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Energy storage solution for the residential sector and its development perspectives in Algeria

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Dedication

The sake of Allah, my Creator and my Master,

To my sweet and loving parents, Razika and Abdelkader whose words of encouragement and push for tenacity ring in my ears. Who have never stopped praying for me and encouraging me, may God protect them.

To my lovely sisters Ghizlaine, Dalal and Ikhlas who have never left my side and lead me through the valley of darkness with light of hope and support. To my brother-in-law Adel for his support and kindness.

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I dedicate this thesis.

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Abstract

With the growing concern about the greenhouse gas emission and other environmental issues the renewable energy technologies such as photovoltaic cells are increasingly being recommended for electricity production. In Algeria the residential sector represents of about 42% of the total energy consumption. The main objective of this thesis is to optimize the electrical load pattern in Algeria using grid connected PV+storage systems and study the performance and the energy balance in the residential building. In order to achieve our goal of reducing total and peak load demand through photovoltaic, a simulated performance of a grid-connected PV system+ storage was analyzed with the simulation tool PVsyst. Simulations were performed using measured climate data and also with data generated by Meteonorm. The results show clearly that the use of saving energy and grid-connected photovoltaic system allows a positive annual electricity balance of the studied residential house and the saving energy approach intend to be accomplished. A case study is applied in the northern west region of Algeria where the installation of the PV system is held.

Résumé

Comme l’augmentation de la concentration des gaz à effet de serre est l’un des facteurs à l’origine du réchauffement climatique, le monde se dirige vers les énergies renouvelables qui permettent de réduire considérablement l’émission de ces gaz, pour la production d’électricité. En Algérie, le secteur résidentiel des ménages représente environ 42% de la consommation totale d'énergie. L'objectif principal de cette thèse est de réduire la pointe électrique en Algérie à l'aide de systèmes PV connectés au réseau et d'étudier les performances et le bilan énergétique dans le secteur résidentiel. Afin d'atteindre notre objectif, une simulation des performances d'un système PV connecté au réseau + stockage a été analysée avec l'outil de simulation PVsyst. Les résultats montrent clairement que l'utilisation de systèmes photovoltaïques connectés au réseau permet de réduire la pointe ainsi une économie énergétique annuel. Une étude de cas est appliquée dans la région nord-ouest de l'Algérie où le système PV + stockage a été installer.

ملخص

نظرًا لأن زيادة تركيز غازات ثاني اكسيد الكربون هي أحد العوامل الكامنة وراء ظاهرة الاحتباس الحراري، فإن العالم يتجه نحو الطاقات المتجددة التي تجعل من الممكن الحد بشكل كبير من انبعاث هذه الغازات، للإنتاج كهرباء. في الجزائر ووفقًا لميزان الطاقة الصادر عن وزارة الطاقة، يمثل القطاع المنزلي السكني حوالي 42٪ من إجمالي استهلاك الطاقة. الهدف الرئيسي من هذه المقالة هو تقليل ذروة الكهرباء في الجزائر باستخدام الأنظمة الكهروضوئية المتصلة بالشبكة ودراسة الأداء وتوازن الطاقة في القطاع السكني. من أجل تحقيقنا، تم تحليل محاكاة أداء نظام الكهروضوئية المتصل بالشبكة مع التخزين باستخدام أداة المحاكاة. PVsyst.

General Introduction

General Introduction

Today, large battles are to be undertaken during the century for the survival of the planet. While energy has become indispensable for the wellbeing and for the improvement of the living conditions of the human being; Health, education, food and transportation are closely linked to the availability of energy and mainly, electrical energy.

According to the World Summit on Sustainable Development in Johannesburg [1] incentive measures should be taken starting with energy efficiency as a priority in international politics, by reducing emissions of greenhouse gases, saving energy for economic development, reducing inequalities, and strengthening global regulation.

Being one of the countries with the largest solar potential in the world, Algeria is committed to the promotion of renewable energy in order to provide comprehensive and sustainable solutions to environmental challenges and to the problems regarding the conservation of the energy resources of fossil origin. In addition, a favourable legal framework for renewable energy development has been developed to be adopted by the Algerian government called 'The National Program for Renewable Energy and Energy Efficiency'.

The national program in Algeria has committed most of its renewable energy sourcing from Solar photovoltaic (PV) due to its vast solar exposure which covers 90% of the country with an area of 2382 million km2 [2].

An interest shown by the Algerian government is the recent creation of a ministry dedicated to the energy transition and renewable energies (June 2020) and planning new objectives (4,500 MW by 2024 and 16,000 MW by 2035).

Representing a clean energy source, renewable, quiet and abundant, solar energy and in particular photovoltaic systems are currently experiencing strong growth globally (16.9% of the photovoltaic power installed in the world in 2015 compared to 2014).

It is considered to be a key element of the future energy mix in the space of a few decades. Renewable energy sources are being increasingly adapted in various applications and different configurations of Photovoltaic systems in use, grid-connected PV systems (On-grid) and stand-alone Photovoltaic systems (Off-grid).[3]

The Building sector is known to be one of the major consumers of energy in the world. According to a recent survey, the energy consumed in buildings accounts for more than 43% of the final energy consumption in Algeria due mainly to population growth and urbanism.[4]

The main objective of this work studied in this thesis is to reduce total and peak load demand through photovoltaic ability. To determine if grid connected PV is comparable to the conventional utility grid, it is important to assess the impact of linking PV directly with electrical loads. Therefore, a simulated performance of a grid-connected PV system+ storage was analyzed with the simulation tool PVsyst. Simulations were performed using measured climate data and also with data generated by Meteonorm. Some of the performance parameters analyzed include: annual energy generated, final yield, reference yield, and reduction of energy used from the grid.

A grid-connected plus storage PV system was then installed in a building located in Boukiou, Ghazaouet in Tlemcen. The results obtained provide an insight on the grid connected system's performance and efficiency.

Chapter I: Analysis of energy consumption in the residential sector in Algeria

I. 1. Introduction

This analysis has the purpose of showing the main energy activities in the Algerian dwellings and their share of total energy usage. Also, it has the objective of breaking down the two main approaches of energy saving that can be applied by the occupants of the Algerian dwellings (use of low-energy devices and reduce of the time of usage). The national electricity use in the Algerian residential sector in 2018 reached 24726 GWH. [5]

The energy sector of the country is the source of 80 per cent of all emissions, 90 per cent of which are in the heat and electric power production sectors. Buildings, primarily in the residential sector, consume about 13.6 per cent of electric power and 40 per cent of heat power. The residential sector is the third largest consumer of heat and electric power in the country, after the energy and manufacturing sectors. [6]

We already know that energy efficiency (EE) is the low-hanging fruit of energy and climate policy, also on households. However, the estimates are based on the assumption that energy efficiency reduces energy demand in a linear and direct manner. Rather, as generally assumed in energy and climate forecasting and scenario planning, the economy is nonlinear, especially when responding to changes in the relative price of goods and services as well as to cultural habits. Earlier research had found that technological improvements have gained more focus than behavioural related measures. In this sense, efficiency is not a way of changing lifestyle but changing technical equipment. This takes the responsibility away from the householders for the side effects, since the increasing demand in more items also includes an increased demand of energy. [7]

I. 2. Energy uses in the Algerian residential sector

I. 2. 1. Determinants of energy consumption and units of measurement

Energy consumption is at the heart of economic development with severe impacts on the consumption of resources and climate change.

Table I-1: *Electrical energy consumption in the residential sector in Algeria. [3][4]*

year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Electrical energy consumption in the residential sector: (GWH)	11757	12915	14764	17181	17579	19672	20210	21776	24726

Table 1 shows the evolution of the residential energy and electricity consumption in Algeria from 2010 to 2018. We can see from the figure that the energy consumption has increased mainly due to the increase in energy services demand.

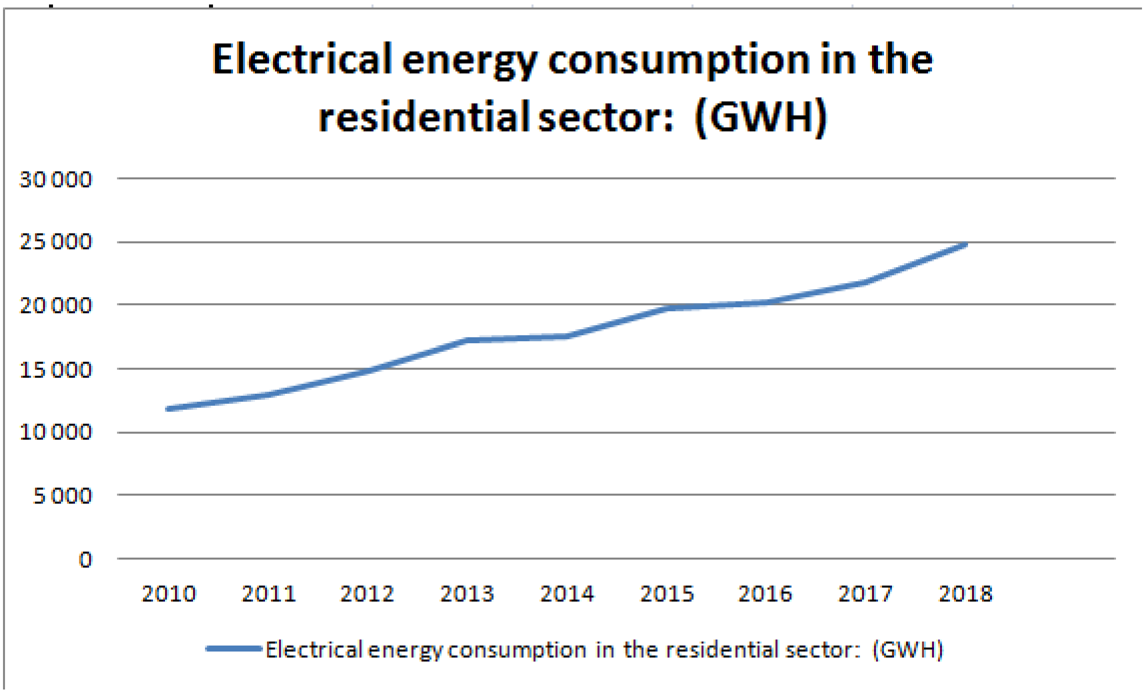

Figure I-1: *Graph of the energy consumption in the residential sector from 2010 to 2018*

Determinants of energy consumption can be defined as the numerous factors that may affect energy consumption in the residential sector.[7]

Buildings are responsible for a significant share of energy consumption worldwide. They can play a crucial role in the transition to a sustainable society as their characteristics of electricity demand; from construction, to operation and disposal are context specific with complex drivers, depending on various energy and material-related sustainability problems. Energy use in residential sector depends on several factors from socio-economic to cultural, technological, climate, as well as, local factors such as architectural traditions, building materials and technical characteristics of the dwelling, which makes it a very complex topic. [7]

Housing characteristics such as size, type, density and envelope affect energy consumption. It has been posited that low density development, along with associated increase in housing area, increasing number of energy consuming appliances have contributed to rapid growth in energy consumption, even while efficiency standards have been tightening (Kaza, 2010), both at the household level and electrical equipment.[7]

Energy consumption refers to all energy consumed by the final consumer for all energy uses within the residential sector (e.g. electricity, natural gas).

Energy efficiency is the use of less energy to provide the same level of performance, comfort, and convenience (energy service). According to Directive 2006/32/CE it is the ratio between an output of performance, service, goods or energy, and an input of energy (e.g. substitution of CFL lamps by LEDs).

The energy needed for household activities can be consumed directly inside or outside the accommodation, either directly by households or indirectly by the entities producing the goods and services consumed by these households. Energy consumption is said to be "direct" when they are consumed by the household and "indirect" when they are consumed upstream of the production chain of goods and services (also known as grey energy. [8]

According to Foster et al. (2000) social and cultural factors such as cooking habits and household characteristics may make households behave contrary to economic predictions based on income and relative fuel prices. There are; therefore, a range of non-economic variables that are important in explaining household decisions regarding energy use.

Table I-2: *Determinants behind residential energy consumption.[6]*

categories	Determinants	Authors
Endogenous Factors (household characteristics)		
Economic characteristics	Income, expenditure	ESMAP (2003); Leiwen and O'Neil (2003); Elias and Victor (2005); Zachariadis and Pashourtidou (2007); Rhoded et al. (2014); Pablo-Romeo et al. (2016).
Non-Economic characteristics	Household size, type and year of construction; Occupants gender, age, education, household, composition, Information, job or occupation, family dimension.	ESMAP (2003); Myors et al (2005); Heltberg (2004); Gruber and Scholmann (2006); Guptaa and Kohlin (2006); Antunes (2008); Larsen et al. (2010); Cayla et al. (2011); Kelly (2011); Hamza and Gilroy (2011); Brounen et al. (2012); Huebner et al. (2015); Risch and Salmon (2017); seebauer and Wolf (2017).
Behavioural and cultural characteristics	Preferences, personality, practices, attitude, lifestyle, social status, religion, ethnicity, environmental awareness and concern, values.	Socolow (1978); Lutzenhiser (1993); Kempton and Schipper (1994); Wei et al. (2007); Gram-Hanssen (2008); Santin et al. (2009); Raw and Varnham (2010); Kowsari and Zerriffi (2011); Carlo and Ahamada (2012); Kavousian et al.(2013); Blight et al. (2013); Blight et al.(2013); Sonnberger and Zwick (2016); Huebner and Schipworth (2017); O'Neil and Xiu (2017).

Exogenous factors (external conditions)		
Physical environment	Geographic location, urbanization level, climatic condition.	Bhatt and Sachan (2004); Elias and Victor (2005); Halicioglu (2007); Filippin and Larsen (2009); Kaza (2010); Rue du can et al. (2010); Steemers (2011); Lescaroux (2011); Weismann et al. (2011); Zhao et al. (2012); Kavousian et al. (2013).
Policies and energy supply factors	Energy policies, environmental policies, subsidies, market and trade policies; Prices and affordability, availability, accessibility, reliability of energy supply.	Van Raaij and Verhallen (1983); Guptaa and Kohlin (2006); Halicioglu (2007); Herter et al. (2007); Schlag and Zuzarte (2008); Alberini and Filippini (2011); Filippini (2011); Lescaroux (2011); Butler (2016); Yoo et al. (2017).
Technology characteristics	Conversion efficiency, cost and payment method, complexity of operation.	Kelly (2011); Lescaroux (2011); Jones et al.(2015)

Another concept is necessary for the analysis of energy consumption: the energy stage at which it is expressed. Three stages are usually distinguished between energy in the form of natural resource and in the form of service received by the end consumer: primary energy, final energy and useful energy. If this distinction has been elementary for several decades among engineers and energy specialists (example [Lovins, 1977; Leach, 1979]), it is most often absent from economic analyzes expressed purely in monetary value.

The first energy stage used is primary energy. It is, according to the definition of INSEE, all of the unprocessed energy products exploited directly imported. These products are mainly crude oil, oil shale, natural gas, solid mineral fuels, biomass, solar radiation, hydro power, wind power and geothermal energy.

The second energy stage used is the final energy. It is the one that is delivered to the consumer, counted and recorded on the bill (where the price of the final energy is generally indicated per kWh).

When the service consumed by the end user is itself a form of energy, another energy stage can be distinguished: useful energy.

Only three types of services fall into this category: driving force, conditioning a volume at a given temperature (different from room temperature) and the production of light. As regards the residential sector, useful energy is mainly used for services relating to thermal comfort (heating, air conditioning and domestic hot water production) but could also be used to quantify the need for production of food cold (refrigerators and freezers), cooking and light production.

