AGGREGATION PLATFORMS FOR DISTRIBUTED ENERGY RESOURCES

ENABLING THE DEVELOPMENT OF DECENTRALIZED RENEWABLE ENERGIES IN AFRICA

WHITE PAPER
INNOVATION

RES4MED

About RES4MED&Africa

Renewable Energy Solutions for the Mediterranean & Africa RES4MED&Africa

Who we are: RES4MED&Africa promotes the deployment of large-scale and decentralized renewable energy and energy efficiency in Southern-Mediterranean and Sub-Saharan African countries to meet local energy needs. Since its inception in 2012, the association gathers the perspectives and expertise of a member network from across the sustainable energy value chain.
Our work: RES4MED&Africa functions as a platform for members and partners of emerging markets to foster dialogue and partnerships, share knowledge and build capacity to advance sustainable energy investments in Southern-Mediterranean and Sub-Saharan African countries.
Our mission: RES4MED&Africa aims to create an enabling environment for renewable energy and energy efficiency investments in emerging markets through on 3 work streams:

- Acting as a **connecting platform for dialogue & strategic partnerships** between members and partners to exchange perspectives and foster cooperation;

- Providing **technical support & market intelligence** through dedicated studies and recommendations based on members' know-how to advance sustainable energy markets;

- Leading **capacity building & training efforts** based on members' expertise to enable skills and knowledge transfer that supports long-term sustainable energy market creation;

At the end of 2015, RES4MED members decided to expand the geographic focus to Sub-Saharan Africa in light of the huge potentials and growth opportunities for Africa's renewable energy sector.
Members: RES4MED&Africa gathers a network of 38 members from across the sustainable energy value chain including industries, agencies, utilities, manufacturers, financing institutions, consultancies, legal and technical services providers, research institutes, and academia.
Partners: RES4MED&Africa works with local, regional and international partners, agencies and organizations to pursue its mission and promote renewable energy and energy efficiency deployment in the region of focus.

IRESEN

IRESEN is the national Institute for Solar Energy and New Energies in Morocco. It was created in 2011 by the Ministry of Energy, Mining and Sustainable development, with the participation of several key players of the energy sector in Morocco devoted to support the national energy strategy, through applied research and innovation in the field of green technologies.

IRESEN provides knowledge and research infrastructures at the disposal of energy innovation, assumes the development of R&D energy projects and plays the role of funding agency for applied research and innovation.

IRESEN funding agency finances R&D and innovation projects, involving universities and Moroccan companies (SMEs and start-ups), through the launch of at least 2 calls for projects annually, in the field of green technologies. The main objective of IRESEN funding agency is to contribute to the establishment and development of centers of excellence and highly specialized research units and to create knowledge and know-how at national level through innovative projects. Each financed project aims to obtain processes, services or products 100% Moroccan products with a high commercial added value.

IRESEN is also developing R&D infrastructures based on the demand, in addition to ensuring supporting and building up university research. For this, IRESEN has adopted an ambitious strategy to develop research infrastructures at the service of innovation and researchers, and to create a large network of shared infrastructures dedicated to research. IRESEN aims to set up several platforms integrating the R & D value chain on priority topics in the field of renewable energies and aims to network these platforms in a group for Applied Research.
To this end, IRESEN has created, with the support of the OCP Group, the platform for testing, research and training in renewable energies and more specifically solar energy (Green Energy Park), in close collaboration with the Mohammed VI Polytechnic University (UM6P). This first and only platform in Africa will create synergies and pool infrastructure of several universities and research centers to create a critical mass to achieve excellence and, also, to acquire knowledge and know-how from all academic and socio-economic partner.

IRESEN
Institut de Recherche en Energie Solaire et en Energies Nouvelles

Three new platforms are being developed by IRESEN:

- The "Green & Smar Building Park" (GSBP), with the support of the OCP Group, which is a platform dedicated to research and development in the field of green buildings, energy efficiency, smart grids and sustainable mobility. GSBP will aim to pool resources, federate the efforts of different institutions and local actors in the building sector (research centers, universities, development agencies, SMEs ...) and encourage research by focusing on the human capital in order to reach the goal set by Morocco, which is achieving 20% energy savings through an energy efficiency program by 2030 .
- The Water Energy Park, with the support of the OCP Group, which is a platform dedicated to rese arch and development in the Nexus Eau-Energie-Agriculture aiming at pooling resources and concentrating efforts on the theme of water (sweet, brackish and salty) and its relationship with energy and agriculture.
- The Bio Energy Park which is a platform dedicated to research and development in the fields of biomass and bioenergy (waste to energy, methanisation, biogas, ...) and energy storage.

IRESEN Strategic lines

- *to support the Moroccan technology roadmap;*
- *to implement and to participate in the financing of projects carried out by research institutions and by industry;*
- *to strengthen national research by appropriate infrastructures:*
- *to valorize the results of R&D projects and to incubate startups;*
- *to bridge the gap between universities and companies;*
- *to offer technical and financial support for companies.*

Abstract

This paper intends to analyse the investment potential in the aggregation platforms for distributed energy resources monitoring. Based on automatic smart programs, the technology allows the creation of a transactive grid where customers equipped with solar panels and batteries can decide easily to store, consume or sell to the neighbouring consumers their energy surplus. A model created is based on isolated interconnected micro grid, with a high consumption profile. It is conceived to allow the monitoring of the micro grid through an automatic process combining prices and energy balance arbitrage. Thanks to a cooperation with the renewable energy research centre of Morocco, IRESEN, providing the data, the model is based on the University of Fes and includes realistic consumption, generation and cost profiles. The results show a significant reduction of the customers' bills while offering a large autonomy from the main grid and a profitable outcome for investors. Utilities' interests are also considered, by providing a load reduction system thanks to a smart storage mechanism. However, the demand load reduction is rather small, due to the limitation of the model to a static architecture. Improvements are likely to be achieved through more sophisticated software allowing dynamic iterations. The paper concludes that the technology has a potential for investments, but its development will depend on the utilities' acceptance towards a mutation in their model and on a faster implementation of electric transportations, smart appliances and interconnected devices.

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1 INTRODUCTION

The energy sector is on the edge of an historic revolution that could change the way we consume energy forever. The reduction of technology costs and the need to spread the intermittent production units throughout the grid is favouring a decentralized implantation of renewable energies (RE) [1]. This created opportunities for both developed country and developing countries with high natural resources but underdeveloped electricity grid. For the firsts it allows to spread the production sources and avoid grid congestion, for the second it is a way to bring energy access in isolated areas in a faster, cheaper way than a centralized system. However, beside their environmental benefits and their increasing profitability, renewable energies are intermittent sources, forcing utilities to adapt the balancing system. Therefore, when RE represent a large share of the electricity production, the change is drastic and costs for utilities increases significantly. The phenomenon is even worse with decentralized systems, as the forecasts lose accuracy with the decrease of the units' size.

