Joint wind water pumping project

WP1 - Socio-technical feasibility report

Summary

1. Technical capabilities evaluation

This report discuss in what extend it is relevant to power a pumping system with wind, both from a technical perspective and from a socio-economic perspective. This information will be combined with a technical expertise in order to perform a risk analysis. This risk analysis will serve as a basis to be used to define the system specification that will be developed during the second phase of the project. As such, the final system specifications will be derived from the needs identified on the field and within the capabilities of WindEmpowerment existing small wind turbines.

1.1 Naming convention

In the following a distinction will be made between state of the art mechanical windmill water pumps and electrical coupled wind water pump that WE is attempting to develop. The difference between the two systems lies in the way the energy is transferred from the mechanical movement of the blade to the pump. The traditional windmill water pump uses a mechanical coupling, meaning that the transmitted energy flow is mechanical. The second solution uses an electrical energy flow to actuate the pump.

Figure 1 Illustration of a mechanical coupled wind water pump (on the left) and an electrical coupled one (on the right)

WindEmpowerment is willing to develop such electrical coupled water pumps because it is foreseen to be useful in many places around the globe. Two former early stage prototypes have been developed in India and in Argentina, and they will respectively be named Indian system and Argentinian system from now on. (See 4.1 Description of the systems)

1.2 Technical introduction

First things first, it is important to remind the reader about few key notions on water pumping, what the state of the art is, what the main design rules are, and what the technical challenges behind a successful wind water pumping system are.

When it comes to design a water system, the energy source is not the first thing to think of. It is necessary to start thinking of how the irrigation system need to be. Once the irrigation system is defined, the adequate pump must be chosen accordingly, that will take into account the requirement of the irrigation system, and the borehole characteristics. Then, finally, the power source for pump is chosen. Therefore the power source is tied to the requirements of the whole pumping system.

In order to size a suitable energy source for the watering system, it is necessary to fully understand the parameters from the irrigation system and the parameters from the well, that are site dependent.

1.3 Site dependent parameters

Each irrigation system as its requirements in term of water supply. It means that a given irrigation system will perform correctly when it will be provided with the correct flow rate at the right pressure. These water supply characteristics highly depends on the type and size of the irrigation system.

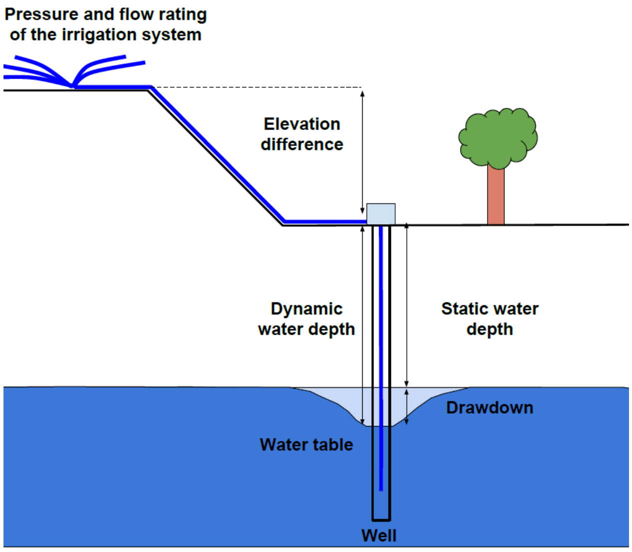

Figure 2 Borehole parameters and matching pump illustration

A well is characterized by its dynamic water depth. It represents the depth of the water will pumping. While pumping, the water level will drop locally, it is called the water drawdown. The pump is chosen depending on this well parameter. Therefore the well determines the pressure of the pump.

$$P_{ressure\ pump} = \frac{(D_{ynamic\ water\ depth} + E_{levation\ difference})}{10.15} + P_{ressure\ rating\ irrigation\ system} \text{ (1)}$$

$$F_{low\ pump} = F_{low\ rating\ irrigation\ system} \text{ (2)}$$

Thus the pump is chosen to perform at the operating point above described by (1) and (2). The pressure rating must ensure that the pump is able to pump the water high enough, while the flow rating ensure that there will be sufficient water pumped for the irrigation system to function properly.

From this operating point, we can finally estimate the electrical power that will have to be supplied to the pump.

$$P_{ower\ electrical} = \frac{\rho \times P_{ressure\ pump} \times F_{low\ pump} \times 9.81}{\eta_{pump}} \text{ (3)}$$

Where ρ is the water mass density;

And η_{pump} is the pump efficiency;

Therefore one can see that this amount of power clearly depends on the need of watering, and on the site characteristics. Consequently in order to get an estimate of the power requirements for water pumping applications (3), it is necessary to collect data from the field practitioners who will be able to provide both a glimpse on the local watering habits and the soil and water table characteristics.

1.4 Wind power

From a wind power perspective, powering up pump means that the pump will be running when sufficient power will be delivered to it. The cut in power of the overall system will be obtained for a given rotor diameter at a given wind speed. This cut in speed can be calculated when the power to be supplied is known. In this case, the power of the wind system must be matching the power rating of the pump at a given wind speed.

Another approach is to use storage between the renewable supply and the pump. By this mean, the system start up does not depend any more on the instantaneous wind speed, but on the amount of energy stored in the battery. Therefore the battery -act as a buffer, where the energy generated during a day, can be spent during few hours to power the pump. In this case, the pump power rating doesn't need to match the wind system power ratings.

1.5 Analytical model

In both case is it important to be able to foresee what would be the performance of a Piggott driven water system in a given region. Making a simple analytical model allows to predict the behavior of the system in a given context, and to be able to tell if we can successfully answer to each particular need on the field in few minutes. Such a model requires all the input hypothesis described in the introduction. The data input quality is the key to ensure that the estimated behavior will be matching the reality. This is why the model is a tool that can be run only after validating the input hypothesis together with the local people on the field who know the watering context.

It is crucial to model the problem prior to make any further technical development, as modeling the problem will make us aware of the key parameters that will increase the performance of the overall system in many different situations.

The model generates a wind speed Weibull distribution, and determine according to the field geological information how much water can be pumped through the year for a given turbine. It is also giving an estimate of the cut in speed of the system. The results allow to plot the water flow depending on the local dynamic water head for a given turbine.

Figure 03 is showing an example of the model output. In this case, it uses the following assumptions:

- A H. Piggott 4.2 meters wind turbine installed on a 12 meters mast is powering the water pump
- Wind speed are modeled with a Weibull distribution with a form factor K=2.0
- The pump is in steady state operation (startup current is not taken into account)

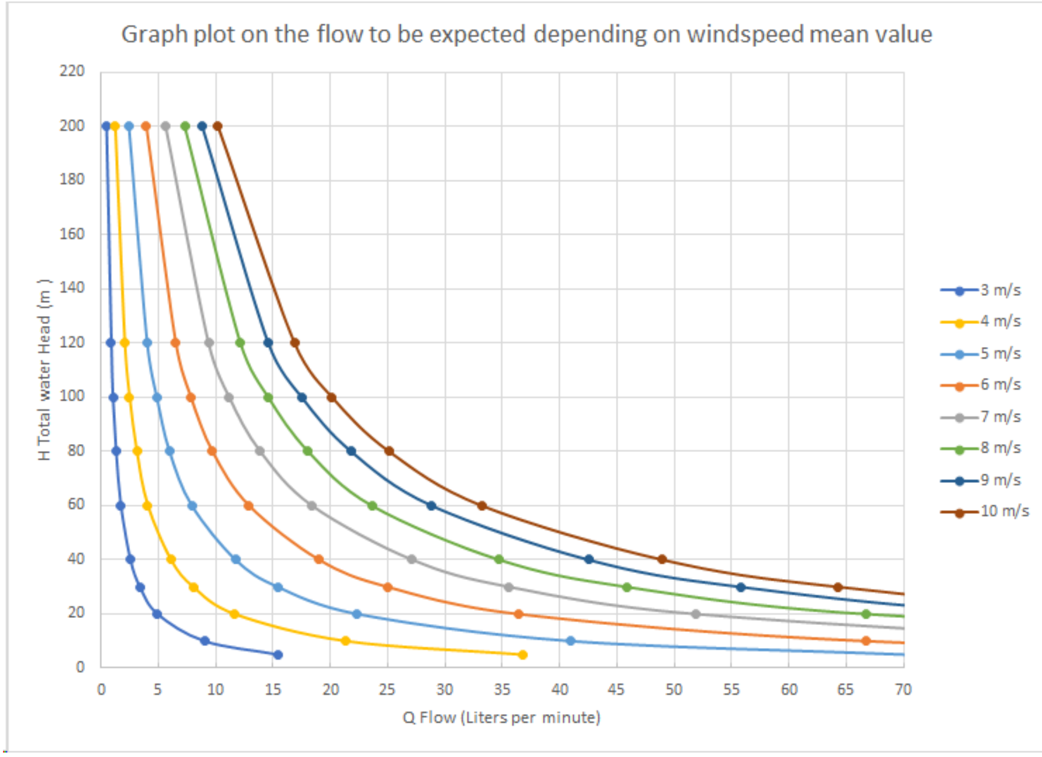

Figure 3 Graph showing the flow rate that can be expected for different wind conditions, depending on the dynamic water head of the well.

