWP) and conventional energies:

Governmental subsidies (GSs) to conventional energies: GSs are known for their tilting effect of the playing field for energy options. For example, in 2011 the global GSs for fossil fuel based energies reached 500 billion US$ compared to only 8 billion US$ for renewable energies. GSs to conventional energies take many forms, both explicit and implicit:

- Direct budgetary transfers,
- Tax incentives,
- R&D spending,
- Land rights-of-way,
- Guarantees (to mitigate project financing or fuel price risks), etc.

Market failure to consider ‘external costs’: A true competitive energy market considers all short-term (ST) and long-term (LT) costs and benefits associated with competing energy options to differentiate between them. SWP is more likely to secure a position in the ‘energy mix’ of countries that internalize the social & environmental costs of energy options (environmental benefits (land and water savings), climate change mitigation, creation of jobs, poverty alleviation, etc.).
It should be mentioned, however, that even in markets that consider such ‘external costs’, the use of high discount rates, as is the case in most financial markets, lowers the net present value (NPV) of the LT benefits associated with SWP projects.

2.4. Institutional, policy & regulatory barriers
In some developing countries, the institutional infrastructure in place constitute a constraint impeding the development of SWP projects. The reported institutional issues include:

- Multiplicity of governmental agencies and organizations intervening in the REs sector, resulting in duplication, overlapping and coordination problems in the implementation of SWP projects;
- Centralized planning process, sometimes opposing the ‘decentralized’ nature of some SWP projects;
- Bureaucratic approach to project implementation, resulting in rigidity in instructions and unnecessary delays.

Similarly, the national policies & regulations governing the land management and the energy sector might also hamper the development and proper implementation of SWP projects. The most reported policy & regulation problems include:

Siting & permitting problems:

- Restriction of potential RE (including SWP) developments to specific areas. In some countries, national territory management documents (so called ‘zoning documents’) might dictate certain regions as preferred zones for the development of RE projects;
- Absence of or inadequate permitting process. The permitting process of RE projects might not be regulated or, if such process already exists, it might not be streamlined and predictable.

Project development & grid access problems:

- Regulation of the electricity generation sector (that is, lack of a national regulation opening the power generation business to potential independent power producers (IPPs) and investors);
- Absence of proper grid access regulations (access to ‘low voltage’ grid in the case of SWP projects);
- Absence of a power off-taking mechanism that provides for financial compensation of certain developers for the electricity generated in excess of their needs and evacuated to the national grid.

This paper conducts a survey to identify the relevant factors that are preventing the development of SWP in Morocco. To do so, 12 Moroccan professionals working for selected private and public organizations operating in the national REs sector are surveyed. The organizations involved are members from the AMISOLE\(^7\) association, the IRESEN institute, and the DHR\(^8\) & DPP\(^9\) directorates of ONEE-BE.

3. Results of The Surveys Used to Identify the Main Challenges in The Development of SWP in Morocco

Despite the limited size of the consulted population of professionals, the answers collected through the questionnaire might be considered as reliable since 100% of the responders have extensive professional

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\(^7\) AMISOLE : Association Marocaine des Industries Solaires & Eoliennes. This association is an active member of the Moroccan industrial federation FENELEC (Fédération Nationale de l’Electricité, de l’Electronique & des Energies Renouvelables).

\(^8\) DHR : Direction Hydraulique & Renouvelables.

\(^9\) DPP : Direction Programmes Production.
experience in the REs sector. In anticipation of the diversity in the professional affiliation of the responders, consulted professionals were asked to provide inputs based either on their experience when they have direct connection with the SWP industry or based on their expertise when they are working in the broader REs sector with non-direct link with the SWP business.

Practically all barriers discussed in the previous section were found to be relevant (or applicable) to the Moroccan context, except the information barrier which was judged by one responder as ‘non important’. As already predicted, not all the barriers were found to be equally important in explaining the low diffusion of SWP systems in Morocco. If we were to define the most relevant barriers as those regarded at least as ‘moderately important’, then the 3 most relevant ones to Morocco would be the following (see figure 1):

- Regulatory barrier (with an ‘aggregate relevance score’ (ARS) of 100%),
- Technical barrier (with an ARS of 92%),
- Financial & market barrier (with an ARS of 83%).

![Figure 1. Relevance & relative importance of the identified barriers in Morocco](image)

All proposed national organizations were found to have some importance (that is, some roles and responsibilities to fulfill) for the introduction and development of SWP in Morocco. However, based on their ‘importance score’ (IS), these organizations can be grouped into two clusters:

- **Cluster I - Policy level organizations:**
  - AMEE (IS=4.5), MEMDD (IS=3.75).

- **Cluster II - Operations level organizations:**
  - ONEE-BE (IS=3.58), Local Authorities (LAs) (IS=3.58), AMISOLE (IS=2.83), National Banks (NBs) (IS=2.75).

Since technical barrier is of great importance to the development of the SWP in Morocco, the next section proposes a design for domestic application in Morocco that follows the design requirements of the international standard of small wind turbines IEC 61400.