As always in history, new challenges raise new solutions, and the importance of the energy sector have attracted other industries, such as the IT sector, which saw an opportunity to use its big data experience to help monitoring a system in need of more and more real-time adaptation. Therefore, new revenues streams are tested to capture a value based on a service offered to the consumers rather than the traditional commodity supply. But utilities are primordial for the systems and the IT sector needs to involve them before implementing any real projects. Therefore, new entrants are trying to create technologies and solutions able to gather the interests of consumers, utilities and investors in a common model. One of the solution is to combine Virtual Power Plants and micro transactions systems in a transactive grid architecture [2]. The idea is to connect all renewable installations, batteries, customers' smart meters and electric vehicles present on the same micro-grid to monitor them optimally through smart software and internal transactions. In concentrated consumption micro grids, the system allows the consumers to install renewable energies without the impact of the peak loads that causes increasing balancing costs and market prices volatility [3].

This paper investigates the potential investments in this technology and the benefits for both consumers and utilities. The broad possibilities of applications of these systems make them possible everywhere in the world, but the paper focuses on the African continent for the experiment, because of its urgency to get rid of fossil dependency, to provide access to more and more industrials starving for cheap, clean and safe electricity supply and its exceptional natural resources. Moreover, thanks to a collaboration between the Italian association RES4MED and the Moroccan research centre IRESEN, precious data have been collected for the conception of a model as close to the ground truth as possible.

2 STATE OF THE ART REVIEW

The transactive grids experiments are rare and started only recently. Nevertheless, some of them present promising possibilities and increasing notoriety from the main energy actors. The most famous experiment currently is the Brooklyn micro grid project. Conceived by the start-up LO3 Energy in a district of New York, it allows transactions between owners of solar PV and their neighbours. The goal is to test the system in a small scale to verify its viability and then scale it to a city size model (Figure 1). The sales mechanism is based on an auction scheme made through mobile applications and website allowing consumers to set a purchasing price of electricity and producers to choose the best offers. The business model of the project is based on transaction fees applied on the transactions between customers and producers. It uses the Ethereum (blockchain technology) to enable secure transactions without a financial entity. However, the use of blockchain is raising scepticism in the energy sector, because the technology's capability to monitor transactions is limited to a few hundred per second, where the energy sector would substantially more.

Another type of experiments is developed by three start-ups (Conjoule, Grid+ and Grid singularity) and is based on a market mechanism, connecting prosumers and interested buyers to allow straight transactions through blockchain, reducing friction costs. In a similar idea, Italian utility Enel and German power provider Eon have launched a first testing phase of direct transactions between them. These projects are in their early development phase and the results are not yet made public, but the companies have successfully raised several million euros each through virtual or real currency, showing an interest from investors.

Finally, the most interesting project for Distributed Energy Resources (DER) development has been launched by the German TSO TenneT and the battery provider Sonnen. It is based on congestion reduction in Germany by gaining access to behind the meter batteries of customers against a reward mechanism. Thereby, the two actors hope to help manage bottlenecks in the main grid and reduce the need for curtailment. This experiment is the closest to the model tested in this paper, although it is centred on storage management and blockchain and not on transactions between customers.

Figure 1: The concept behind the Brooklyn micro-grid

3 DECENTRALIZATION OF THE GENERATION

3.1 The next step for renewable energy deployment

The architecture of the energy system has changed considerably during the last two decades, with growing consideration towards global warming and the tremendous decrease of renewable technologies costs [4]. Besides, the liberalization allowed more and more actors to enter the energy generation sector, until reaching the consumers themselves. Accountable for a third of the energy consumption around the world [5], their involvement represents a huge step towards a green economy through rooftop PV and batteries installations. As RE production is highly dependent on the weather, decentralised generation is a way to attenuate this dependence by spreading the production units over a larger area (Figure 2).

Indeed, some countries (cf. Ireland, Denmark, Germany, Italy...) are facing difficult challenges because of the concentration of the RE generation units. With nearly 50GW of wind installed mostly in the north of the country, Germany experiences grid balancing issues and bottlenecks in the grid [6] because the transmission grid is incapable to bring this energy correctly to the south of the country. Bottlenecks and emergency balancing cost several hundred millions euros per year [7] and became a real struggle for utilities during the last decade. The paper does not question the need of big RE installations, but considers that in peri urban and rural areas, with a lower demand than the big cities, decentralized small and middle scale plants can reduce grid congestion. However, the residential distributed generation in its current model is a struggle for utilities. They must balance unpredictable and spread electricity flows entering the grid and purchase them at a fixed price, often when market prices are close to zero.

With the new challenges, new innovative solutions emerge from diverse sectors and both developed and developing country can beneficiate of an efficient decentralization of RE. Therefore, the scope of the model created is not limited to the site selected. However, considering the emergency of the African continent to electrify more than 600 million people, but also the numerous industries starving for electricity, the paper focuses on the potential development in the region.

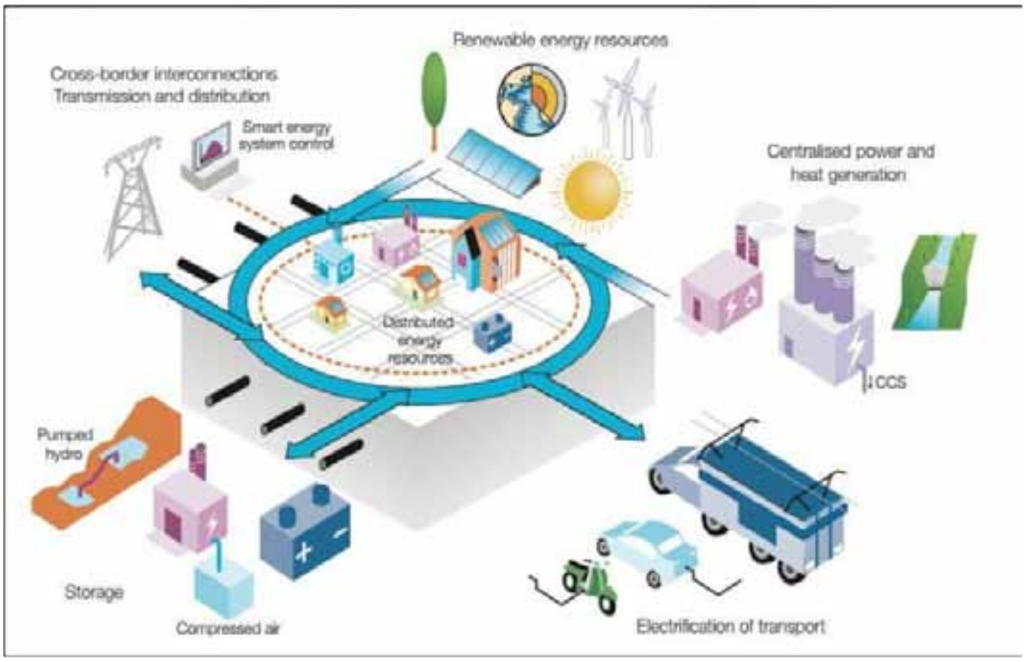

Figure 1: The concept behind the Brooklyn micro-grid

3.2 Fostering the economic development of Africa

Although Africa is part of the regions of the world that contains the best natural resources for RE, the continent suffers from a drastic lack of electricity access. Sub Saharan Africa represents 13% of the world's population, and yet it accounts for 48% of the worldwide population without electricity access [8]. And yet, Africa is starving for electricity, companies and households have a rapidly increasing demand and they pay a way higher price than occidental countries for their electricity (from three to six times), often generated by diesel generators. Estimations plan that in 2040 the African demand for electricity will be the equivalent of Latin America and India combined (Figure 3), with almost 1900TWh per year among which 1300TWh coming from SSA [8]. This important increase in energy demand is caused by the fast development of the countries, with industrial development and innovation as a leitmotiv. If coupled to large scale power plants for the cities, decentralized installations in the more rural and peri urban areas can help to electrify the continent in a more sustainable and a quicker way than with a fully large scale based system. With costs constantly decreasing and abundant resources, the continent would most likely benefit from such orientation of its electrification.