2. Current project context

2.1 Where is wind pumping technically relevant?

Wind pumping will work correctly where a given wind turbine will be able meet the watering demand that justify the money investment. The water quantity sucked from the well depends mainly on the wind resource, and on the depth of the water table, as seen previously. With the help of the analytical model, it is possible to process maps that are giving an estimate of the quantity of water pumped daily. We've processed such maps at the country level, for the three country in the scope of the present report. Present maps are based on §1.5 assumptions.

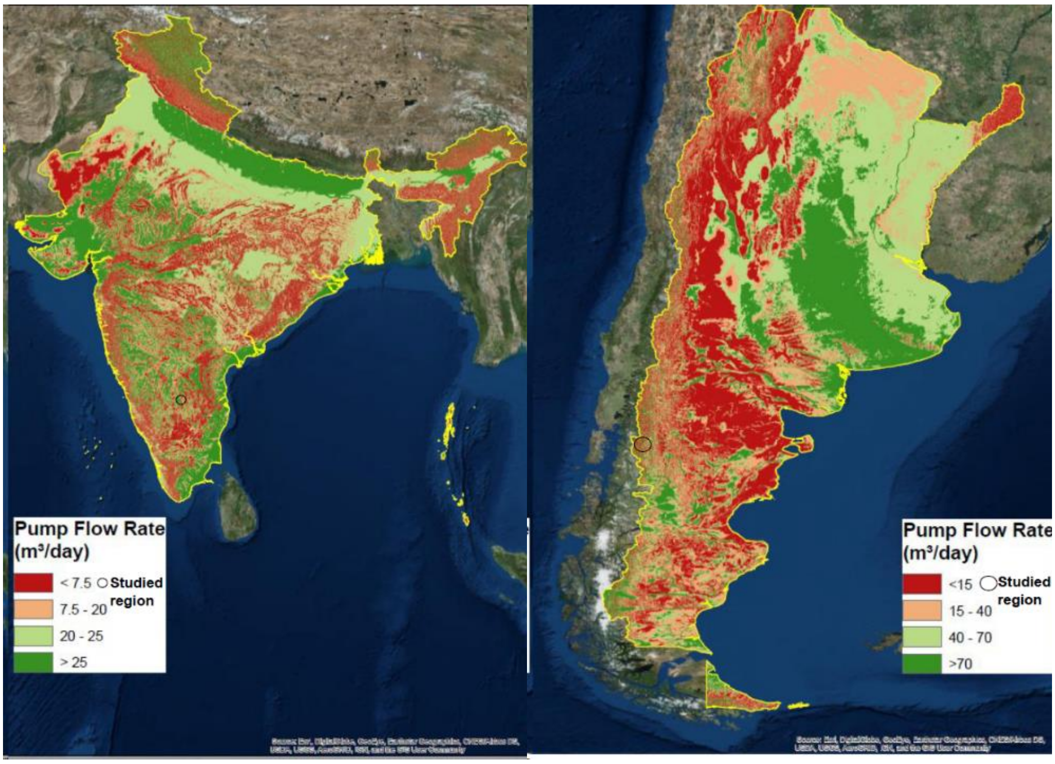

Figure 4 Daily water flow rate expected in India (left) and Argentina (right)

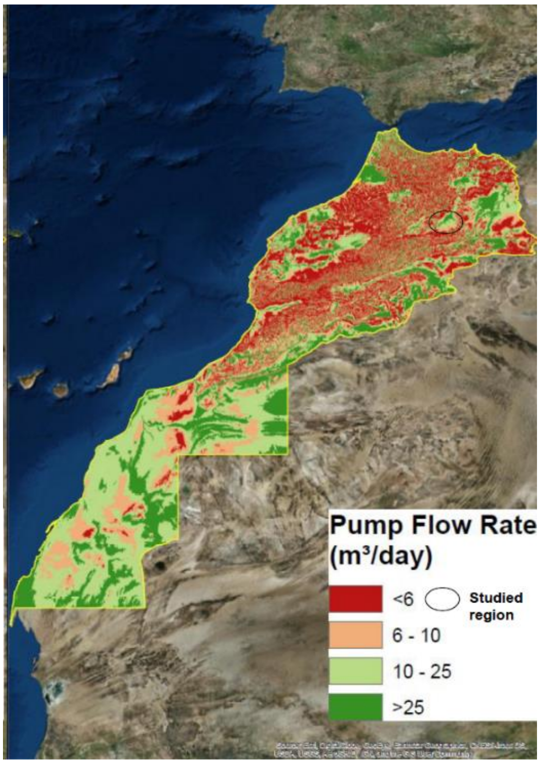

Figure 5 Daily water flow rate expected in Morocco

2.2 What are the technical challenges to overcome?

State of the art

Wind turbines for water pumping is not a new idea. In fact wind water pumping will immediately remind mechanical windmill to most readers. Since the late 1800 wind have been used to pump water. Back in time it has been a key enabler for population to settle in hostile region no water was present at the surface level. Back then, in the US more than 100 000 turbines were produced each year.

The success of the technology was lying in the scattered population that needed to access the groundwater together with an efficient maintenance network with readily available spare parts. Each house had his turbine providing water for farming and living. The trend faded out when it slowly get replaced by distribution systems and motor pumps. Today, the market downed around 3000 units sold per year in this country.

Acknowledgment

The water pumping windmill success can be explained by the need of pumping in remote area before any competing other source of energy was readily available. This monopoly led to the creation of a supply chain for spare parts, enabling final users to maintain their own system. The monopoly for energy generation is over for now more than one century with the competing fossil technologies and more recently photovoltaics. Affordable energy is seen as a key enabler in remote areas and wind can compete with fossil based generators.

2.3 The proposition value of the system

What make us different from old wind turbines?

The discussed electrical coupling allows to combine different energy sources to run the pump conveniently. In this case, wind is no longer competing with solar, but completing it. All the possible combinations offered thanks to the flexibility of the electrical coupling are foreseen to improve the pumping efficiency but also to give further usages capabilities by being able to power up other electrical appliances. Besides, working with electrically coupled wind water pumps give better efficiencies that competing multi bladed mechanical wind water pumps, as shown in Figure 06 and Figure 07.

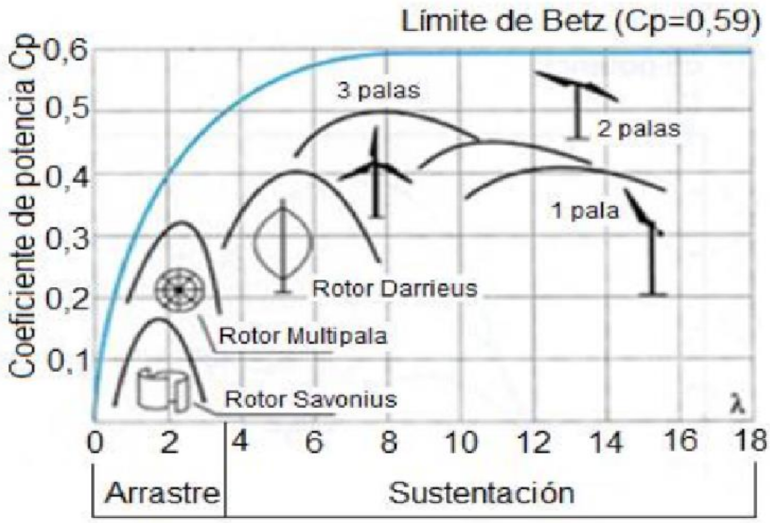

Figure 6 Aero dynamical efficiency for different rotor designs

Three bladed wind turbines are known to be more resilient to high wind conditions i.e. in the regions where wind energy have more chance to be competitive with other sources of energy. In high wind regions, an electrical pumping system will yield up to three times the yield expected with a mechanical pumping system.

