Haute Ecole

« ICHEC – ECAM – ISFSC »

Enseignement supérieur de type long de niveau universitaire

Could the storage and improvement of transportability of electricity produced by small renewable energy production units mitigate energy peaks?

An application of V2G technology on electricity networks.

Mémoire présenté par :

Adrien Everard de Harzir

Pour l'obtention du diplôme de :

Master's degree in International Business Management

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Promoteur :

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Summary of the Thesis

In recent years, energy prices have fluctuated significantly. These fluctuations are mainly due to the ever-increasing tension between demand growth and the green energy production capacity desired by governments. Due to this, many consumers, whether they are businesses (B2B) or individuals (B2C), are looking for ways to reduce their energy budget/costs.

One of the main solutions nowadays is photovoltaic electricity production. The main problem encountered with this solution is intermittency, it is equivalent to those encountered with most renewable energies such as wind power for example. This is mainly because the production is not stable and depends on factors beyond human control, sunshine, and wind. Moreover, the moments of production peaks with these solutions are not necessarily synchronised with the electricity consumption peaks. To remedy this, much research is made to maximise the self-consumption of the energies produced in these ways and not lose this precious resource.

Today, many storage technologies exist to optimise the use of the electricity produced. These storage solutions can be subdivided into several categories:
Mechanical storage: this includes Hydraulic storage, kinetic energy storage, and compression storage.
Electromechanical storage: storage methods falling under this category are storage using hydrogen, electromechanical production, and circulating batteries.
Electromagnetic storage: using a magnetic field produced by the supplied electricity.
Finally, thermal storage is restoring electricity thanks to the heat produced by the surplus of electricity.

Some of those technologies require a lot of space to implement and are too expensive for small businesses or individual households. To this end, the thesis will mainly be focusing on two promising technologies. Those are the production of hydrogen and batteries. Regarding batteries, this thesis will be analysing an innovative technology making use of a resource that has been increasingly present in the last few years, electric vehicles. Those vehicles are using electric batteries to store the electricity required to move the vehicle. Those vehicles' batteries are often more than five times bigger than home batteries already on the market. Moreover, those batteries are not used to full capacity most of the time. Last but not least, the fact that Electric cars are potentially connected to the grid up to 95% of the time (due to their periods of non-use) allows a lot of possibilities. The idea would be to use the vehicle as a storage solution more than only a mobility solution. Some brands are already proposing this technology on a few of their models. The name of this technology is V2G (Vehicle to Grid).

Regarding Hydrogen, the surplus of electricity production could be used to produce it which would then be green hydrogen. This product could be used for cars or in the different industries requiring it.

This thesis will analyse how those innovative solutions could be a solution to prevent energy losses and increase auto-consumption. To achieve this, we will analyse the various aspects of the solutions (technology (maturity), costs, etc.).

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Finally, I would like to thank my parents and friends for the support they have given me during the last months and my five years of study at ICHEC.

I, the undersigned, Everard de Harzir, Adrien, 2022-2023, hereby declare that the attached work is free of any plagiarism and complies in all respects with the study regulations on borrowing, citing and exploiting various sources signed when I registered at ICHEC, as well as the instructions concerning referencing in the text complying with the APA standard, the bibliography complying with the APA standard, etc.". made available to me on Moodle. By my signature, I certify on my honour that I have read the aforementioned documents and that the work presented is original and free of any borrowing from a third party not properly cited".

Date and Signature.

22 May 2023

Adrien Everard de Harzir

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Introduction

Today's world is changing quickly. The last few hundred years have seen humanity change radically. The world has become highly industrialised, and we have completely changed our way of living. Moreover, we have gathered in the same places (cities), leaving the countryside behind. Energy is one of the main resources which made it possible to change the world in this way. Energy is what gives us humans the capability to go further and faster than ever, to transport/produce huge quantities, to communicate, etc.
To further develop our world and way of living we have a constant need for energy.
This constant need generates two issues:

- Production peaks where there is not enough consumption compared to what is produced which causes a loss of the energy produced. Those peaks have become even more important in the last few years with the massive investments in renewable energy production systems. Those electricity production methods are mostly non-predictable which makes it difficult to adapt their production depending on the actual demand.

- Consumption peaks are moments when consumption suddenly increases. Often the consumption peaks occur at fixed times of the day, such as when people return home. However, they can also occur exceptionally, such as during periods of extreme cold or, on the other hand, during heat waves. In contrast to production peaks, it is easier to manage consumption peaks thanks to controllable electrical production units that can be triggered quickly when needed to avoid shortages. Those predictable production units are using Gas, Coal or even Nuclear as combustion resources but these aren't taken into consideration because of their sustainability issue.

To be able to deal more easily with these peaks and more especially with the production peaks, by not losing the energy produced, lots of research have been done over the past few years.
The researchers' preferred method would be the implementation of electricity storage units. Nowadays different methods are existing such as mechanical storage with for example hydraulic storage; hydroelectric storage units which include among other batteries; electromechanical storage solutions and finally thermal storage.
This thesis will demonstrate that some of those solutions are not adapted to all uses and in particular to the use by individuals. The main characteristics that make this implementation on a smaller scale more complicated are the initial investment and the

size. In addition, some solutions are not storage solutions as such, but rather power regulation solutions.

One of the most promising technologies is the V2G technology. This technology allows the use of electric vehicles as storage units that are also mobile. As will be developed later, this technology allows a bi-directional charge.
The vehicle is always rechargeable, but the charge can also take place in the other direction by transmitting the energy from the vehicle to the grid as the name of the technology "Vehicle to Grid" (V2G) indicates.

To this end, this master thesis will focus on the use of already available electric vehicles as energy storage units to possibly reduce the investment costs at first.
Moreover, could this increase in renewable energy storage and transportability help mitigate the energy peaks?

Chapter 1: Rises in Electricity Prices Causes

Since late 2020, energy prices began to rise to historic peaks. The recent increases in energy prices have several causes such as the economic recovery around the world, and the past decisions to reduce nuclear capacity. Finally, of course, the decrease in natural gas supplies from Russia, which fell by more than 60% following the beginning of the conflict with Ukraine in 2021, impacted a large part of Europe.

Since the beginning of the conflict, oil deliveries have also been disrupted, which has caused increased stress on the energy market. Aside from the geopolitical impact of the war in Ukraine, the post-covid recovery of the Chinese economy has also had a strong impact on the demand for energy worldwide.

In addition to these production changes, an energy transition has been underway to turn to greener energies. This requires, for example, massive electrification of the European car fleet, but also energy suppliers who turn their backs on certain sources of electrical energy such as coal, and gas. Next to those production methods suppliers are also trying to turn their backs on nuclear power plants while those are producing nuclear waste which is harmful to the environment. All this results in a sharp increase in demand while supply does not increase proportionately. As a result, suppliers are forced to switch to other countries to be able to supply their customers with electricity. This results in an increase in energy prices, which in parallel, follows the price curves of other energies such as gas and oil. (Luminus, 2023)

When analysing the electricity price curve in recent months (Figure 1) it can be seen that initially as mentioned above it follows the same evolution as the rates of gas (Figure 2). In general, the curve has risen sharply following the increase in demand related to the post-covid economic recovery that occurred in mid-2021. It has also strongly increased following the conflict between Russia and Ukraine and the incident on North Stream 2. (CONNAISSANCE DES ENRGIES, 2022)

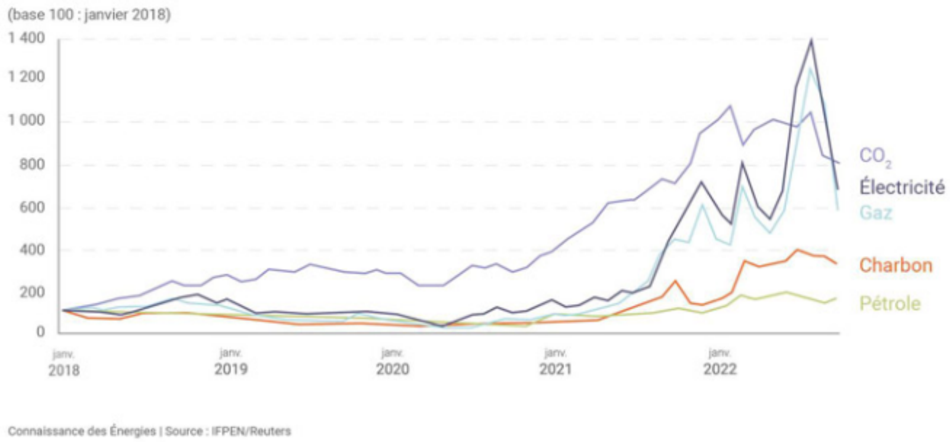

Figure 1: Comparative graph (evolution of prices with base 100 in January 2018) (CONNAISSANCE DES ÉNERGIES, 2022)

In France, small ERM plants should replace old-fashioned nuclear power plants. This policy started in 2022 with the temporary closure of 4 power plants affected by corrosion problems. Next to those temporary closures, France is planning to definitely shut down 14 nuclear power plants by 2035.
Moreover, droughts during recent years have also not been kind to thermal facilities. To cool down they are using water from nearby watercourses whose low levels impacted the cooling circuits. This slows down the restart of power plants but also causes the definitive closure of some of the French plants.

In Belgium, the subject of nuclear power has been on the table of politics for several years to decide what action will be taken with this source of electricity supply. Some parties such as the ecologists advocate a total shutdown for 2025 as provided by government agreements. Other parties would like to continue the production of at least 2 reactors after 2025 to keep a margin of safety.

In March 2022, after long negotiations, this option was chosen by the government. The activities of the Doel 4 and Tihange 3 reactors were extended for a period of 10 years. The discussions about the conservation or not of nuclear power also influence electricity prices in addition to some doubts about the state of nuclear power plants in Belgium. Belgium still relies heavily on nuclear energy with nearly 50% of electricity production coming from this source (Figure 3), so it is essential to find new sources of production and set them up before completely abolishing this source of production. (FEBEG, 2022)

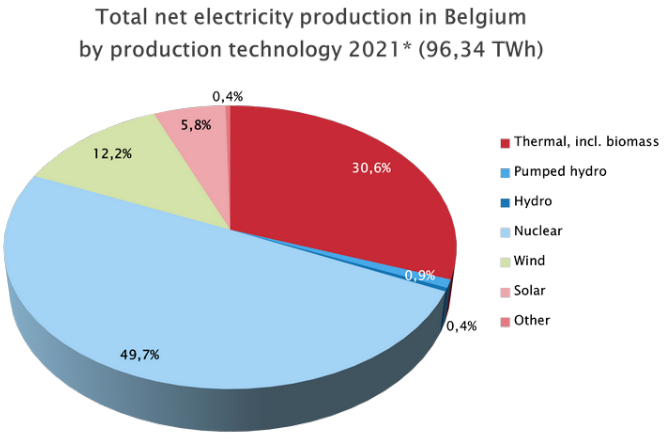

Figure 2: Total Net Electricity Production in Belgium by Production Technology 2021* (96,34 TWh) (FEBEG, 2022)

Germany on the other hand is still highly dependent on fossil fuel power plants such as gas and coal with a total of 36% of electricity production coming from fossil sources. However, the share of renewable energy in their energy mix is increasing (50% in 2020)

making Germany one of the leading actors of renewable energy production. (Berger, 2021)
Moreover, coal-fired power plants are also pending on supply and cooling by neighboured rivers, but the recurrent droughts of recent years have caused a decrease in the levels of the waterways in Germany making the supply of the plants more complicated than in the past.
(Aussems, 2022)

This is only a small overview of the current electricity supply situation in Western Europe and mainly in Belgium, but it is already clear that there is a problem regarding the supply level that is not sufficient to meet the demand which leads to energy price increases.

i. Carbon Dioxide

In some countries in Europe, there has been a carbon tax which has been introduced in 2014. The implementation of this tax is pushed forward by the EU to motivate the governments of the different member states to implement it in their countries. This tax influences the price per ton of CO2. The principle is that companies emitting CO2 into the atmosphere must pay a certain amount per ton of CO2 emitted. When it was launched in France in 2014 the price was 7 € / ton, nowadays it amounts to 44,60 € / ton. In Belgium, this tax is only applied on a smaller scale and only to large companies. The tax aims to reduce the environmental impact of companies while avoiding harming economic growth. The tax has a strong impact on energy prices in Belgium while most of the electricity suppliers are part of the scope of this tax. (Brand, 2022)

In addition to the CO2 tax, at the European level, it was decided to implement the objective of carbon neutrality for 2050 as part of the European green deal. To achieve this, a greenhouse gas emission allowance trading scheme was implemented.
On an annual basis, companies receive an emission quota. Of course, the market is so diverse, that some companies won't need all their emission quotas and others will need more than what has been allocated. To benefit from more quotas a market system exists between the different companies and according to the law of supply and demand the prices of the quotas are fixed. Companies that do not need all their annual emission allowances can resell the unused quotas on this market, but it is also possible for those companies to keep them for the future.
In addition, it is important to mention that each year the number of the so-named "allowances to pollute" are decreasing, which will result in a constant increase in the prices.

Chapter 2: Search for Energy Autonomy

First, let us develop what energy autonomy means. This concept has come into the spotlight for some years now. This concept can apply to communities, entire buildings or even households. The main goal to achieve energy autonomy is to reduce the impact on climate change by reducing greenhouse gas emissions but mostly it is a way to strongly reduce its dependence on fossil fuels and energy provided by the grid.
More commonly energy autonomy would be defined to generate and use energy commonly provided by a renewable energy source without needing to rely on an external energy-providing source. (Boutaud, 2022)

A crucial factor when consumers are looking for energy autonomy is the financial part of it. Indeed, by producing and consuming their energy, households can make big financial savings on their electricity bills by using the energy produced by their solar panels or wind turbines. During the periods when they are not producing as much as their consumption, they can use the surplus of energy which was stored during the production peak hours. (Boutaud, 2022)
This capability is linked to the ownership of a battery. Owning such a battery means that there must be an investment this investment is sometimes difficult to evaluate with regard to the savings.

Next, it is important to mention the impact of energy autonomy on grid intermittency. Autonomy will provide a backup source for the consumers and more broadly reduce the demand on the grid during peak consumption periods.
By having the ability to produce and store its energy autonomously the consumer will lower his risk of being impacted in case of grid disruption. The consumer storing his energy which he will use later, will also smooth out fluctuations in energy demand and offer and minimise the risks of service interruptions. (Boutaud, 2022)

While grid intermittency could not seem an issue in industrialised countries like ours it could become an issue in the future. When looking at the energy mixes (Cf. Supra, p.4) we can notice that renewable energy sources are increasing and taking up a big part of the energy mix. This is for example the case with solar and wind energy production. The significant difference between those energy sources and more conventional production methods like gas, coal, etc., is the fact that those energy methods are relying on external factors on which no one can have an impact. Solar energy is relying on the hours of light during the day and the brightness of it. Wind energy is depending on the speed/power of the wind and its direction. This makes the production of electricity using those production methods less controllable. (Boutaud, 2022)

In less developed countries energy autonomy could help improve energy access of local populations. By providing the opportunity to areas located off-grid to benefit from access to energy. This would improve the life quality of local populations and give more possibilities for economic development.