There are also substantial economic incentives, as RE do not need any fuel to generate electricity and thereby bring independence to the countries by avoiding imports. Especially because the continent's estimated capacity of renewables generation is huge, with at least 10 TW of potential capacity in solar and wind [9]. However, the development of decentralized RE in Africa must be done in the best way to avoid the struggles European utilities are facing. The paper assesses the potential of the aggregation platforms to do so, by creating transactive grids allowing a quasi-auto-production and a reduction of costs, while providing an automatic and smart balance of the system. The model concentrates on Morocco because the country has a leadership role for innovation in Africa and ambitious goals for RE development, making it an ideal site for experimenting such technology.

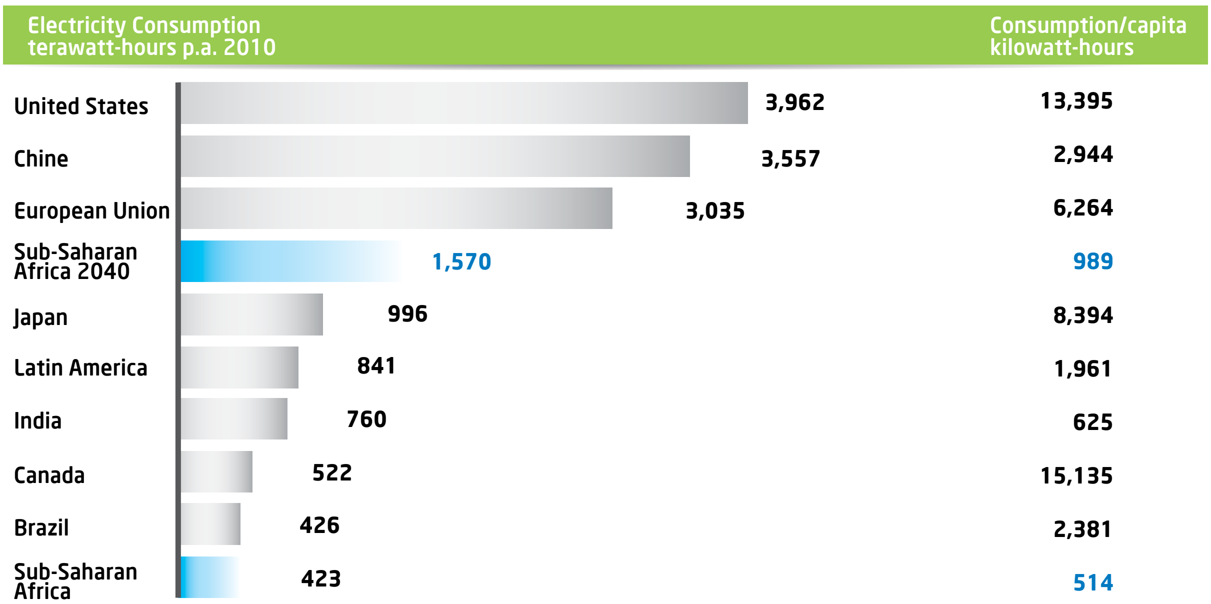

Figure 3: Forecast for Sub-Saharan electricity consumption in 2040

3.3 Morocco: an ambitious renewable energy revolution

Morocco confirmed its RE goals with an exceptional commitment during the last Conferences of the Parties (COP) in Paris (2015) and Marrakech (2016). The country engaged in Paris to reach 52% of its national consumption fed by RE sources in 2030. One of the reason of this ambition is the lack of national fossil fuel resources: the energy system is thereby heavily subsidized by the government. Currently, the country relies on 91% from import for its energy use [10] ,composed mainly of oil, coal and gas, which is both economically and politically problematic. Hence, the country plans to reach 42% of RE in the total capacity by 2020 and 52% by 2030. This will require several billion euros per year, partly assumed by the Moroccan state but mainly by private investments, which can create both a healthy and sustainable economic growth but needs attractive investments, both in large scale and medium scale installations.

The main law framing the RE development in Morocco is the so called "renewable energy law", the law n°13-09. Adopted in 2009, the law focuses on RE development, opening the production to competition, granting access to the grid and expanding the lines when needed. The liberalization of the production was a success, however, most of the projects have been mostly focused on large power plants, because of the nature of the law itself that forbids small scale installations by preventing access to low voltage grid. The government took an important orientation a few years ago by planning the liberalization of the energy system, to introduce competition in the market and reduce the investments carried by the government. Finally, the latest energy law of the country, the law n°58-15 published in 2015 introduces a net metering scheme as well as the access to low voltage grid for RE installations. Nevertheless, the level of electricity surplus sold to the grid is limited to 20% of the yearly production for small scale installations, which highlights the will of the country to avoid massive disturbance of the national grid.

3.4 Moroccan's main challenges for an efficient renewable deployment

The country will have to face significant challenges to face to reach the goals it set for 2020 and 2030. The first and most difficult one is the technical integration of RE into the grid. Indeed, Morocco has just finished to build its national electric infrastructure, conceived to transport fossil fuel generated electricity from large power plants to consumers. Hence, the system is not fitted for the requirements of a high penetration of RE and will need innovative technologies and solutions to support the 42% targeted for 2020, as a deep transformation of the infrastructures itself would be long and expensive. Furthermore, the country could face the same kind of challenges as Germany or Italy, because of the geographical position of its natural resources. The potential of wind and solar are both mostly concentrated in the Western Sahara region. As opposed to the cities, and therefore the consumption, concentrated in the north and north-west part of the country. In this context, the unavoidable upgrade of the transmission grid could be contained if combined with a deployment of aggregated Distributed Energy Resources (DER). The term gathers several technologies, including the Decentralized Renewable Energy solutions. It also accounts for the energy efficiency and demand response programs, storage (before and behind the meter) and electric vehicles (EVs).

The second issue is the market disturbance of the RE. Indeed, RE production makes the market prices more volatile. As Morocco is planning to liberalize its system in the coming years, the country will have to deal with high fluctuating market prices if the RE integration is not adapted (Figure 4). Moreover, as a fast and ambitious development of RE is facilitated by a combination of large and medium to small-scale installations, small investors need to be protected from the risks of the markets.