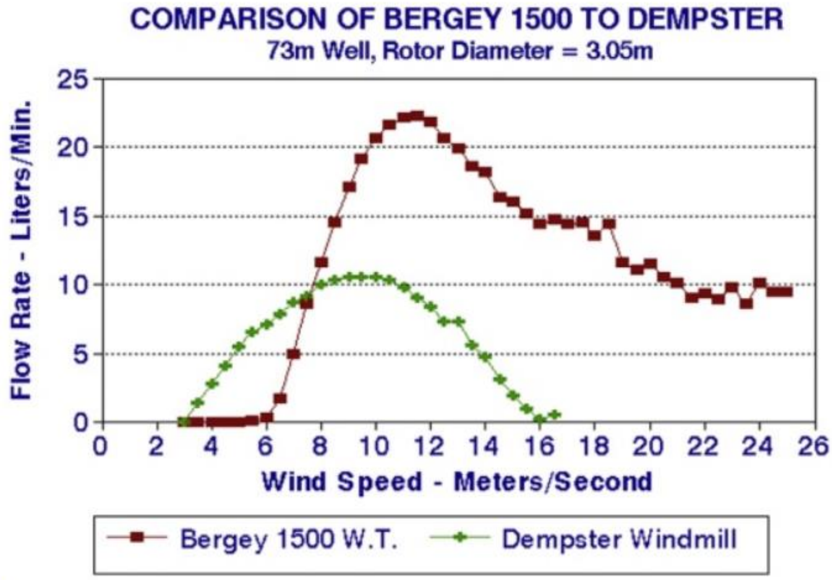

Figure 7 Comparison of flow rates for a mechanically coupled wind water pumps and electrically coupled ones

Therefore our attention is focused on high wind regions where the population is scattered and is struggling to get a reliable water access. Our work hypothesis is to consider that a Piggott SWT cleverly combined with a water pump could create a good solution for these people. The maintenance success factor would be ensured by a local stakeholder that would act as a relay for spare parts and/or maintenance tasks.

In regions of lower wind, a success factor will be to lower the cutting speed, in order to increase the yield and stay competitive regarding mechanical wind water pumps. Developing a technological solution mitigating this issue is in the scope of this project, and is to be one of the specification of the improved system.

To summarize, it is foreseen that in windy regions, such system could relieve farmers that are depending on water pumping for living, by proposing them a renewable based system that answer their productive needs, and give them further development capabilities through an affordable energy access. In medium wind zones, further technological development will allow wind to come in completion with solar to provide a steadier water supply. In low wind regions, electrical coupling is not to be seen as a viable solution, and photovoltaics or mechanical coupling should be preferred.

3. Social contexts: needs and applications

3.1 Site description from our expertise: Argentina

Cholila (Province of Chubut) is a rural area located in the Patagonian steppe, at the foot of the Andes, better known for its low population density. Our work was carried out in the rural area of Cholila, in the communities of Cushamen and Gualjaina, where approximately 670 families live, mostly from Mapuche native peoples. The small family communities are living from goats and sheep breeding to get meat and wool. In the last 10 years this activity has come backwards, mainly due to two causes: the cut of the rainy season and the fall in the international price of wool. We also find a wide variety of self-consumption economic activities, such as horticulture and textile crafts, and others that are in the development stage, such as viticulture and the reforestation of native species, rural tourism. 500rpm (member organization of WindEmpowerment in Argentina) has been working since 2014 together with the Agro-technical School of Cholila (managed by the Cruzada Patagónica Foundation), where teachers and students manufacture and install between one and two Piggotts wind turbines per year in the framework of a socio-educational project driven by the school, a population of the educational community who do not have access to electricity. In addition, during the year 2017, in joint work with the BAF Foundation, a 500rpm water pumping system was installed and tested at the school.

Field work details

In-depth interviews were conducted with two broad categories of actors:

a) Actors already located in the territory;

b) Potential rural residents who will benefit from pumping systems.

Among the first category, we are trying to find local actors with technical, financial and logistic capabilities that can contribute to the sustainability and replication of the project. On one side, we found technical actors like the National Institutes for Agriculture Technic (INTA) that conduce local programs together with the communities Gualjaina, Cushamen and Esquel. On the other side, we have identified various political decision-makers of local development: Mesa de Desarrollo Local Cushamen, Referents community of Cushamen and Gualjaina, Director of Production CEA Cholilla School.

Among the second category, we focus on identifying and interviewing rural people with different pumping needs in order to help them expand their various small-scale productive activities such as goats and sheep breeding, small horticulture and textile crafts making.

Local socioeconomic context

The study focus on 2600 rural inhabitants experiencing water access issues. These people are from 670 families living in two rural communities, 350 Mapuche in Cushamen and 320 families in Gualjaina. The main economic activities of the families are: the small production of sheep and goats, horticulture for self-consumption and commercialization, forage for animals. 30% of the families are settled in areas of valleys near rivers, while 70% of them reside in the mountains, where water access is limited. The average size of their land is 625 hectares, where one or several families can reside. The families have been relocated in these lands from a governmental policy for native peoples that existed in argentina from the beginning of the 20th century until the 50’s. The land productivity is really low because it’s mainly desertic lands.

In reference to its current situation, the small rural economies of the Patagonian steppe have been decreasing in size and production capacity. A few years ago, a small rural economy had 1,000 animals, currently small economies have between 70 and 400 animals, with an average of 100; currently, those who own 1000 animals are considered medium-scale producers. Two reasons explain this decay: the change in climatic conditions ("since 2004 the climate has become drier" relates one of the interviewees), and the variation of the international price of wool.

In the last 10 years, the rain period have been shortened, and the hot season have strengthen and extended. While the substitution of wool for other synthetic products in the global textile market caused the fall in international demand for wool, in addition to the instability in the variation of the price of the dollar in the local economy, highly sensitive to changes. While most camps are not financially sustainable, villagers sustain their activities for cultural and historical reasons, reinforcing family income with other jobs and / or allocations from the public sector, or from non-traditional economic activities found in experimentation phase, such as the commercialization of textile crafts, alternative tourism, viticulture, among others. In addition, family economies have a large part of production for the self-consumption of vegetables, meat and textiles, so the need to obtain everything through the market is lower than in other contexts.

Wool prices vary widely, depending on the capacity of the producers to wait for the best price offered and the ability to process it and therefore to add value to the product. For example, a small producer who is forced to sell the wool to local intermediaries, without any extra process, obtains between 40-50% of what the producer can expect. The moments in which the wool has greater value are in the months of September and March, the best way to market it is through the local cooperative (which collects and selects the wool, and can sell through a tender process to large national or international buyers), and production costs are lower for those producers who can take over the shearing on their own. The reality shows that more and more small producers must sell their production untimely and disadvantaged, this is because they need the money immediately to meet the needs of their families. If the cooperative paid in 2018 at a rate of 179 Argentine pesos per kilo of wool (6 uss/kg), the small rural producer with urgency of sale obtained 80 Argentine pesos (2.60 uss/kg); If the medium or large producer with a certain technical capacity can perform the shearing of their animals, the small producer must pay at a rate of 45 Argentine pesos (1.5 uss) per animal throughout the year (an average of 5 kg is estimated) wool per animal per year).

In addition to the sale of wool, meat is sold but it represents a smaller share of revenue, although it follows a dynamic similar to the wool market, where small producers with greater urgency receive approximately 1000 Argentine pesos (34 uss) per animal, compared to 1800 (60 uss) Argentine pesos from those who can sell in better conditions. Although the percentage of sale of meat compared to the sale of wool is lower, it is important and it is a strong indicator of the need to obtain liquid money from the producer. Generally, producers market animals for meat according to the need for money they have in that year, using this mechanism as a way to balance their family finances before the time of sale of wool. Small producers are the ones with the highest percentage of animals for meat to be sold annually, which gradually reduces the volume of animals to produce wool.