Finally, we could mention a final point which is increasing the personal satisfaction of consumers. This point is strongly linked to the points previously mentioned. But if the consumer is producing and consuming the energy he has harvested and stored independently of the energy providers it will increase his general satisfaction and the positive talks he will do about his installation to his surroundings. (Boutaud, 2022)

If we look at what we have seen during our courses at ICHEC we could compare this satisfaction of producing his energy on his own to the top level of the pyramid of Maslow which is self-actualisation. However, if we look at production due to the fact of being located in a less industrialised country where the grid is not as reliable as in our countries. In this case, the level is the security level of the pyramid of Maslow regarding energy security and autonomy. (Verbeek, 2021)

Chapter 3: Energy Storage

The present current context brings a real demand for energy storage on a larger scale. Indeed, the growing share of autonomous energy production by individuals and companies leads to a growing search for storage techniques for the energy produced. (ADEME, 2022)

Many energies such as fossil fuels, gas and uranium are stored without too many difficulties. On the other hand, the large-scale storage of electricity is a more complicated task due to the energy density of electricity (corresponds to the number of kWh per kg/litre). This density with the storage technologies available on the market is currently still low compared to other energies such as oil.
We will therefore analyse the different modes of energy storage existing for electricity. (ADEME, 2022)

i. Mechanical Storage

Nowadays, mechanical storage consists of three main solutions; storage using potential energy which corresponds to hydraulic storage. Kinetic energy storage, which is more of an energy regulation solution as we will develop hereunder. And finally, compression storage. (Larcher, Morcrette & Simon, 2023)

Hydraulic Storage

This form of storage uses pumping stations and gravity. An upstream water reservoir is created to create a pond. This pond is connected by a system of pipes to a second pond located on a lower level. The two water reservoirs can be both natural (rivers, sea) and artificial (lakes or dams). Globally, this storage technology is by far the most used with 96% of the world's storage capacity using this technology. (Larcher, Morcrette & Simon, 2023)

In off-peak hours when energy is abundant, the pumping system transfers water from the lower pond to the upper pond, then in peak hours when there is high demand the pumping station operates like a conventional hydroelectric station using gravity and a turbine to produce electricity when water from the upper basin is transferred to the lower basin.
The big advantages of the pumping station are that it can be mobilised in a few minutes in case of production needs but also it is flexible depending on the needs. In addition, the storage units generally have a long lifetime (generally more than 40 years) some storage units are more than a century old and are still in a satisfactory state despite their undersized capacity compared to current needs. This makes it the cheapest storage option to date in euros per kWh (CRE, 2022).

However, the development of this type of facility is constrained by geographical and ecological constraints.
Geographical because it is not possible to install them in all places given the requirements for a sufficient difference in altitude to operate the turbine.
Regarding the ecological parts, it is especially the case when it comes to artificial retention basins. Those are mainly related to the aquatic biodiversity which is impacted or the fact that areas that were not flooded in the past are submerged, which may require the displacement of populations and impact the local biodiversity. Finally, the size of those installations must be substantial due to the low energy density of this storage method. (Rabattet & Brusa-Pasqué, 2019)

Kinetic Energy Storage

This storage technology was originally used to standardise the energy produced by steam engines and release a constant flow of energy. Nowadays this technology makes it possible to temporarily store electrical energy based on mechanical rotations. Compared to hydraulic storage, this technology is significantly less used with only 1% of the world's storage capacity using this technology. (Larcher, Morcrette & Simon, 2023)

The operation is based on a flywheel consisting of a carbon fibre mass which is driven by an electric motor in a vacuum cylinder to minimise energy losses due to friction.
During electricity supply, the flywheel picks up speed to reach a speed between 8000 and 16000 rpm. During restitution needs, a motor is used as an electric generator which, by causing the steering wheel to drop in rotational speed, will make it possible to transform movement energy into electricity. (Larcher, Morcrette & Simon, 2023)

This technology makes it possible to deliver high power in a fast-operating time while having a long service life.
However, this technology is not optimal, which results in its low use in electrical storage systems. First, the mass-energy density is 8 Wh per kg, which is limited compared to most other technologies. Secondly, there is a strong self-discharge due to friction which is inevitable despite the vacuum environment, this makes it an effective storage solution only for a short storage time. Finally, inertial storage can only store a limited amount compared to other technologies such as hydraulic storage as mentioned above. In general, we can say that this storage system is more suitable for energy regulation applications to improve quality by avoiding short interruptions than for storage. (CRE, 2022)

Compressed Air Energy Storage

This method is compressing air in a big container, natural caves or even old salt mines thanks to electricity powering the compressors. When required the compressed air is released to produce energy. When it is released, it is heated after which it goes through a turbine and powers it.

The main advantage of this technology is storing a large amount of energy over a long period. However, it has some downsides like the fact suitable locations with underground storage cavities are not available everywhere. This type of infrastructure has high installation costs and maintenance costs. Finally, its efficiency is low compared to other methods due to the heat losses during the storage process and the heat required during electricity production. (CRE, 2022)

ii. Electrochemical storage

Nowadays three main types of electrochemical storage are used for stationary energy storage. Those are hydrogen production, electrochemical batteries, and flow batteries.

Storage using Hydrogen.

Hydrogen (H_2) is not an energy as a whole, but more an energy vector, because it is produced as a result of a chemical reaction using a primary resource. Currently, 95% of hydrogen production is produced by manufacturing processes using fossil fuels, mainly gas. (Gençer, 2021)

Hydrogen is called an e-fuel; however, it is important to mention that even if hydrogen is the main one other are existing and are being studied at the moment.

To produce hydrogen three methods, exist:

- Reforming natural gas with heated water steam. This is the most widely used method currently.
- Gasification is a method of producing hydrogen by burning charcoal.
- Finally, the last method is the electrolysis of water. In our case, it is the method in which we are interested while it is using electricity.

To produce hydrogen by electrification of water, an electric current will break down the water molecule (H_2O) into two components, dioxygen (O_2) and hydrogen (H_2). Production by electrification produces significantly purer hydrogen than the other two methods mentioned above (Cf. Supra). However, this method of hydrogen production is the most expensive one with a cost of 1.5 € / kg of H_2 which is 2 to 3 times more expensive than reforming natural gas. (Planete energies, 2014)

Following the production method used, hydrogen is categorised into 4 segments:

- Green hydrogen: which is produced by electrolysing water with green electricity which is coming from green energies.
- Grey hydrogen: is produced with thermochemical methods using energy from fossil sources.

- Blue hydrogen is equivalent to grey hydrogen with the only difference being that the CO2 emitted during manufacturing is captured unlike the CO2 of grey hydrogen released into the atmosphere.
- Finally, yellow hydrogen is also produced using electrolysis, but the electricity used comes from nuclear energy.

(IFP energies nouvelles, 2023)

Once produced hydrogen can be stored in small quantities in a pressurised environment which makes its storage dense. Another method that allows hydrogen to be stored in greater quantities is the use of salt cavities that can be natural or former salt mines. This method can store up to 500.000 cubic meters with pressure reaching 2,900 psi. This corresponds to 100 GWh of storage. This allows massive storage over long periods to be able to deal with variations in energy production.
To transform hydrogen back into energy, it is necessary to go through a re-electrification process, which is efficient at a rate of 50% or to use hydrogen in gas plants by combining it with regular gas which increases efficiency to 60%. (ESA, 2021)

Apart from re-electrification, other uses of the hydrogen produced are existing such as its use for combustion engines, by combining it with natural gas, or using it in the petrochemical and chemical industries which is one of the main industries using hydrogen.

Electrochemical Batteries

Apart from applications for static storage, electrochemical batteries are also heavily used for mobile storage uses such as our mobile phones, computers, electric cars, etc.

Electrochemical batteries consist of discs stacked on top of each other. The discs are composed of different chemical elements which makes the production of several types of batteries possible, each type with a capacity (Wh/kg) and a lifetime counted in charging cycles that are variable depending on the material used. The most frequently used battery component is lithium, followed by those using nickel, and sodium chloride batteries. Finally, lead-acid batteries are used in a slight proportion compared to the other ones due to their low storage capacities. However, lead-acid batteries are still used in the thermal automobile sector to start cars, the main advantage of this type of battery is that it’s a cost-effective product. On the other hand, lithium batteries are the most used.
The stacks of the different discs are connected to an electronic system transforming direct current into alternating current at a desired frequency and power.
To recharge the batteries, the system is reversed and transforms alternating current into direct current. (CRE, 2022)

Batteries have two main advantages:
The flexibility of dimensioning according to the needs and the responsiveness of the batteries which when required can release the energy instantaneously.
On the other hand, the battery is not yet suitable for mass storage due to the not optimal Wh/kg ratio (the more a battery can store energy, the heavier it is) which makes the storage of quantities comparable to the one stored with hydraulic storage expensive and nearly impossible. (CRE, 2022)

Circulating Fluids Batteries

The last method of electrochemical storage is circulating batteries. This method is still under development and experimental projects are currently underway.
The system is composed of two electrolyte liquids that contain a certain level of metal ions. Between the two liquids, a membrane allows the exchange of protons. This exchange makes it possible to produce or receive the electrical charge.
The power that the battery can process is variable and depends on the size of the membrane, the energy stored is a variable depending on the volume of electrolyte contained in the battery. (CRE, 2022)

iii. Electromagnetic Storage

This form of storage is based on the creation of a magnetic field contained in a coil produced thanks to the energy supplied.
The storage time with this solution is extremely short which does not make it suitable for massive storage applications and storage over a longer period. As a result, the implementation of this technology is done on a small scale, it is also mainly used in some electrical installations to improve current flows. (CEA, 2022)

iv. Thermal Storage

This storage method accounts for 2% of the world's total storage capacity. To date, this storage method is mainly used in concentrated solar thermal power plants. This form of storage allows power plants to continue to provide energy even during periods without sunlight.
Large-scale storage systems mainly use the temperature variation of materials, for example by melting salt. During periods without sunlight, the accumulated heat is returned and transformed into electricity.
On smaller-scale installations such as heating water balloons, for example, the energy is used to heat water or solid materials such as ceramics or concrete.
In general, this form of storage has two big advantages compared with others. First, its operating cost is low compared to the other solutions even if the auxiliary costs such as maintenance are important. The second advantage is the possibility of benefiting from large-scale installations with a storage time of a few months.

Regarding the weak points of this technology, it is important to mention the thermal losses that are unavoidable over longer periods and the limited restitution power compared to the other technologies mentioned above. (Larcher, Morcrette & Simon, 2023)

v. Comparison of the Different Storage Methods

Following the analysis of the hereabove mentioned different storage technologies above it is obvious that not all are suitable for electrical storage when aiming for electric autonomy.

Figure 4 gives us a good overview of the power and storage times of the different technologies.

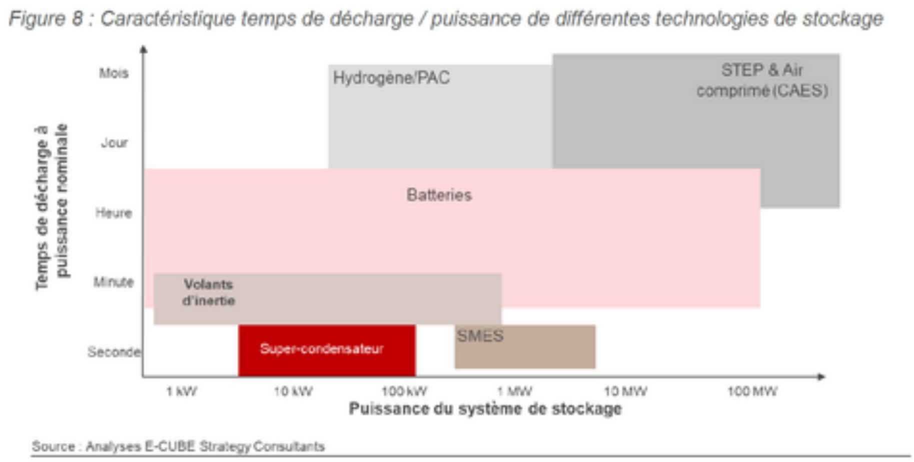

Figure 3: Discharging Time / Power Characteristics of Different Storage Technologies (CRE, 2022)

By analysing this figure, we can already eliminate three technologies:

- Supercapacitors (= electromechanical storage)
- Kinetic energy storage
- Electromagnetic storage

Indeed, we can see that the power of those storage systems is low compared to other solutions but more importantly the discharge time and therefore the storage time is counted in a maximum of a few minutes which is largely insufficient for the storage applications we are looking for.

In general, as mentioned above, the three technologies are more energy power regulation technologies than long-term storage solutions. They make it possible to continuously optimise the power of the network while being able to cope with micro-cuts. (CRE, 2022)

Chapter 4: The Energy Market.

i. The Different Actors on the Electricity Market

The electricity market as we can see in the figure here below is subdivided into four big categories.
It all starts with production followed by transport, distribution, and finally the suppliers. To oversee all activities of the actors mentioned above, regulators are overseeing the activities of the different actors mentioned above. Below we will analyse each category in detail.

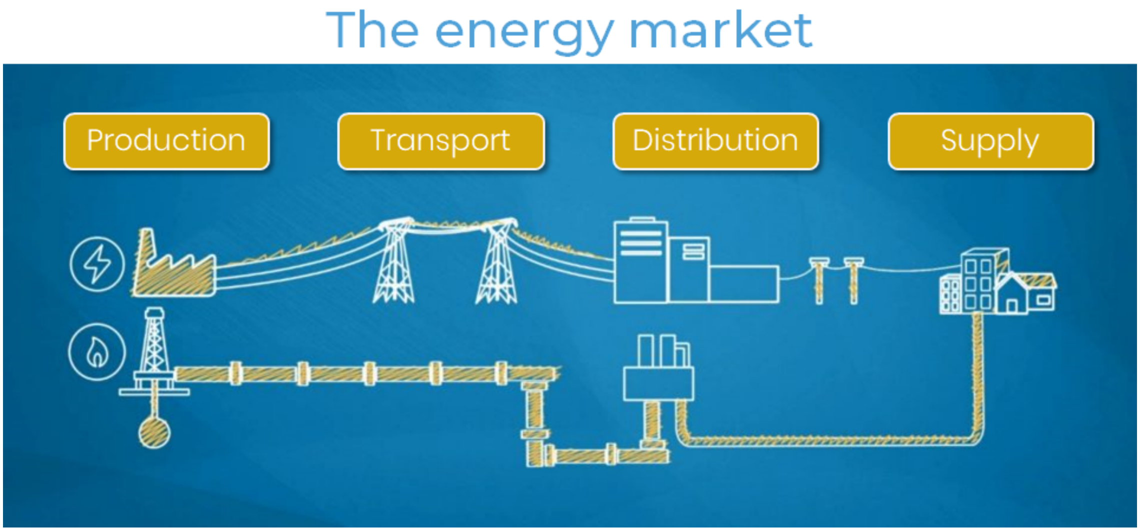

Figure 4: The Energy Market (Nguyen, 2022)

1. Electricity Producers:

The electricity producer is the industry producing the electricity which afterwards is consumed by various consumers.
electricity producers are divided into two categories: green producers and others. Green electricity (produced by green producers) is energy originating from a renewable source. Nowadays several sources are existing.
Wind energy, which is produced by wind, is itself produced as a result of changes in atmospheric pressure varying across the globe which creates air movements. The wind turbine is built with a mast, a propeller, a nacelle containing the alternator that is producing electricity, and electrical wiring used for transporting energy after production. Wind turbines are installed in areas with a high wind coefficient, those can be located both on land and offshore. (EDF, n.d.)