The modelling of the thermal parameters of a building depends on its own dynamics, climatic variations and the materials used. However, the programs (table 3) operate in development and research in building in two modes: static and dynamic mode.

a- Static: Calculation of the energy balance, contributions and losses of energies in the steady state. In this case, no account will be taken of the variations neither of heating and cooling undergone by the building, nor of the changes which have occurred in the operating mode of the installations and equipment. The calculation methods applied are relatively simple and are applied to the modelling of less complex buildings.

b- Dynamics: In this case, the variations over time of the different parameters of the building and the installations must be considered. For their modeling, it requires complex calculation means. The programs based on digital methods, allow the modeling over time of the temperature, heating and cooling needs, taking into account the dynamics of the building. [9]

Table I-3: *Programme and software used for building information and modeling[7]*

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Tableau 3: Exemple de programmes ou logiciels de modélisation des bâtiments [3]

Programme	Développé/Commercialisé par	Applications
COMFIE	Ecole des Mines de Paris	Simulation de maisons solaires
DIAS 2.1	CUEPE, Université de Genève	Données interactives d'architecture solaire
TRNSYS	Solar. Energy Lab. Université Wiscosin - Madison	Simulation des systèmes complexes de l'habitat
TSOL	Valentin Energie software	Simulation dynamique des installations solaires
PVS2.001	Econcept Energieplannung GmbH	Simulation des systèmes PV
ADELINE	Lawrence Berkley Nat. Laboratory	Simulation complète des bâtiments
DOE-2	Lawrence Berkley Nat. Laboratory	Planification et recherche en énergie
METEONORM	Meteotest, Berne, Suisse	Modélisation des paramètres climatiques
SPARK	Lawrence Berkley Nat. Laboratory	Systèmes complexes à objets orientés

I. 2. 2. Site settings

I. 2. 2. 1. Climatic data

Solar radiations, outside temperature and wind speed are the parameters that most influence the thermal behavior of a building. Taking these elements into account, it is possible to design a home with maximum interior comfort, controlled, whatever the outdoor climate. In sunny areas, the solar gain in winter, for backup heating and hot water, should be maximized. [9]

I. 2. 2. 2. Type of assignment

The allocation of the building, which can be a dwelling, a training room or a set of administrative offices, influences both the distribution of spaces and the level of comfort required. The requirements in terms of visual comfort, thermal and air renewal are specific to each space (bedroom, living room and bathroom). They are a function of daily, weekly and seasonal occupancy. Thus the orientation of these spaces is established according to the movement of the sun. [9]

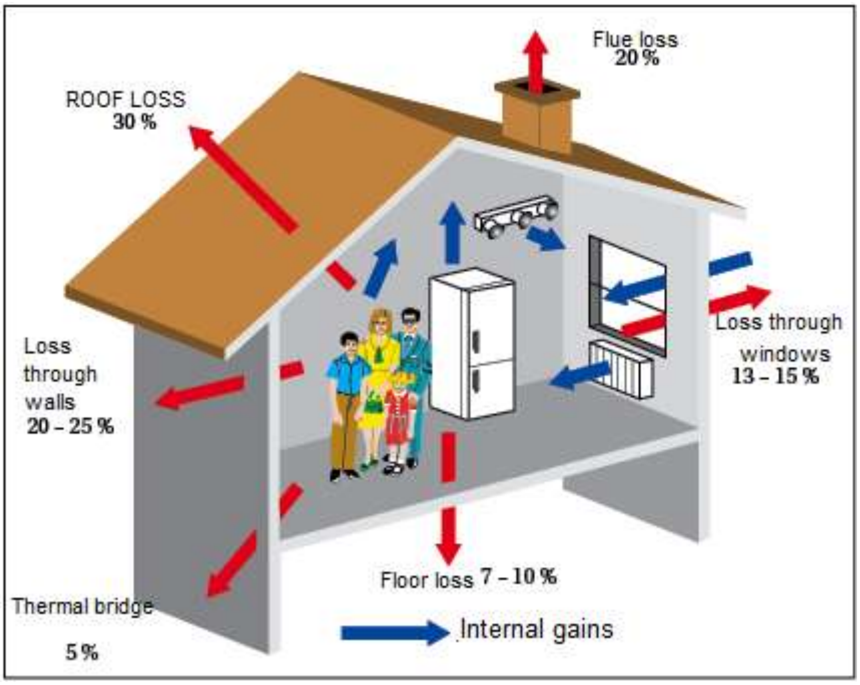


Figure I-2: *Heat loss and gain in houses*

I. 2. 3. Electricity consumption by type of use

The average consumption of an Algerian household is 12607, 4 kWh a year [10], with a predominance of fuels in terms of final energy. 62% of the electric consumption is related to household appliances, and to a lesser extent, to cooking, heating and hot water services.

Table I-4: *disaggregation by thermal and electric consumption*

	Average annual consumption per household / year
FINAL USES	Kwh
Sanitary hot water	1074
Cooker	7925
Air cooling	720
Lightning	518
Refrigerators	353
Freezer	478
Washing machines	653
microwaves	8.4

TV	278
Computers	600
Total consumption	12607,4

I. 3. Recent history of energy consumption in the residential sector in Algeria

I. 3. 1. Available data and classification of determinants

Preliminary data analysis was carried out in order to ascertain which surveyed factors appear to significantly influence average annual household electricity demand.

Table I-5: *final energy consumption by sector, Algeria 2018* [5]

sector	Industry	Transport	Households and tertiary
Energy consumption (GWh)	20669	1173	36311

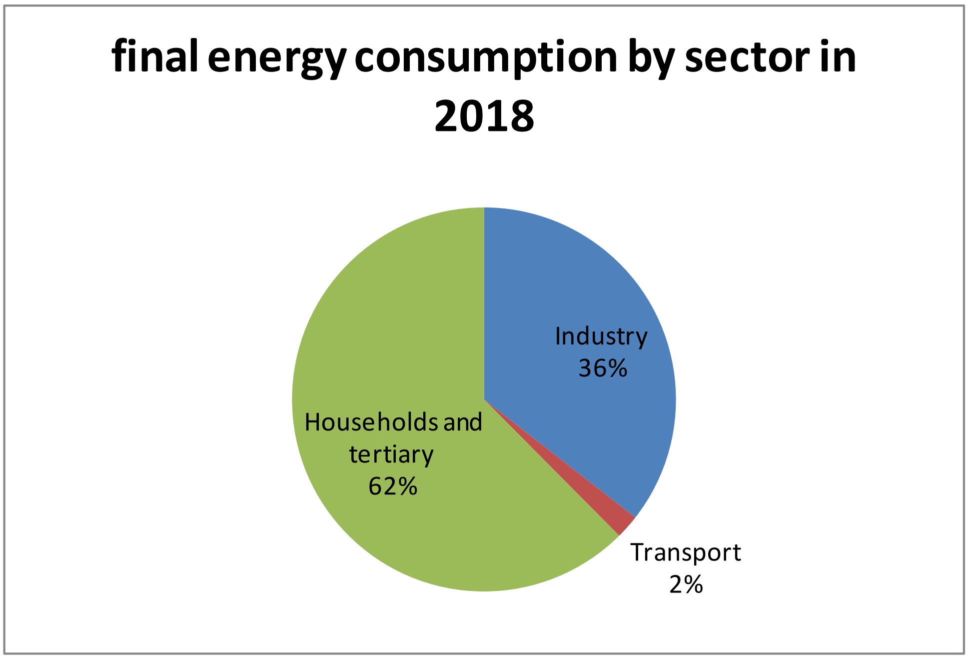


Figure I-3: *Final energy consumption by sector in Algeria, 2018.*

The evidence from this pie chart shows that 62% of the final electric consumption in Algeria is related to household. Buildings are responsible for a significant share of energy consumption in Algeria and worldwide. They can play a crucial role in the transition to a sustainable society, comes after it the industry with 36% of the total final consumption and transport with only 2 %.

I. 4. Conclusion

The results show that the electricity consumed by the residential sector is the highest. The energy sector of the country is the source of 80 per cent of all emissions, 90 per cent of which are in the heat and electric power production sectors. Buildings, primarily in the residential sector, consume about 13.6 per cent of electric power and 40 per cent of heat power.

Energy policy should encourage the introduction of hybrid possibilities and support other forms, including electricity generation by the private sector to share the heavy burden on her. This is the only condition that the energy mix of Algeria will grow potential of renewable energy.

Chapter II: Energy storage systems market analysis and perspectives in the near and long term

II. 1. Introduction

For the effective usage of renewable energy and grid resiliency, a new movement in electric power production has seen intense growth during the recent past years, which is energy storage.

The annual growth rate of the market for energy storage is expected to be approximately equal to 24.38% during the forecast period of 2020 – 2025 and the costs are assumed to escalate at that rate during the storage plant’s financial life, which will make the storage become increasingly competitive, and the range of economical services that can be provided will only increase. [11]

The increasing development of renewable power infrastructure, coupled with the surging need for ancillary services in the power sector, is a big boost for the energy storage market. Due to lower costs, renewable energy is becoming competitive and, cheaper than conventional power plants. Besides improving solar and wind power generation, Electricity storage will permit sharp decarbonisation in vital segments of the energy market.

In this chapter, we will be focusing on energy storage systems drivers and the network segments as the different drivers and barriers for energy storage around the world stem from numerous factors, covering the differences in the physical structure of the grid, needs and desires of customers, and the regulatory and market structure in each country or region.

The chapter includes also the expected cost and economies of energy storage market in the coming years more precisely, the residential sector as it is expected to account for the largest share in the energy storage market.

II. 2. Energy storage market drivers and trends

II. 2. 1. UTILITY-SCALE

Utility-scale battery storage is increasingly playing an important role in the operation of the electric grid, supplying economic savings, environmental advantages and new flexibility for the grid.

Utility-scale storage, also commonly referred to as large-scale or grid-scale storage, refers to systems installed on transmission or distribution networks providing services to grid operators.[12]

Utility-scale battery storage is spoken about in megawatts (1 megawatt = 1,000 kilowatts). A classic utility-scale battery storage system is both rated in megawatts and hours of duration, such as Tesla’s Mira Loma Battery Storage Facility, which has a rated capacity of 20 megawatts and a 4-hour duration (which means it is able to store 80 megawatt-hours of electricity). [13]

This process allows utilities to charge energy storage devices at times when the cost of electricity is inexpensive (in the middle of the night, for instance), and discharge storage when electricity costs are higher and extra energy is needed on the grid. In essence, storage allows utilities to reduce the impact of time as a constraint to resource availability.

This operational scheme (time shifting) also results in both cost and productivity inefficiencies.

Arbitrage over time, a power market activity, allows a utility to take advantage of price differences over time. A common application is load levelling (see Figure 1).

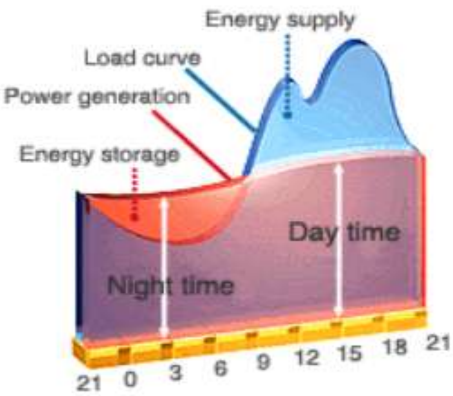


Figure II-1: *Daily load levelling*

The first major driver of utility-scale ESSs is the substantial growth in the amount of renewable energy being deployed around the world. By the end of 2019[1], Solar PV reach a record of 118 GW representing 651 GW cumulative capacity greater than wind capacity installed (644 GW).[14]

The following significant driver is the effort by nations around the globe to reduce air pollution. In 2015, the Paris Climate Pact was haggled by 197 nations that consented to set discharges toward the reduction of CO2 emissions at the earliest and dependency on renewable sources of energy. According to the United Nations Sustainable Energy for All initiative, $45 billion in investment through 2030 will be required to provide universal access to modern electric power. [15]

The last important driver is the need to improve the flexibility of the electrical grid. Ongoing common catastrophes have highlighted the delicacy of a centralized grid design. [15]

Studies and real-world experience have demonstrated that interconnected power systems can safely and reliably integrate high levels of renewable energy from variable renewable energy (VRE) sources without new energy storage resources.

Six potential benefits of consolidating mass bulk energy storage systems into the electricity grid are:

(1) Enabling time-move of vitality conveyance to encourage the adjusting of power gracefully and load at diminished expense,

(2) Supplying limit credit to postpone interests in producing limit,

(3) Providing framework operational help to encourage smooth, facilitated activity of the segments of the power gracefully framework,

(4) Providing transmission and dissemination backing to defer speculations to update segments of the transmission and dispersion framework,

(5) Maintaining power quality and unwavering quality by furnishing vitality to the framework with exceptionally short reaction times, and

(6) Allowing reconciliation of irregular renewable age by smoothing their vitality yield after some time.

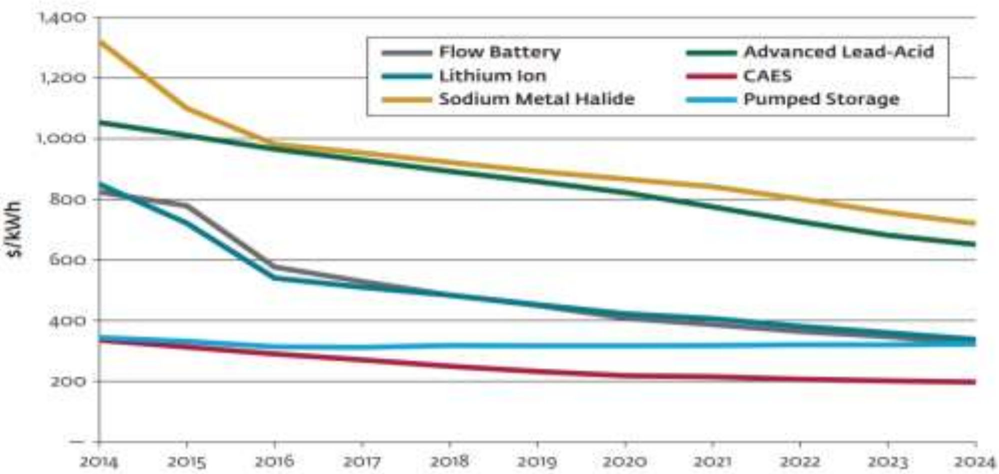


Figure II-2: *Utility-scale energy storage cost trends by technology, global average between 2014 and 2024* [15]

Despite the major reductions in system costs that have been achieved over the past several years, utility-scale energy storage remains an expensive technology. The upfront cost for systems is considered the major barrier to the market's growth. Figure III-2 provides a comparison of the cost trends and forecasts for various ESS technologies. This assumes a duration of 4 hours for battery technologies (ex. 1 MW / 4 MWh), and a 10-hour duration for compressed air and pumped storage systems.

II. 2. 2. Behind the meter

Behind the meter (BTM) term alludes to sustainable energy systems, which are installed on the customer side. These systems are situated in a single building or at numerous facilities (as shown in Figs.III 3 and III-4) claimed by a single entity, for example university campuses, usually operated with distributed generation and capacity units to supply all or some portion of the end user‘s energy request.

BTM systems help decrease costs and improve flexibility for commercial and industrial (C&I) or residential clients, they are usually connected end user's meter permitting the client to sell energy back to the grid. In such manner, behind the meter energy management systems refers to a system which satisfies the end customer’s energy needs while realizing certain objectives for example decreasing operation cost, improving energy efficiency, adjusting demand and supply, and reducing CO2 emissions. [16]

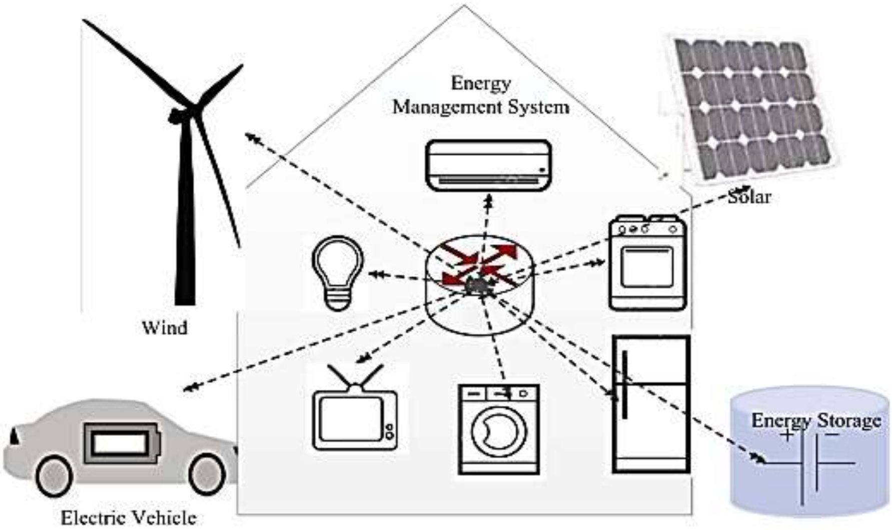


Figure II-3: *Behind the meter system: case for a single building* [17]

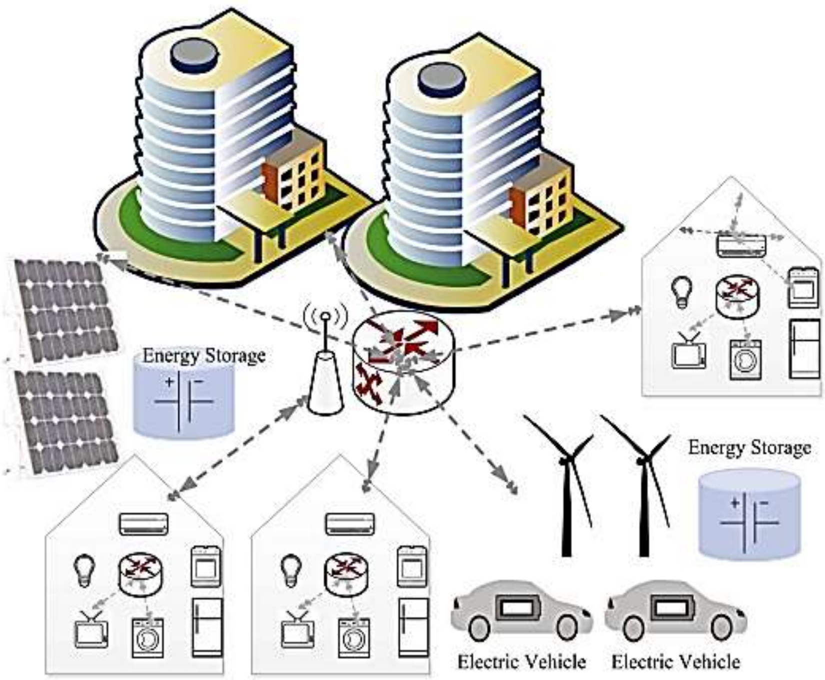


Figure II-4: *Behind the meter system: case for a campus*[18]

In addition to that, behind-the-meter (BTM) energy systems offers economic advantages as they enable end-users make profit from different tariffs for shifting peak hour demand and they can even make benefit by selling the extra local production back to the grid. Regulators and utilities can benefit from increased use of network components and reduced investments.