Water Problems

In Chubut Province families live in scattered rural areas and have partial or no access to water. In the last ten years, the periods of rains have been decreasing, affecting the flow of water available for domestic consumption and family economic activities. We find two dissimilar characteristics of the same problem: rural settlers who live in highland areas, and obtain the water through "aguadas", currently do not arrive by gravity to homes and productive plots. On the other hand, rural inhabitants who live in the valleys, and are supplied with water through streams and canals, due to the decrease in water flow, also water does not reach homes and productive plots.

Currently, some of the small horticultural producers (who have generational customs of production in orchards) irrigate with buckets, on the one hand this takes a lot of effort and is inefficient, and on the other, it allows to maintain small plots of crops for self-consumption but not for surplus marketing. The local producers interviewed agree that improving access to water directly improves their productive activities and their quality of life. Both for those who are engaged in horticultural production, and who currently can only produce for self-consumption and fail to generate the surplus for marketing that the market demands; as for those producers dedicated to animal husbandry, who must buy in the market the necessary pastures during the winter because they cannot produce it on their own as they did in other times the demand, for those cases, which are representative of the current situation of most producers, generating a solution to water access would improve the current situation of their domestic economies.

Technical local conditions

The technical pumping conditions are similar in all the region. They have 20 meters depth wells for pumping, with a need of 7.000 lts/day on average for domestic and horticulture applications, and a 100.000 lts/day on average for alfalfa applications, per hectare.

3.2 Site description from our expertise: Morocco

Social evaluation

The area studied is Midelt province, which is a region located at the border of the Atlas Mountains. The main town, Midelt, is located at 1500m above the sea level, which makes it one of the highest town in Morocco. The province economy is historically based on mining. Although the mining activities are now slowly fading out and this low income region is now relying on agriculture and internal tourism. This hinterland region is famous for its apples orchard and craftsmanship.

The region has cold desert climatic conditions. In winter, snow is common, and in summer the temperature are milder than in the rest of the country. Although the evaporation is higher than the precipitations. The mountains topology have a macro impact and there is a wind corridor that leads to high wind averages (around 8m/s) and Morocco plans to build a major - utility scale - wind farm in the region.

The region is for its major part arid but landscapes can change dramatically in few hundred meters when there is some underground water or a river nearby. Local farmers take profit of these local situations to grow apples.

We have visited isolated farmers in the countryside and also a pump reseller. We encountered difficulties with the language barrier as farmers were speaking the local dialect. We lost a lot of information because of that.

The people we met can be sorted in three categories:

a. Wealthy high income farmer owning multiples hectares of apple orchard
b. Medium farmer owning smaller farms or farmers employed by wealthy farmer
c. Poor shepherds living for grazing

Farmers highly depend on groundwater has they need to irrigate their orchard in order not to lose the entire production during the drought of summertime. They mainly use fossil fuel based pumps as the power grid is not reaching their farms, or the network is reaching it, but there is no power inside of the cables.

Wealthy farmers also have cannons to fire up silver capsule in the cloud to artificially trigger rainfalls. Sometimes, these machines are shared between multiple farms. As apple orchard request a lot of water resources, local pump resellers are flourishing in Midelt and the other smaller towns of the region. It is easy to supply any kind of centrifugal pump, piping, solar systems etc… Power ratings of available pumps vary between few hundred of watts (mainly for solar applications) to a dozen of kW (for diesel pumps). We have seen many advertisements for pumps on the road while entering towns.

Morocco also have a public policy in favor or solar pumping, to help farmers accessing these technologies, and it is common to see solar structures powering pumps next to main roads.

Although, even if the global picture seem favorable, major outcomes have been noted:

- We have no local partner there to ensure spare part distribution / maintenance advisory.
- There is a major issue with the language barrier in the countryside.
- The solar pumping prices are hard to compete with, and the offer is flourishing.
- The grid might evolve soon (in about 5 to 10 years) with the incoming wind farm

An intent of supporting the establishment of a SWT manufacturer could have a meaningfulness in the region, but it would be out of the scope of this project.

Technical local conditions

The average deepness of the wells varies between 20m and 100m in the region, with water needs that are often out of the reach for Piggott wind turbines.

3.3 Site description from our expertise: India

Social Evaluation

The area studied is in Anantapur, Andhra Pradesh which is in the northern border of Karnataka. The closest town is Hindupur. This is the 2nd driest district in India also making it a low income area and it has a good enough wind resource that wind farms have been developed nearby.

We have a local strategic partner called Protovillage which is a community development project established in the region. This project includes training and development programs for the surrounding villages and region in areas such as rural entrepreneurship, improved use of soil, cottage industries including millet processing, oil processing, soap making, etc.

At Protovillage they have an existing solar water pumping system running a 3HP submersible pump. During last year's monsoon season they suffered drought conditions which meant cloudy days with no rain. Their dependence on solar water pumping and because they had no backup created a crisis and they were required to buy water from tanker trucks. This was a crisis that not only affected Protovillage but the whole state and region. After this experience they requested to Minvayu to install a wind-electric water pumping system that would run in parallel to their solar water pumping system and also serve their battery bank.

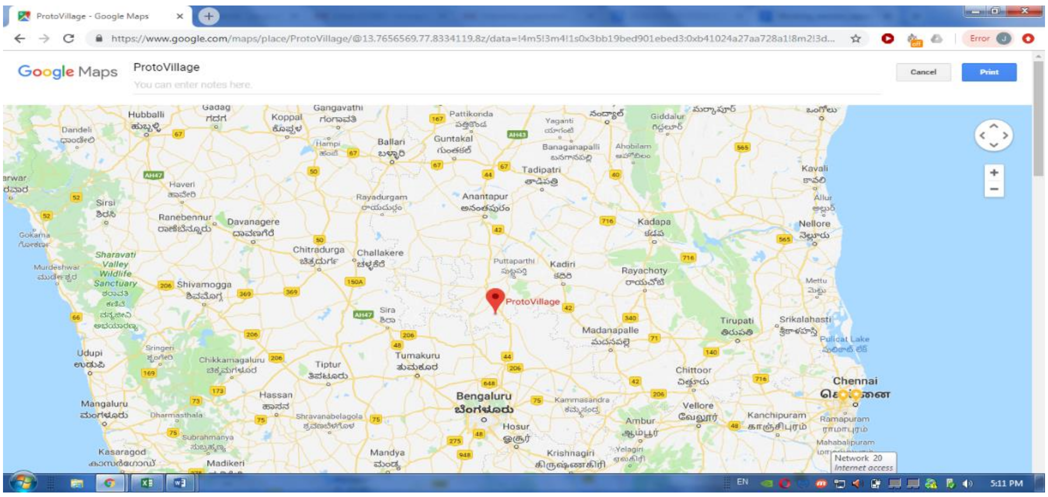

Figure 8 ProtoVillage localization

The turbine was built in-situ with the members of Protovillage and the tower was built simultaneously. The commissioning happened in the month of January 2018 after the civil works were finalized. For half the year the system was a dedicated battery charging system connected to their new 240V battery bank which was a new expansion to provide power to their productive uses which consisted of a makerspace, carpentry shop, millet processing and oil extraction facilities. This was effectively a 5kW solar and 2.5kW wind system supplying power to their industrial off-grid facility. The use of the turbine is dependent on the priorities for the Protovillage project and as their energy needs have increased as well as the resource is varying per season they require flexibility in the use of their power inputs.

An upgrade of the system was made with a smart WattMon data logger that serves as a control system for the system and also as a way to remotely control and gather data. At this time the Wattmon is operating the turbine as a hybrid battery charging and water pumping system. A problem occurred in October 2018 because the battery bank suffered a degradation of their operation because water level in the battery banks was low. This was a lapse in maintenance which is currently being corrected with a replacement of 7 batteries that had failed prematurely. When the failure happened it also caused problems on the Wattmon controller which suffered a burnout. We have repaired this and now the Wattmon is again working. In addition to the upgrade of the battery bank we have installed the digital flow meter and data logging system which is now operational. Unfortunately the next 3 months are the low wind season and it is cloudy, so the system is right now only operating as a battery charger. Once high winds start the system will start operating as a battery charging and water pumping system and data for the water delivery can be made.