### 4. Design of a Horizontal Axis Wind Turbine for Domestic Application in Moroccan

In designing a wind turbine system, the wind energy community adopts different systematic approaches. Manuell JF et al. [7] give an example of a generalized approach that can be used in wind turbine design and analysis. For the present study, the design procedure will be based on an iterative method. This design process is composed of three main steps. The first step consists in defining different energy requirements. The design requirements usually act as design constraints for which a product should be designed. The second step consists in generating and developing solutions and concepts that can satisfy
the already defined requirements. In this step, all design solutions have the same weight. The third and final step consists in evaluating design solutions. This last step is the most important phase in the design process as it decides on the technical feasibility of the selected solutions. An iterative process is generally based on a cyclic process of prototyping, analyzing and refining of the wind turbine design. That is, based on the obtained results from the most recent design iteration, changes and refinements can be made. The chosen design process is intended to ultimately improve both the quality and functionality of the final prototype. The key steps that will be taken towards the final small wind turbine design are given in figure 2. The analysis undertaken in this paper summarizes steps one through four following the recommendations in the book of Wood D titled ‘Small wind turbines analysis, design, and application’ [8].

Figure 2. Systematic approach for the design of a small wind turbine

4.1. Wind potential assessment
The wind data analysis is carried out using annual mean wind speed data of different locations across Morocco. A time series of daily measured wind speeds, recorded over a period of 20 years, is used for the statistical analysis of the wind speed and the wind power density. The used wind data are provided by the Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA [9]). Climate data provided by this source is used in a wide variety of applications, including agriculture, construction, education, energy, and engineering. Also, this data represents a reliable reference for wind energy community, especially for pre-feasibility study of wind farm projects development. Statistical methods based on Weibull distribution function [10, 11] is used to evaluate the wind speed characteristics and the wind potential at a height of 10 m above the ground. Annual mean wind speed is derived for three hub heights of 18 m, 24 m, and 40 m. These hub heights are considered because they are commonly used in small wind turbine installations. The number of locations that have been analyzed is 45. Among these, 16 windiest locations are selected for the statistical analysis. The analysis includes calculation of shape and scale parameters, annual mean wind speed, and mean power density. The results of wind data analysis showed that a mean annual wind speed of 7.3 m/s is to be expected when installing a small wind turbine at a hub height of 40 m. According to the IEC 61400-2 standard, this particular wind speed corresponds to a wind class III [8].

4.2. Load demand estimation
Several approaches [12, 13, 14, 15, 16] were used to determine a typical electricity consumption of households in rural areas. Some of these are based on simplistic assumptions, while others give an estimation based on complex approaches describing the possible relationship that may exist between the habits of the occupants and the household appliances use. The estimation of the average household power consumption in this work is assessed using the results of the national survey on the standard of living of
households in Morocco [17]. This approach presents some advantages such as the availability of the all required data, the simplicity of estimation method, the accuracy of its results compared to the other approaches and the possibility to improve the quality of the need assessment by including other some parameters like the appliances ‘load factors and the power consumption of appliances during standby mode. To identify the most common end-household appliances in rural areas, the acquisition rate of each appliance is assessed. This is defined as the ratio of the number of households owning the appliance at the total number of households. To ensure that the estimated electricity consumption is as representative as possible, only appliances with high acquisition rates are considered. In order to determine the electricity requirements of a typical household, the rated power of each of the household appliances must be determined. Then, the required electrical energy is identified by multiplying the rated power of each appliance by the number of operating hours per day. Based on this approach, a total daily electricity consumption of 103 kWh was found in rural areas. This corresponds to total annual electricity consumption of 37 MWh. This value is relatively high due to the fact that the needs of the majority of the pumping systems in Morocco have an average Total Dynamic Head (THD) of 80 m with a daily water flow of 300 m$^3$. This need corresponds to the water required to irrigate 5 hectares of agricultural area in a typical farm.

4.3. Small wind turbine rated power output

Based on the average daily consumption of a typical rural household in Morocco of 103 kWh and by using an annual mean wind speed of 7.5 m/s (which corresponds to a design wind speed of 10.5 m/s according to the IEC 61400-2 standard), a rated power output of 11 kW is found to be a power that would be the most in demand.

4.4. Technical barriers towards local implementation

The list of components necessary for the assembly of a 11 kW small wind turbine is defined as follows: the rotor (including the nose, the hub and the blades), the main shaft, the cover of the nacelle and the chassis, the system of training and orientation, the braking system, the electric generator, the tower and the foundation, and the control and safety system. Locally manufactured components are limited to the rotor, main shaft, nacelle cover and chassis, tower and foundation. The costs associated with other components that cannot be manufactured locally (the drive and steering system, the braking system, the electric generator, and the control and safety system) remain the highest. This is how the industrial integration rate associated with this prototype does not exceed 30% as can be seen in figure 3. Technical barriers find their origin here. The reliability of the assembly and the energy efficiency ("reliability and efficiency") following the directives of the IEC standard impose that the choice of components which cannot be manufactured locally is constrained by quality requirements accentuating the final cost of the prototype. This study also revealed that manufacturing the blades according to the current form of the IEC standard leads to oversized and more expensive structures. The constraint of designing the final product's economic viability (‘low cost’) can therefore only be fully satisfied if the local manufacture of all components is considered.

Figure 3. Component costs expressed as a percentage of total machine cost
5. Conclusion
This paper investigates the limited diffusion of SWP in Morocco. In the first stage, we use a survey to identify the relevant factors that are preventing the development of SWP. Three main factors are recognized as the most important ones namely regulatory barriers, technical barriers, and financial & market barriers. We perform a design of a 11 kW SWT to better define the technical barrier. The reliability and the efficiency requirements based on the IEC guidelines constrain the selection process of high quality components which affect the production cost. The economic viability of a SWP project can only be fully satisfied if a local manufacturing process of all components is implemented. Potential participants can pursue various business activities: sourcing of raw materials, partial or full fabrication of SWT components, SWT component/system testing, logistics, installation/commissioning, financial, technical and project management consulting, loan granting etc.

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