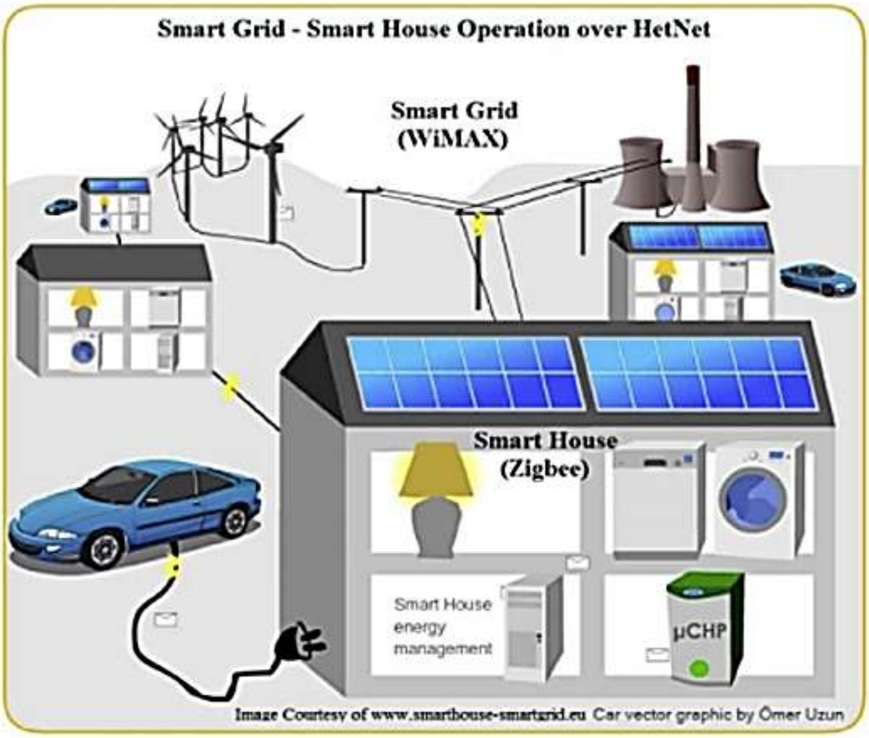


Figure II-5*: Smart house design with BTM equipment* [19]

Fig II-5 shows an ordinary BTM Smart House set-up where electricity can be produced from solar photovoltaic panels on a large number of clients' rooftops meeting the costumers' needs by feeding distributed generators, consumer gadgets for example, PCs and lighting as well as hybrid devices which can likewise be utilized as storage (such as electric vehicles). The consumers may turn into prosumers by feeding the network instead of taking from it, at least on sunny hours of the day.

The main driver for these systems has been the ability to reduce electricity expenses. This is primarily done by reducing peak demand and time-of-use (TOU) rates.

In the other hand, and important market driver is the distributed renewable, particularly solar PV, which can cause significant issues for distribution networks when too much power is fed back onto the grid.

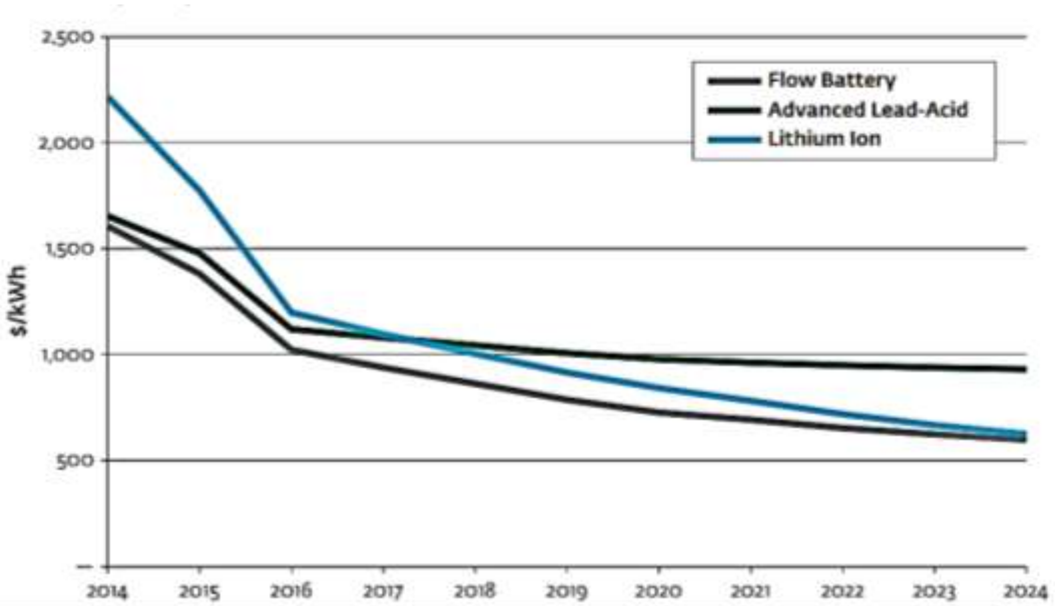


***Figure II-6**: Behind the meter energy storage cost trends by technology, global average between 2014 and 2024*[15]

Figure III-6 provides an illustration of the pricing trends and forecasts for BTM energy storage. This represents an average of costs across both residential and C&I markets, and assumes systems with 2-hour duration (for example 50 kW / 100 kWh). As shown in the chart, system costs have come down dramatically between 2014 and 2016, these markets were nearly non-existent in most regions in early 2014.

II. 3. Future cost of battery storage technologies

In this section we document the actual cost of batteries as we discuss the development of their cost and performance. We will also present PV market projections in the world.

II. 3. 1. Battery capital cost

The characteristics and cost projection data were compiled from various sources, including company websites, local distributors, company webinars, reports and journal papers.

Various types of batteries used in energy storage systems are lithium-ion, lead-acid, nickel cadmium (Ni-CD), nickel-zinc (NiZn), and flow batteries, among others. The selection was made according to their variable operations and maintenance, lifetimes, efficiencies etc. [20]

The chemistries that are examined in this report are lead acid, lithium-ion, Nickel cadmium and molten salt. The technical readiness level (TRL), manufacturing readiness level (MRL) and current cost ranges of these chemistries are shown in Table III-1.

Table II-1: *differentiating characteristics and cost range of different battery technologies*[21], [22], [23],[24], [25], [25]

	Lead acid	Li-ion	Nickel-cadmium Ni-Cd	Molten salt
Nominal Cell voltage	2 v	3.2 ~3.7 v	1.2v	2v
Energy efficiency	60%~70%	90%~95%	60% ~80%	80%~85%
Number of cycles (80% DOD)	1000~1200 Cycles	2400~4000 Cycles	2000 cycles	4000
Energy density	25 to 45 WH/kg	80 to 250 WH/kg	18 to 75 WH/kg	224 WH/ kg
Power density	80-90 Wh/L	250-693 Wh/L	50-150 Wh/L	290 Wh/L
Self discharge	4% to 8% per month	1% to 2% per month	5% to 20% per month	<15%
Temperature performance	-20°C~60°C	-20°C~60°C	-20°C~60°C	50°C
Life time (years)	3-6	10-15	5-10	10
Average charging time	5 h	3.5 h	4.3 h	4 h
capital	$ 50-600/kWh			

The characteristics shown in Table III-1 influence the performance of batteries and their application. Meanwhile cycle life, DOD and efficiency effect on the cost.

- The DoD refers to the degree to which a battery has been used comparing to its total capacity. if a battery is used beyond its DoD its performance tends to degrade. That's why it is preferable not to use batteries beyond their DoD.

- The value of the cycle life represents the number of cycles of complete discharge (down to the DoD) that a battery can go through before its performance degrades substantially. Once the life cycle is reached, the battery would be replaced.

- The lifetime has a similar purpose to the cycle life, in that it represents the number of years for which a battery's performance is warranted

- The efficiency is the percentage of energy a battery releases, relative to the energy provided. The efficiency is used in the modelling to represent loss of energy of ES.

Table III-1 shows a comparison of different battery technologies, their energy efficiency, and number of cycles, self-discharge amount, and life time. When looking at the energy efficiency and number of cycles the Li-ion batteries comes in the first place in both with a percentage of 90% to 95% and 4000 cycle respectively. These batteries have also the maximum energy density and power density coming after it the molten salt battery. The four battery technologies are capable of providing short-to-medium term storage over a vast range of output capacity with the highest life time is up to 15 years in Li-ion batteries, a lesser life time is marked in molten salt batteries and Ni-Cd equal to 10 years and the shortest life time is 6 years in lead acid batteries. The four technologies have high MRL and TRL in general, with the highest level in Ni-cd and Li-ion reaching 9, and 7 and 8 for the 2 other technologies in the MRL and TRL respectively.

II. 3. 2. . Energy storage cost trajectories:

The projected battery cost trajectories are shown in Figure III-7, Figure III-8 and Figure III-9 for advanced lead acid, Li-ion and molten salt batteries, respectively.

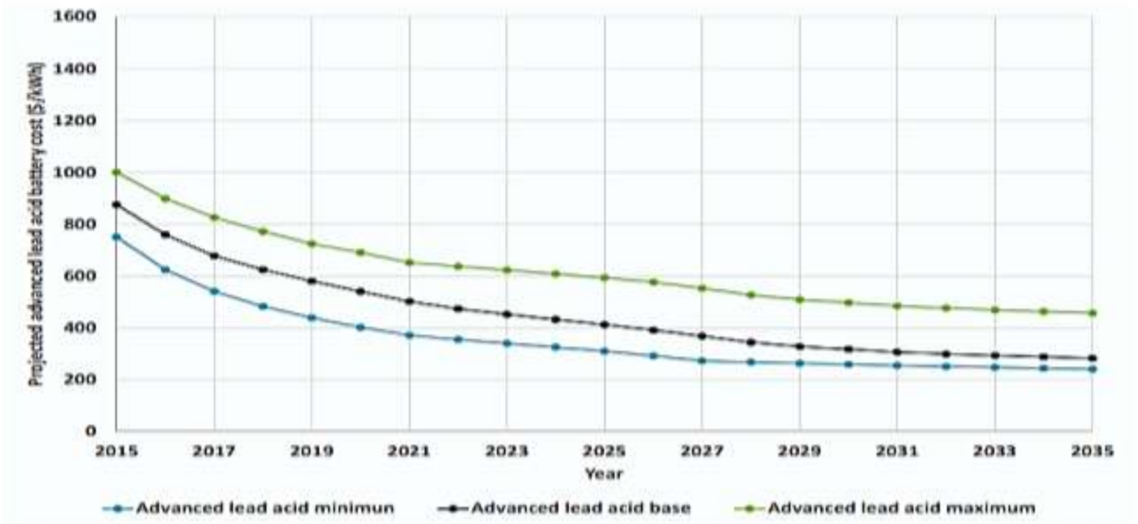


Figure II-7: *Lead acid batteries price outlook* [15]

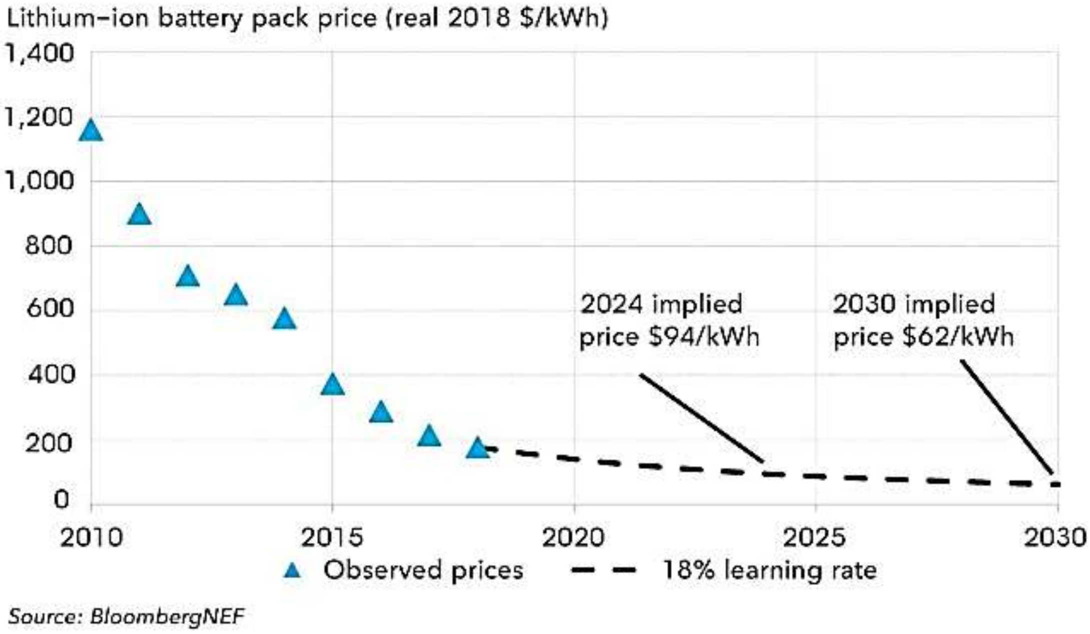


***Figure II-8**: lithium-ion batteries price outlook*

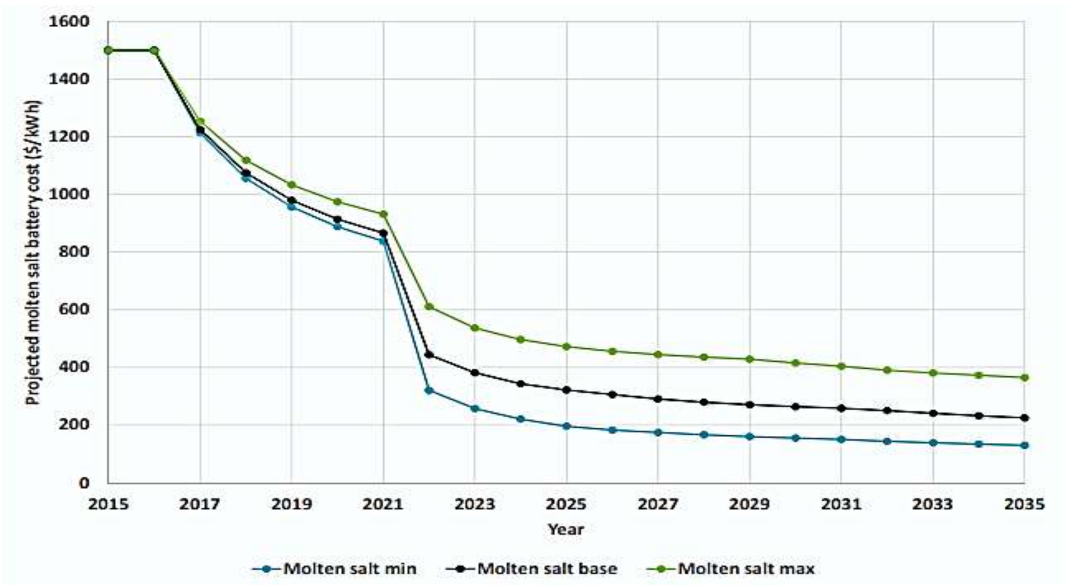


***Figure II-9:** molten salt batteries price outlook* [15]

The state of the trajectories is markedly different between the grown technologies (Li-ion and lead acid) and the less mature innovation (molten salt). The newest innovation has a higher learning rate, and along these lines a more extreme decrease in capital expense after the year 2016, which at that point levels out in the year 2022.The decline from 2021 to 2022 is particularly steep. After this point, the cost reduces slowly, and the technology could be considered mature.

The more experienced technologies have a much flatter cost trajectory. Taking in consideration the EV battery capacity that existed before, the cost start at as of now low and decreases. A lot of capacity is installed, however, and the learning has saturated by 2025.

Lithium-ion batteries are seeing an enormous demand in the market, owing to their declining costs. The US Department of Energy (DOE) has declared a cost target of USD 125/kWh by 2020 and the prices for lithium-ion batteries are estimated to fall to as low as USD 73/kWh by 2030. Also, lithium-ion batteries are expected to hold the most important share in the battery energy storage market, as they require little maintenance, are light-weight, and have a great cycle life, just as a high energy density regarding volume and high charge/discharge efficiency. [20]

Although most batteries in the energy storage market are lithium-ion (Li-ion), other battery technologies, such as sodium and lead-acid are expected to provide extra advantages, as higher life time durability or expanded energy capacity for longer-term storage.

II. 3. 3. Renewable power generation costs and the long term planning:

According to IRENA’s latest statistics, electricity cost from utility-scale solar photovoltaic fell 82% between 2010 and 2019.

Renewable power generation is now growing faster than overall power demand. A new record was reached by Portugal in the latest August 27^{th} 2020 for PV cost: $0.01316/kWh, making the PV technology the cheapest among all the sources.[26]

In spite of the fall down in renewable energy subsidies and slowing global GDP growth, sustainable energy generation technologies are setting records for low costs and new capacity. In the scenario of transforming Energy, electricity would become the central energy carrier by 2050, growing from a 20% portion of final consumption to an almost 50% share; in consequence, gross electricity consumption will be more than double.

Based on Bloomberg observation, and the battery demand forecast, it is that expect the price of an average battery pack will continue to fall down and reach around $94/kWh by 2024 and $62/kWh by the year 2030.

To achieve the Energy Transformation Scenario, Annual energy-related CO2 emissions would need to decline by 70% below today’s level by 2050.

Wind and PV energy are expected to represent 50% of the world energy by 2050.