Social Aspects

The region is a dry flat region where most people are small scale farmers. Typically farms are 2-3 acres in size and the size is limited by the capacity of each person to take care of the land. Some equipment such as tractors are available and are used, but the limiting factor is water scarcity and availability of labor.

We have visited individual farmers during our surveys and stayed mostly close to the main roads. This was for ease of access and time constraints.

We interviewed 15 households in an area of 15 km surrounding ProtoVillage and found 3 types of farmers.

a) Wealthy high income farmers with silkworm processing 10hp pumps

b) Medium income farmers with 3-5 Acres of land. 3-7hp pumps

c) Low income farmers with 2-3 Acres of rain-fed land. No pump, no well

All farmers are facing drought and low water level in their wells. Half the farmers have recently made new wells as their original wells have gone dry. It costs between 1,300 to 1,500 dollars to dig a well and many farmers are going into debt to invest in this. About half the time the new wells are dry, so this is not always a solution to their problems.

From these initial observations and also seeing the priorities at ProtoVillage it is clear that there are three activities that are becoming critical for this area.

i) Promote low water usage practices using drip irrigation,
ii) Promoting crops that are more resistant to drought conditions
Teaching well recharging techniques including bunding and reforestation techniques. As part of this project the wind-electric water pumping system is a perfect example of lower water use as this pump is small compared to pumps being used in the surrounding villages and ProtoVillage is using drip irrigation techniques with this system.

Another important component that ProtoVillage is encouraging is the use of renewable energy in productive applications. It is clear that the region needs additional forms of economic activity and the makerspace and agro industrial setup shows what other forms of production can be implemented in the village level. The productive uses are powered by the mix of solar and wind power and they complement themselves well since in monsoon season, when solar energy is low is the strongest months for wind allowing the energy to be available year-round.

Technical local conditions

As we said, we have 3 kinds of farmers with differing amounts of water consumption per day, with a range between 105 and 305 m, with a need of 100.000 L/day. Those farmers with pumps receive free electricity for a range of pumps up to 7.5hp in capacity. The typical energy provided is 4-6 hrs/day of power (3 phase power). In rural India scheduled and unscheduled power cuts are common.

A typical system of 5Hp in capacity pumps enough water for 2-3 Acres of land and most farmers handle this land individually or with outside help. No farmers know how much water they consume, there is a complete lack of understanding that overconsumption of water affects the water table. There is a labor shortage so most farmers are only able to manage on their own up to 2 Acres limiting their income. The average income per harvest is between 10,000 to 15,000 INR (125 - 187 Euro). For rain fed farms one harvest a year is possible. For fields with pumps two harvests are possible. The main growing season is during Monsoon, which is June/August.

The region is undergoing drought conditions with poor rainfall causing wells to dry up forcing farmers to go into debt when they need to drill new wells. Even using local experts with magnetized wands and conductivity measurement devices success rate for new wells is less than 50%. A regional effort addressing well recharge, efficient use of water and use of drought resistant crops needs to be reinforced. The situation is becoming critical requiring stronger limits in water wastage.

At ProtoVillage the main well has gone dry and two additional wells have been dug. In the month of April 2019 a new pump will be set up to the wind turbine and the controller will be moved to be under the turbine. A cable of 100m connecting the turbine to the new well will be laid down. A new main pipeline is being built to connect the new wells to the main water tank and water recharging of the wells is being prepared. It is critical to do the reconnection of the wind turbine and pump by April since in May the typical monsoon season will begin which also coincides with high winds.

There are subsidy programs for solar water pumping, wind water pumpers, drip irrigation infrastructure, but all these require the farmer to have a good working relationship with local government agencies. Typically the upper and high income farmers get easier access to subsidies than the lower income farmers and this can be attributed to cronyism, preferential caste treatment and corruption.

4. Technical advances

4.1 Description of the two systems

a) **Direct transmission system (India) with submersible asynchronous pump:** It is a 2.5 kWp system, Piggott design that works without batteries and controllers, starting pumping when the wind speed is enough to power a 3 HP three phase and asynchronous pump. It works because the number of magnetic poles in the wind turbine is higher than the number of poles the pump engine. By now, this relation is 5 times. It solves the problem of low revolutions per minutes in the wind turbine, reaching the maximum power of the pump engine, near to 3Hp.

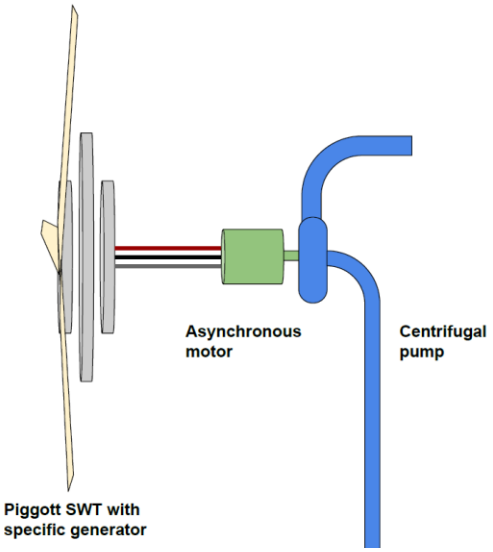

Figure 9 Schematic of the Indian system

Figure 10 Pictures of the Indian test bench that have been used for the exchange activities in Chennai

Improvement to be done during WP2:

It is necessary to develop a small regulator to prevent pump startup when the current frequency is too low or too high. Operating a centrifugal pump run outside of its speed specifications lead to damaging the pump. The main purpose of the regulator will be to startup the pump will ensuring that the frequency is in the specified domain and prevent any degradation through the cavitation phenomena. This startup controller could also be used to reduce the cut in speed of the system by adding a small energy storage just for the startup sequence.

Upgrades to this system are a hybrid option with solar water pumping. Solar pumpers have a Variable Frequency Drive (VFD) which feeds solar input (DC) and output is 3 phase AC power for pump. A homemade variable frequency drive is considered where our direct transmission system connects to the DC Input and works together with solar power. An initial system in Pune has been working for a year and a half and an open source alternative is being pursued. It is foreseen to develop an open source solar VFD based on the French converter.

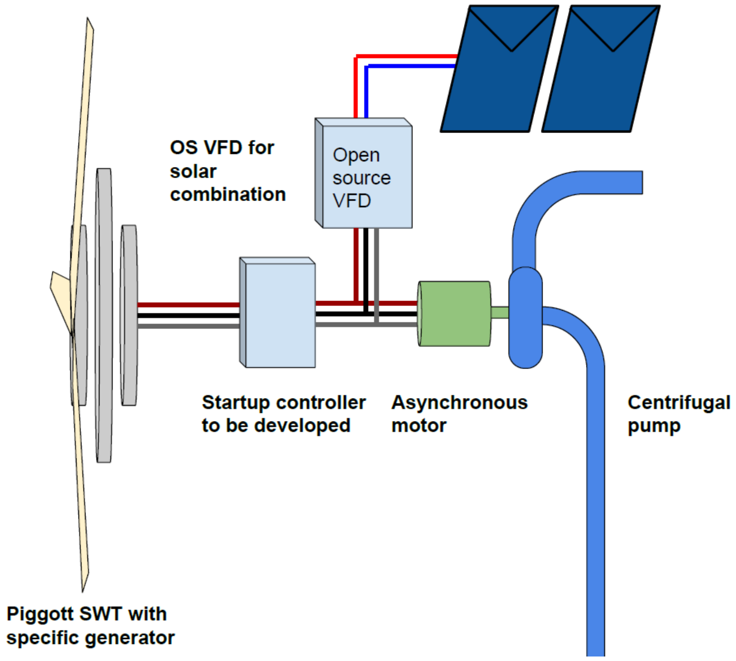

Figure 11 Schematic presenting the expected improvements of the Indian system

b) **Controlled transmission system (Argentina) with a positive displacement pump with synchronous motor:**

It is a 350 W system, Piggott design, which works without batteries, but with a special controller. The electronics controls the frequency and power of the turbine, in time intervals less than 1 second, making the power of the pump (turbine charge), variable, and optimize the operation of the mill. So, the power of the turbine and the RPM have to be match with the same parameters in the pump. The last one, is a positive displacement pump (SAPO), very common in Argentina, which is driven by a 500 W and 24 VDC brushless motor.