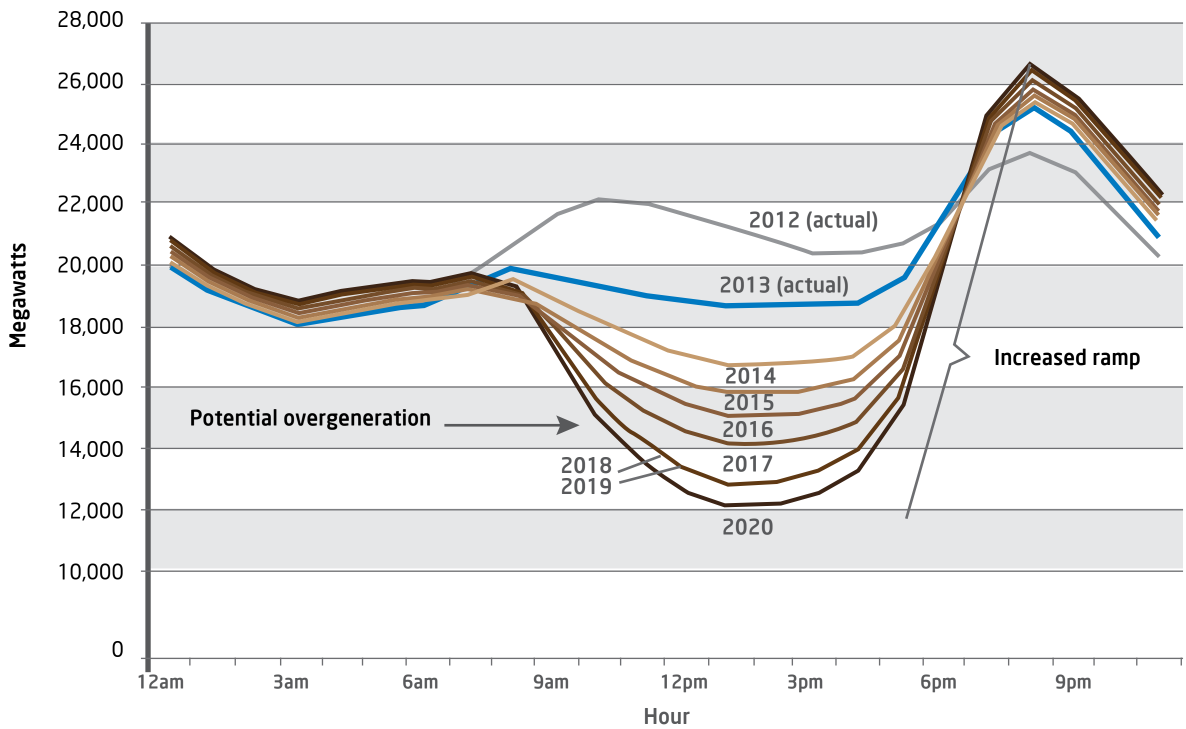

Figure 4: Effects of renewable energy generation on the electricity market prices

4 OPTIMIZATION OF DISTRIBUTED ENERGY RESOURCES MONITORING

4.1 Stabilizing the grid for high renewable energy penetration

One of the benefits of the transactive grids platforms is to help the stabilization of the grid frequency, real value added for utilities that must support significant costs to balance the grid. Thanks to the technology, virtual offer and demand are reduced and through the integration of smart battery software the actual electricity flows injected in and pulled from the grid are reduced, helping the utilities to anticipate the flows and to monitor the grid frequency. Although smart micro grids are quite rare currently and are mostly experimental projects, the decentralization of the RE generation combined with utilities' need for a more efficient balancing system will likely create the need for their worldwide development.

4.2 Fighting the duck curve

Because of the concordance of sun intensity and peak hours (lunch time) or sudden high wind speed causing the wind turbines to produce massively, the prices are significantly changed by RE generation. This phenomenon, called the "Duck curve", because of the shape of the price curve, will worsen as the share of intermittent energy sources increases. The aggregation platforms would be able to protect small and medium size prosumers if used individually, but once scaled they could act as peak shaving mechanisms for the national system, providing protection and cost reductions for large producers and utilities.

4.3 Empowering the customers

The last problem to solve by the utilities and retailers in the energy sector the small interest customers have towards the electricity sector. This created a struggle for energy providers: profits are getting thinner for whereas the number of producers and retailers raised with the liberalization. To solve this problem, the sector is looking towards the electricity as a service instead of a commodity. That means providing a bunch of solutions to customers that are not limited to electricity supplying but that widens to the service offering (battery or solar PV installation loans and leasing, applications for demand response, EVs integration...). The transactive grids technology intends to facilitate such services so the consumers do not have to spend much time managing its energy consumption or services. Furthermore, micro transactions enabled by the platforms gives an economic incentive to the customers, with an access to a more stable energy market with low transaction costs.

Such multi-purpose micro-grid monitoring model is represented in Figure 5. It combines low and medium voltage consumers equipped with batteries and solar panels together with central installations owned by the micro-grid manager. These systems are all monitored by a common entity, allowing cohesion effects and efficiency. Offering security and flexibility, the Distributed Ledger Technology seems well fitted for the management of these systems.