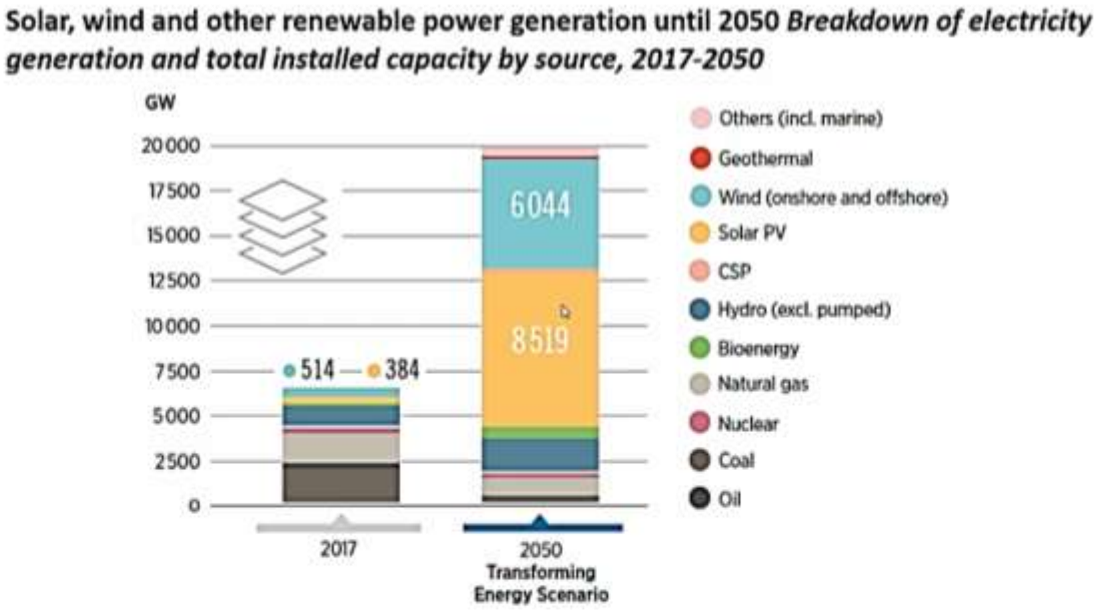


Figure II-10: *renewable power generation until 2050*[27]

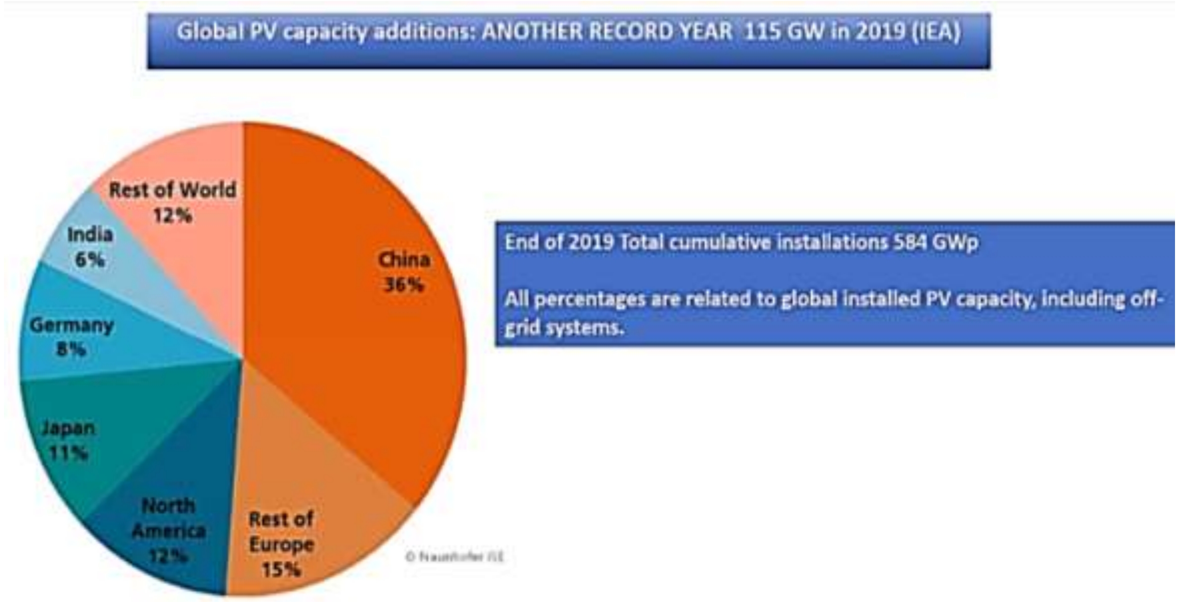


Figure II-11*: global installed PV capacity in the world* . [27]

II. 4. Impact of Covid-19 outbreak on global energy storage market

The international energy agency (IEA) shown in her latest study that the covid-19 had a positive impact on the energy demand, and the renewable sources are likely to experience growth for the rest of 2020.

II. 5. Conclusion

The energy storage systems have different drivers as the different barriers for energy storage around the world stem from numerous factors, covering the differences in the physical structure of the grid, needs and desires of customers, and the regulatory and market structure in each country or region. We also discussed in this chapter the cost that the energy storage market is expecting in the upcoming years.

Chapter III: Detailed analysis of the approach using energy storage around the world

III. 1. Introduction

In 2018, energy storage deployment achieved a record level, almost multiplying from 2017. Behind-the-meter storage expansion was especially strong; right around three times that of 2017.

The leading nation was South Korea, succeeded by China, the United States of America and Germany. New markets have developed rapidly in different governments and supportive mechanisms have been created by, including in Southeast Asia and South Africa, demonstrating that storage keeps on requiring support.

While there may be a single global climate objective, different energy transformation pathways need to be considered and solutions tailored to fit regional circumstances.

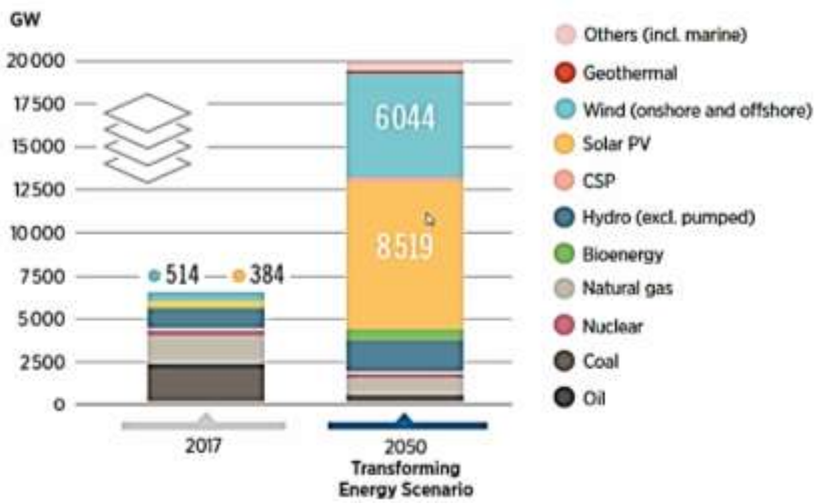


Figure III-1*: renewable power generation until 2050 breakdown of electricity generation and total installed capacity by source [1]*

Chart on fig.II-1 provides forecasts for new energy storage capacity and revenue for each one of the six major developing regions identified in this report.

The development of distributed and local energy resources, including renewable and energy storage, can provide significant economic growth, jobs, and a sustainable energy future in emerging markets. The following sections explore energy storage market activity, challenges, and potential in emerging markets worldwide.

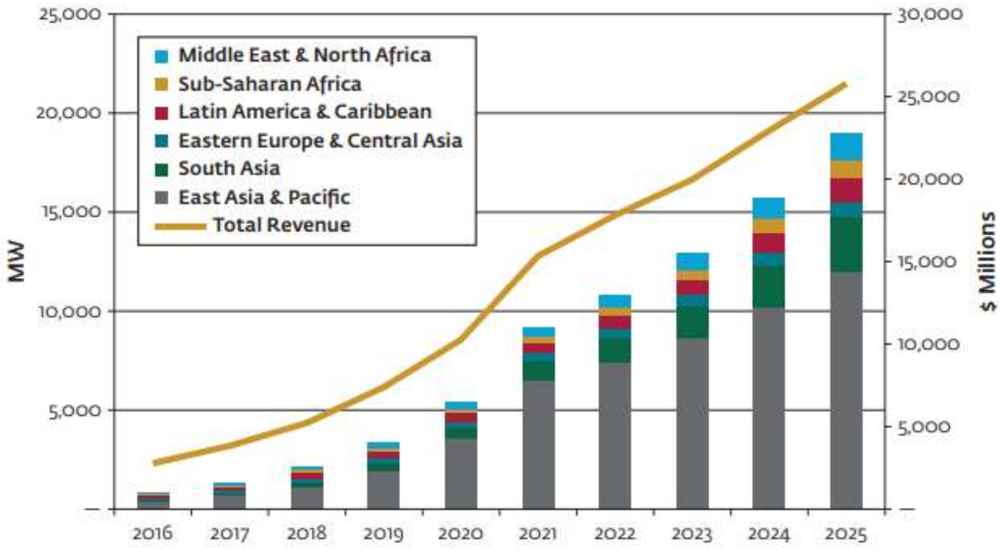


Figure III-2*: Annual stationary energy storage deployments, power capacity and revenue by region, emerging markets: 2016-2050* [15]

III. 2. East Asia and Pacific

There are two important types of power grids that can be found in the Asia Pacific region, the two types have distinct characteristics and opportunities for energy storage. On one side are the highly advanced countries —as Japan, South Korea, New Zealand, and Australia—and certain big cities with advanced grids that operate reliably and utilize high technologies. On the other side, many countries in the region are still in progress, developing fundamental infrastructure systems and have bounded or unreliable power grids. These developing regions are also experiencing rapid population growth and urbanization, resulting in an increasing demand for electricity. [27]

We expect that the largest energy storage market in the East Asia & Pacific region will be China. The economy in China has gradually been opening to foreign investment and free market forces over the past several decades, and this trend has been accelerating in recent years. The Grid Corporation of China owned by the state—the world’s largest utility—has already been deploying energy storage systems to provide different services throughout its grid. Furthermore, China is in the process of reforming its energy markets to allow non-state owned power providers to enter the market, opening opportunities for IPPs to provide ancillary and capacity services with ESSs. (See fig. II-3)

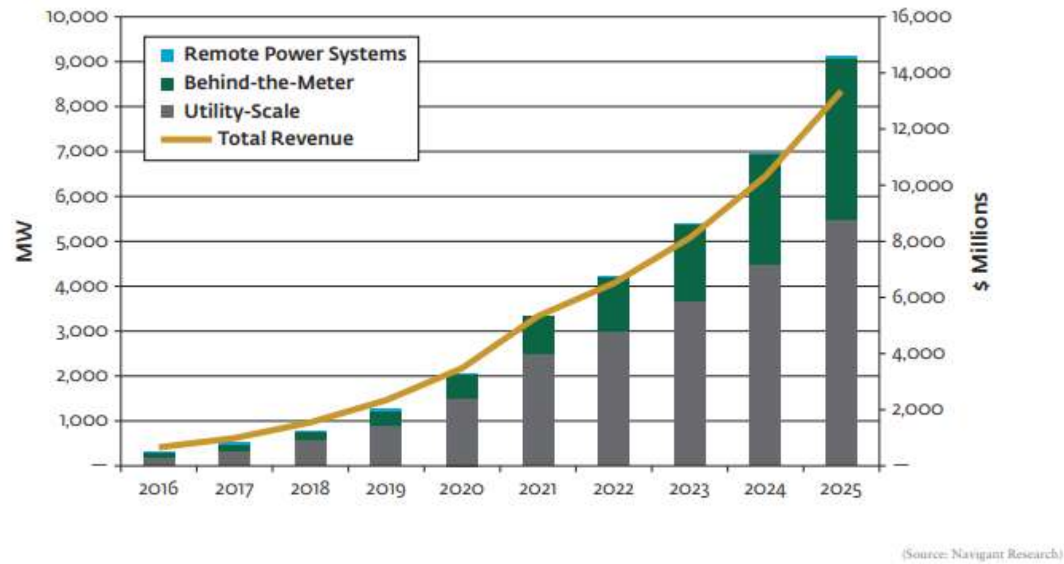


Figure III-3: Annual stationary energy storage in China: 2016-2025 [15]

The region is expected to be a major market for remote micro grids, although the requirements for these projects vary greatly on a country-by-country basis.

Outside of the developed markets of Japan, South Korea, Australia, there are currently 28,610 MW of energy storage

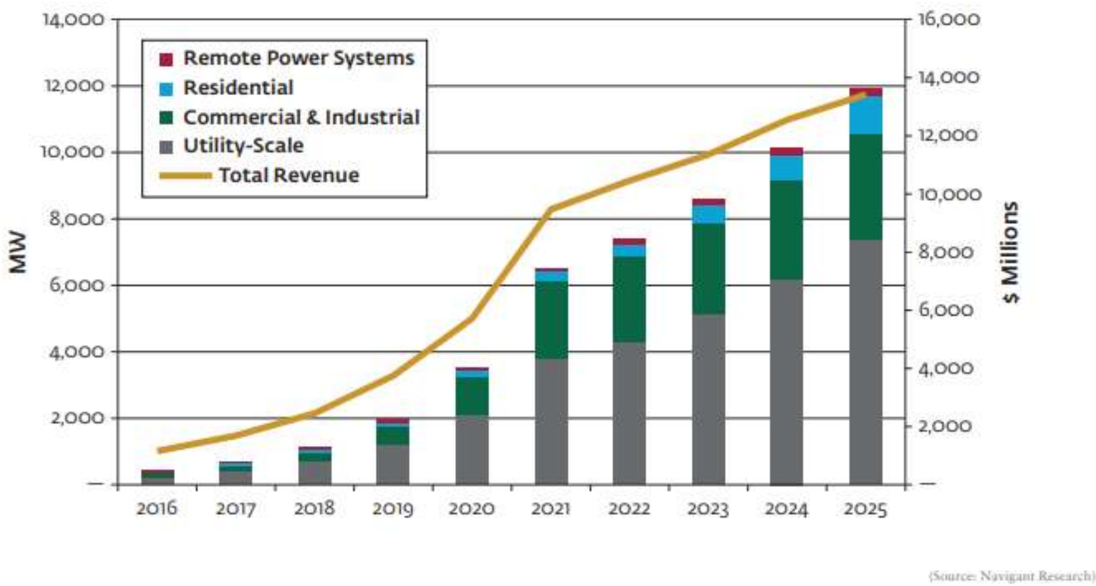


***Figure III-4**: Annual stationary energy storage in East Asia and Pacific: 2016-2025*[15]

However, over 88 percent of this capacity comes from pumped hydro storage (PHS), which are primarily state-owned plants in China (25,399 MW).

III. 3. South Asia:

The market for energy storage in the South Asia region is dominated by India.

The ambitious National Solar Mission in India is one of the important key factors, which are driving the market for energy storage. In the year of 2014, Prime Minister Narendra Modi announced a national target to install 100 GW (out of 175 GW program) of solar PV capacity by 2022, which would make the country one of the largest solar power markets in the world. As of the end of March 2020 [28], the cumulative installed solar capacity was over 37 GWp. India's rapid population growth, particularly in urban areas, is driving the need for increased investment in both electricity generation capacity and T&D infrastructure across the country. In addition, India is experiencing regular power outages because of the harsh weather, the insufficient capacity generated, and fragile infrastructure Furthermore, the country experiences frequent power outages due to severe weather, insufficient generation capacity, and fragile infrastructure that have a strong impact on the need for new investments to improve the grid's resilience and reliability.[27]

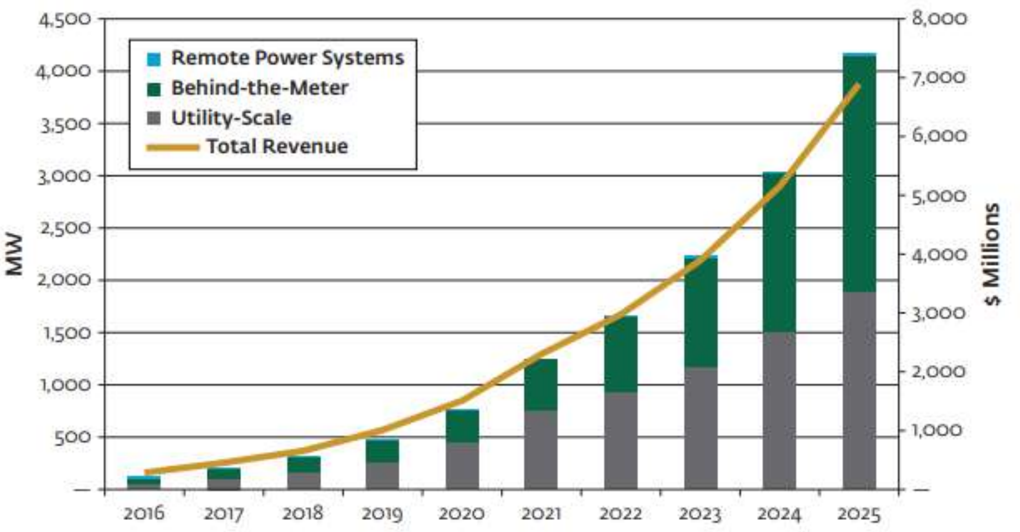


Figure III-5*: Annual stationary energy storage in India: 2016-2025*[15]

South Asia Market Barriers:

• Underdeveloped grid infrastructure

• Limited local experience and knowledge of energy storage.

Other than India, there have been very few energy storage market developments in South Asia to date, and deployments are expected to be limited over the coming decade (See figure II-6). One exception would be increasing interest in pumped hydro storage throughout the region. In October 2016, governments from Bangladesh and Nepal signed an agreement to develop a total of 1,600 MW of PHS capacities in Nepal through two different projects.