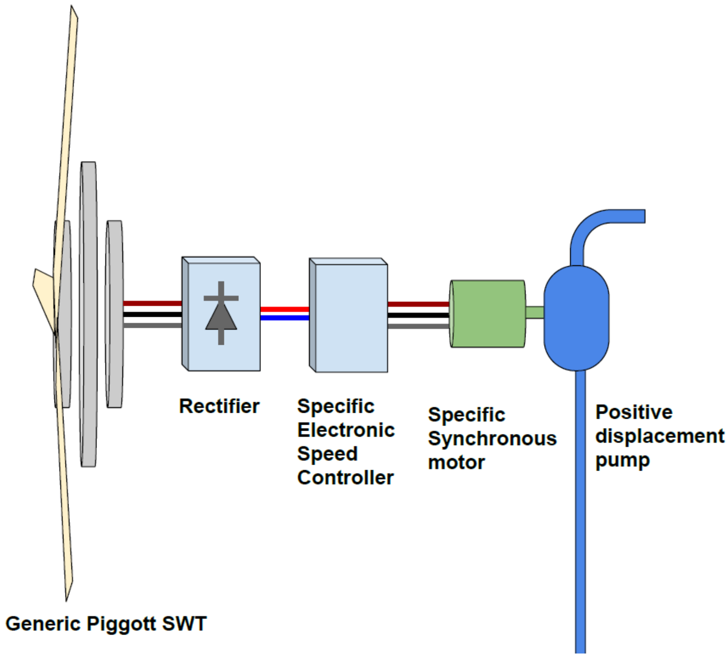

Figure 12 Schematic of the Argentinian System

Figure 13 Pictures of the Argentinian demonstrator during a field testing experiment

The advantages of both systems, and what makes them different from a standard SWT system, is the fact of avoiding the batteries. It makes them much cheaper system, and also reduce the maintenance cost and the CAPEX amount.

Improvement to be done during WP2:

It is planned to replace the proprietary electronic speed controller with a solution based on the French converter. This would allow to power any kind of motor and not only the specific kind of motor that the former prototype was working with.

Changing for an open source converter will enable us to improve the algorithm controlling the pump. It is foreseen to greatly improve the performances and the robustness of the system. It could also be used to include a small energy storage to handle the startup of the pump when the wind speed is insufficient for the startup phase.

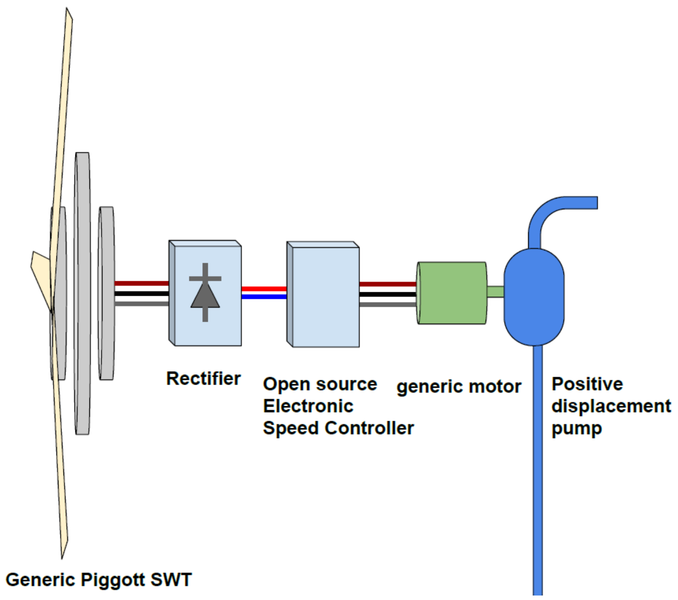

Figure 14 Schematic presenting the expected improvements of the Argentinian system

4.2 Exchanges made in India

During the WindEmpowerment small wind turbine conference held December 2018 in Chennai, India, we built a wind-electric water pumping test bench where we could simulate the energy produced by the wind turbine and measure water produced by the pump. Minvayu built a custom frame to support one of the wind turbine generators and with the use of an induction motor and variable speed drive as prime movers we could simulate different wind speed conditions. By operating and different speeds we could measure water production and get an idea of how well the system is working and if there are aspects of the system that need adjustment.

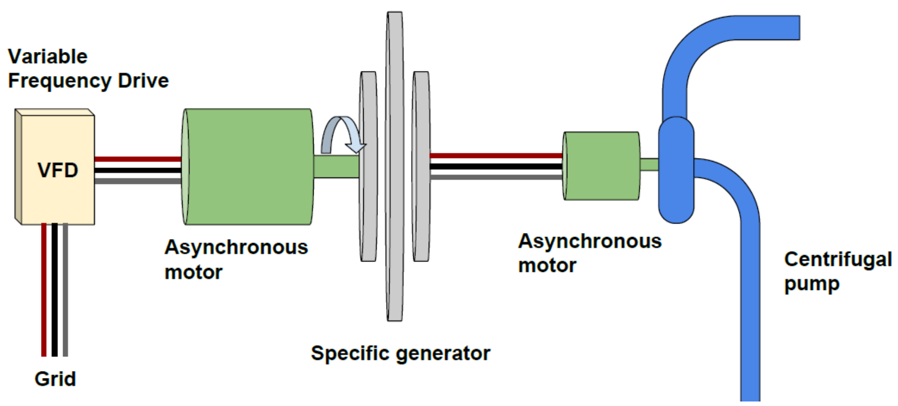

Figure 15 Schematic presenting the test bench working principle

The turbine tested was one of the first prototypes built by Minvayu. This turbine uses 20 magnets per side of 2”x1”x0.5” NdFeB (neodymium) magnets of N40 grade. Our stator was wound for 440V, 3 Phase operation with 4 wires coming out of the stator coils. These represent a 3 phase output with a Neutral wire.

The turbine output was connected to an on/off contactor that could be used to connect the system to a pump. The pump used was a 2Hp, 3 phase, surface centrifugal pump that was 2m above the water source (water tank). The pump for this test was set at the same height as the pump so we could simulate what typically is done by farmers in the region which is pumping the water to their fields nearby, at the same level as the pump.

Figure 16 Picture taken during the exchange activity

The system was tested using the Wattmon Pro that was connected to a flow meter. The AC power output was connected to several multimeters and an oscilloscope and rpm measurement was done using an optical rpm probe. Measurements of amps, volts, hertz, rpm and water flow were performed. The pumping results are given in the following graph. The 2HP system can pump 102 Lt/min (6,120 Lt/Hr) at 5.5 m/s winds.

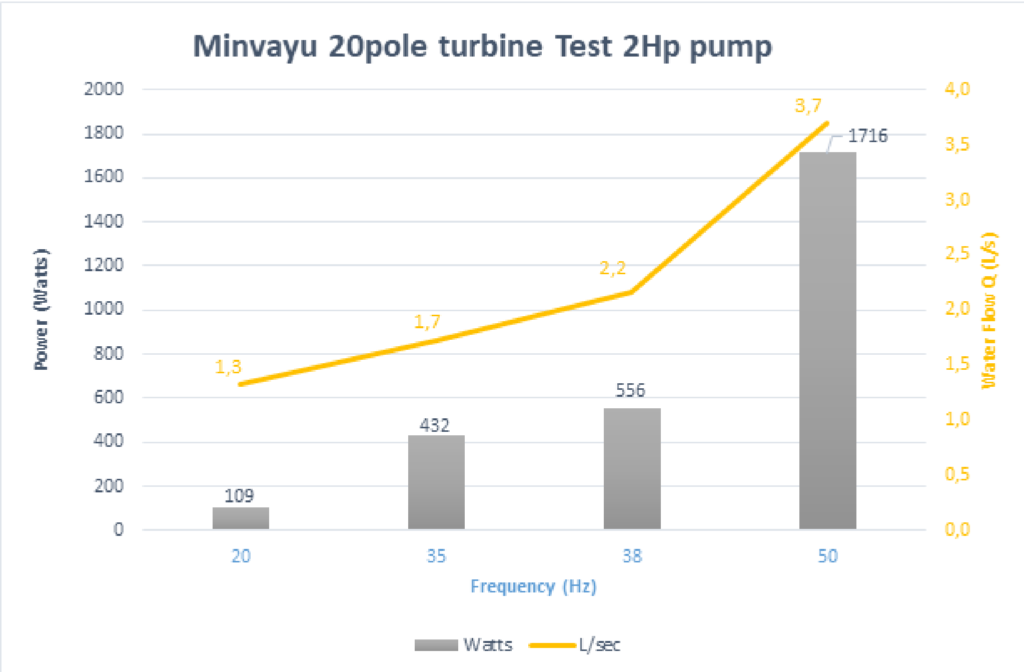

Figure 17 Graph showing the result of the experiment - the water flow obtained in given depending on the frequency and power level of the electrical output of the wind generator.