A second type of green electricity production which is much talked about nowadays is solar energy. This energy allows the production of electricity using solar panels installations or thermal power plants.

Just like the wind, one of the great advantages of solar energy is that it is inexhaustible. A solar installation consists of three elements: solar panels, an inverter, and an electricity meter. (EDF, n.d.)
We will come back to solar energy in more detail later.

In addition to the two sources mentioned above, others are existing.
Producing electricity using a hydraulic source such as the tides or hydroelectric installation which is widely used in Canada. But also, energy production by using the heat of the earth, biomass which is producing energy by using the energy released by the combustion of organic materials. (Total Energies, 2022)

The second category of energy includes other ways of generating electricity like nuclear power stations, gas turbines, and coal-fired power stations. (Total Energies, 2022)
If we analyse the distribution of the energy mix in Belgium (Figure 3) we can see that most of the electricity is produced by a nuclear source with 49.7% of production originating from this production source. Thermal sources are following with 30.6% of the total production. This production method is grouping gas turbines and biomass and wastes power plants but, it does not include coal-fired power plants due to the shutdown of all coal-fired power plants in the country.
The following sources are taking a small share of the production in Belgium with 12.2% originating from wind turbines, the majority of which is produced offshore. Solar energy takes a smaller share with only 5.8% of the energy produced in this way. The remaining 0.4% originates from other energy sources. (FEBEG, 2022)

The leading energy producer in Belgium is Engie Electrabel with a fleet presenting a production capacity of 9077 MW including 523 MW of renewable energy. EDF Luminus is located in second place with an installed capacity of 1998 MW. Eneco is located in third place and has the merit of providing 100% green production. Their production facilities in Belgium give them the possibility to produce 50% of the total amount they are selling in Belgium, the rest is imported from abroad. Finally, in fourth place, Lampiris which in 2016 was bought by the Total Energies group. However, Total Energies is mainly a supplier in Belgium since they produce practically no energy themselves. (Killmybill, 2023)
The production landscape in Belgium will drastically evolve during the coming years with the arrival of new capacities from the North Sea wind farms, some new and existing players will produce significant quantities of energy from these new production units.

2. Transport & Distribution (DNO)

Transport in Belgium is divided into two categories: first, the carrier handing over the energy to the distribution network operator (DNO). If we compare this to the road network, the transporter is the one in charge of the motorways while the DNOs

(Distribution Network Operators) oversee taking care of the small roads following the motorway.

More broadly, the carrier oversees high-voltage lines as well as the transport to and from abroad. DNOs take care of the energy provided to homes and businesses.

For the electricity grid, the transporter in Belgium is Elia.

As mentioned above, this company is responsible for transporting electricity from power plants and abroad to the distribution networks and supplying customers with high voltage needs.

At the same time, they are responsible for checking the proper functioning of their network and ensuring the proper balancing of the network to avoid electricity being lost or too much of it on the grid. (Total Energies, 2022)

Regarding network operators, they are divided by region: in Flanders Fluvius, in Brussels Sibelga and finally in Wallonia which is the most complex region with ORES, Resa, REW, AIEG, and AIESH. Their functions are to distribute energy from the high-voltage lines to the meters, to maintain the network and to develop it, and to hold a database of the energy meters installed at their client's location. Finally, they also play the supplier's role in a situation where a customer does not pay his supplier. In this case, the network operator is the one supplying the customer. (Total Energies, 2022)

3. Suppliers

In Belgium there are currently about fifteen suppliers, this number is mainly due to the opening of the market. The supplier is also the name that we see printed on the electricity bill at the end of the month since it is the company that sells electricity to consumers. The best-known suppliers on the market are Engie and Luminus, other suppliers with a smaller market share are also present such as Total Energies (Previously Lampiris), Eneco, etc.

In addition to electricity, suppliers also often offer gas supply.

It is important to mention that due to the political situation in Belgium suppliers are not necessarily present in all regions.

To conclude, the roles of the suppliers are:

- Buying electricity from producers.
- Provide the purchased electricity to the customer and provide services related to this product.
- Intermediary with the network manager.
- Helping to maintain the grid balance by estimating the energy needed and transmitting this information to the network operator.
- Paying their charges to the state (taxes), transporter, and DNOs (costs related to transport and distribution).

It is important to mention that not all suppliers have production units in Belgium. Some of them are buying energy produced by other companies to create their electricity mix and selling it under their name. In Belgium, the producers-suppliers are Engie Electrabel and Luminus. (Energy Comparator, 2022)

4. The Regulators

The regulators correspond to the police officers on the market. Their task is to make sure that everything runs smoothly. There is one regulator for each region (CWAPE in Wallonia, Brugel in Brussels, and VREG in Flanders) and finally, there is also one regulator at the federal level (CREG).

Several tasks are part of their responsibility:

- Ensuring that rules and standards are respected.
- Act as an advisor to various governments and public institutions.
- Have the role of mediator in case of conflicts.
- Inform the public about their rights and duties.
- Finally, their last function is to monitor the proper application of laws and decrees.

(Total Energies, 2022)

5. The Consumers

Apart from the 4 categories of actors mentioned above, a fifth one is important. Those actors are the different consumers, whether households or companies, they are important players because consumption is made by them.

Consumers have a contract with a supplier who in exchange supplies them with electricity, without a contract the consumer takes the risk of being cut off. The consumer is protected by a set of rules such as, for example, the prohibition of being cut off during winter periods.

In recent years, the consumer has also taken on a role other than only a consumer, because he is also able to produce energy by himself. This can be done among other things through a photovoltaic installation at home.

This production will impact the network due to the fact the exchange of energy is no longer only from the supplier to the consumer but also from the consumer to the supplier. In this situation, the consumer becomes a prosumer.

A prosumer is a combination between consumer and producer which is the case of the client in this situation. The producer is producing a little energy which is most commonly renewable energy. This energy is mostly consumed by himself, but the surplus can be reinjected on the grid in exchange for financial compensation on his invoice. Linked to this prosumer role the supplier is asking a prosumer tax to be able to reinject power on the grid.

This point will be further developed later in this thesis.

(Total Energies, 2022)

The consumers can be divided into two main categories: individuals and professionals. Professionals can also be divided into three subgroups: SMEs, B2B and large B2B.

- SMEs have commonly a limited electricity consumption of less than 50.000 kWh/year.
- B2B consumers who have a consumption between 50.000 and 150.000 kWh/year.
- Large B2Bs are administrations or large companies with a consumption greater than 150.000 kWh/year.
- Unlike individuals, professional customers are obliged to remain bound to their supplier until the end date of their contract, failing which they will have to pay termination fees to the supplier.

(Total Energies, 2022)

ii. Liberalisation of the Energy Market

In Belgium, the energy market has been liberalised since 2007. This means that the individual consumer can take advantage of the free competition between the supplier and choose his supplier according to his personal requirements and price differences. The change of supplier is a simple procedure which costs nothing if the notice periods are respected. The change does not require any modification since the installation is already existing and does not belong to the supplier but to the distribution network operator who remains the same even following a supplier change. Once the registration with the supplier, he will be responsible for requesting the network manager who will inform the previous supplier of the termination of the contract. (Monenergie, n.d.)

In the past, a customer was linked to one producer, one transporter, one distributor, and one supplier. As a result, he had no choice or freedom regarding his supplier.

Chapter 5: Vehicle-to-Grid Technology

The Vehicle-to-Grid (V2G) technology allows communication from the vehicle to the electrical grid. This technology offers the possibility to charge and discharge the battery of an electric or even hybrid vehicle as needed.

V2G is part of a larger term, V2X, which is the abbreviation for vehicle to everything, which allows communication from the vehicle to be sent to any other source. Besides V2G, V2X also includes other technologies such as vehicle-to-home (V2H) and vehicle-to-building (V2B) but, in this thesis, we will focus on V2G. (Izi, 2022)

The Vehicle to Grid technology can be compared with smart charging (V1G), which allows the real-time optimisation of the amount of energy to be sent to load the vehicle's battery. The difference with V2G is the possibility to send energy in the other direction, if necessary, as well, for example in the case of a sudden increase in demand on the network. (Shariff et al., 2019)

i. Utility of the V2G Technology Nowadays

If we look at the use of a car nowadays and thus electric vehicles, we can see that according to studies a vehicle spends 95% of its time parked and thus is not used. It is therefore possible to take advantage of these periods of non-use. (Mathieu, 2018)

If we look at the current energy production network, we can quickly realise that the production of renewable energies is starting to take up more space in the energy mix to fight against climate change.
The use of renewable energies such as wind and solar energy presents one major challenge. Unlike fossil fuels, it is impossible to store them until they are transformed into electricity. Wind and solar energy can only be stored once they have been transformed, and in most cases, the electricity is consumed directly once it has been produced.
Moreover, the energy demand is not stable throughout the day and presents peaks and troughs throughout the day. It is therefore important to consider how to respond to peak consumption periods when no energy is produced with those renewable energy sources. For example, when there is a peak of energy demand in the middle of the night it corresponds to a period when the photovoltaic energy production is at its lowest.
The increase in renewable energy production will inevitably lead to an increase in instability that can only be solved with efficient electricity storage and regulation solutions. (Izi, 2022)

When we look at the current electric industry, we can see that another sector is experiencing a revolution. This is the transportation sector, which is showing an increasing number of hybrid and electric vehicles joining the fleet. By 2030, between 140 and 240 million electric vehicles will be in circulation on the roads. If we take into consideration the low ceiling of 140 million vehicles, this corresponds to a storage capacity of more or less 7 TWh of energy. The V2G technology will allow the electric vehicle fleet to be a mobile battery fleet. (Izi, 2022)

Currently, for individuals wishing to store the energy they have produced at home, there is only one reasonable and affordable solution. It consists of storing the surplus of produced energy in a domestic battery. As mentioned above (Cf. Supra), domestic batteries allow the storage of electricity produced for example by the photovoltaic installation during periods when there is more production compared to what is consumed. The batteries are working with direct current (DC), the type produced by solar panels. However, between the solar panels and the grid where the battery is located there is often an inverter whose role is to transform the direct current into alternating current (AC). Therefore, to install a battery, it is important to transform the alternating current back into a direct current. For this, several solutions exist:

- A hybrid inverter: The hybrid inverter is an intelligent inverter that in case of overproduction will send the energy produced directly into the battery(ies) without transforming the current into alternating current. This avoids the current transformation, causing a loss of energy when it is transformed.

- A second option is to install a second inverter dedicated only to the battery. However, it is important to mention that some batteries, even if it is not the norm, are integrated with an inverter. Nevertheless, those batteries are more expensive.

(Izi, 2022)

Even if the technologies are evolving quickly, the average maximum capacity of the current domestic batteries is around 14kWh and the price of the installation of the batteries excl. VAT in Belgium is roughly 10.000 €. In comparison, an average car is equipped with a battery of about 70 to 80 kWh. This is equivalent to more than five times the capacity of large domestic batteries. If we analyse the price of a battery per kWh, it is around 140 €/kWh. In comparison, if we take the price of a domestic battery mentioned above, we arrive at 715 €/kWh which is more than five times more expensive. Nevertheless, it is important to mention that the battery of an electric vehicle is not bought without the car and that you must pay the price of the vehicle, as well as the different taxes and charges linked to the purchase of a vehicle. But the difference is impressive, especially when you consider that the battery of an electric vehicle also allows a vehicle to move. (Csere, 2022)

An important challenge for the use of V2G technology and thus the use of an electric vehicle as a domestic battery is to ensure that the drivers of those vehicles have sufficient autonomy following the use of the batteries. Indeed, if the battery is used for domestic purposes, it is also used for mobility purposes. It is therefore important to keep a minimum charge rate for when needed. (Virta Ltd., 2021)

V2G technology takes this into account and offers the driver the possibility to choose in advance the hours of use of the vehicle as well as the necessary autonomy to benefit from an optimal charge.

ii. How does it work?

V2G technology does not see the vehicle as a product consuming electricity but more as an extension of the grid which offers a reserve of energy which can be used in case of need. In this way, charging is becoming a bidirectional process. This means the user of an electric vehicle can decide for example to store energy when the energy rates are at their lowest points and use the stored energy when those rates are going up.

First, V2G technology gives the possibility to use it from the grid (or the home production installation) to charge the vehicle. When the battery is at capacity an inverter which can be on the charger or even included in the car, gives the possibility to transfer energy from the car back to the grid to fill the demand. The limit of transfer quantities is fixed by the car owner as mentioned above. (Shariff et al., 2019)

iii. Vehicles Supporting the Technology.

To date, there are few vehicles compatible with and including V2G technology, but this is growing. V2G compatible vehicles can be divided into three categories:

1. Full electric vehicles with a battery
2. Plug-in hybrid vehicles
3. Electric vehicles with a hydrogen fuel cell.

(Nouvel R, 2022)

Currently, only a few brands offer vehicles with V2G technology in their catalogues, those are Nissan, Mitsubishi, Kia, Hyundai, and Sono.
However, given the innovative potential of this technology, other brands are working on the development of bidirectional charging on their models.

- Renault with the Zoe model,
- Peugeot with the iON model,
- Citroën Co,
- Volkswagen in its ID range,
- Finally, Tesla will likely include this technology in its next models even though Mr Musk has mentioned being reluctant to use it in the past.

(Nouvel R, 2022)

iv. The Requirements for the Use of V2G

First, it is important to have a vehicle which is compatible with this technology.
Furthermore, it is important not to forget the installation of a bidirectional charging station without which the technology will be unusable. Indeed, a classic charging station does not allow the use of bidirectional charging technology. (IFP Energies Nouvelles, 2023)

v. Battery Wear

One of the first constraints which come to mind when thinking about a battery that charges and discharges is the wear and tear of that battery and whether charging and discharging it more often could have an impact on the battery and its life duration.
This is a legitimate question, while using your vehicle as a home battery would lead to increased wear and tear and therefore earlier end-of-life of the battery, therefore, the use of this technology may be less beneficial than it could seem at first. (Hive Power, 2021)

The answer to this question is that batteries with V2G technology do not wear out faster than conventional batteries; it could even be the opposite.