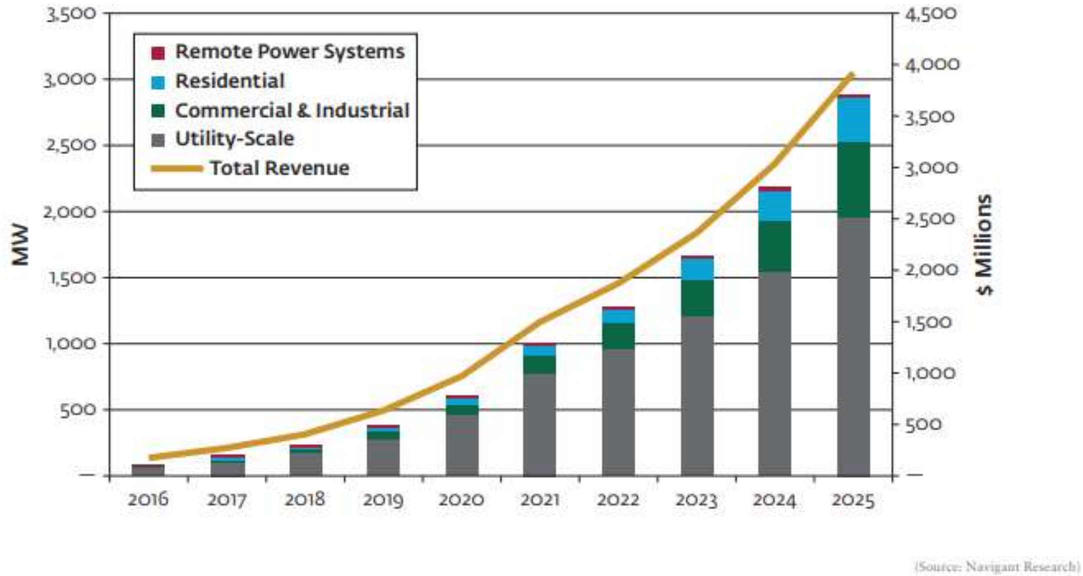


Figure III-6*: Annual stationary energy storage in South Asia: 2016-2025*[15]

III. 4. Eastern Europe and central Asia

The market in Eastern Europe & Central Asia for energy storage is dominated by a single technology, pumped hydro storage. This region has a significant installed base of energy storage resources with 9.3 GW of pumped hydro capacity installed, and an additional 3.5 GW that is either under construction or in planning stages. Storage systems are spread among 10 countries in the region. The countries with the largest capacity are Ukraine with 2,568 MW, Poland with 1,158 MW, and the Czech Republic with 1,102 MW.[27]

There are several challenges facing energy storage development in Eastern Europe. Electricity markets in the region have traditionally been very highly regulated and dominated by state-owned enterprises dating back to the Soviet era. Although there is a push for greater competition through deregulation, that transition is happening at different rates throughout the region, with little progress being made in most markets. Given the lack of competitive markets, there are limited opportunities for independent companies to own storage assets.

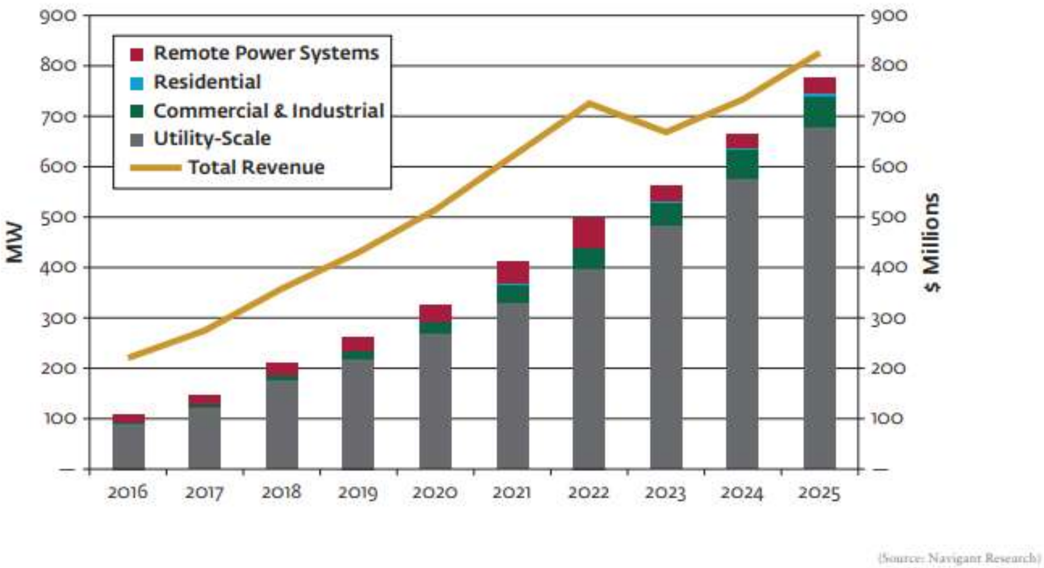


Figure III-7*: Annual stationary energy storage in Eastern Europe and central Asia: 2016-2025*[15]

III. 5. Latin America and the Caribbean

Latin America is seen as one of the biggest emerging markets for energy storage development. The anticipated growth in renewable generation, rapidly growing populations, and relatively unstable grid conditions are among the major factors driving interest in energy storage throughout the region. From 2016 to 2020, Navigant Research expects that an additional 21 GW of wind and 15 GW of solar generation will be added to the grid in Latin America. In order to effectively integrate and utilize these new resources, grid operators must invest in new infrastructure, including energy storage, to help match supply with demand and to ensure system stability. To date there is approximately 1 GW of ESS capacity installed in the region. However nearly 95 percent of that capacity comes from two pumped hydro storage facilities in Argentina.

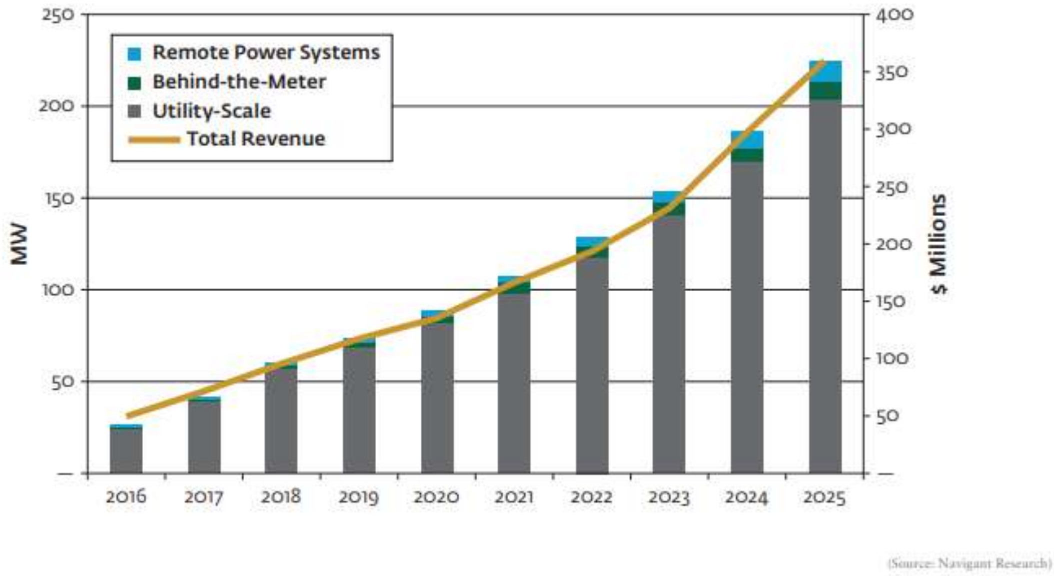


***Figure III-8**: Annual stationary energy storage in Brazil: 2016-2025*[15]

Though activity has been limited to date, the Mexican market is ramping up, driven in part by regulatory reforms to break up the state-owned electricity monopoly the Comisión Federal de Electricidad (CFE). Under these reforms, independent operators could sell both capacity and ancillary services in a competitive market, presenting opportunities for renewable and energy storage developers.

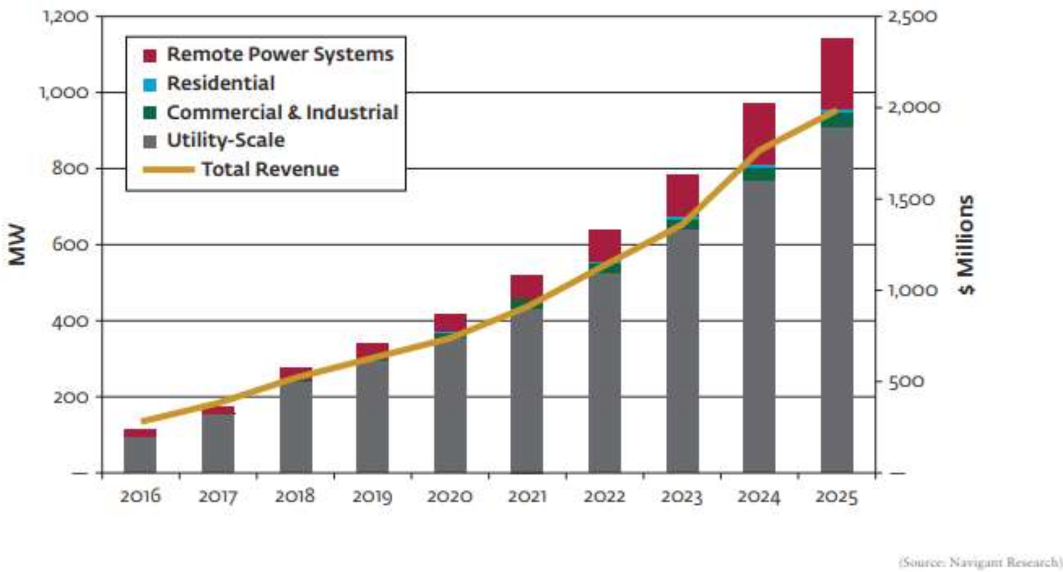


***Figure III-9**: Annual stationary energy storage in Latin America and Caribbean: 2016-2025*[15]

III. 6. Sub-Saharan Africa

A number of challenges have resulted in limited energy storage market activity in Sub-Saharan Africa to date. The market has been restricted by a lack of affordable financing, limited local technical experience, and a lack of familiarity with newer technologies that are used in utility scale energy storage systems, in addition to the logistical challenges faced by pilot pioneering infrastructure projects in much of the region. Although an estimated 1.6 GW of grid-tied energy storage has to date been installed in Africa, 1.4 GW of it comes from large pumped hydro storage.

As has been seen in South Africa, the integration of renewable generation is likely to be the key driver for energy storage in Africa. There are strong renewable resources in the region, with a growing level of government support in many countries. We expect an estimated 25.9 GW of new wind and solar capacity to be installed by 2025. A portion of this capacity will come from distributed solar PV systems which may include energy storage to enable islanding micro grids for facilities to maintain power supply during the region’s frequent outages.

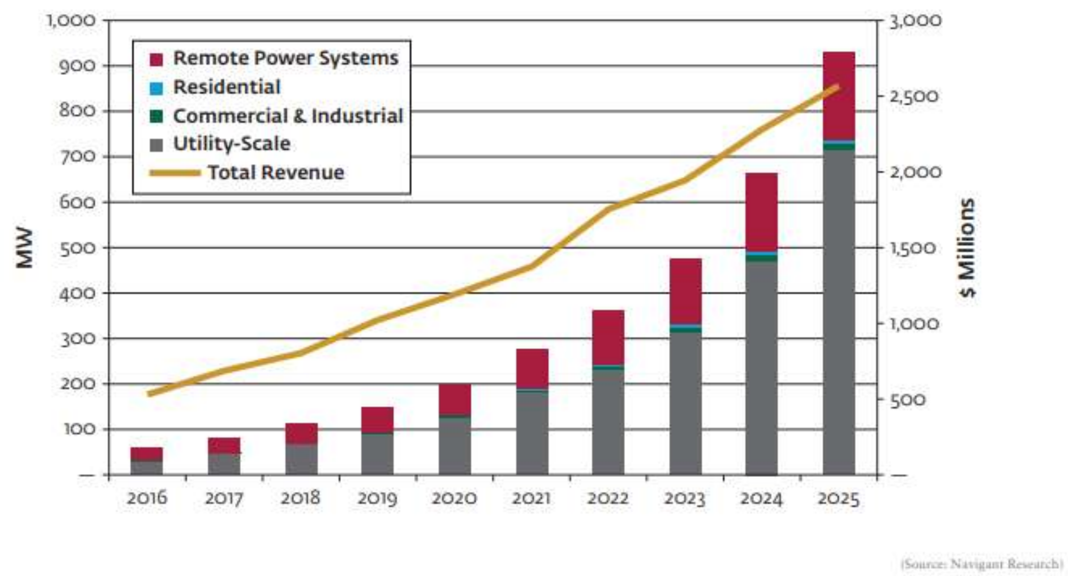


Figure III-10: *Annual stationary energy storage in sub-Saharan Africa: 2016-2025*[15]

III. 7. Middle East and North Africa

In the Middle East and North Africa region, there has been limited energy storage project activity to date. Of the 1,026 MW of capacity currently installed, 1,020 MW comes from a single pumped hydro plant in Iran. While most battery projects have been very small research and development (R&D) systems, there is currently a pipeline of 128 MW of a battery energy storage system (BESS). This includes two NaS battery projects from NGK Insulators in the United Arab Emirates, representing a combined 648 MWh of capacity, as well as a project in Jordan. There are also a number of CSP projects that contain thermal energy storage installed in Morocco and the United Arab Emirates. While to date there have been limited energy storage deployments in the Middle East, nations in the region are working to exploit their significant renewable energy resources. Utility-scale solar deployments are expected to increase at a compound annual growth rate (CAGR) of 16.2 percent over the coming decade with 33 GW of new capacity expected (See Figure 11). These developments, combined with a rapidly growing and increasingly urbanized population, are expected to lead to increasing demand for energy storage to help manage intermittency and to improve grid resilience in the region. Many countries in the Gulf region are looking to deploy large amounts of renewable energy to reduce the amount of domestic fossil fuels used for local power generation. This will free up that fuel to be sold abroad, bringing in much needed revenue for government programs. These countries are exploring energy storage in order to help integrate these new generation resources and to help improve the grid's stability and reliability. However the historical low cost for fossil fuels and subsidized retail electricity, combined with highly regulated electricity markets, remain significant barriers to storage development since there is little urgency or ability for customers to deploy BTM technologies.[29]

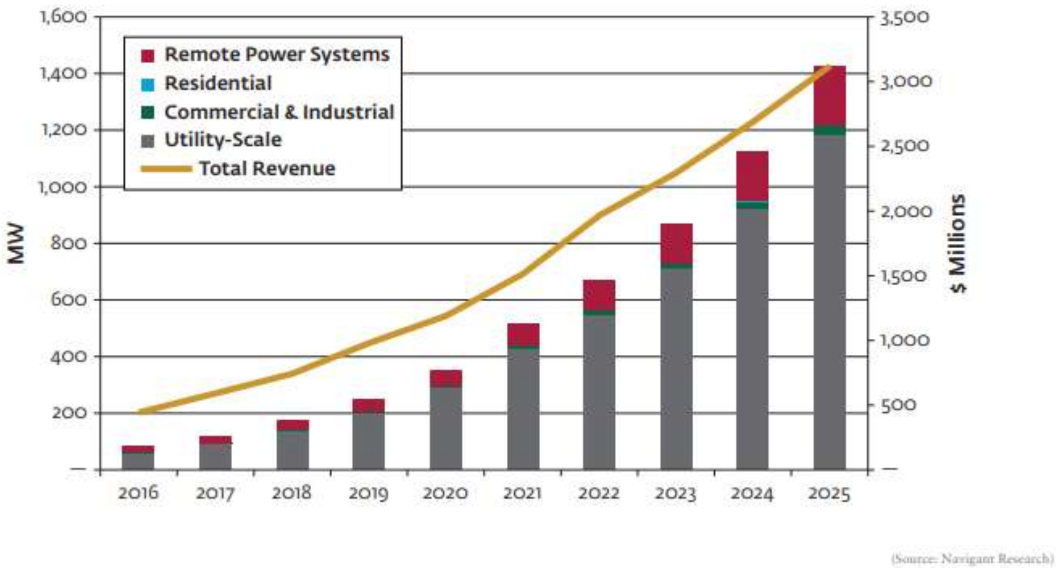


Figure III-11*: Annual stationary energy storage in Middle East and North Africa: 2016-2025*[15]

The potential for energy storage development in the Middle East and North Africa is driven mainly by a rapidly growing urban population throughout the region, as well as by expected additions to renewable energy capacity. Both factors will result in the need for new flexible generation resources and peaking capacity in addition to new infrastructure to accommodate increasing demand and variable generation. A notable market with high potential for energy storage in the region is Jordan, where a leading project developer, AES Energy Storage, is currently developing a 20 MW lithium ion ESS. [15]

III. 8. Conclusion

The rapidly falling costs and improving capabilities of stationary ESSs, along with growing industry expertise, will quickly open new markets and cost effective applications for energy storage. It is important to utilize technology from reputable and established vendors that can offer warranties and performance guaranties on their products.

The development of distributed and local energy resources in the whole world, including renewable and energy storage, can bring an important economic growth, jobs, and a sustainable energy future in emerging markets.

Chapter IV: Development of Solution able to be applied in Algeria

IV. 1. Introduction

With the increasing spread between PV costs and prices of grid electricity, using the PV generated electricity on-site on the household level is becoming more attractive than feeding it into the grid. Nevertheless, the simultaneity of the PV generation and load consumption in private households is limited. Shifting the consumption of deferrable loads by demand-side management to periods with PV surpluses is one solution to increase the local self-consumption of PV electricity in the residential sector. The conjunction of PV systems with storage batteries allows a further increase of self-consumed PV electricity. With a battery system, the excess PV electricity during the day is buffered and later used at night. In this way, households equipped with a PV+ battery system can reduce the energy drawn from the grid and therefore increase their self-sufficiency. ESS has also the ability to provide benefits at the transmission, distribution, and utilization levels. One of the best values of storage system is to provide peak load shaving. A Peak load shaving is a process of making the load curve flattens by reducing the peak amount of load and shifting it to times of lower load[2].