Besides, we've showcased the Argentinian system, which use a modified e-bike converter to maximize the efficiency and power up a brushless motor, which is basically an e-bike motor without any major modifications. The motor, a 400w (500w peak) is moving a simple diaphragm pump, that is cost competitive and simple to maintain. The system wasn't fully functional in India because the pump have not been brought, but a dry run took place where the converter was powering up the motor without any pump attached.

During the field test in Argentina, this system has successfully pumped about 400 liters per hour with a 5m/s average wind speed, with a 2 meters head. This means that on a single windy day it could pump over 10.000 liters of water. The pump maximum operating point is 1.200 liters per hour. But the same motor can be coiled up to 1.500 w and the pump can be replaced for a larger one. Therefore, the all system is expandable and can be adapted to cover the specificity of the local needs.

An educational class took place, explaining the differences of the two technical approach (with and without converter) and their respective pros and cons.

4.3 Reverse engineering of the Argentinian converter

Gathering in India helped us at understanding a technology that was proprietary and appeared to us as a black box beforehand. Understanding this converter allow us to figure out how to implement similar functionalities with our own open source technology that have been developed in France.

Figure 18 Pictures illustrating the reverse engineering procedure. The Argentinian proprietary converter in order to understand its behavior.

During the conference, copies of the open-source converter have been given to the Argentinian team to jointly develop an embedded code that will replace the existing black box. It is foreseen that the capabilities will be improved. Many drawbacks of the existing design can be solved with the French converter.

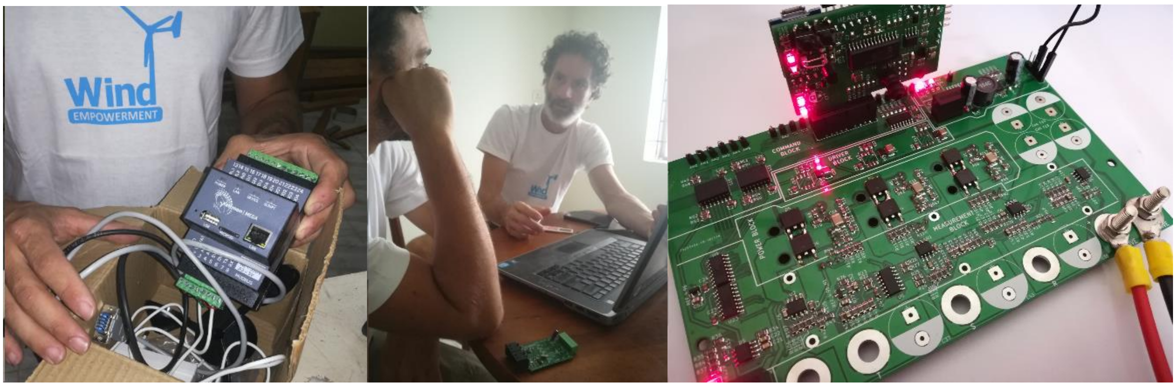

Figure 19 Pictures illustrating the instrumentation and power board exchange that occurred in India.

The meeting gave us the opportunity to exchange best practices on data logging, and Indian technology have been transferred to Argentina in order to equip 500RPM's field prototype.

4.4 Summary of what have been discussed together in India

Gathering helped us in defining the next phase of the project at the light of the data we've collected.

- It has been decided to focus on India and Argentina and to forgot about Morocco because of the described drawbacks (cf §3.2.)
- We've summarized the risks and the actions that will be taken to mitigate them. (cf §6)
- We've defined a new macro schedule (cf §8) at the light of the time constraints of each member

5. SWOT Diagrams

Here the two systems are compared through a SWOT analysis.

5.1 Indian System

Strengths	Weaknesses
- Operating costs are lower than competing fossil fuel based solutions and the long-term VNA is expected to be higher - Maintenance is lower than competing fossil fuel based solutions - As seen with the field survey, the current prototype delivers a water flow compaptible with the majority of both the local domestic and productive uses water consumption - It uses a renewable energy source, its environmental impact is dramatically lower compared to the fossil fuel based alternatives - The system benefits of a political support because of its positive social impact.	- An average wind speed of 5m/s is necessary to consider installing a such system. It makes this technical solution viable only for high wind regions. - Water output depend on wind ressource seaseonality. A backup system maybe needed for the bad season. - This solution is not mature compared to existing solar pumping technologies or traditional windmill water pumps - Capital investment could be higher than a competing solar solution
Opportunities	**Threats**
- The price of fossil fuels should continue to rise due to its scarcity, hence wind based technologies will tend to be increasingly profitable - It can be mixed with a solar power supply, to ensure the water output availability. - The system can be adapted for different pumps and thus covering a wide range of water pumping use cases all around the globe - Passive electronics ensure additional robustness and lower the maintenance	- Not being able to lower the cut in speed could question the usefulness of a such system for medium wind zones - Not to be able to control the electrical coupling in order to supress the cavitation phenomena that could occurs at startup phase, and divert the power when water flow is not needed to prevent drying the well - Not being able to hybridize with solar could lower the usufulness of the solution - Specific design of the generator could be to much of an hassle to adapt for different kind of pump. - Not to be able to transmit the necessary knowledge for a good use and maintenance of this type of systems. - The distance to the test sites makes it difficult to retrieve and compare experimental data that are crucial to refine the design

5.1 Argentinian System

Strengths	Weaknesses
- Operating costs are lower than competing fossil fuel based solutions and the long-term VNA is expected to be higher	- An average wind speed of 5m/s is necessary to consider installing a such system. It makes this technical solution viable only for high wind regions.
- Maintenance is lower than competing fossil fuel based solutions	- This solution is not mature compared to existing solar pumping technologies or traditional windmill water pumps
- As seen with the field survey, the current prototype deliver a water flow compaptible with the local domestic and productive uses water consumption	- Capital investment could be higher than a competing solar solution
- It uses a renewable energy source, its environmental impact is dramatically lower compared to the fossil fuel based alternatives	- Higher use of electronics often leads to lower robustness in remote areas
- The system benefits of a political support because of its positive social impact.	- Maintenance is more difficult than for the Indian solution because of the extensive use of electronics
Opportunities	**Threats**
- The price of fossil fuels should continue to rise due to its scarcity, hence wind based technologies will tend to be increasingly profitable	- Not being able to lower the cut in speed could question the usefulness of a such system for medium wind zones
- It can be mixed with a solar power supply, to ensure the water output availability.	- Not to reach enough robustness for the power converter
- The system can be adapted for different pumps and thus covering a wide range of water pumping use cases all around the globe	- Not to be able to transmit the necessary knowledge for a good use and maintenance of this type of systems.
- Capital Investment could decrease if the production volume increase	
- The system could be used to power up other electrical appliances	

5.3 Discussions

As it has been assessed with the SWOT diagrams, it is foreseen that the Indian system will be easier to maintain and more robust because the amount of electronics will be significantly lower. But the specific generator design could be a shortcoming for the adaptability with other kind of pumps. On the opposite the Argentinian system architecture is expected to be more versatile, but less robust and more difficult to maintain in remote places.

In both cases it will be necessary to explore ways to reduce the cut in speed of both systems to increase the efficiency and expand the usefulness of the technology for medium wind zones.