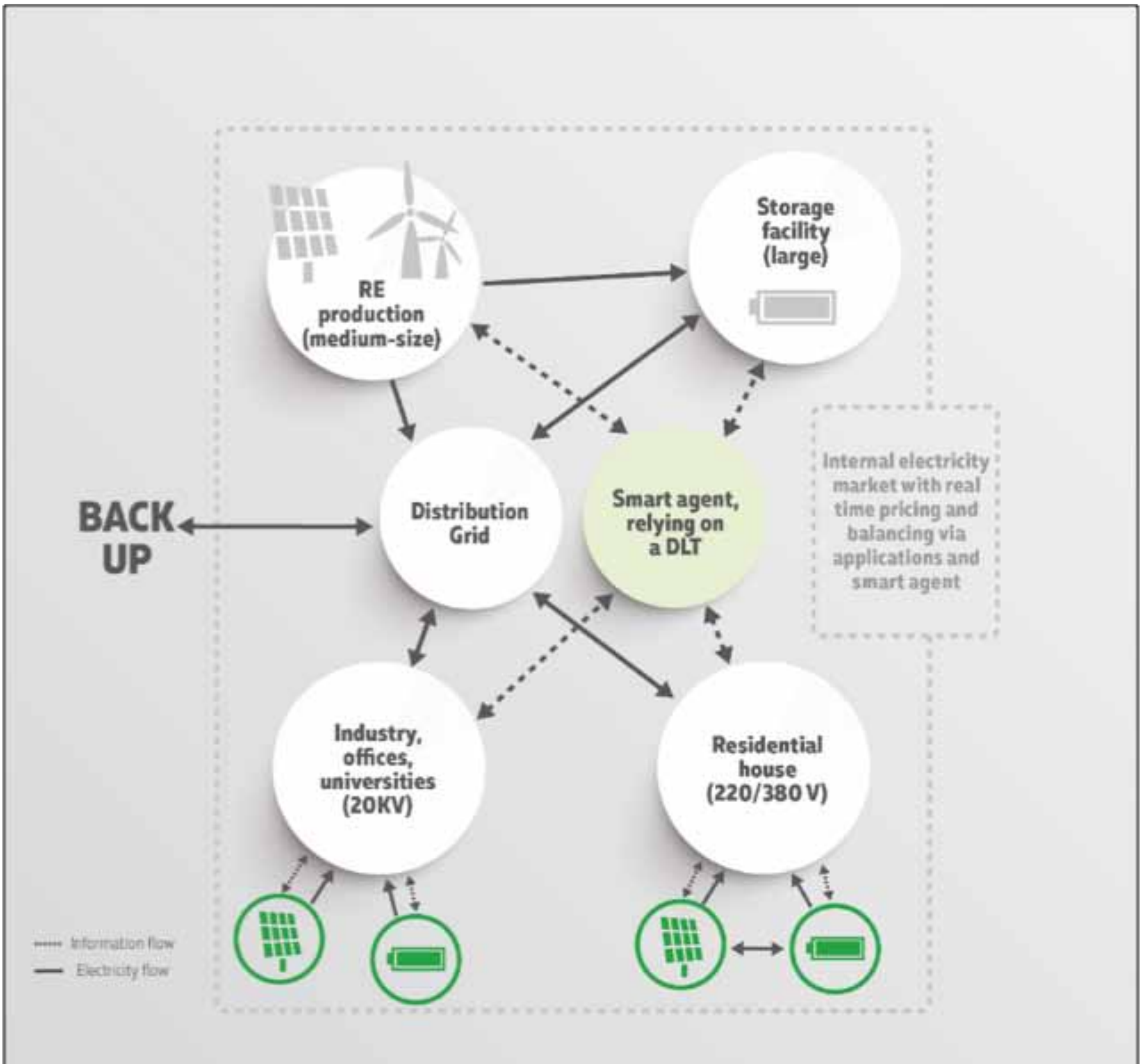

Figure 5: Smart monitoring of a micro-grid

5 UNIVERSITY OF FES TRANSACTIVE MACRO GRID: METHODOLOGY

5.1 The model architecture

The model is organized as a transactive network between the buildings, the storage units, the RE installations and the central software. Each flow is registered by the software and monitored through automatic programs, allowing the best optimization of the system. The micro grid is connected to the distribution grid and can interact with the national grid, however, one of the main purposes is to lower the loads (offer and demand) so the grid balancing is easier for the utility and the market disturbances at peak demand and peak offer hours are reduced. As an analysis of the possibilities of investment in the technology, the aim of the model to offer a balancing service to utilities, significant incentives to the customers with benefits for investors. Hence, the dispatching of the electricity flows is made optimally inside the micro through exchanges, the balance of the load is done by calibrating the storage and PV system to shave the peaks, but as the profitability for potential investors is primordial, the size of the batteries and PV are limited. The university campus still has the same overall bill and budget, but transactions allow a better allocation of the energy flows while favouring energy efficiency through market price and peer pressure. Transactions are made in a virtual money, the tokens, on which fees could be charged by the project investors but that allow an exchange system more adapted to university campus.

5.2 Elaboration of the model

A wind assessment has been conducted for the project, however, as the potential found with the data collected is too low for a viable investment, it is not discussed in the paper. Moreover, the abundant solar resources of the country provide excellent outputs for the solar PV installations.

5.2.1 Production

Thanks to the data collection, 8760 hours of a full year can be used for each building available in the micro grid. Hence, after analysing the different potential of each building and assessing the capacity installed on them, the production can be known for every hour of a year. The data about irradiation have been collected through the PVGIS tool of the European Commission. The conversion into electricity is made with solar panels of 18% efficiency. Once the surface required is known, the outcome of the solar installations can be calculated, for each building. The PV system is composed by six different units. Four units of 300kWp are installed on the rooftops of the Engineering laboratory, the General teaching building, the SHS laboratory and the Engineering teaching building. One unit of 350kWp is installed on the rooftop of the Public areas and offices buildings and the biggest, the 400kWh unit is spread on the different rooftops of the student residences. Each unit are fitted to the available surface of the buildings, extrapolated from the architectural plan provided by IRESEN, and to the consumption profile. The final generation with a 1.950kWp PV system is more than 3.593MWh per year (Figure 6), implying a capacity factor of 21% (Figure 2). This would theoretically allow to cover 93% of the 3.869MWh campus consumption, but a lower autonomy is obviously expected, as the storage capacity cannot provide a 100% energy supply.

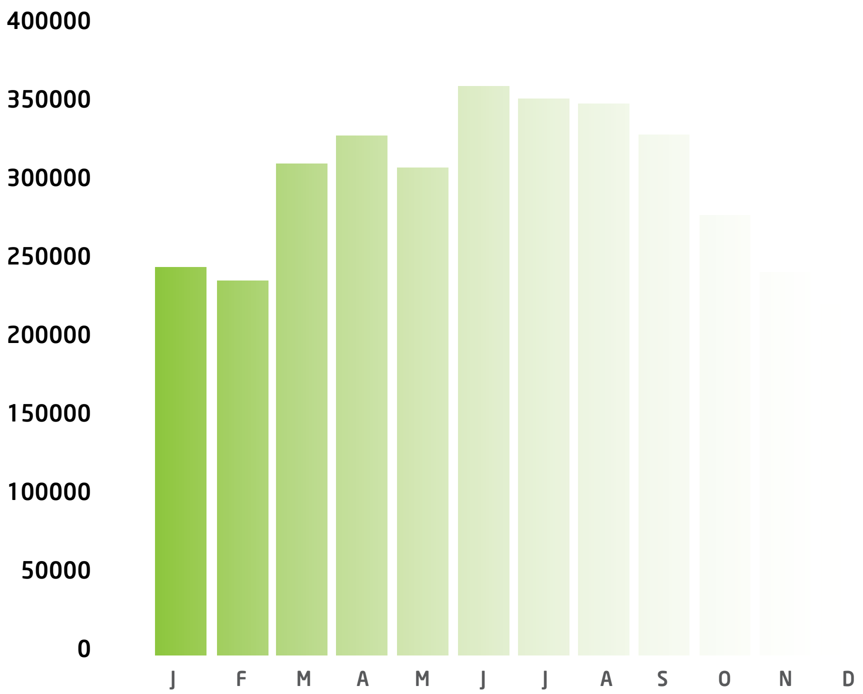

Figure 6: Monthly production of the PV panels

5.2.2 Consumption

The consumption data have collected thanks to IRESEN which provided an hourly consumption profile of a university laboratory. The data provided were those of the RE laboratory of Ben Guerir, the IRESEN research facility with similar consumption profile. A consumption profile has been extrapolated to the campus of Fes through a matrix 24x12. A similar mechanism was used to model the student residences consumptions. The profile of the consumption has been separated into a summer/winter basic pattern [11], then extrapolated per hour of the day for each season. Finally, the pattern has been adapted to the 1.2MWh consumption per year of the residences through a matrix 12x24. Finally, the offices, classrooms and public spaces consumptions have been simulated by following the profile of a typical commercial load, fitted to the global consumption of classrooms, public spaces and service facilities, respectively 18, 11 and 27kWh/m2 [12]. After treating the data and extrapolating more realistic profiles of consumption from it, the overall consumption of the campus is 3 869MWh.

5.2.3 Smart storage and energy exchanges

As the core of this paper, this section composes the real innovation offered by the transactive grids. The exchanges process is modelled through three different interaction steps. The first one aims to fit the three main demands with the three main offers of the different building. The second exchange happens between the buildings that have the biggest production remaining after the first exchange and the ones that have the biggest demand left unsatisfied. Finally, the third exchange tries to make the buildings with both a different profile and opposite load to interact with each other. Five buildings have a 300kWh storage unit, the student residences have a 130kWh unit and a central storage unit of 300kWh is placed to control the final load before the flows interact with the national grid. At every hour, after the exchanges, if some energy remains in the battery, it is stored according to an hourly coefficient profile elaborated by a manual iteration process, to flatten final offers and demands.
In an intent to optimally reduce the loads coming from and going to the national grid, the discharge and charge have different patterns, themselves different for building's batteries and central storage. Through this process, the central battery can shave the peak demand without emptying the batteries for the next peak, since the energy stored during the days is very low. This mechanism allows to guarantee the utility that it will not have to manage excessive peaks.