In this chapter, a residential PV+ battery system will be analyzed by simulations in order to gain insights into their sizing. The simulation model and the used input data are described. Afterwards, a sensitivity analysis is conducted varying the size of the PV battery system to identify appropriate system configurations. Finally, an economic assessment of residential PV battery systems is conducted to derive recommendations for cost optimal sizing.

IV. 2. Approach

In order to analyze the energy flows of a household equipped with a PV battery system, a simulation model was developed. The method consists also a techno-economic model that provides solar technology integration and optimization capabilities. Both meteorological and load demand data sets were used as input for the simulation.

The objective function of the model is to minimize the life cycle cost of energy for a single entity by optimally selecting, sizing, and dispatching from a set of available technologies. For the purposes of our study, we minimize life cycle energy costs for a residential household by deploying an optimal configuration of PV and battery storage.

Algeria has committed most of its renewable energy sourcing from Solar photovoltaic (PVs) due to its vast solar exposure which covers 90% of the country with an area of 2382 million km2. The estimated sunshine is valued at 3000 h per year and daily energy reaching up to 5 kWh/m2. [2]

IV. 3. Methodology

The main objective of this work is to address the photovoltaic ability to reduce total and peak load demand. To determine if grid connected PV is comparable to the conventional utility grid, it is important to assess the impact of linking PV directly with electrical loads. The reduction in load demand depends on the PV system performance as well as the instant match between the peak load and PV output.

In order to achieve our economic goal, a study was undertaken for this research and analysed the situation in 8 different houses and flats with the aim of exploring the energy consumption and implement some optimum energy efficiency solutions. The research also sought to establish the average energy consumption for these sample 8 LV consumers.

The study involved two stages: first, we analysed the households' consumption to establish a solution in the second stage, where a model was developed with PV energy and storage solution.

IV. 4. Analysing household's consumption:

In the first stage, we analysed the latest electricity bills of 8 different houses during two years (2018 and 2019), for 4 quarters each year. After drawing the bills on excel tables and analysing them, we noticed that all the houses consumption was divided into: stable energy consumption and a variant one each quarter.

The stable power consumption concerned the two first tranches with a consumed energy of 250 KWh and a 1,7787 DA as a unit price for the first 125 KWh consumed and 4,1789 DA for the second 125 KWh. After adding the VAT (value added tax), the first two instalments cost 811.723 DA for all the different 8 houses each quarter.

The second part of the consumed energy varies from a quarter to another, depending on how much the household consumes, and it goes from 4.8120 DA for the first 750 KWh consumed in the third tranche to 5.4796 DA in the fourth tranche for each KWh if more energy is consumed.

Table IV-1: *electrical bills splitting the energy consumed into tranches with its unit price*

Tariff 54M	First Tranche	Second Tranche	Third Tranche	Fourth Tranche
Energy per quarter (kWh)	From 0 to 125	From >125 to 250	From >250 to 750	>1000
Energy per year (kWh)	500	1000	3000	4000
Energy price	1,7787	4,1789	4,8120	5,4796

(DZD/kWh)				

The following bar chart compares the yearly consumption of the 8 different consumers (represented by alphabetic letters from A to H) during 2018 and 2019 and also shows the consumers who are on the fourth tranche. 6 of 8 customers consume more than 4000 kWh per year and are on the fourth tranche using energy between 500 kWh to 3000 kWh as for the consumers B, C, D, E and G. the consumer F comes in the first place consuming more than 10 000 KWh yearly with more than 6000 kWh in the fourth tranche, making the bills much more expensive. The consumers A and H use the least energy per year among the 8, and almost 0 KWh in the fourth tranche.

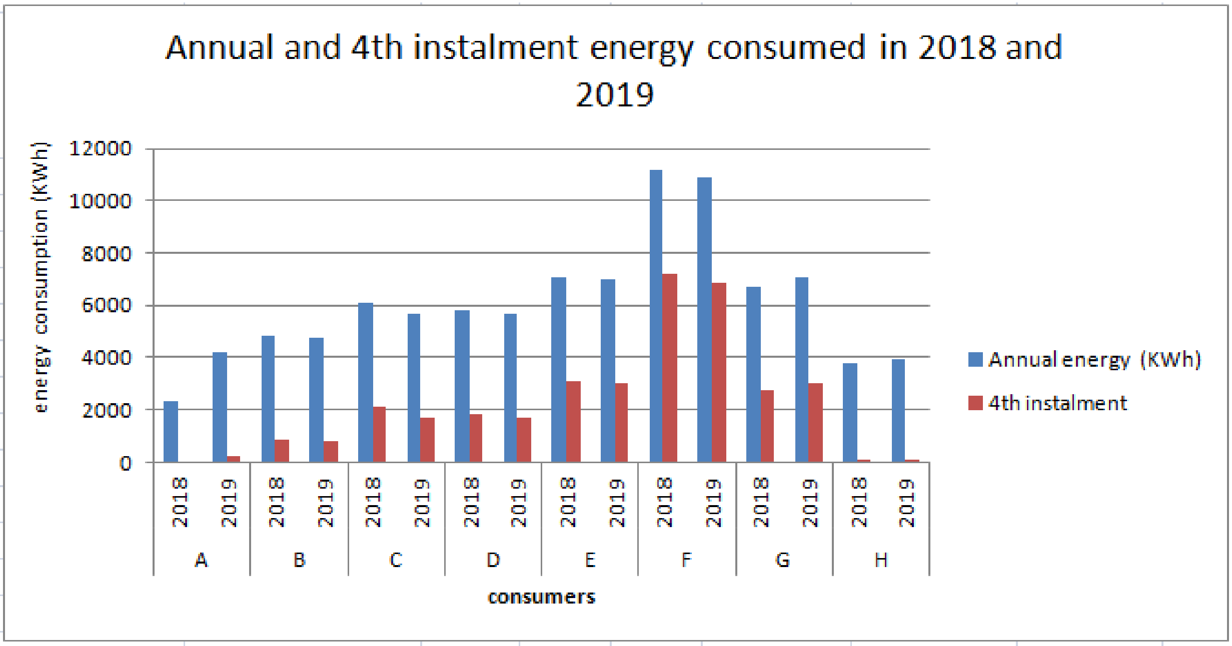


***Figure IV-1**: Annual and 4th istalment energy consumed in 2018 and 2019*

To have a clear idea about how much energy is consumed generally in the fourth tranche; we calculated the average of energy in this section for our 8 consumers and the average cost as well in the following table.

***Table IV-2:** average energy consumed in the fourth tranche*

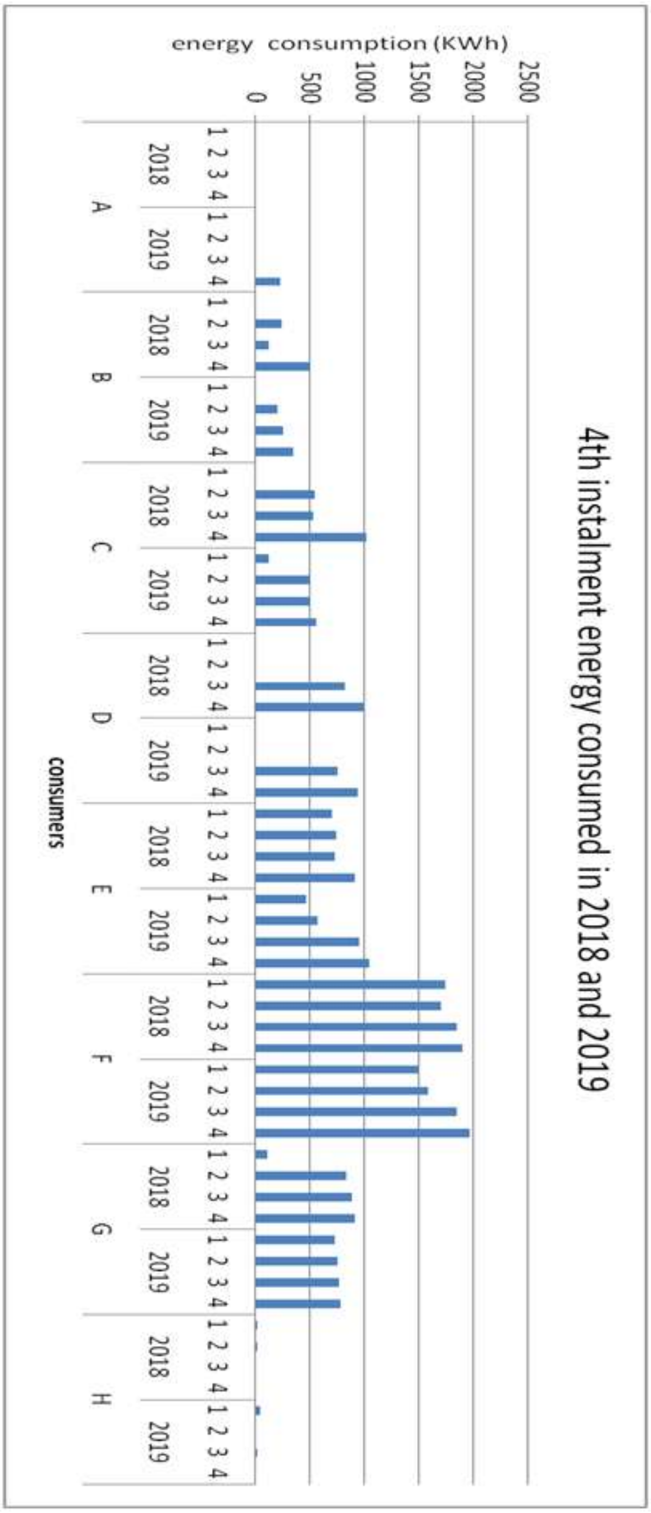
Average consumption per quarter	Unit price	Price (DA)	VAT %	VAT (DA)	Total price (DA)
550,04 kWh	5,4796	3014,03	19%	572,66	3586,70

As shown in the table 1, the average of energy consumed in the fourth tranche is about 550 KWh in one quarter (three months).

Generally, it is found that the total energy generated during a certain month in the year is increased in the following year. We can clearly see from the bar chart in figure 2 that a sharp increase in the energy generation in each year is noticed during the hot months (June–September). This may be attributed to the increased demand of AC systems that represent the main load during the summer months each year. It is also observed that during the first quarter of each year, the electrical load is at its minimum, especially in the third quarter that corresponds to the months of March and April and May, because the weather is warm, the temperature is reasonable and, consequently, the consumers do not switch on either their air conditioners or their heaters.

Fig below presents the variation of the maximum and minimum load during the year 2018 and 2019 for the 8 consumers. The peak load of first quarter is the minimum peak load throughout the year. That may be attributed to the fact that during these months, people usually do not use electricity for cooling or heating, so any load equal to the peak load of this quarter or less is used for other appliances. This leads to the fact that any load higher than that of quarter is used for cooling, and the ones higher between December and February are used for heating, while other appliances are common in all months.

The idea that we are suggesting is to replace this energy with a photovoltaic system instead of having it from the grid that produces energy from fossil fuels. The strategy is better explained in the section below.



IV. 5. PV energy production and storage: case-study

In order to know the economic impact of our strategy; for the consumer and for the government as well as the environmental side of it, we studied the case of replacing the fourth tranche energy of a specific house with a PV+storage system. We test the price impacts on demand in the deregulated retail electricity.

In the first section we collected information about the household's energy consumption, while in this section we developed a model in order to minimize the price of electricity in the residential sector principally.

As the steady part of energy consumption is much cheaper than the second part, we suggest a strategy where a grid-connected PV power system is proposed to replace the energy of the fourth part which is more expensive and cover the needed energy from the grid when the PV system becomes insufficient. The purpose of this study is to lower our annual power costs without making our home less comfortable, but making it more valuable.

For our study purpose, we realized a simulation of grid-connected PV system with storage, for real house energy consumption.

IV. 5. 1. System description

To investigate the economic viability of storage in distributed PV systems, we simulate electricity generation and consumption for a household in Boukiou, in ghazaouat Tlemcen.

To achieve our goal, we analysed all the electrical appliance consumptions and starting from there, we made calculations and explained the results; in fact, it consequently lowered the electricity bill.

We supplied the house with PV system and storage so that it covers the amount of energy required for the fourth tranche and power the loads from network if more energy is needed. We make sure that the PV system covers the energy needed; and the load no more than the energy consumed from the three first tranches.

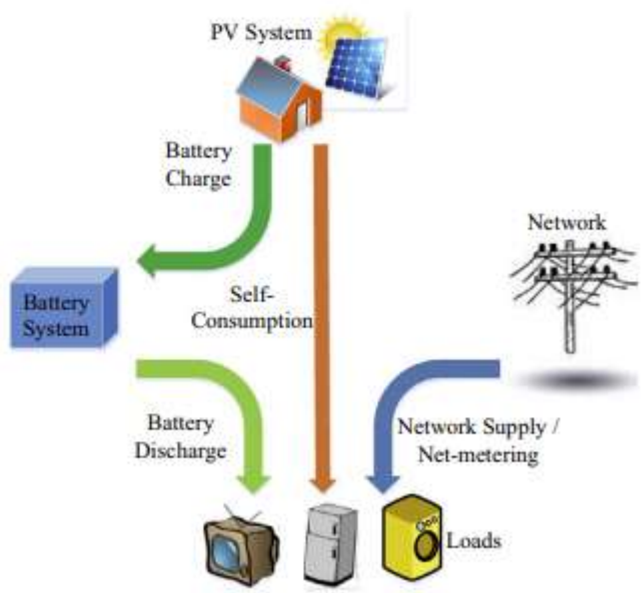


***Figure IV-2**:Electrical energy in residential customers with PV and storage system.*

As shown in figure IV-2, the PV panels will supply the loads and then charge the batteries when there's a surplus in energy. As soon as PV system output begins to be insufficient to supply the demand, the battery starts operation. After batteries discharge, loads are powered by the network. In the charge process, batteries are charged using only the generated PV electricity. In the discharge process, batteries electricity is used merely to supply the domestic demand. Therefore, discharging the battery to the network or charging the battery from the network was not taken into account in this work.

A schematic diagram of the grid-connected PV-storage system to be investigated is shown in Fig. 2. It consists of the PV system, battery storage, DC–AC inverter and an AC bus.

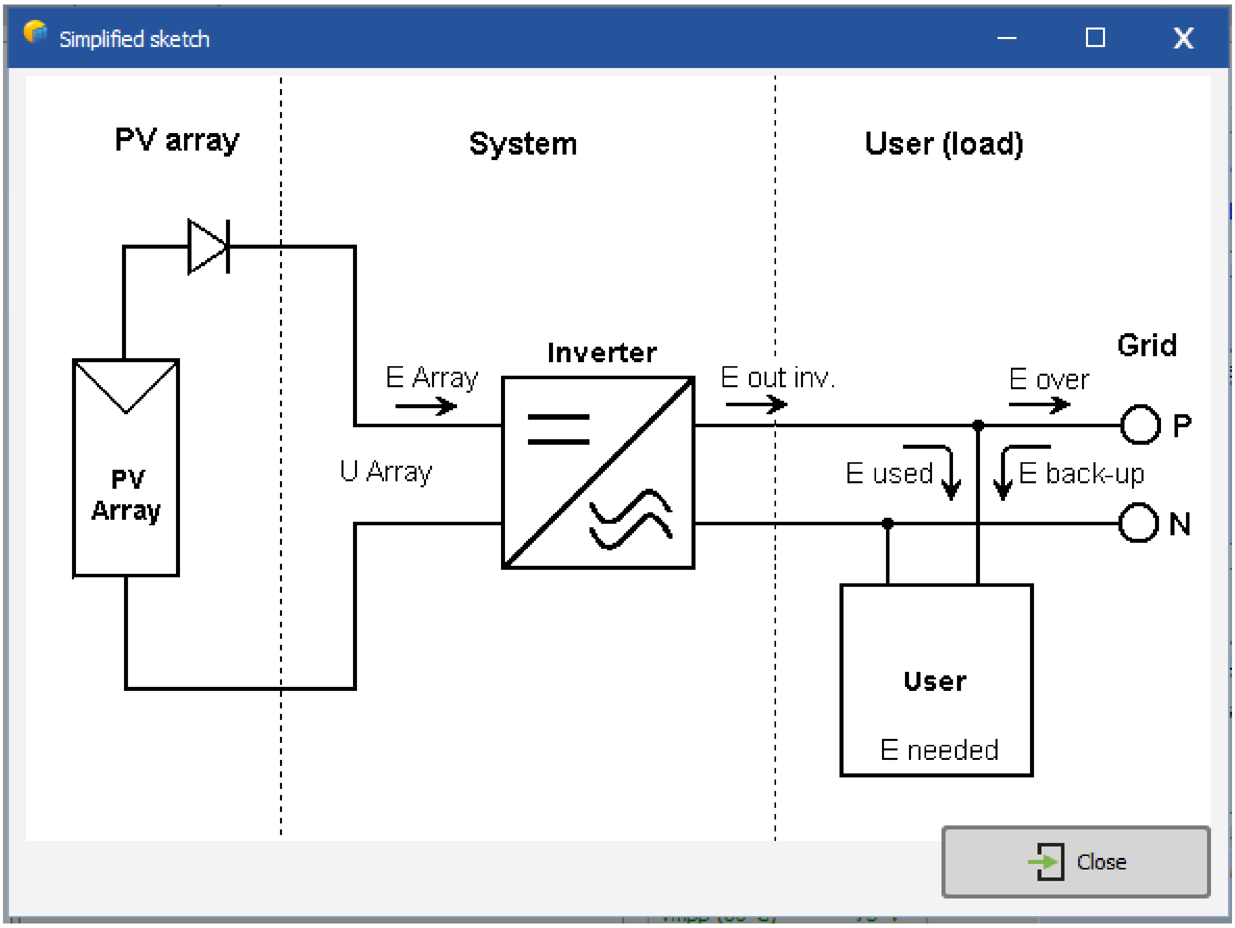


Figure IV-3: *schematic diagram of the grid-connected PV+storage system*

The electricity generated by the PV system is inverted and transmitted to an AC bus where it can either be directly assigned to the loads of the household or stored in the storage system.