First, it is important to understand how the wear of a battery occurs. The assembly of a battery is designed to guarantee an optimal battery life. However, it has been proven that the efficiency and the maximum charge capacity of a battery are decreasing with its normal use.

To measure the degradation of a battery two perspectives are considered: the calendar ageing of a battery and the ageing of the battery due to charging cycles.

- Calendar ageing refers to any ageing of a battery that is not related to a charge or discharging cycle. This causes battery degradation when it is at rest because no current flows in it.

- The ageing of a battery due to charge cycles is mainly due to the intensive use of a battery and the stresses placed on the battery as a result. This is among other the case during fast charging or intensive use of the battery. This causes more extreme wear to the battery compared to normal use where the battery follows a classic wear curve.

(Hive Power, 2021)

According to a study by the University of Warwick, V2G technology does not harm the performance of the battery and can even increase it.
According to them, battery wear is due to not using a charged battery for extended periods. As seen above (Cf. Supra), electric vehicles spend most of their time at a standstill and on charge. Following them, by optimising the use of the battery and coupling this to the smart grid the wear and tear on the battery capacity could be reduced by 9.1% and the wear and tear on its power could be reduced by 12.1%. (Hive Power, 2021)

Based on the previous points we can see that the battery wear is not an obvious point and that even if the use of the V2G technology has an impact on the life span it also allows for optimisation, compared to a vehicle remaining immobilised and not used most of the day.

Chapter 6: Use of Hydrogen

The resources allowed to produce hydrogen are water and hydrocarbons such as gas or oil.
Hydrogen is also available in its natural state on the planet. Unfortunately, the costs of exploiting those natural resources are extremely high and research is still necessary before we can imagine profitably exploiting those resources.

As mentioned before (Cf Supra, p.10), hydrogen can be used to store energy by transforming a primary resource into hydrogen thanks to a chemical reaction. Due to this hydrogen is not an energy on its own but an energy vector. Now, 95% of hydrogen production is produced using fossil energies and half of it is natural gas.

However, besides being used for energy storage purposes, hydrogen is also used in three main ways.
First, it is used as a raw material for ammonia production, which is used as a fertiliser in agriculture and to produce methanol.
Secondly, it is also used to refine crude oils into fuels, biofuels, and oil products.
Finally, hydrogen has a promising future in the transport sector as well as in aviation and shipping as we will see hereunder.

Uses of Hydrogen in the Global Energy Transition

When we look at the carbon emissions of the transport sector in Europe (Figure 6) and more precisely in Belgium, we can see that 25.65 million Tonnes (18.32% of the total greenhouse gasses) of the total emissions are coming from the transport sector. This is a huge figure but if we combine it with the aviation and shipping sector (31.81 million tonnes) it becomes even bigger with 41.03% of the total emissions coming from it.

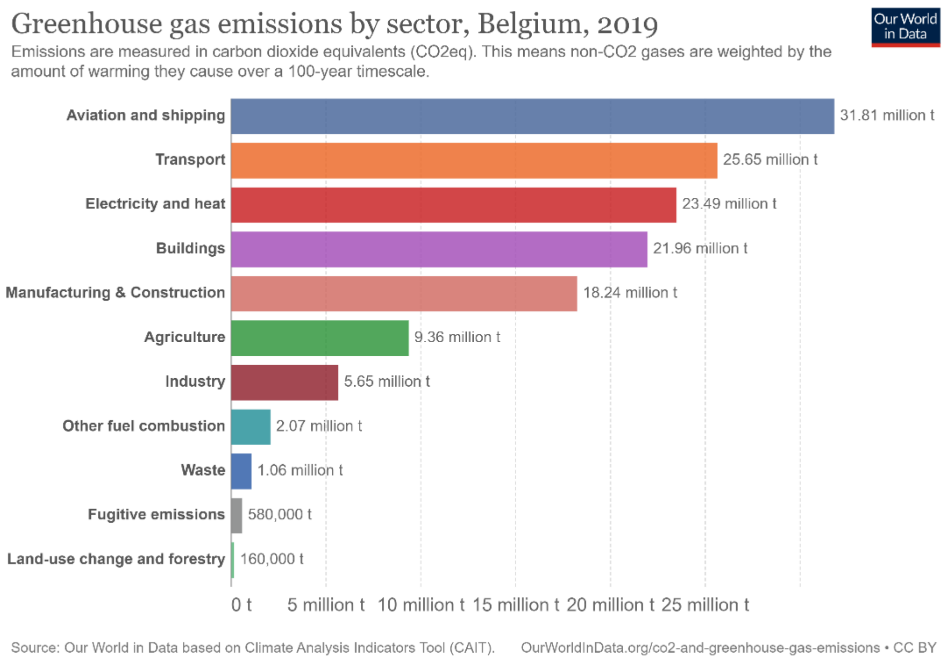

Figure 5: Greenhouse Gas Emissions by Sector, Belgium, 2019 (Richie, 2020)

Those figures show us the importance of decarbonating the transport sector and the use of hydrogen could be part of the solution towards greener mobility.

Use of Hydrogen in Vehicles

Today two solutions are existing on the market for using of hydrogen in the transport sector:

- Hydrogen internal combustion engine
- Electric engine using a fuel cell.

Hydrogen internal combustion engine

This engine enters the category of combustion engines. The motor is transforming the chemical reaction between dihydrogen and dioxygen into mechanical energy and water following this chemical formula:

$2H_2 + O_2 = H_2O + energy.$

The energy produced thanks to the combustion is transferred to a piston following the same way as a gas/diesel engine. However, compared to an ordinary combustion engine some modifications must be considered like the storage under pressure of hydrogen, the fact it has a quicker combustion and the corrosion on the mechanical pieces due to the production of water next to energy. Moreover, the efficiency of such an engine is between 30 and 40% less than a fossil-fuel engine. (Futura, 2019)

Now there are barely any vehicles using a 100% hydrogen engine. The engines using hydrogen are often combined with other energy technologies such as flex-fuel or hybrid engines. In this way, the major defects of this type of engine, which are the lack of hydrogen distribution points, and the autonomy are compensated. (Futura, 2019)

Fuel cell

A fuel cell is an energy converter, which is transforming fuel into electricity to power an electric vehicle with side products that are water and hot air. The fuel cell thus has a low environmental impact, and it is an effective way for car manufacturers to develop sustainable solutions in their vehicle catalogues.

The fuel cell is composed of different components.

- Two electrodes: one oxidising anode which is emitting electrons and one reducing cathode which is collecting the electrons.
- Both components are separated by an electrolyte which can be liquid or solid to make the transition of the ions between both easy.

Everything starts in the anode where hydrogen is separated into electrons and ions with the catalyser. Following this, the ions are transiting through the electrolyte to the cathode. This transition is generating electricity which is providing energy to the engine. In the cathode, oxygen directly comes from the vehicle's environment and the electrons are combined to produce oxygen. When this oxygen is meeting the hydrogen ions produced following electrolysis, they become water molecules. This water molecule is the only emission of a fuel cell engine together with hot air. (Deca, 2023)

The major advantage of a fuel cell-powered vehicle is its refuelling time which is faster compared to an electric vehicle using a battery pack. But the poor charging network makes it a technology difficult to implement at the moment for massive use. (Deca, 2023)

Use of hydrogen for planes, trains, public transport, and ships

Regarding the use of hydrogen for public transport we have seen for some years that a lot of cities are embracing this solution for their public transport infrastructures this is for example the case of the public transport company of Brussels MIVB which is testing the solution since the end of 2021 in the city. In Germany, the federal government is also funding the procurement of hydrogen buses in the country. Those hydrogen buses are also operated in other European countries and elsewhere around the world.

Hydrogen fuel cells in buses have as a main advantage their low weight compared to electric batteries. (Wood, 2022)

Regarding the railways the UK and Germany are currently testing hydrogen-powered vehicles. In both of those countries, approximately 1/3 of the railways are non-electrified which means they must use diesel-powered vehicles to operate on those sections. Bringing electrified trains using hydrogen would make it possible for those countries to make their railways greener but also more cost-effective than passing through overline electrification of the line. (Wood, 2022)

Aviation is a more difficult subject to tackle. The International Energy Agency (IEA) is exploring Sustainable Aviation Fuels (SAF) as a potential way of lowering the global greenhouse gas emissions of the aviation sector. Some of those SAF are hydrogen-based fuels.
The major issue with the electrification of planes is the fact that batteries are heavy and implementing it on planes would be impacting the power-to-weight ratio of planes, moreover, those batteries are also providing a lower distance range compared to classic aviation fuels. In this way, hydrogen-powered planes could be a solution for the future and scientists and engineers are working on it around the globe to make it more effective. (Wood, 2022)

By 2050 the international shipping industry will have to halve its greenhouse gas emissions. This has been decided by the UN's International Maritime Organisation (IMO). Currently, solutions involving batteries are tested, but they are only viable for limited-range routes like ferries and internal maritime roads.
A solution could be the use of ammonia which can be produced with hydrogen and has as its main advantage the fact it is denser than hydrogen and makes it possible to use hydrogen over longer distances. Lots of companies such as Mitsubishi Shipbuilding are experimenting with those solutions and developing engines capable of dealing with the requirements of heavy load moving of maritime shipping. (Wood, 2022)

In 2020, the Volkswagen Group declared that hydrogen-powered vehicles could be a solution to reduce emissions. However, it is not suitable for cars following their opinion. At this moment technology and infrastructure make this not suitable for cars, but this could be the case in the future following further development. The group has decided to give top priority to the development of electric vehicles using battery packs instead of hydrogen-powered vehicles.
However, following their declarations, the longer the distance and the heavier the transport load will make the use of hydrogen-powered vehicles more suitable in the future. (Piot, 2020)

Chapter 7: Construction of a Photovoltaic Installation

i. Construction of a Module

The other name of a solar panel in the photovoltaic industry is also a module, in this part when we will be talking about a panel, we will be naming it a module.

Most of the modules available on the market use the same main material. This material is crystalline silicon which is the material which absorbs solar energy from its environment. To produce the module, it is necessary to pass through some manufacturing steps which we will be developing now.

1. Production of polysilicon and ingots:

   To produce polysilicon three main technologies are existing now on the market. The most used technology is the modified Siemens process. This process is used in China. Two metallurgical grade silicon of high purity (between 95 and 99%) are combined using liquid chlorine to produce trichlorosilane. Following this process, the obtained product will be mixed with hydrogen gas and the obtained silicon rods are heated at elevated temperatures (1.100 °C). This process is deposing high-purity silicon on the rods and will be repeated until the rod has a diameter between 150 and 200mm. (Lees & Fugmann, 2023)

   The two other processes are:

   The Fluidised bed reactor process which is using less energy than the previous production process and has a higher convention rate. Moreover, they are using silicon seed particles instead of silicon rods. However, this technology is less mature, so it is not often used in the manufacturing process.

   The second process is an upgraded metallurgical-grade silicon process. But having a low purity level compared to the two other technologies it is not widely used. (Lees & Fugmann, 2023)

2. Production of wafers:

   To produce wafers, silicon ingots are sliced in thin slices using a wire saw coated with diamonds. One manufacturing process is producing cooled layers of silicon which are molten in a bath to produce the wafers.

   It is also possible to produce the wafers using gaseous silicon deposited in thin layers on a crystalline template shaped like a wafer. (US Department of Energy, 2022)

3. Cell fabrication and module assembly:
   Following the wafer production, the wafers are transformed into photovoltaic cells. This process is done by chemically texturing the wafer surface to remove damage and increase the amount of light exposed to one cell. Following this, each cell is exposed to a flashlight to determine its power, which varies from one cell to another. Each cell is sorted by its power absorption capability.
   Those cells are then assembled using copper ribbon plates and silver busbars to tab and string the cells together. The connected cells are placed on a sheet of glass and a sheet of polymer encapsulant. On the back of the cells is set another polymer encapsulant sheet as well as a tough polymer black sheet and a piece of glass. This assemblage is laminated in an oven to protect it from water damage and fitted with an aluminium frame. On the module's back, a junction box is placed to connect the modules during installation. (TESB, 2023)

ii. Installing Panels

To develop the complete installation process of a solar installation this thesis will base the development on the experience of a client at Total Energies Solutions Belgium which is the company where I am performing my internship. The installation will be done on a sloped roof.

Everything starts with the client contacting the company of his choice based on positive reviews he has heard, marketing campaigns or just because he knew the company beforehand.
This contact can be made either by phone, by sending an email or by using the website contact form of the company. When the client enters into contact with the company, he becomes a potential.
From that moment together with the client, an appointment is fixed with a salesperson. The salesperson will evaluate together with the client what his needs are and the different requirements he has. This will result in a quote including the number of panels needed, the inverter which suits the best for the installation and the other costs and requirements to conduct the installation to a good end.

When the commercial part of the project is completed, the project is pushed to a project coordinator who will oversee the technical aspects of the installation.
Based on the information collected by the commercial he will design the installation and complete the technical plan. When the project coordinator is done with his intake his work will be reviewed to make sure everything is fine.

When the technical part of the installation is done the planning team can plan the installation in the installer's planning.

Day of the project:

0. On the day of the project the team of installers are arriving with the necessary materials.

1. First, the mounts are fixed on the roofs, which will support the modules. The mounts are fixed on the side of the roof with the best exposure to sunlight. In Belgium the best direction is south but in case this is not possible, East, and West will be good as well even if the performance will be slightly impacted. The angle of the mounting structure should be between 18 and 36° to have the best performance.

2. The following step is installing the modules on the mounting structure. The modules are fixed with bolts and clamps.

3. The next step is the electrical wiring of the modules. To ease the connections between the panels universal connectors are used which can be used with most modules. The panels can be interconnected using the following string methods:
    a. Series connection where the positive wire of a module is connected to the negative wire of the next one and repeated for the next panels of the string.
    b. The parallel connection is where the connections made are positive to positive and negative to negative.

4. The following step is to connect the module strings to the chosen solar inverter. Ideally, the inverter must be installed close to the electricity meter to ease the connection. The connection used here is to connect the positive wire to the positive plug and the negative wire to the negative plug of the inverter.

5. Finally, the inverter is connected to the grid and if the client has chosen this option, the inverter can also be connected to a battery.

6. When everything is installed, a final check is done to make sure everything is fine. When everything is clear the inverter is started by switching the switch to ON. It is also important to mention that in Belgium a solar installation must be checked by an official controller.