6. Risk analysis

We've assessed the following risks for the development of both systems. In phase two, it will be necessary to take actions to mitigate these risks.

Social risks

1. **Not be able to raise awareness about water scarcity, or improve efficiency in its consumption, with the consequence that renewable pumping produces the drying of water wells.**

Probability:

The probability depend on the resource of the local water table. In general, the water pumps that are compatible with the power capabilities of Piggott SWT are quite small compared with the fossil fuel based pump. But one possible consequence of lowering the operative costs of water pumping is increasing the water demand as it gets cheaper.

Consequence:

It can then lead to dry out the well if the water resource is not used in a sustainable way. We've understood that is can be a major issue through the testimonies of several Indian interviewees.

Risk mitigation strategy:

To combine the installation of wind water pumps together with a reflection on how to reduce the water demand. By proposing support for drip irrigation for instance.

2. Not to be able to transfer the knowledge and the technology on the field

Probability:

In regions where it is implemented with a local member, this risk is unlikely to occur. We are encouraging local stakeholders to support the long-term initiative. In regions without any local partner, this risk is really high. **That is why we have abandoned Moroccan development.**

Consequence:

As we've seen with the mechanical wind turbines, the availability of support and spare parts is a success factor for the deployment of the technology. Wind turbines and water pumps are complicated technologies that are difficult to master. Not being able to create local knowledge centers would lead to a slower deployment of the technology.

Risk mitigation strategy:

We will have to figure out a strategy to transfer the technology at a global scale to replicate to new local members. Not to be able to transfer the knowledge is a major risk, and we will have to take that into account in the following phases. We discussed about many options to accelerate the deployment of the technology, mainly through online tools and support, and it will remain a major working subject in following phases.

Financial risks

3. Not to be able to reach a competitive price regarding competing solutions (USD / kWh)

Probability:

From the glimpse of the situation we had on the field, reaching a competitive price is possible when competing with fossil fuel powered pumps. The profitability of a wind based system compared to other energy source, is site and usage dependent. We do have in mind an estimate of the cost breakdown of the future system, but haven't developed a tool to perform financial analysis yet.

Consequence:

Not being competitive would restrain the use of wind based pump to marginal use cases. It would have major consequences on the deployment of the technology.

Risk mitigation strategy:

Developing a financial model in order to estimate the associated cost of a wind based water pump. Both in term of CAPEX and OPEX, to get rough idea of the profitability for each specific cases.

Management risks

4. Human resources availability / delays

Probability:

Our time and dedication to the joint water pumping depending on our availability. During WP1 the project took more time than expected. Time constraint was not the main cause as we've also experienced a lot of unforeseen events leading to various delay in order to collect the data from the field.

We strongly believe that we won't face the same issues in WP2 as this phase will not depend from field work, that is always more uncertain.

Consequence:

The consequences would be to have the project running slower than expected but would not impact the final outcomes.

Risk mitigation strategy:

We've scheduled next steps all together in India, and we have some more human resource added to the project.

Technical risks

5. Not to be able to improve the cutting speed point of the wind pumping system

Probability:

As discussed in the §2.3, an electrically coupled wind pump as a cut in speed higher than a traditional mechanical wind water pump. In region of medium wind, it is possible that the yield of an electrical wind pump could be lower than this competing technology. Nevertheless, we are pretty confident in our capacity of lowering the cutting of the system.

Consequence:

Not being able to lower the cut in speed would result in lowering the usefulness of the technology in medium wind zones**.**

Risk mitigation strategy:

Defining the cut in speed as a major parameter in the specification of the improved version of the technology to be developed during phase 2.

6. Not to be able to use standardized motor leading to low availability of the spare parts

Probability:

The Argentinian prototype relies for now on a specific bike motor that contains sensors internally. This motor that include internally Hall Effect sensors is not widely available. The spirit of the project is to be able to combine the existing water pumping that are already in place on the field, and to adapt a wind turbine to power it up with renewable energy instead of fossil based energy. For now, the technology is not reaching this goal yet.

Consequence:

A possible risk is not being able to develop an adaptive system, and to rely on spare parts that can't be supplied locally. As we have seen in §2.2, it would be a major issue.

Risk mitigation strategy:

Technology to be adaptive will be part of the specification of the improvement of the technology that will be developed during phase two of the project.

7. Not to be able to create an open source system.

Probability:

By now, the actual prototypes are hardly relying on proprietary technologies. Developing a proprietary technology can be attractive, because it is possible to start the development process from parts that are already reliable and mature. On the other side, it is not possible to share the knowledge easily, as we have seen in §4.3 with the difficult reverse engineering required.

Consequence:

We've seen that technology that is not open source is really difficult to share and to replicate. We've struggled with reverse engineering in the past and we would like to avoid that to happen again.

Risk mitigation strategy:

All the technologies that are currently under development are based on open source licenses. We agreed not to use proprietary parts in future development phase to simplify the knowledge exchange process.

8. Not to be able to meet the water demand

Probability:

In India and in Morocco we have found some applications in the field where the required water flows was too high for our SWT. Not to be able to cover this needs is likely to happen, because the maximum power rating of the Piggott design is limited to around 3kW. Even if the scope of the project is not to focus on large scale water pumping, it is necessary to be able to propose a technical challenge for higher water demand through a hybridization solar/wind scheme.

Consequence:

Not to be able to hybridize would lead to lower the potential interest for our technology. But it would not affect the core objective that is to help the small scale productive uses where Piggott design is largely sufficient.

Risk mitigation strategy:

Being able to hybridize the technology with solar will be part of the system specification.

7. Conclusion

This first phase of the project led us to the following conclusions:

We have found that there are important variability in the needs and applications in the field with on one side applications for productive uses with quantities of water needed exceeding 100,000 liters / day, and on another side applications of productive and household uses with a need of 7,000 liters / day. This variation in the water demand being independent from the water resources, with depth of water tables also varying from 20 m to 300 m.

Such variability in the demand requires the design to be highly flexible and adaptive, to be able to match the power requirements of the specific water pump and water infrastructure that often already in place on the field.
Pumping systems should be differentiated according to their power scale and this rise an open question for the incoming development phase: Is there a single technical solution that can cover all this range of power ratings, or it should be considered to develop two solutions?

This social analysis led us to realize the importance of working on limiting the water consumption by improving the watering efficiency. It has been seen in many case that over pumping was a severe issue causing wells to dry. Therefore, the system implementation should be combined with some advisory and awareness campaigns on how to improve water consumption sustainability through a better watering infrastructure.

From the technical perspective, the first prototypes showed encouraging result. Both systems, the passive coupling and the active electrical coupling ran successfully during the tests that have been carried out.
The first run of existing prototypes on the field have showed that the actual systems are found to be useful and effective for windy zones where the average wind speed is above 5m/s.
For all the applications, it is interesting to evaluate the possibility of combining the wind systems, with solar energy, or with motor pumps, to guarantee a steady and reliable water supply since it will be a key argument to convince the rural world in investing money in renewable based water pumping systems.

This socio-technical study permitted perform a risk analysis for the final system. The development phase will be carried out at the light of these risks, and will use the mitigation strategy above described to minimize them.

8. Macro Schedule for phase 2

At the light of the risk analysis that have been performed, specifications of the final system will be written. It is foreseen that deeper testing will be performed on the both prototypes and improved versions including joint modifications. As such, this phase will intend to create technical solutions covering the range of needs that have been discovered during the field survey.

The macro schedule giving the next steps can be found below:

Argentine System		
Number	***Task***	***Date***
1	Define the specifications of the entire system	April
2	Install a datta logger in the test bench of argentina	May
3	Replicate the converter developed in France, to be used in the Argentine test bench	June
4	Test the system with the french converter in the test bench	July to September
5	Make improvements in the pumping control system, working all together	October

Indian system		
Number	***Task***	***Date***
1	Define the specifications of the entire system	April
2	Adapt the converter or develop a starter controller for asynchronous motors	May to August
3	Test of the complete systems with the starter controller in the test bench	September
4	Perform iteration in system improvements to optimize its operation	October to December

We will pursue the objective of unifying the systems to obtain a unique solution, applicable to the different social contexts surveyed. As a final objective, we will test the developed systems in the test benches, making improvements in them until we have a version ready to be tested in an open field installation in the next stage of the project.