5.2.4 Financial data

The different costs of the PV panels and storage units are based on IEA data and on costs assumptions used by the professionals of the sector. The PV system costs retained for the model are 1 200€/kWp, installations and inverters included [13] and the storage units' costs is 550€/kWh. This last value is coming from conservative estimations of the IEA, but a recent market study from Bloomberg shows even cheaper costs, with 209$/kWh (around 180€/kWh) in 2017 for lithium-ion battery. The analysis even forecasts a reduction of the costs down to 80c in 2025, which would be a real breakthrough in the massive adoption of centralized and decentralized storage, both for the grid and the electric vehicles.

6 RESULTS AND DISCUSSIONS

The transactive grid models rely on three pillars: the customers, the utility and the investors. These three group of stakeholders have to get an interest in the transactive grids or any project is vowed to fail. This section analyses what each of them gain, but also what could influence these gains.

6.1 The prosumers

After testing different earnings profiles, a different approach towards have been chosen compared to what is tested in other projects. It combines the traditional billing model and the innovative systems allowing transactions between prosumers and their empowerment. In addition, customers receive a virtual currency, the tokens, based on each kWh not consumed or exchanged and on the hour of the day: 1kWh is equal to 0.8 tokens in low load, 1 in full load and 1.2 in peak load hour. Each token can then be used for diverse services inside the micro-grid, such as electric car charge, energy purchase...The bills are successfully reduced by 25% compared to what each building would pay by purchasing their demand from the national grid. The amount of exchanges calculated through this scheme is also satisfying, with 14% of the total energy generated exchanged, whereas 53% is consumed by the generators themselves (Table 2). Overall, the system provides a 69.4% autonomy to the prosumers, compared to 49% with the PV only system, and to 70.5% compared to the regular storage system. The loss of 1% autonomy is then minor compared to the reduction of the loads discussed in the next chapter. Considering that the savings are made in a country where electricity prices are extremely cheap, between 0.66 €/kWh at low load hours and 0.127 €/kWh at peak load, if applied in Sub Saharan Africa, the systems could experience even more profitable models.

6.2 Load shaving for utilities

Compared to a business as usual scenario, the maximum demand load per hour throughout the year have been reduced by 29% (Figure 4). Then, compared to a traditional decentralized solar PV system on rooftops, the maximum demand load has been reduced by 20% and the offer reduced by 43% (Figure 5). Furthermore, the amount of energy sold to the national grid during the year is reduced by 41% compared to the system with only PV generation installed, and the total demand by 24%. Finally, the model has also been compared to a PV + storage traditional system. Once again, results show promising possibilities, as the peak demand is reduced by 12% and the peak offer by 43%. Although the overall amount of energy sold throughout the year is slightly higher, around 1% more, the loads reduction is large enough to compensate the quantity of energy offered. If several small isolated transactive grid forecast and flatten the curve, utilities are provided with a system helping to forecast the loads, reduce the peaks and the amount of energy bought (Figure 5 and 6).

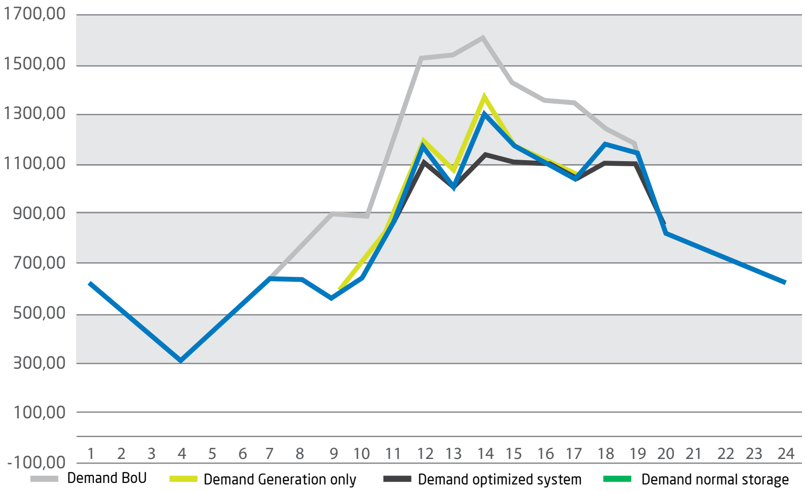

Figure 7: Maximum demand loads comparison – kWh

Such significant reduction of maximum demands through exchanges and smart storage would allow a reduction of the costs of back-up units activation for utilities, as much as providing them a more accurate forecast of what the energy load will be at any time of the year. Indeed, the storage system, if made intelligent, can decide how much electricity must be charged or discharged, not only according to what is needed or produced, but to what the utilities can accept at that time of the day.

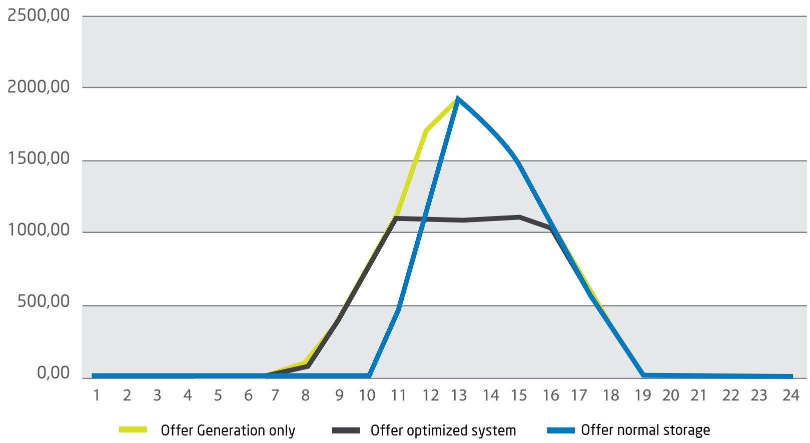

Figure 8: Maximum offer loads comparison – kWh

As for the offer load reduction, it has two main benefits for utilities and customers. Utilities (or governments) are bound to buy the excess energy from customers' generation units in an attempt to favour small scale RE development. But the price paid for the energy is low for customers but high for utilities, as the purchase happens mostly around midday, when electricity prices are low, at the belly of the duck curve. Moreover, they must balance that excess of energy and forecasting numerous small generation plants is much more difficult than large PV or wind farms, especially for a traditional centralized monitoring system. If several small isolated transactive grid forecast and flatten the curve, utilities are provided with a system helping to forecast the loads, reduce the peaks and the amount of energy bought.