Chapter 8: Photovoltaic Installations in Belgium

i. Profitability of Solar Panels in Belgium

When we talk about the profitability of solar panels, we are talking about the period over which the original investment will be covered by the savings made thanks to this installation. This depends on several factors, some of which are variable:

- The price of electricity, as seen above (Cf Supra, p.3) we know that the price of energy varies depending on many factors and will therefore be subject to fluctuations throughout time which will impact the duration of the return on investment.
- The type of solar panels used.
- The installation price and maintenance price when necessary.
  (Eco Habitat Belge, 2021)

However, on average an installation will be profitable between eight and twelve years. This duration could even have become shorter for the last two years due to the rise of energy prices. The reasons that make the installation of a photovoltaic installation in Belgium interesting are the fact that the installations are becoming increasingly affordable, and their quality/production is constantly improving. The installation brings a consequent decrease in the energy bill and the installations benefit in general from a life span of 25 years while requiring little maintenance. In addition, if the house is more than 10 years old, the VAT paid on the installation is reduced to 6% instead of the usual 21%. Moreover, it is important to mention that, depending on the region, certain bonuses may be applicable (we will develop this below). (Eco Habitat Belge, 2021)

ii. Financial Advantages of a photovoltaic installation in Belgium

In Belgium, the installation of solar panels offers several financial and fiscal advantages in addition to the fact that you produce your energy and reduce your impact on the environment.

1. First of all, the **reduction of energy costs**: we will not develop further this point while it was already developed above. (Cf. Supra)

2. **The green certificat**es.
   The Green certificates were introduced to support the production of green electricity. The certificate is immaterial and has a financial value. When installing a photovoltaic installation, individuals and companies receive the certificates free of charge, after which they can sell them to the electricity market regulator, which will cover their investments.

In Flanders and Wallonia, the green certificates have been abandoned for new residential installations and are only available for existing installations. The number of green certificates obtained will depend on the power of the installation. (Engie, 2021)

3. **Installation allowances.**

   Some regions in Belgium offer bonuses for the installation of a photovoltaic system.

   a. Wallonia:

      In Wallonia there are no more direct allowances for the installation of solar panels, however, other financial aids are available.

      i. The compensation allowance of the prosumer tariff which is equivalent to 54.27% of the amount of the prosumer tariff in 2023 this allowance will no longer be relevant from 2024.

      ii. The electricity meter is running backwards. Households installing panels before the end of 2023 will be able to keep their old meter and thus benefit from the meter running backwards until 2030, the year when all meters will have to be changed. A meter running backwards means that when energy is fed back into the grid, it will decrease because it turns backwards. This will result in the consumer paying only the net balance of what has been taken from the grid. This mechanism is called compensation.

      iii. Finally, there is an allowance for the installation of a dual flow meter. This allowance is equal to the price of the meter, i.e., 160 euros excluding VAT in 2023 at the time of writing. The dual-flow meter is also called a smart meter, this type of meter allows to benefit from a proportional prosumer tariff calculated based on the quantity of electricity consumed on the network, this is more advantageous when the consumer has a high rate of self-consumption and cannot be a disadvantage for the consumer, meaning that if the calculated cost is higher than the prosumer tariff, the second one is applied to the consumer.

      (Solvari, 2023)

   b. Brussels:

      In Brussels, the distribution of green certificates is still in operation for all installations. The minimum resale price in Brussels is 65 euros (guaranteed by the region) and on average each certificate is sold for 95 euros. Each green certificate is valid for 10 years. (Solvari, 2023)

Moreover, in Brussels, some municipalities of the region are distributing their allowances to encourage residents to install solar panels, so it is important to check with your municipality to find out if there is such an allowance. (Solvari, 2023)

c. Flanders:
In Flanders, a bonus is granted by the network manager Fluvius. The bonus will depend on the power of the installation and cannot exceed 40% of the total investment with a maximum of 750 euros. This amount decreases gradually from year to year (see table below). To benefit from this allowance, the building must have been connected no later than December 31, 2013, i.e., 10 years ago. Furthermore, the installation must have been done by a certified installer and the application for the premium must be made when the installation is commissioned. (Solvari, 2023)

Year in service	Amount of the prime (up to 4 KWh)	Amount of the prime (4 to 6 KWh)
2022	300 €/KWh	150 €/KWh
2023	150 €/KWh	75 €/KWh
2024	75 €/KWh	37.5 €/KWh

Table 1: Prime Yearly Evolution Amount (Solvari, 2023)

4. **Tax deduction:**
This tax benefit was only applicable to companies and self-employed people. This deduction allowed to reduce the amount of tax by a certain percentage of the total amount of the investment after the installation. This tax deduction ended in 2022, so it will not be developed further. (Energreen, 2021)

5. **Reduced VAT:**
Buildings that are at least 10 years old are entitled to a reduced VAT rate of 6% instead of 21% when doing renovation which includes the installation of solar panels.
Given the increase in energy costs, the government has decided to issue a decree to make the installation of solar panels more accessible to individuals having more recent houses.
Following this decree emitted by the Federal Public Service of Finances the installations made between April 1st, 2022, and December 31st, 2023, can benefit from a VAT rate of 6% instead of 21% on the invoice issued by the installer. This decree concerns the delivery and installation of photovoltaic solar

panels, thermal solar panels, solar water heaters and heat pumps. However, certain conditions must be met:

a. The installation is invoiced to the final consumer.
b. At the end of the installation, the building is solely or predominantly used as private housing.
c. The building has been in use for less than 10 years. Otherwise, the work is subject to a reduced VAT rate based on the permanent regime.
d. The installation meets the different criteria concerning emissions established by European regulations.

(FPS Finance, 2022)

The different points mentioned above are making photovoltaic installations more simple and more affordable for companies and individuals in Belgium to invest in. However, as seen above, the separation of powers in Belgium makes the financial advantages vary between the different regions. It is therefore important to be informed about the different regulations in force in the region where you are located.

Chapter 9: Specific Research Question, Hypothesis, and Methodology

The research question which will be developed in this thesis will be: Could the storage and improvement of the transportability of electricity produced by small renewable energy production units mitigate energy peaks?

Hypothesis:
In order to confirm or reject this research question a hypothesis as well as a null hypothesis will be written.

- The hypothesis is:
  An increase in the storage and transportability of electricity produced by renewable production methods could mitigate energy peaks.

- The null hypothesis is:
  An increase in the storage and transportability of electricity produced by renewable production methods would not mitigate energy peaks.

i. Methodology

Regarding the methodology used for the research, most of the information discussed is based on existing papers and articles but also diverse websites of companies involved in the energy distribution sector. Those companies can be producers, distributors, governmental institutions, home energy production systems installers but also companies active in the mobility sector.

Moreover, the development will also be based on personal research made. Those are both quantitative and qualitative. The qualitative research is based on personal discussions with actors and consumers met during my internship or later.
The quantitative research was conducted with the help of a survey. This survey was made with Microsoft Forms. The survey was made out of 17 questions out of which some were only visible depending on the previous answers thanks to the junctions' options. The questions were divided into three types of questions (multiple) choice questions, open questions, and a Likert question.

The main objective of the survey was to collect data regarding the consumption habits of the users as well as to have their opinion and inputs about potential solutions.
The survey collected a total of 82 respondents of which 24 owned both solar panels and an electric vehicle. This is not a huge number but both technologies are still quite new

even if they know more and more participants. Moreover, both technologies require a big investment and for the electric vehicle compared to standard motorised vehicles, it is not yet interesting because the initial investment is too high for a large number of potentially interested users.

Chapter 10: Prices and Volatility

In recent years, electricity prices and energy prices, in general, have fluctuated significantly and have been highly volatile.
The main causes that have contributed to the fluctuations are the following:

- Like in every market, the demand has a big impact on the prices, the energy market is not an exemption to this. The demand in this case is varying through the year depending on multiple factors. Those factors are multiple like the weather conditions, the economic activity and the consumption patterns which are varying through the year. A concrete example is the decrease in consumption in the summer, due to the usually higher temperatures during summer houses are not required to be heated. Moreover, due to the fact the sun sets later, it is not necessary to turn on the lights in the buildings as well as in the public infrastructures (i.e., the public lighting) as often as in the winter. those fluctuations in demand will influence prices according to the law of supply and demand given the mismatch between supply and demand. (SPF Economie, 2020)

- For the last dozen years, the share of renewable energy in the energy mix has been increasing. The production of solar and wind energy is increasing due to the increasing amount of infrastructure. The positive effect is that those installations allow the reduction of greenhouse gases. However, a more negative effect that is not often mentioned is that those production methods lead to an increase in the variability of the electricity supply because the production of this type of renewable energy depends entirely on weather conditions, in this case, sunshine and wind.

- Fossil fuel costs, as seen above (Cf Supra, p.4) electricity can also be produced with fossil fuels such as natural gas and coal (in Belgium it is mainly natural gas, but coal is still strongly used in the energy mix of some European countries such as Germany or Poland). If the price of fossil fuels and therefore of the raw material used to produce electricity increases, the price of electricity will logically increase proportionally to this price increase. In Belgium, thermal power generation mainly uses gas, which accounts for more than 30% (Cf supra, p.4) of the energy mix, so, logically, an increase in gas prices has a real impact on electricity prices.

- The various investments in production also have an impact on the price of electricity. In the case of companies producing or distributing electricity, the investments in question may be made in production plants or transmission lines and the various electrical networks, which have significant costs that will be reflected in the price that the customer pays, as in any other company.

- In recent years, new regulations such as greenhouse gas emissions limits and energy security have had an impact on energy prices. The transition to cleaner energies requires a large investment that will increase production costs and will be passed on to the customer. However, regulations that facilitate the use of renewable energies such as subsidies or tax exemptions can reduce production costs. (Cf. Supra, p.5)

As seen here above but also in the literature review energy prices are impacted by multiple factors. Those factors are evolving which causes a high volatility of energy prices in the past, but they will also continue to have an impact in the future.

Chapter 11: Reasons for B2B and B2C Clients to Install Solar Panels.

In recent years, the installation of power generation solutions at the place of consumption is becoming more and more important. Even if other solutions such as wind power exist, we will only focus on the installation of solar panels. This type of installation is simple to install and is therefore suitable for the largest number of customers. On the other hand, it would be complicated or impossible to install a wind farm or even one wind turbine on an individual’s property or at a small business that does not have a large space. In addition, the installation of a wind turbine is also more restrictive from a legal point of view.

i. B2C

For some years now private consumers are installing solar panels at home this figure is strongly increasing every year. In 2018 482.800 households were equipped with solar panels; this is 1 out of ten homes in Belgium equipped with photovoltaic installation. (Maisch, 2018)

To complete the thesis, a survey was performed, in this survey it appears that out of all the respondents, 49% of them have a photovoltaic installation at home. (Appendix 3)

When looking at the 5 main reasons why private clients are installing photovoltaic installations.

1. First, the main reason is a cost-saving motivation. Installing solar panels will give them the ability to generate their electricity thanks to the sun and thus this will reduce their energy bills. By using their home-produced energy, they will need less energy from the grid, and they could even sell the surplus of energy production not used back to the grid.

2. A second reason is environmental benefits. More and more people are paying attention to their environmental impact.
   To this end, solar panels are a good way of reducing their carbon footprint and have a lower impact on the environment regarding energy consumption.

3. For a lot of households, a solar installation is seen as an investment that will increase the value of the home and strengthen the PEB profile of the house. This will increase the attractiveness for potential buyers while a lot of them are interested in houses where solar panels are already installed.

4. Government incentives are also an important factor, it is not the reason in itself why people are installing panels but more a motivation to do it. To motivate households to install panels governments are offering VAT reductions, bonuses, or rebates, this makes the installations more affordable. It will also enlarge the potential market to people who maybe didn't have the finances for such an installation. However, while they are more and more photovoltaic installations, those incentives tend to disappear in Belgium like was developed before. (Cf. Supra, p.31)

5. Finally, installing solar panels is a way of increasing energy independence. The installation will provide the owners with an increase in energy independence by allowing them to produce their energy themselves. This can be even more important than only personal convictions in regions where the electricity grid is unreliable or where power outrages are occurring frequently.
   However, the periods of production are not necessarily matching the moments when energy is needed. It is then needed to find a way of storing the produced energy to mitigate the production and consumption peaks. This point will be developed further.

ii. B2B

B2B and B2C clients installing solar panels have both their reasons to install a photovoltaic installation even if some points are differing, the primary reasons are similar to the household's reasons to install those solar solutions.
For the companies installing photovoltaic installations at their business activity locations the reasons for installing are mainly:

1. Reducing their energy costs thanks to the fact they are generating partly or all the energy they are consuming. Those reductions in their energy bills will reduce the operating costs of the company and thus improve their profitability.

2. A second reason which is proper to the companies is regarding the corporate social responsibility of the company. Environmental concerns are taking more and more importance for clients and if a company is acting positively to reduce its impact on the environment customers tend to buy products from this company instead of another company performing less well in that field. By installing solar panels, the company is demonstrating its high commitment to environmental problems and their concerns about them.
   Shareholders as well as clients will see thanks to this that the company is taking positive actions to strengthen its corporate social responsibility. (Chui, 2022)

3. Linked to the previous question companies installing solar panels can use it as a point differentiating them from their competitors and include it in their marketing and branding strategy. This will attract customers who want to do business with environmentally concerned companies.

4. As for the B2C clients in some countries, the grid is unstable, unreliable, or power cuts can happen making business activities difficult and having serious consequences for the business's operations. By installing a photovoltaic installation, they will increase their energy independence and thus reduce their dependency on the grid.

5. Finally, companies can also receive incentives or benefit from tax reductions from the government if they are installing solar panels. Those incentives will make the installation cost-effective for the company and help them accelerate their environmentally friendly transition.

When comparing both B2B and B2C the cost savings and environmental concerns are similar for both. However, those motivations are deferred while CSR and energy security are having a more important position in the eyes of the companies while households are more focused on the immediate cost-saving and the fact, that they are reducing their environmental impact.

Regarding the type of installations, it is important to mention both are not having the same installation characteristics. More than just their size other factors are differing B2B installations from the ones of households.

- The first one is their size and their complexity. B2B installations are often way bigger due to the size of their buildings/plants and their bigger energy needs. This is also due to the fact B2B electrical installations are often already more complex and thus they could be able to manage more complex photovoltaic installations. Their projects are often tailor-made to suit the needs of the clients in the best conditions possible, increasing the complexity compared to B2C projects which are more standard.
- On the legal side, B2B and B2C installations are also differing. Households will usually not go above 10kWc installations while they would be then considered as producers. This would impose greater legal constraints on them that are more easily managed by B2B clients.
- Regarding the financial part, B2B clients have access to other financing plans for their installations like flexible loans, installations leasings or even power sales agreements giving them the possibility to have a return on investment quicker.

- The motivations as seen in the two parts here above are also differing.
- Finally, the usage of the produced energy is also an important difference that is impacting the size of the installation. On B2C projects the used energy will be used to power the house consumption and the home appliances. The B2B projects will serve to power various types of consumption installations like offices, machinery, etc. Moreover, it is important to note that some B2B projects also have the only objective to reinject the totality of their production on the grid.

Chapter 12: Consumption & Production Peaks

One of the direct consequences of the increase in renewable energy installations is the parallel increase of energy production peaks. Energy production peaks are mainly occurring when energy production increases strongly without a similar increase in energy demand.
Some factors have an impact on the peaks such as the weather which intermittently influences renewable energy production and energy consumption as said above.