Excess energy produced during times with low loads charge the battery, while at times with low solar radiation the load are met by discharging it.

IV. 5. 2. Model input parameters

IV. 5. 2. 1. Technological input parameters

The technological input parameters can be broadly divided into three categories: those pertaining to electricity generation, the electricity storage and the electric load. In the following, each of the categories will be discussed separately.

The system has an inverter converting electricity between DC and AC (Alternating Current), because the load is AC and different from PV current type.

IV. 5. 2. 2. Electric load profile

The load consumption in the household that will be covered by the PV system is given in Tables 1. We simulate electricity generation and consumption for a household in Boukiou, Ghazaouet, Tlemcen.

Table IV-3: *Load consumption in the household covered by the PV system [2] [3]*

Type of electrical load	AC Power per unit (W)	Number	Total Power (W)	Hours of operation per day (h)	Daily consumed energy (Wh)
LED lamp	Lamps(LED): 7W/lamp	5	35	10	350
Fridge	Fridge: 200 W	1	200	continuously	1370
TV+Demo	TV : 50W + demo: 15W	1	75	10	750
Exterior spotlight	exterior spotlight: 50W	4	200	6	1200
Laptop	150	1	150	6	900
	Total energy consumption and power per 24 hours (Wh)		660 W		4 570Wh

IV. 5. 2. 3. Electricity generation

The PV electricity production is a function of the available Global Horizontal Irradiation (GHI expressed in kWh/ m²/day or year), the outside air temperature as well as the tilt, orientation and performance characteristics of the PV module. Orientation and tilt were chosen such that the PV modules could operate under optimal conditions. In Tlemcen, this corresponds to an orientation to the south and a tilt of 30 °.

In line with previous studies we choose crystalline silicon as a PV technology. This choice is made as currently crystalline silicon PV offers higher conversion efficiencies than thin-film PV and therefore has a market share in residential markets that exceeds 80%. To reflect inefficiencies in the PV system, such as inversion losses, the PV system rated output is multiplied with a performance ratio (PR) of 85%.

In order to determine how many solar panels, we will need, we calculated how much KWh we will cover up with the panels. We assumed that 1000 KWh will be cover by the grid during one quarter (90 days) corresponding to 3 tranches (1+2+3), which means about 2.8 KWh per day (250/90=2.77KWH), and dimensioned the PV panels as it covers the difference between total daily needs and those supplied by the grid mentioned in table 1.

As mentioned on the table above, the house needs a system that generates 2990 kWh per day.

The PV panels' generated power depends on two factors: direct sunlight during the day and the peak power of the panel.

The direct sunlight is defined by the sunlight that hits a certain spot without interference or obstruction.

The peak power (in Watt peak) is defined as the maximum electric power. It's registered under standard test conditions: a light intensity of 1000 W/m^2, sunlight hitting the positioned solar cells perpendicularly and a temperature of 25°C at the solar cells and 1 m/s wind speed. Since the real conditions are never ideal, we consider that the panel produces 80% of its peak power, and then the coefficient for losses is 0.8. The formula for calculating the solar panel's power output is as follows:

$P_p=E/(S*K)$, where:

P_p: peak power (Wp);

E: daily energy consumed (Wh);

S: annual average solar radiation hours per day;

K: coefficient for losses (range between 0.5 and 0.9).

To determine the PV system size used for this study, we're going to use the simulation tool PVsyst.

IV. 5. 2. 4. Electricity storage:

Now to dimension battery system we calculate it with the following formula:

$C=E*A/(D_{od}*U_{service})$, where:

C: batteries capacity (Ah);

E: daily energy consumed (Wh);

A: number of days of autonomy required;

D_{od}: depth of discharge of the battery;

$U_{service}$: voltage of service, equal to 12V when the P_p <500 Wp, and 24 V when P_p>500 Wp.

To optimize the backup batteries, we encourage the consumer to use only the necessary appliances after that the PV panels stop producing electricity due to sunset, as the fridge and some other appliances mentioned in the table below, to minimize the number of batteries and optimize the cost of installation.

We urge the consumer to use the washing machine for example, during the day when the PV panels produce the peak of energy, and let the backup for necessary needs of energy.

Table IV-4: *load consumption at night*

Electrical load and capacity(W)	Number	Power (W)	Hours of operation per day (h)	Daily consumed energy (Wh)
Lamps(LED):7W/lamp	5	35	6	210
Fridge: 200 W	1	200	continuously	1370
exterior spotlight: 50W	4	200	6	1200
Total energy consumption per day Wh				2780 Wh

Similar to the majority of previous studies, we choose lead-acid gel batteries as the storage technology for our model. Compared to other battery technologies, lead-acid batteries have a short lifetime and low energy and power density. However, currently, due to their high reliability, low self-discharge as well as low investment and maintenance costs, they are the dominant technology in small scale, residential applications.

The nominal voltage of batteries used is 12V with a rated capacity of 120 Ah for each battery.

IV. 5. 2. 5. Sizing the inverter and regulator:

Inverter: an inverted is used in the system in order to convert the Dc power to AC power. The input rating of the inverter should never be lower than the total watt of appliances, and must have the same nominal voltage as the batteries. The power of the inverter is calculated by the formula: $P_{inverter}$=total power/(P_f*P_e), where:

$P_{inverter}$: Power of the inverter

Total power: the total power of the system

P_f: power factor = 0.9

P_e: efficiency 96%

The input current is calculated as follows: module short circuit current* modules in parallel*safety factor= Array short circuit current.

IV. 5. 3. System simulation on PVsyst
IV. 5. 3. 1. Software general description

PVsyst 7.0 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems, and includes extensive meteo and PV systems components databases, as well as general solar energy tools this software is geared to the needs of architects, engineers, researchers. It is also very helpful for educational training.[30]

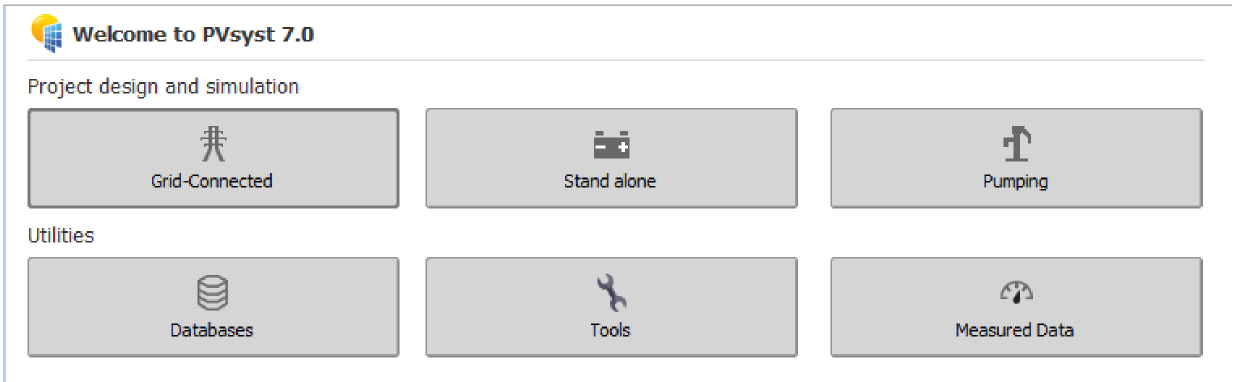


Figure IV-4: *Project designs available on the simulation software PVsyst*

IV. 5. 3. 2. SYSTEM DEFINING PARAMETERS

a) Inclination and Orientation

Our system is installed in Oued Boukiou Ghazaouet, shown in map in figure 4. PV panels are optimized for the best orientation according to solar path in Oued boukiou figure 5.

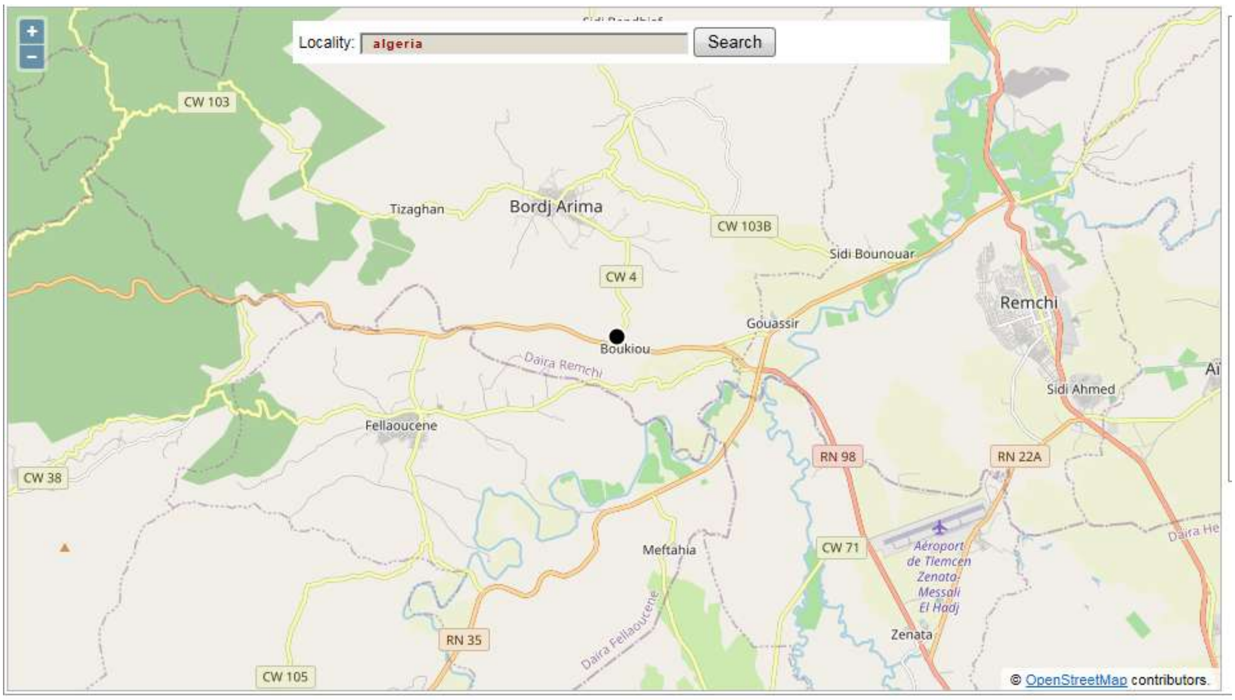


Figure IV-5: *grid-connected PV system location*

To gain maximum solar irradiation and the result is that the tilt angle is 30° and Azimuth angle is 0° figure .5. The tilt angle for PV array is kept as equal to the latitude of the corresponding location to get maximum solar Irradiation [6, 7].

Fig 5 shows the inclination and orientation for the solar panel for our site while the figure 6 shows the solar path in the location.

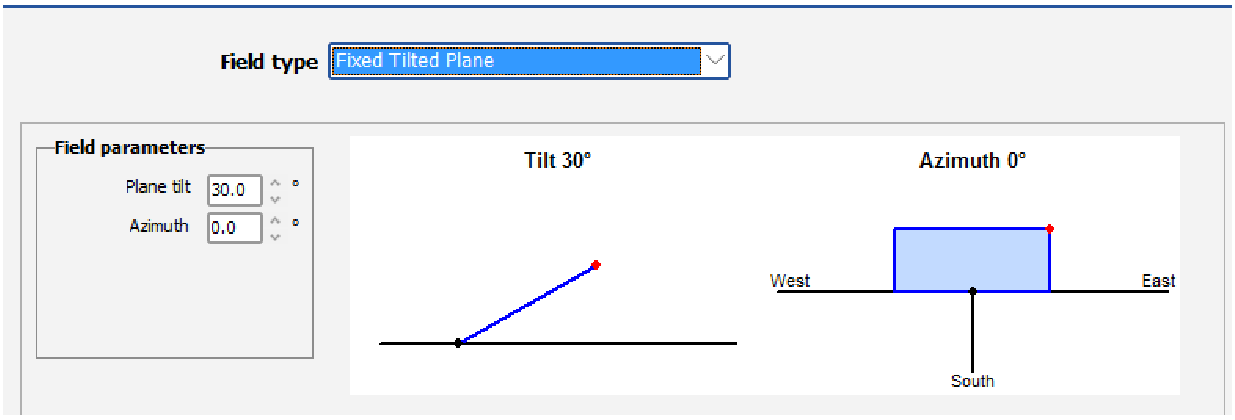


Figure IV-6: *inclination and orientation for the solar panel*

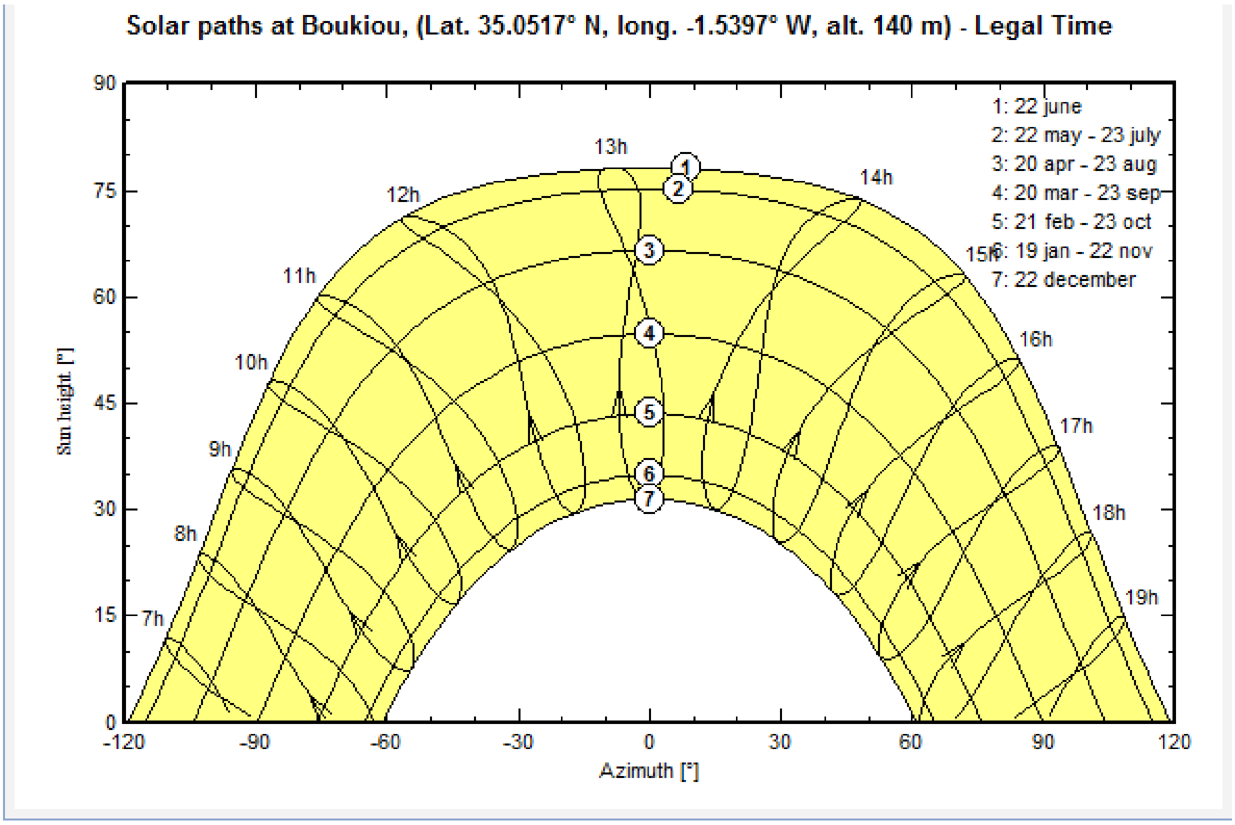


Figure IV-7: *Solar path*

b) PV panels, storage and inverter

The following are the details used in the simulation software, about the Grid connected PV systems for Oued Boukiou, Ghazaouet site.

The equipments used to construct the grid connected PV system for our case study described above are summarized in the table 4 with some details.

Table IV-5*:GLOBAL SYSTEM SUMMARY*

Number of modules	2
Nominal PV Power	1000 KWp
Maximum PV Power / voltage	315 Wp – 37 V
Number of batteries	4 (2 in series and 2 strings)
Battery voltage	12 V
Battery capacity	120 Ah
Inverter PWM	3kW - 24VDC 230Vac.
Inverter efficiency	DC/AC 90%.

As a total number, we used 2 poly crystalline modules of 315 Wp each, in series to generate 630 Wp of power daily. The annual energy of the system is 1124 kWh/year. The modules specifications are provided in Table 1. A single inverter is used to convert DC to AC to be directly used. The inverter has a maximum DC input power of 3 kW and maximum AC power output of 3 kW.