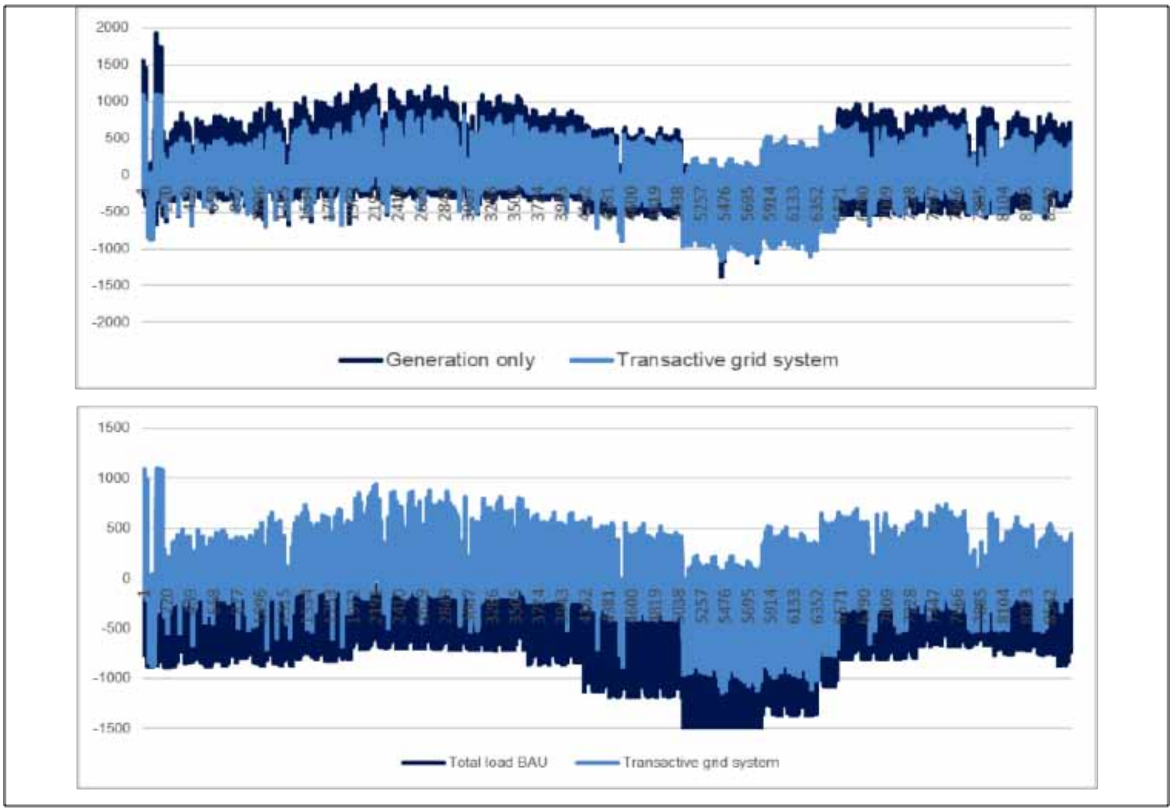

Figure 9: Peak loads reduction and control compared to Regular PV system and Business as Usual - kWh

6.3 Investment opportunity

Here lies the principal interest of the paper: fitting the interests of both customers and utilities while keeping a profitability for investors. With a Weighted Average Cost of Capital of 4.3% including 5% for the cost of equity and 4% for the cost of debt, the Net Present Value fluctuates between 800 000 and 300 000€, depending on the proportion of the debt to equity ratio and on the conversion of the tokens. The range of the Internal Rate of Retur (IRR) is around 1.6% with an equity based investment, but it raises with the share of debt due to the leverage effect. These numbers are quite satisfying and correspond to the energy sector's profitability profiles even though they are based on conservative costs structure.

6.4 Sensitivity analysis

The key parameter here is the cost of the digital monitoring of the system. Indeed, as experiments are recent, and results are still awaited, it has been very difficult to gather information about the cost structure of the transactive grids monitoring. Hence, the reverse approach is used, and the maximum costs of data treatment and software monitoring is set according to the end results. By that approach, the maximum yearly costs of monitoring the grid through smart programs and data treatment cannot exceed 40 000€ per year in case of a full equity investment and 80 000€ in case of an investment backed up by a 60 to 70% debt (Figure 10).

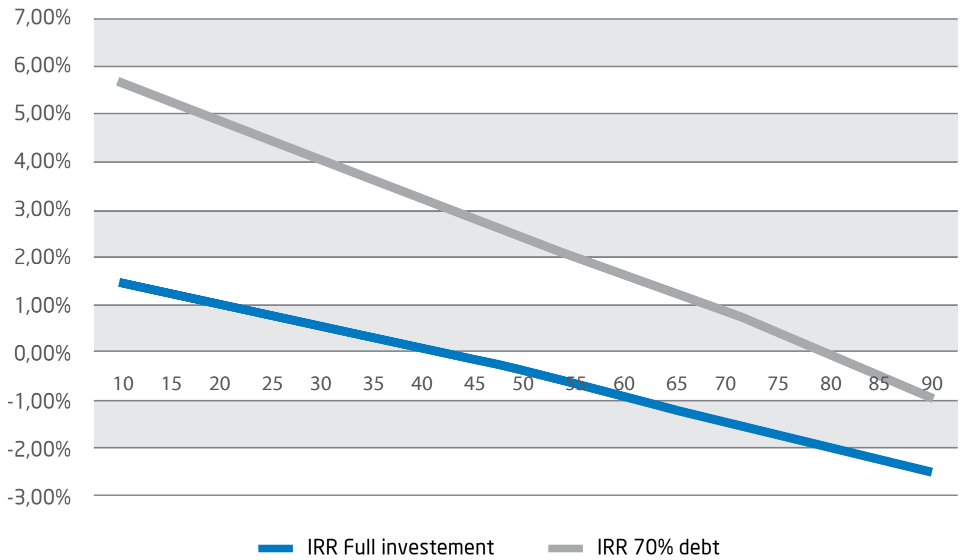

Figure 10: IRR sensitivity to monitoring costs (thousands of euros)

Fortunately, digital costs are part of the fastest to decrease with the better improvements of technologies and especially the large-scale development. For instance, the costs of sensors have already decreased by more than 95%, the battery storage by more than two-thirds thanks to the development of EVs and congestion management and the smart meters costs decreased by 25%. As mentioned earlier, Bloomberg's market analysis about the costs of Lithium-ion batteries are likely to decrease significantly, causing a consequent increase of the profitability (Figure 11).

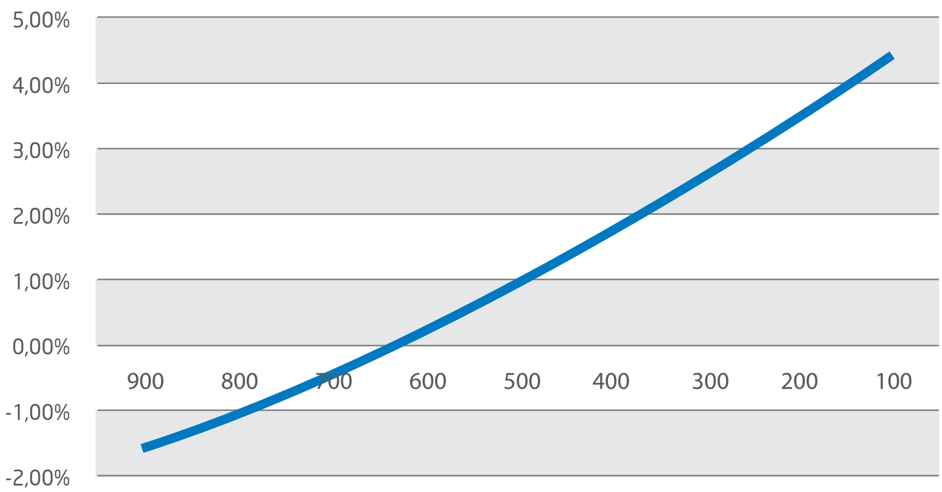

Figure 11: IRR reaction to battery costs decrease (€/kWh) - full equity investment