During summer, for example, high temperatures days are increasing the energy demand. This is due among others because consumers use air conditioners (which are big energy consumers), fridges must work more intensively and massive use of fans. All this creates a strong increase in the energy demand that is needed directly. However, during normal regular summer days, the electricity demand is low while lights don't need to be turned on during the day and other electric using systems like domestic electric items heating which are high energy consumers are not used.

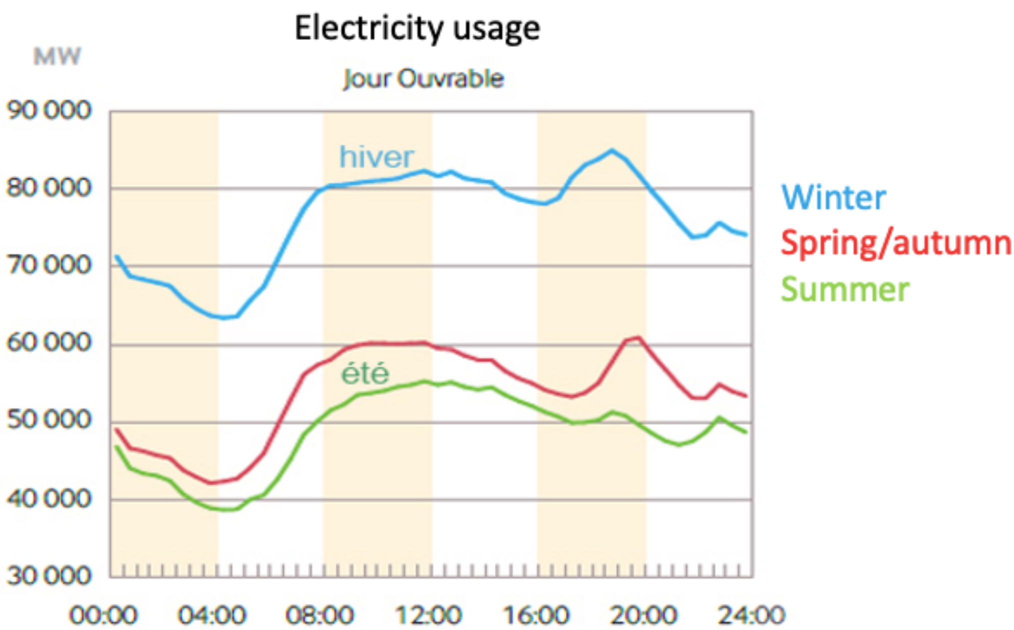

Figure 6: Daily Electricity Usage per Season (Hervé, 2012)

The graph above represents the energy consumption curves during summer and winter. When we analyse this graph, we can see that the summer consumption is much lower than the winter consumption. This graph is also interesting because it shows our daily consumption habits which vary from one period of the year to another. However, the data should be taken with caution as they date from 2012 and consumed energy quantities have changed since then. However, even if the quantities of energy consumed have changed, the consumption habits and curves have remained similar, except for the night consumption which has slightly increased due to the increase of electric cars which are mostly charged during the night.

The graph above allows us to visualise the consumption habits during winter in blue and during summer in green and mid-season in red (autumn/spring).
If we analyse the graph, we can see that depending on the season the energy peak occurs at a different time of day. In winter it occurs around 7 pm when we return home with the preparation of the meal, the lights on due to the low light outside and the heating is turned on. During summer, on the other hand, the peak occurs at lunchtime, when temperatures are at their highest and air conditioners and fans are turned on.

If we analyse the daily consumption curve during winter, we can see that the consumption strongly evolves compared to the consumption during summer.

- At night consumption is at its lowest
- Between 4 and 8 a.m. consumption is increasing, this corresponds to the awakening of human activity: the bakers turn on their ovens, the heaters are turned on, etc.
- During the lunch break, consumption is stabilising.
- Consumption increases again at the end of the afternoon until 7 pm corresponding to the daily peak. The population goes home, the appliances are turned on, cooking is done, the heating is increased, and the public lighting is turned off at night. All these factors are causing an increase in consumption which leads to the peak.
- After the peak, human activity goes down and the energy consumption is correspondingly reduced till the next day.

Renewable energies often have intermittent production. This is the case for the two main ones which are solar energy and wind energy. On sunny days the production increases strongly as well as when the wind conditions are ideal, this will accentuate the production peaks.

Peak production periods can create a problem on the grid, as the energy generation facilities are not instantly modifiable to follow the oscillating generation trends. This can lead to voltage problems on the grid that will damage connected electrical equipment and cause grid failures. Fortunately, up to a certain limit, transformers can manage voltage changes on the grid and prevent grid failures.

In addition, to avoid major grid failures, distribution system operators (=DSO, gestionnaire de reseau de distribution in French), generators and suppliers constantly monitor demand and production, adjusting production at the best to meet needs and achieve a balance between production and demand. Therefore, for large photovoltaic installations, the DSO can remotely activate and deactivate the production to avoid over- or under-production on the local grid.

When analysing specific data related to the production of wind turbines and solar panels like in the graphic below, we can observe a certain seasonality regarding the production periods.

- The wind energy production is displayed in blue, and the peaks of wind energy production occur during the autumn and winter months.
  From October to March winds are stronger compared to the other months of the year. During this period the difference in temperature between the equator and the north pole is greater than during the rest of the year. This difference creates a change in pressure that will accentuate the Jetstream and therefore Europe will have stronger wind. On average 66% of the wind production happens during those months and the other 34% is produced during the summer months. (Energie Schweiz, n.d.)

- On the other hand, solar energy production displayed in red is more present during the summer months. However, even if during winter months there is less sun due to the sun being lower and the days being shorter, there is still some solar energy production. If we look at the statistics 70% of the solar energy is produced during summer and 30% during winter months. (Energie Schweiz, n.d.)

Overall, wind and solar energy in Western Europe appear complimentary. And when analysing the graph, we can see both production methods are growing due to the increase of solar power plants and wind farms.

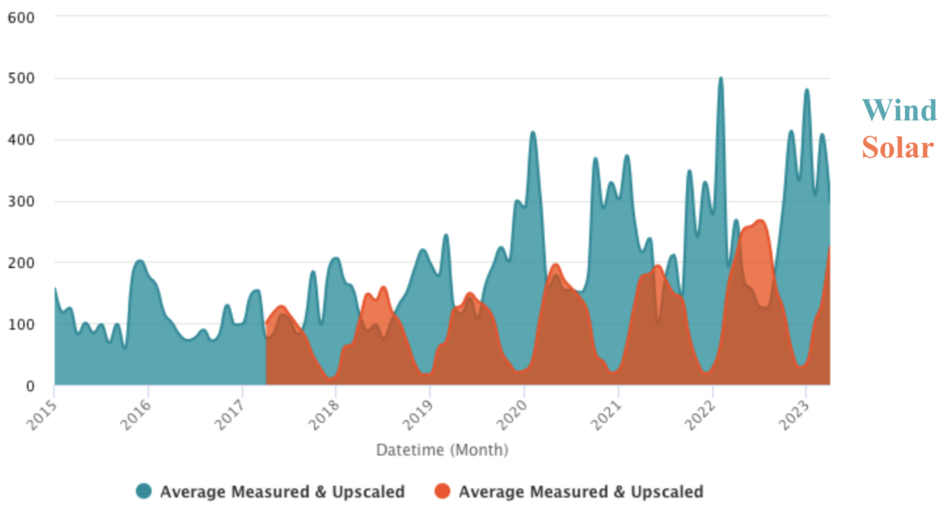

Figure 7: Average Measured & Upscaled Wind and Solar Energy Production in Belgium (Elia, 2023)

It is also possible to analyse the total electricity consumption. The graph hereunder shows the evolution of the average energy total load on the grid from 2015 till today (April 2023).
Grid's electricity load is referring to the total amount of electricity consumed at a specific time by all the users connected to the grid.
As seen before and as we can see on the graph the energy consumption is low during summer months and higher during winter. However other macroeconomic events have impacted the energy consumption this was particularly the case during the last year.

- In the early months of 2020, the covid disrupted the lives of everyone. This was also the case for the energy sector which has seen a clear decrease in energy consumption compared to the same period without covid as shown on the graph. This decrease in consumption is mainly due to a strong slowdown in economic activity, unlike household consumption which has not decreased during this period.

- Another macro event which impacted energy consumption is the war between Ukraine and Russia. Energy prices increased a lot and led to a diminution of consumption to decrease the costs. This is visible from mid-2022 onwards compared to equivalent periods in the past where consumption was higher.

- It is important to mention that data is missing for 2021.

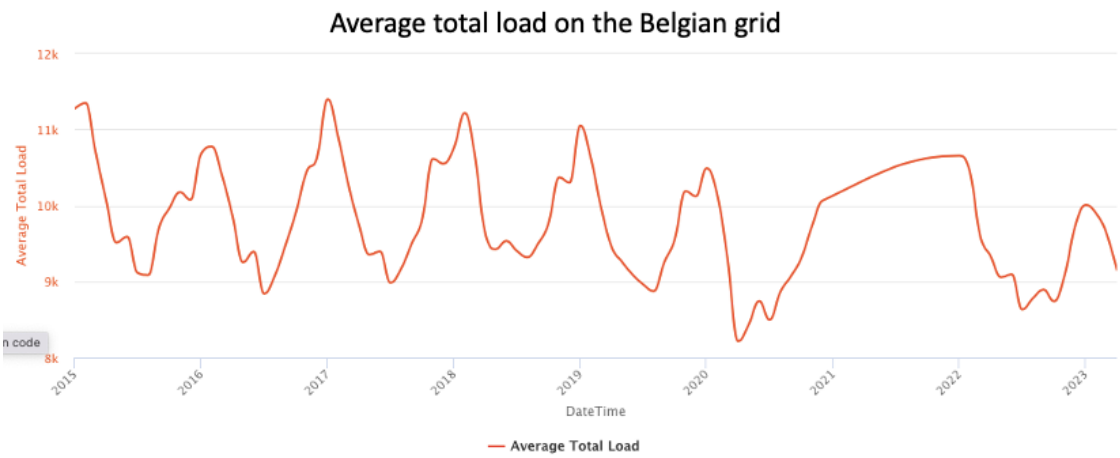

Figure 8: Average Total Electricity Load on the Belgian Grid (Elia, 2023)

For some years now, information technologies combined with photovoltaic installations and the electrical system of houses allow getting useful information to the user to optimise his consumption.

The operation of such a system is easy as well as its installation.

- First, it is necessary to install the different measurement sensors in the places and on the devices whose energy consumption and production we want to know.

This is done by installing a metering device on the inverter of the photovoltaic installation, after the meter to know the general consumption of the house and finally on the electric plugs, switches, and various household appliances.

- Once installed, the sensors will collect the data and send them to a central console corresponding to the home automation hub. This hub will centralise the data and store it for future analyses and visualisation.

- The home data hub will analyse the collected data in real-time or at regular intervals depending on what has been decided by the user. The analysed data will be visible on the screen of the console or even directly on the owner's smartphone thanks to a mobile application.

(HomeWizard, 2023)

This system is useful for owners concerned about their consumption because it allows them to identify sources of energy loss/waste and optimise the use of the different consumption items. It is even possible nowadays to automate consumption habits such as turning off the lights or lowering or raising the temperature of the house according to the outside temperature and day schedules. (HomeWizard, 2023)

Those hubs give the possibility to view the consumption of gas and water of the household which gives the possibility to have a report of the total energy consumption of the households.

If we take screenshots issued from such a home automation system, we can see that it gives us valuable information regarding the usage and production of a household. Before analysing, it is important to mention that the user of this app is already trying to optimise its usage by using the big energy-consuming items during periods when the solar panels are producing. However, in the absence of a battery, some energy consumption comes from the grid when the solar panels are not producing.

Another important point to mention is the fact that the electricity used to charge the car is not included in the total electricity consumption while this is taken in charge by the employer (part of the salary). Due to this, the consumption is not added to the general consumption of the house while this is probably the biggest consumption item. Moreover, this data was retrieved on Saturday 15 April 2023, if the data was retrieved during a winter month the consumption would have been higher and the production probably lower. (Van Walsum, 2023)

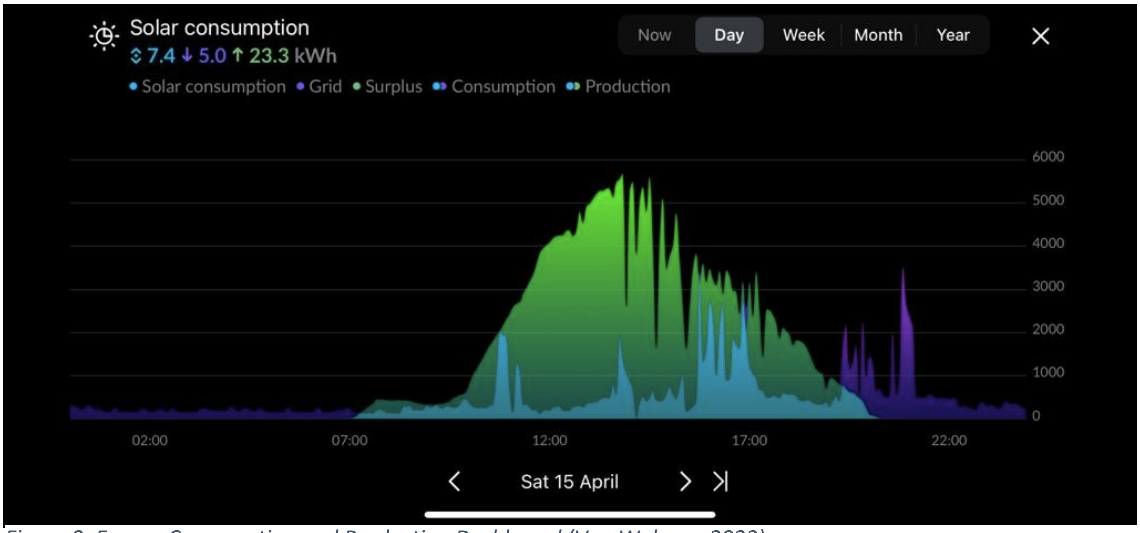

Figure 9: Energy Consumption and Production Dashboard (Van Walsum, 2023)

First, if we analyse the production, we can see that during the day the solar installation produced a total of 23.3 kWh. The production started when the sun raised around 7 AM and till 8 PM time when the sun went down.
The data displayed in blue is the solar consumption which corresponds to the auto/self-consumption of the household. This auto consumption corresponds to 7.4 kWh. Finally, in purple, the amount of energy issued from the grid happened from 8 PM a moment when the sun went down till the next morning. The amount of energy taken directly from the grid is thanks to the improvement of consumption habits low and equals only 5kWh. (Van Walsum, 2023)

If we look at the consumption items, we can see most of them are occurring during the afternoon when people are coming back from work. During the summer months, this is not a problem while solar energy production is occurring till the evening when the sun is going down. However, during the winter months, it could be more problematic because the sun is going down earlier and up later making self-consumption more difficult. On average the devices are used from 5 PM onwards like the washing machine, the dishwasher or even the electric tackle and oven to prepare dinner in the evening. (Van Walsum, 2023)

The biggest consumption item as mentioned before is charging the car. From the screenshots here above, we can see that this is mostly not happening during the solar production hours while at that moment the car is used to go to work, do the groceries, bring the kids to their different activities, etc.
For consumers where the electricity consumed by the vehicle is not paid by the employer, this can be problematic because it represents a large expense which is difficult to reduce if the consumption habits are not changed completely.