The number of batteries used to reach the capacity of backup needed is 2 batteries in series. However the voltage of the service is 24V and the one of two batteries is series is 12V; therefore we're going to connect two other batteries in parallel with the first two ones to get the required voltage and capacity.

As shown in the simulation (Figure 3), for the backup battery pack, we used 4 gel batteries 2 in series and 2 in string with a capacity of 120 Ah each of them and a voltage equal to 12 V. The total capacity is 240 Ah and the voltage is 24 V as required. These batteries are used for self-consumption during the night.

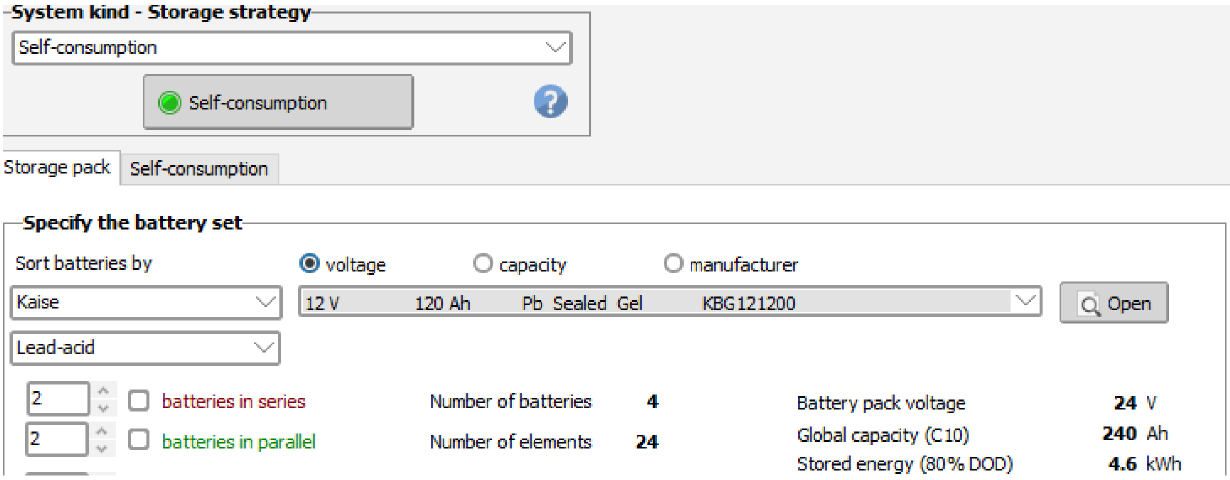


***Figure IV-8**:Battery and storage strategy simulation on PVsyst*

IV. 6. RESULTS AND D1SSCUSSION

Table 5 shows the balances and main results of Grid connected PV system. Yearly global horizontal irradiation is 1919.3 KWh/m2. The yearly global incident energy on the collector plane is 2208.6 KWh/m2. Energy available at the output of the PV array is 1083.1 KWh.

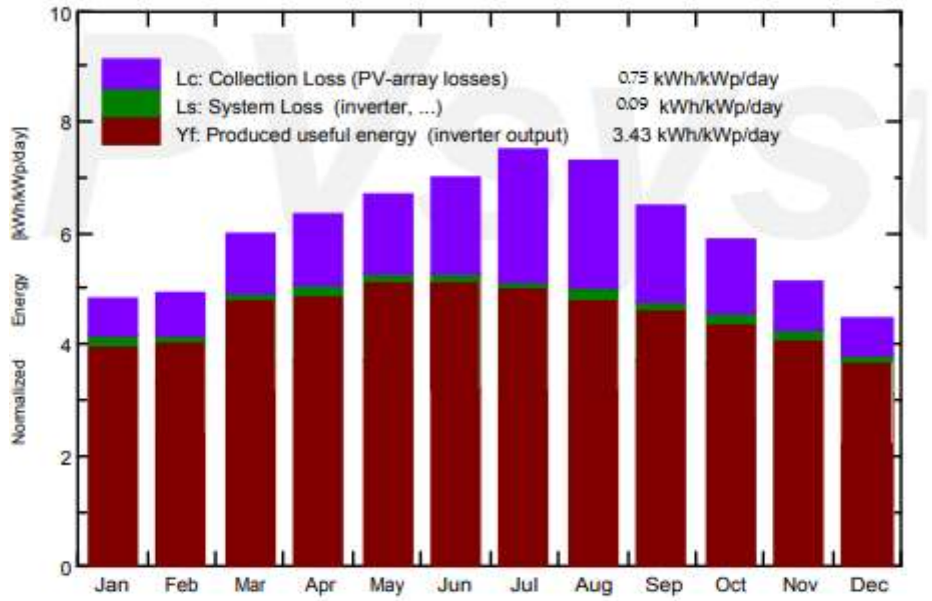
***Table IV-6**: Balances and main results*

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_User kWh	E_Solar kWh	EUnused kWh
January	93.0	27.79	11.15	149.6	146.4	81.1	79.15	66.65	0.00
February	100.8	36.13	12.31	137.7	134.8	73.1	71.49	57.95	0.00
March	154.0	52.70	14.48	186.1	181.9	96.0	72.64	70.59	0.03
April	179.2	68.07	16.03	189.7	184.9	96.3	70.30	70.30	4.23
May	214.7	77.42	19.55	208.1	202.4	103.0	72.64	72.64	7.57
June	227.2	78.42	23.46	210.4	204.4	100.1	60.25	60.25	16.04
July	245.7	62.05	26.86	232.6	226.5	100.3	62.25	62.25	14.12
August	217.8	64.39	26.89	225.5	220.1	97.7	62.25	62.25	11.17
September	168.2	55.55	23.42	194.4	189.7	90.6	70.30	70.30	1.35
October	135.4	42.26	20.32	181.7	178.0	89.5	72.64	71.97	0.00
November	99.4	28.96	15.16	154.1	150.8	80.9	70.30	62.46	0.00
December	84.0	24.00	12.60	138.7	135.9	74.5	79.15	60.66	0.00
Year	1919.3	617.74	18.56	2208.6	2155.8	1083.1	843.35	788.25	54.52

The annual energy yield for this PV power plants is defined as the amount of energy fed into the building grid after due consideration of all kinds of generation and distribution losses. The simulation tool (PVSYST v6.04) has been used to estimate 364Kwp power plant to yield energy from PV power plants. PVSYST simulation result is in Fig. 8.

Figure 8 represents the total energy output throughout the year which is 3.43 kWh/day, collection loss which is 0.75 KWh/day and system or inverter losses which is 0.09 KWh/day.

***Table IV-7:** Monthly normalized production from 630 Wp system*



The loss in the PV system depends on the PV module and inverter technology; efficiency and quality of PV modules, inverter, junction box and wires; workmanship of installation and scheduled maintenance and cleaning. In the simulation process, Losses have been considered best quality modules and inverters of international standard. [31] How PVSYST is produced losses, it is shown thoroughly in Fig. 10.

The overall system loss diagram for our system in Boukiou site is represented in the figure 9. The horizontal global irradiation is 1919 kWh/m2 .The effective irradiation on the collector plane is 2156 kWh/m2 .So the loss in energy is 2.39 %.Then the PV cell convert solar energy into electrical energy. After PV conversion, array nominal energy is 1369 kWh. The efficiency of PV array is 11.64 % at Standard Test Condition (STC). Array virtual energy obtained is 1143 KWh. After the inverter loss, the available energy at the inverter output is 967 KWh.

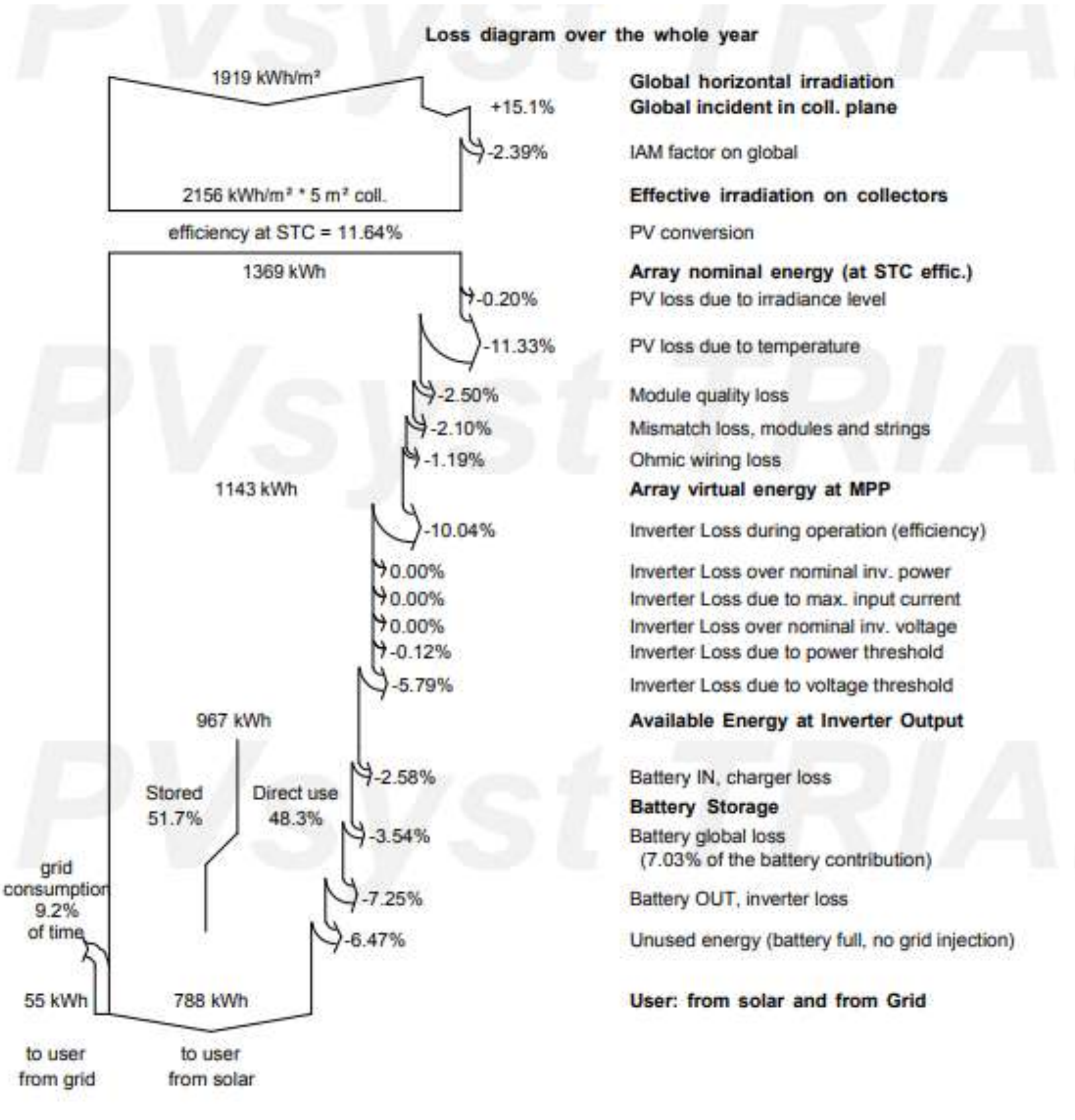


Figure IV-9: *loss diagram of the system over the year.*

IV. 7. PV system installation

The PV system is installed on a rack structure mounted on the ground with a clearance distance, at a building in Boukiou, ghazaouat located in the state of Tlemcen, Algeria. The system consists of 2 multi-crystalline silicon modules connected in 1 string of 2 series-connected modules.

The modules were oriented facing south at a fixed tilt of 30° and azimuth angle of 0. As shown in figure 10.

Figure IV-10: *Photographs of the installed system.*

IV. 8. Economic and environmental analysis

Considering the PV system and calculation made on the previous sections, the house is equipped with 2 PV panels each one of them generating 315 Wp, with a current of 9A and a nominal voltage of 37 V. The backup is equipped with 4 batteries; each battery has a nominal voltage of 12V and 120Ah capacity. The installation contains also an inverter and a regulator. The finance estimation is listed table.

Table IV-8: *finance estimation of the installed system*

Equipment	Power or Capacity	Reference	Number of equipment	Unit price	Total price DA
PV panels	315 Wp		2	20 000 DA	40000
Battery	120 Ah 12 V	RITAR A GEL DG12-120Ah	4	20 300DA	81200
Inverter	3 kW 24VDC 230Vac	On grid VICTRON SOLAR MAX 3KW 24 v	1	138 000 DA	138000
Total price	(HT)				259 200

The total price of the installed system with a 630 Wp is 265 700 DA. The daily generated energy is: E= P_p*6*0.8=630*6*0.8=3024 Wh.

The average consumption by each household in one quarter is about 550 KWh and 2200 KWh in one year in the fourth installment. If 100 houses install a PV system with storage it would allow us to save 220 000 KWh per year, as a result the government would have an economic income from selling this energy for exportation.

The simulations results obtained using this method, based in the evaluation of the main PV module parameters, have shown that the presented model of the PV system will help to mitigate carbon emissions by replacing more carbon intensive sources of heat and power and the carbon in our environment will decrease dramatically. As shown in figure During 30 years and amount of 13.5 T have been saved instead of its emission and cut down the greenhouse gases effect.

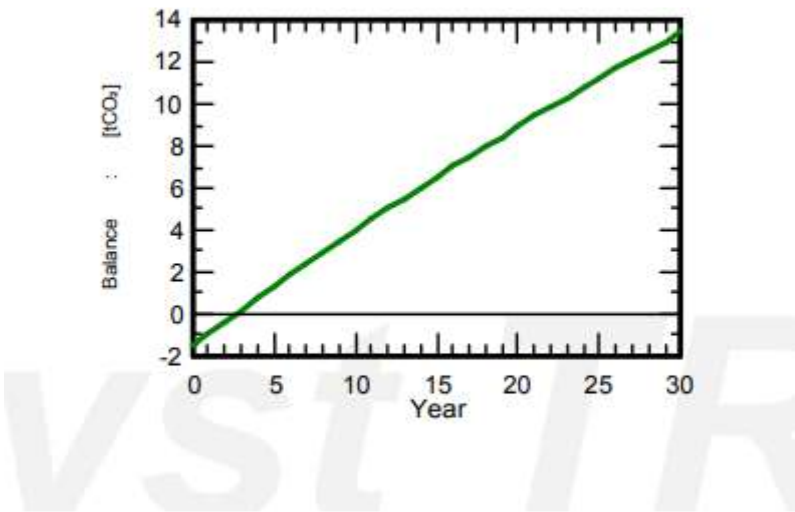


Figure IV-11*: saved CO2 emissions during time while using PV system*

If all homes except for rented or low-income homes install solar, then at least 60% of all homes will still have solar systems; there will be a significant reduction in carbon emissions when compared to baseline emissions. [32]

Finally, the simulation of the whole system: PV generator and single phase inverter, including the inverter modelling, offers a good choice to predict the energy production of the whole plant connected to the utility grid. The dynamic behaviour of the photovoltaic generator can be also be evaluated in real conditions of work using this method.

IV. 9. Conclusions

The main results concerning the optimal sizing of a grid-connected PV system are: - the parameter that most affects the relative size of the inverter and the PV array is the efficiency curve of the chosen inverter

PV system is designed and implemented in this work for grid connected environment using PVsyst software. The backup storage can remarkably improve system stability during rapidly changing process of insulation, and help to make the system more efficient.

The measured annual performance indicates the vast solar potential in site that is suitable for solar power generation. The results show that the maximum solar irradiation was achieved at a tilt angle of 30° with an environmental and an economic income, reducing the CO_2 gas emission with 13.5 T in 30 years for one household.

General Conclusion

General Conclusion

The growing concern for climate change has participated in the growing number of grid-connected PV systems.

After the experience of dozens of years of application internationally, grid-connected photovoltaic systems and their components today have higher efficiencies, are relatively reliable but still are quite costly. Most technical and non-technical barriers could be overcome in Algeria during recent decades. Private house owners as well as small and large enterprises are free to transfer sunlight to electricity, which either can be consumed by the plant owners or can be sold to the public grid. Even though there is an immense energetic potential for PV systems and also high personal commitment of many Algerian citizens to solar energy, the cost factor will be crucial for the large-scale application of grid-connected PV.

This paper has evaluated the technical impact of PV systems on peak load consumption in Algeria. Results showed that the PV system would reduce the energy and peak demand load. Although other factors, as economic feasibility, are not considered, a 630 Wp fixed PV system could reduce the peak demand by about 20% (1205 MW) with PV output never exceeding the load. Also, this system can reduce the average yearly peak load by approximately 967 KWh for each 360 Wp PV system. In addition, a PV system has been observed to minimize the total annual energy consumption by about. It appears that a grid connected PV system is a promising technique to enhance the performance of the traditional grid utility system by reducing the total and peak electrical load demands for Algeria. It is important to continue this study by evaluating the economic impact of PV grid connected systems. Such information will assist the government in evaluating the potential of grid connected PV systems in the Algerian climate.

Moreover, the integration of renewable energy sources in buildings provides positive impact on both the environment and excess energy demands. In addition to the advantages of this system, it has neither electrochemical storage nor preventive maintenance. As a result, the cost of the electricity production can be greatly reduced.

The residential sector has a lot of factors that influence its consumption, such as the kind of appliances and the efficiency of the appliances to be used, if we manage to reduce some of all the factors, great results will be remarkable.

During studying this subject, we noticed an insufficient data about this kind of subjects in Algeria, so the residential sector needs more attention from the researchers. As long as the data and statistics are rarely available about the consumption in the residential sector in Algeria, this study hopefully will give a closer look about this sector.

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