7 ENABLERS AND THREATS OF THE TRANSACTIVE GRIDS

7.1 Interconnection and communication between smart devices

Since a few years, the industry looks towards the potential applications of the IoT in the energy sector. Among its various possibilities, the automatic on/off switching of a device when the electricity prices are cheap, either because it is a low load period, or because RE sources are overproducing, or because the consumer or a neighbour also has RE installed and use that energy... And more importantly, all this happens without more than a few minutes of involvement from the consumer, deciding the threshold of activation for the device through an application or a website. Nevertheless, such connected devices depend highly on the telecommunication technologies and networks development. Thus, the improvement of the mobile networks and internet infrastructure, such as the 5G networks and the optical fibre, is crucial for the good transmission of massive information flows needing real time treatment. Outdated communication systems would interfere heavily with the well-functioning of the transactive grids, since require the processing of numerous operations in a millisecond time scale.

7.2 Electric Vehicles development

One of the most challenging but also most promising element of both transactive grid development and energy sector evolution are the electric vehicles (EVs). Their development is growing at an increasing pace and the forecasts of their share in the transport sector for the next decades are promising. These vehicles are perceived both as an opportunity for the reduction of carbon emissions and a threat for the stability of the networks [14]. Indeed, with a widespread deployment of these cars, the grid balancing system is highly threatened. Assuming the Tesla car battery size of 100kWh, if 100 of these cars charge in fast charging station at the same time, the grid will have to suddenly supply around 5 000kWh for 2 hours. But if these cars are charged with a smart system, then the load could be spread. Now, with systems such as the transactive grids and the aggregation platforms, the integration of the EVs as a part of the system and not as a burden, commonly called Vehicle-To-Grid (V2G), you can even shut down a fuel based power plant. In that scenario, the electric car batteries are used as an alternative storage system for the main grid. With a fleet of EVs large enough, the potential of storage is tremendous and could help the grid instead of threatening it. Putting the V2G technology into the transactive micro grid of Fes could provide the necessary storage lacking to shave the last peak loads while providing additional revenues for investors and a cheap service of car renting for customers (Figure 12). The tokens earned by customers could be used as money to pay for the service, and the fleet could be reserved for the days anticipated as extreme peak demand or offer probabilities.

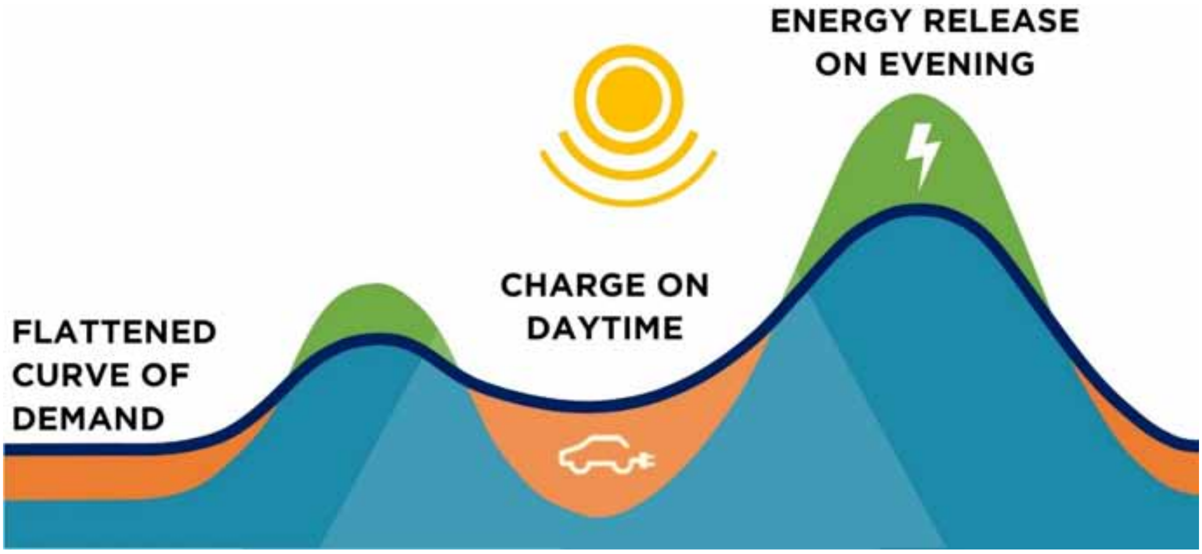

Figure 12: Load shaving with the Vehicles to Grid

7.3 The Distributed Ledger Technology

As presented briefly in the state of the art review, the DLT is a technology allowing to share a ledger containing every transaction ever executed between participants. The technology removes the need of trust in transactions by implementing a system of tampered proof ledger. It could represent a great possibility for the transactive grids as they allow to execute automatically safe peer to peer transactions. However, the technology needs to improve significantly its transaction time to be perceived as a real disruptive solution.

7.4 Potential threats to the development of transactive grids

Besides the opportunities, some elements may arise against the development of the technology. First and probably the most difficult is the utilities' scepticism against new models disrupting their traditional revenue streams. Utilities would have to adapt and rethink their business models to create new ways of capturing value from the energy sector. The second challenge to face is not to be considered lightly as it concerns the customers themselves. The digitalization of things, or Internet of Things, may be great to better forecast and fit customers' behaviours but it also implies a significant breach in the privacy of customers. Collecting data about household's occupancy pattern, energy usage, and having a device capable to act inside their homes is frightening many customers.

8 CONCLUSION

Conceived as an analysis on investment possibilities, the model was created to fit the future campus of the University of Fes in the most precise way possible. Consumption data have been extrapolated from real data collected on similar profiles and hourly electricity production are calculated thanks to accurate tools provided by the European Commission. The results show a significant decrease of the maximum loads, for both extreme values, averages and hourly loads. The exchanges and smart storage lowered peak demand by 29% compared to a traditional electricity supplying system and by 20% compared to a normal PV production system. The latest scenario would potentially inject peak loads 43% higher than with the aggregation platform system, even when equipped with regular storage units. A decrease of a quarter of the consumer's bills is also achieved and a system of reward for the energy surplus produced by consumers and not consumed by the micro grid (21% of the total production) is elaborated to favour lower consumptions. Based on the business model selected, combination between virtual currency payments and fix bill in real money, the Net Present Value for investors is positive even when a 5% interest rate is included for investors. Therefore, it appears that such system could already be profitable for investors in Morocco and Sub Saharan Africa. Nevertheless, uncertainty is still important concerning the future of such technologies.
Utilities' involvement it a key point of the transactive grids success, but the technology disrupts their business models and could decrease it significantly without an adaptation. Plus, the monitoring costs of such systems are not yet known, as experiments are being tested during the writing of this paper and results will come in early 2018. Finally, important opposition is expected from customers without a proper information system, as private sensitive data are collected, and their safe storage is put in doubt as digitalization increases.

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