Overall, those data show us, as said before, that consumption hours are not necessarily equalling production hours. This gap is causing stress on the grid which can cause issues. We will analyse the consequences caused by this stress on the grid in the next chapter.

Figure 11: Energy Consumption and Production Dashboard 3 (Van Walsum, 2023)

Figure 10: Energy Consumption and Production Dashboard 2 (Van Walsum, 2023)

Chapter 13: Stress on the Grid

As seen in the previous chapter, a grid stress situation occurs when the electricity demand exceeds the production and distribution capacity of the grid (this distribution capacity is also linked to the sizing of the electrical wiring and the relay booths). It can also be due to the opposite situation where the production exceeds the demand which creates a surge on the network since the production of private producers (solar panels installations) is not adaptable instantly. The causes of network stress due to a situation where consumption exceeds production are:

- Exceptional weather conditions (for example heat waves or cold waves)
- Shutdowns of power plants due to for example breakdowns or shutdowns
- A sudden increase in demand such as during peak hours or major events (Wasson, 2023)

Suppliers will do everything to avoid over or under-production problems. To do so, they can use several solutions such as importing from abroad or exporting electricity, adding additional production plants, using pricing solutions such as peak and off-peak tariffs, pausing temporarily power plants, or using storage systems. (Wasson, 2023)
Even on a government level, it is possible to find solutions to ensure a stable electricity grid by putting in place solutions and preventing possible issues like a blackout for example or even working with them when those issues are occurring. To do this the government of the United States of America promoted the installation of microgrid solutions. A microgrid solution is a decentralised solution installed near the consumption location that can sustain itself in case of need. But those microgrids can also come in handy to sustain other consumers. (Vox, 2020)

However, even with the above measures in place, it is possible that the stress on the grid could have negative consequences, although this is less common in developed countries such as ours.

The direct or indirect negative consequences are then:

- **Voltage instability on the network**: the voltage on the network is maintained within a certain range to avoid damaging the network and the devices connected to it. If the voltage decreases too much it will cause a failure of the network and some devices connected to it will not work anymore because of the low voltage. On the other hand, a voltage surge can be more dangerous as it can burn out the electrical circuit and permanently damage the electrical appliances connected to the network or even cause fires.

- **Increased costs**: To face the lack of production, it is sometimes necessary to fill the gap with other sources of production such as the reactivation of power plants, the use of generators, etc. All this has a cost and therefore increases the final bill.

- **Environmental impact**: As seen above, to face the lack of production some power plants can be reactivated. However, the generation plants that can be activated when needed are often fossil-powered. This causes an increase in greenhouse gas emissions and is therefore harmful to the environment and health.

- **Power outages**: A difference between demand and production can cause power outages that will strongly affect private users but also the public sector and companies which could even endanger lives by impacting first aid services for example and cause economic losses for businesses.

- **Reduced grid reliability**: If the pressure on the grid is not optimally handled, power outages or grid instability may occur, which adversely affects the consumer experience.

(Wasson, 2023)

The grid stress analysed in this work is the grid stress due to production exceeding consumption. To mitigate this, several solutions exist as seen above. (Cf. Supra p.8) Those solutions will be developed in the next chapter.

Chapter 14: Solution

We have seen above that grid stress can be a real problem. Moreover, with the increase of photovoltaic installations at home, the problem of production not corresponding to the demand or, in this case, not corresponding to the demand at the time of production, is increasing.
To better manage energy flows, the best method is to store the excess electricity produced by the solar panels to release this electricity later.
As seen above (Cf. Supra, p.8) different storage techniques exist, all having their particularities. However, they are not all ideal for the storage of excess energy.
The different storage technologies are divided into three subcategories:

- Mechanical storage
    - Hydraulic storage: As we mentioned before (Cf. Supra, p.8) this solution requires a location with the possibility to store large amounts of water at a sufficient difference in altitude.

    - Kinetic energy storage: This storage solution is as we have seen before (Cf. Supra, p.9) more suitable for energy regulations purposes than storage purposes.

    - Compression storage: Just like hydraulic storage compression storage is not applicable for domestic storage purposes due to geographic constraints. (Cf. Supra, p.9)

- Electrochemical storage
    - Storage using hydrogen: Hydrogen production could be a good option, but the installation needed to produce it would require decentralising it and using it for multiple buildings or even a whole city. This would make it difficult to make it available in the short term. (Cf. Supra, p.10)

    - Electrochemical batteries & Circulating batteries:
      Batteries are at this moment one of the best methods for energy storage for small installations thanks to their flexibility, a good discharging time at nominal power and a storage system power which can vary from 0 to 100Mw. (Cf. Supra, p.11)

- Electromagnetic storage: As seen in the bibliographic research chapter (Cf. Supra, p.12) this solution due to the short storage period is not suitable for our problematic.

- Thermal storage: Thermal storage could be a good solution however compared to other solutions here above it is not the best solution because there are a lot of energy losses. (Cf. Supra, p.12)

Following this we can see that the batteries are one of the easiest solutions available at this moment on the market to store excess energy and release it when needed. A lot of solar suppliers are already offering domestic energy batteries as storage modules in their offers to complete photovoltaic installations with it. On average those batteries have a capacity between 7 and 10 kWh. This is sufficient for a home installation when we know that a household's energy consumption is on average equal to 9.6kWh a day. (Solvarly, 2023) However, in Belgium, a photovoltaic installation produces on average 12.1 kWh a day and this production capacity is going up to 20.5 KWh on an average spring day. (Paul, 2022)
This difference in capacity is not lost but as we explained before it is reinjected on the grid while it could be stored to avoid stress on the grid during the peak production periods.
To this end, bigger batteries would be an optimal solution.

When looking at our environment we are using batteries in a lot of our daily usage objects: cell phones, computers, cameras, electric bikes, etc. However, none of them has a large battery which could be an optimal solution to store electricity produced at home compared to domestic home batteries.
None, except maybe one.

In 1991 General Motors launches a fund to develop a new electric car, the EV1. The EV1 has been sold in 1117 units between 1996 and 1998. However, it has not been a great success and the brand did stop the production of the car in 2002 after two versions and 6 years after its release.
Shortly after, in 1997 Toyota will release the Prius the first hybrid car being commercialised on a large scale. During the first year, it will be sold in more than 18.000 units only in Japan. The Prius is until today the best-sold hybrid vehicle in the world.
Following those events, a lot of constructors have spent a significant budget on research for electric cars. The Nissan Leaf is one of the best examples. It came out in 2010 and it was for a decennium the best-sold fully electric car. (Voiture Electrique, 2021)

A lot of households in Belgium have at least one car at home with an average of 1,06 cars per household (STATBEL, 2023). In Belgium, the total amount of private cars equals 5.947.479 of which 71.651 (1,2%) are fully electric and 375.107 (6,31%) are hybrid cars. This means 7,5% of the private cars in Belgium have a battery. (STATBEL, 2023) This percentage is going to grow continuously during the coming years with the government pushing towards zero emissions vehicles. The European Parliament acted in 2022 with a ban on sales of new petrol and diesel cars from 2035 onwards. This decision has been taken to make sure all cars on the road in 2050 are carbon neutral. (European Parliament, 2022)

Those data and political decisions show us the high potential of an interaction between a photovoltaic installation and an electric car.

The technology making this interaction possible is already existing and is called V2G for Vehicle to Grid. Standard car chargers are only going one way from the grid to the car to load it. V2G makes it also possible for a car to unload to the grid when needed. This technology gives the possibility to an electric car and its battery to be used as a mobile energy storage source for the grid just as a portable battery which is used to load electronic devices when not connected to the grid.
In other words, V2G technology brings a new component to electric grid management by using the batteries of electric vehicles as buffer batteries to smooth operations. In this way, the batteries are storing the energy during overproduction periods with low demand and releasing afterwards when it is needed. (Cf Supra, p.19)

In order to understand all the factors (internal and external) influencing the V2G technology it is important to perform a strategic analysis of it.

i. Strategic Analysis

Five Forces of Porter Model

1. **Potential development of substitute products**
   Concerning the substitution products of the V2G technology, it is necessary to consider the substitution products for the use of an electric car battery as an energy storage solution for households. As we have seen earlier, many storage solutions exist, however only batteries are easily applicable to the desired use here due to their flexibility and the fact that they are compact compared to other solutions. If we compare the domestic storage batteries already on the market, we realise that as seen above the domestic battery has an average storage capacity of 14kW which is on average more than 5 times smaller than a 100% electric vehicle battery. However, regarding this bigger capacity, it is important to keep in mind it will not be fully used in order to keep energy to be able to move the car. (Cf. Supra. p.20)
   However, it is important to mention that storage technologies are evolving fast and that consequently, other adequate solutions could arise in the market by then.

Considering the different elements above we can say that the threat of substitutes is moderate but could be higher in the future.

2. **Bargaining power of suppliers**

When analysing the bargaining power of suppliers, it is important to consider the two types of suppliers of this technology.

First, car manufacturers are offering electric vehicles with V2G technology in their product line. The manufacturers have a strong pressure lever because they could regulate access to the technology by including it as an option or not on their vehicles. Which could give them the option to control access to V2G technology.

It is important to consider another type of supplier who also has some lever pressure on the technology. Those are the providers of electric charging stations. Indeed, if the charging station is not able to support the two-way charge exchange, benefiting from a vehicle with this technology will not be of much use. Moreover, charging station suppliers can add additional functionalities to their charging stations to optimise the transfer flows in both directions.

Therefore, the bargaining power of the suppliers is high.

3. **Potential entry of new competitors**

V2G technology is a technology that has been emerging in the mind of many manufacturers for a few years now, only some of them have already integrated it on some of their models (Nissan, Kia, Hyundai, etc.) while others are strongly interested in it given the strong growth potential of the technology. Moreover, the electric vehicle market is a fast-growing market, all manufacturers are interested in it and invest heavily in research to improve the technology of electric vehicles.

As a result, and when analysing the different points seen above (Cf. Supra p.21), the threat of new entrants competing with the brands already with this technology on their models is quite high.

4. **Bargaining power of customers**

To answer the question of customer bargaining power it is first important to identify the customers. The customers of the V2G technology are the owners of electric vehicles and solar panels. To this, we must add the potential customers who are the people wishing to install solar panels and/or invest in an electric vehicle. Those customers are interested in this technology to reduce their recharging costs, but also to generate additional income by losing less of the energy they produce. In addition, another type of customer indirectly interested in this technology is the electrical network management companies because as

seen above (Cf. Supra p.50) it allows them to better respond to fluctuations in demand and production peaks.
Currently, the demand for V2G technology is still limited, which means that the negotiation power of customers is moderately low.

5. **Rivalry among existing competitors**
   If we analyse the intensity of competition between the existing companies, we realise that it is still moderate since the incorporation of this technology in vehicles is still recent. The market is still in development, but it has a strong potential for growth, so the competition in this day is moderate. (Cf. Supra p.21)
   However, when this technology will be available to individuals and on a wide range of vehicles, the intensity of competition will be high.

SWOT Analysis

In order to analyse the different strengths and weaknesses of this technology we performed a SWOT analysis based on the information collected previously. (Cf. Supra)

- **Strengths**
  First of all, the V2G allows the transformation of the use of the electric vehicle. In addition to being a mobility tool for people and physical goods, it allows vehicles to be mobile energy storage units.
  Indirectly, the V2G technology allows reducing greenhouse gas emissions. This is by limiting the loss of renewable energy not consumed by redistributing it later in time or elsewhere.
  By using existing infrastructures (electric vehicles), V2G technology reduces the cost of energy storage. The use of vehicles will also allow a faster amortisation of the vehicle thanks to a diversification of its use.

- **Weaknesses**
  The biggest weakness of the V2G technology is the fact that it is a recent technology that is not necessarily mature at the technical and legal level (it is not yet possible for individuals to benefit from this technology).
  As we can see on the graph here below the share of vehicles with batteries is still low in the passenger cars fleet in Belgium with 446.758 electric and hybrid cars which corresponds to 7.5% of the total amount of passenger cars. Even if this figure is low, we can see that it tends to grow over the year and it will probably continue to strongly increase.

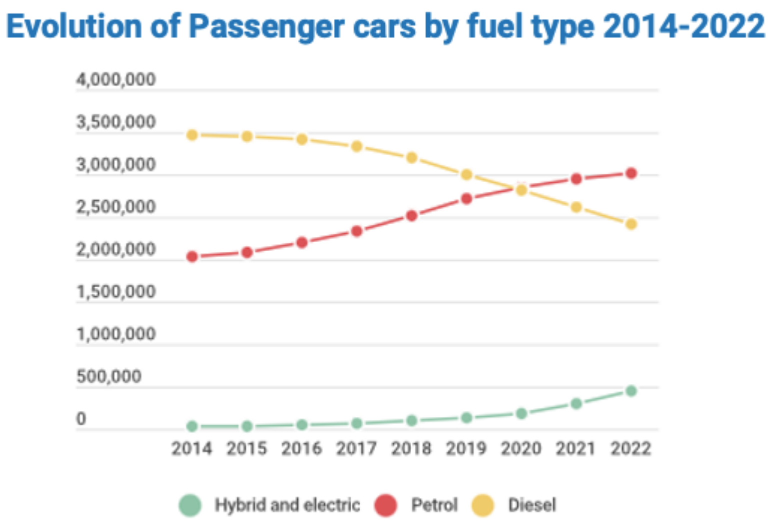

Figure 12: Evolution of Passenger Cars by Fuel Type 2014-2022 (Statbell, 2023)

Strongly linked to the last point, the moment when the solar panels produce the most at home corresponds to the moment when the vehicles are not connected to the domestic electrical network because the households are not at home at that moment.

A major weakness that does not only concern V2G technology but the field of electric vehicle charging, in general, is a lack of uniformity between charging outlets. However, this will soon disappear with the regulated standardisation of the recharging plugs at the European level.

An important point for the V2G user is if the use of the technology wears out the batteries early. A lot of research has already been done on this and as we have already seen above (Cf. Supra p.22) this does not affect the life span of the battery; it would even be a question of an increased life span. However, this remains to be verified over time with daily usage.

Finally, as the technology is not yet available, other forms of storage such as domestic storage batteries have already taken market shares.

- **Opportunities**

  The biggest opportunity of this technology is the constantly growing share of electric vehicles in the proportion of vehicles on the road in Belgium. Moreover, according to the European regulation seen above, thermal vehicles will be banned from sale by 2035, which increases the number of potential users.

  V2G can be used in combination with other forms of storage to make storage flexible both in capacity and location.

  Using the vehicle as a storage solution will allow the creation of new business models by rethinking our approach to mobility.

- **Threats**

  A threat that comes up often is the cyber threat to the grid of the V2G technology. Many specialists see vehicles not only as mobility tools anymore but also as computers on wheels. By making two-way communication even more possible, it adds a hacking factor to the network that can generate blackouts or other threats. (Latief, 2023)

  A second threat could issue from the regulations around this technology. If a proper regulatory environment is not made up by the concerned authorities, this could become a serious threat to the massive implementation of V2G.

  Finally, a last threat is regarding the total number of vehicles. We saw earlier (Cf. Supra, p.53) that at the moment each household has on average 1,06 cars. With the continuous changes regarding climatic regulations, for example, this figure could decrease reducing the potentially available storage capacity. However, this threat should be taken with caution while the number of cars is strongly linked to economic growth which should remain steady.

PESTEL

The PESTEL analysis allows us to perform a strategic analysis of the V2G technology by considering and analysing political, environmental, social, technological, economic, and legal factors.

- **Political**:

  Governments have several pressure levers of action that can have a strong impact on V2G technology.

  First of all, subsidies can be issued to help and motivate both private and professional actors to install and use the technology. Apart from subsidies governments can also issue tax exemptions/reductions which are just as interesting.

  A second point on which governments have the power of action is the environmental policies which if well-developed can strongly motivate or even force the installation of solutions that reduce greenhouse gas emissions. As we saw earlier, by storing the energy produced sustainably, this energy will not be lost and will avoid overproduction by other more polluting facilities such as fossil fuel power plants for example. In addition, government policies have already been put in place at the European level to prohibit the sale of new fossil fuel vehicles which is promoting electric vehicles or other alternatives. (Cf. Supra, p.53) In addition, policies play a key role in setting safety standards to ensure that the adoption of V2G technology is safe.

- **Economical**

  The economic factor is a heavy point in the analysis; indeed, several points can motivate both the final consumers of installing it and the companies developing the technology.

  The first one is the initial investment which can be high and slow down the installation by households but also the development and research costs for the vehicle manufacturers and the energy suppliers adapting their networks. However, as with many technologies, initial installation costs tend to decrease over time as the technology develops and adoption increases.

  Another important economic factor is the savings that the technology allows end users to benefit from it. By using a tool that the user already owns (the electric car), they do not have to invest in a storage tool such as a home battery. The electric car also has another function, it gives the possibility to the consumer to use it to move. Moreover, this technology allows, as seen above, for end users as well as for energy suppliers, a reduction in energy costs.

  Furthermore, as already mentioned above, this will also impact the economic structure by redesigning the role of households who will be able to sell the energy stored in their batteries when they want to, which will affect the pricing of energy, which suppliers will have to adapt to.

  (Cf. Supra, p.37)

- **Social**

  Consumer consumption habits have been changing in recent years. Consumers are turning to more sustainable lifestyles which include mobility and therefore the use of electric vehicles. If the consumer is convinced that the adoption of V2G technology allows him to reduce his impact on the environment and therefore his production of greenhouse gas emissions, this would be beneficial for V2G technology. However, it is important that the user has confidence and sees real benefits when he uses it, otherwise, he will probably be less interested in investing in it.

  It is also important to mention that the mobility needs are different from one user to another. Consumers who drive a lot of kilometres need the full capacity of their battery to cover the distances they need to cover. As a result, these are users who are less likely to use V2G technology.

  This shows us that it is important to identify the needs of the users to offer them a solution adapted to their daily mobility and energy needs.

- **Technological**

  Storage technologies are evolving rapidly, as is the case with V2G. Technical advances are needed to improve storage capacity, transfer speeds and improved durability. The arrival of smart grids also allows to optimise and improve the performance of storage technologies.

  In addition, technological advances are driving down the cost of storage solutions as the technologies are evolving and new ones coming on the market.

  As mentioned earlier (Cf. Supra, p.21), for the technology to be widely adopted, it needs to be compatible with the different vehicle models and brands. This implies a standardisation of the charging ports and the communication protocols between the vehicles and the charging stations. In Europe, this problem tends to disappear thanks to the European policies which are aiming for high standardisation. (De Oliveira, 2022)

  Finally, it is also important to guarantee optimal security to minimise the risk of technical problems that could cause problems such as fires due to short circuits or even data leaks as mentioned above in the SWOT analysis. (Cf. Supra, p.56)

- **Environmental**

  As already mentioned several times, V2G technology aims among other things at reducing greenhouse gas emissions by optimising the use of renewable energy sources, which in this case are photovoltaic installations. In addition, it allows the reduction of electricity losses during peak production periods by using the energy produced and not used during off-peak consumption periods. This reduces the use of polluting production facilities such as fossil fuel plants. (Cf. Supra, p.48)

  It is important to mention in this point that the production of batteries has a strong impact on the environment due to the materials used for their production as well as the energy needed for it. The production of a battery alone represents between 35 and 41% of the carbon footprint of the production of an electric vehicle. However, the technology will allow for a wider range of uses for EV batteries, which will spread the negative effects of battery production over a wider range of battery applications.

  Besides the production, the recycling process of EV batteries is a problem (in Europe only 5% of lithium batteries are recycled) even if this problem should tend to disappear soon thanks to research to create a recycling chain for EV batteries. As the first electric cars produced are reaching the end of their lives, they are generating more electronic material waste. It is therefore important to take this point into account in our analysis. (Fournier, 2021)

- **Legal**
  The main points to consider when analysing the legal aspects of V2G technology are the safety and usage standards that need to be put in place by competent legal institutions. In Belgium, the regions are in charge of the energy sector and are responsible for setting the legal framework of the technology. (Cf. Supra, p.17)
  Besides this, it is important to define the responsibilities of each of the actors when using the technology. This can be done with a contract containing the terms and conditions of the interaction between the user and the energy provider to avoid a "who is responsible" problem in the future.

As seen before the major problem regarding the V2G technology is the fact an electric car is not always connected to the photovoltaic installation when the production is at its peak. (Cf. Supra, p.48)

The strategical analysis shows us this same issue as a major one along with other points like cyber security and the regulations framing the technology which have yet to be analysed and implemented.
However, the strategic analysis shows us also the positive points of implementing this technology for the final user as well as for the energy suppliers and of course the environment.

In order to deal with the issue of storing energy when the production capacity is at its peak it is important for the vehicle and so the battery to be connected to the grid. To achieve this, it is necessary to rethink the way we are interacting with our cars and thus reorganising mobility.

Chapter 15: Reorganisation of the Mobility

In the previous chapters, we analysed solar energy production trends as well as consumer consumption trends. However, we could see that those did not necessarily correspond. Indeed, as we have seen, the peak of production takes place during the day, while the consumption takes place mainly in the evening and late afternoon when the households go home. Therefore, self-consumption is not optimal, and a large part of the energy produced is sent back to the grid unless the consumer has a domestic battery at home. However, a domestic battery is expensive, and we found that another product which we use every day could be a good alternative to this product, the electric car.

In the previous chapter, we have seen that just like the consumption that does not take place during the day and a car is mainly connected to the home grid at the end of the day and during the night. In order to be able to use the electric car as a domestic battery it is necessary to connect it to the electrical grid of the house with a photovoltaic installation during the peak production periods. Therefore, it is necessary to rethink the mobility of electric vehicles. We will therefore analyse how to adapt this mobility to the production but also how to discharge the vehicles once charged efficiently without leaving the vehicle without enough battery for the daily trips.

i. Charging the Battery

As mentioned before (Cf. Supra, p.48) solar panels are producing energy during daylight hours and all the seasons even if the production is higher during spring and summer. Moreover, solar panels are producing as well but with a lower production during cloudy days.

The solar panels are thus producing from sunrise till sunset but with the highest production rate being located on average between 11 AM and 4 PM. This is the period where solar irradiance is reaching a power of on average 1.000 per square meter during sunny days. (WAARE, 2021)

Nowadays most people around Belgium and more broadly in Europe are charging their cars at home and their offices. Those home chargers mostly are regular chargers with an AC power between 3 and 7 kW, and Rapid chargers with an AC power located between 11 and 22 kW. Next to those chargers, other types of chargers are also existing: Fast chargers (AC 43 kW), Fast chargers (CCS. 50 kW), and Ultra-fast chargers (CCS. > 50 kW). However, those chargers are mostly public chargers and thus not applicable to our problem. When looking at the graph here below we can see that Belgium is one of the countries in Europe having the most charging points (6^{th} place) however when comparing to the Netherlands we can see that Belgium still has a lot of work to do. The graph also shows us the high presence of normal and rapid chargers in the public chargers around Europe, together those types of chargers are representing nearly 85% of the total installed chargers. (Virta, 2022)

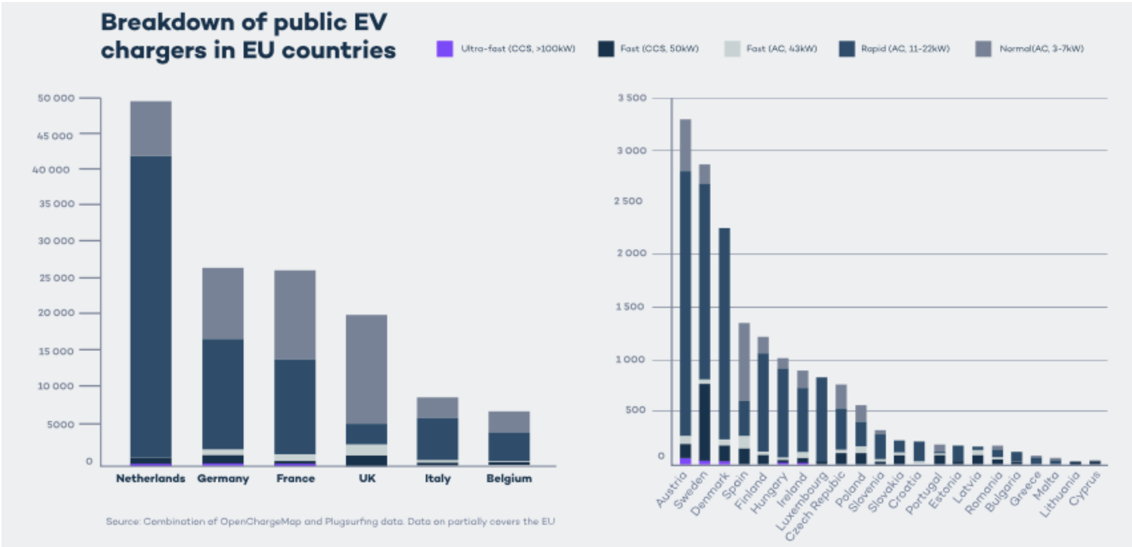

Figure 13: Breakdown of Public EV Chargers in EU Countries (Virta, 2022)

When comparing those charging trends with the data collected in our quantitative survey, we can see that this trend is confirmed. People are mostly charging their car at home with 80% of the people who answered charging their car at home, 20% at their work location, and 0% charging it on the street.

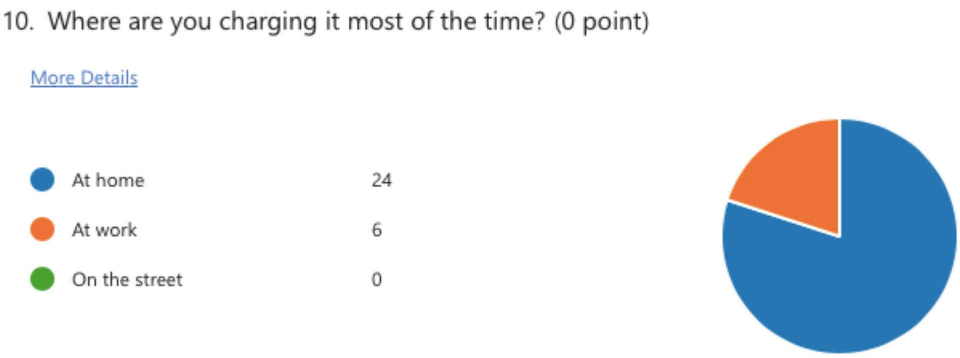

Figure 14: Charging Locations Repartition by Usage (Appendix 3)

The fact the amount of people charging their cars on the street is low is probably due to it is not yet well developed in Belgium. Moreover, most of the people who answered are not living in Brussels where most of the public charging points in Belgium are located next to other major cities in Belgium. This is mostly because public chargers are more expensive than charging the car at home or the workplace. (Virta, 2022)
However, this is a good point for our hypothesis, while people charging their cars at home and having solar panels as well will be able to use the V2G technology.

The rate of people having both solar panels and a car with an electric battery (fully electric or a plug-in hybrid car) is not very high out of the 82 persons who answered the survey only 24 people did have both. Despite this figure being low it is supposed to grow during the coming years thanks to the regulations, the incentives, and other changes of mindset regarding energy use and production in consumer's minds.

If we analyse the periods when people are charging their cars, we can see there is work to be done to motivate the users to charge their cars during production hours. Among all the people owning a car, a lot of them (62%) are charging their cars during night hours and evening hours. During the day 18% is charging it in the morning, 20% in the afternoon, and 24% during the evening. The rate of people charging their cars during the late morning hours and the afternoon should increase to maximise the storage of energy produced during peak production hours. (Appendix 3)

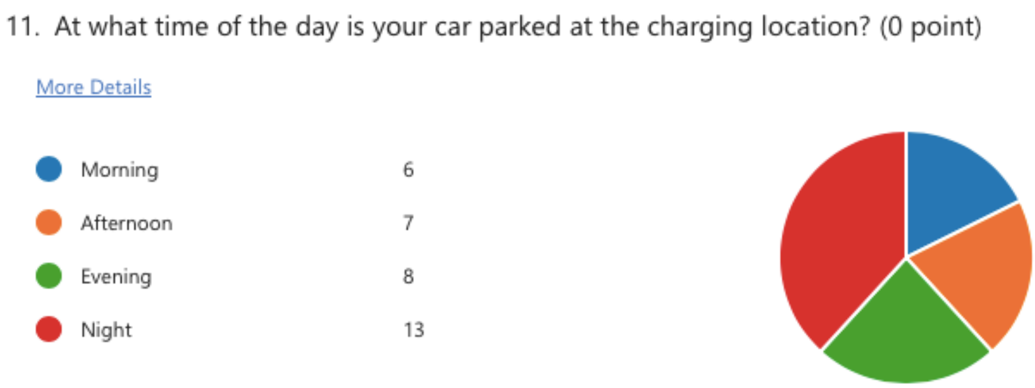

Figure 15: At What Time of the Day is Your Car Parked at the Charging Location? (Appendix 3)

As seen in the results of the survey we can see that the target population (who have solar panels as well as a car with a battery) is motivated to use their electric battery and therefore their vehicle as a storage solution. In fact, 79% of the respondents having an electric car would not mind using their vehicle as a storage solution.

In order to increase the number of cars connected to the home grid during peak production hours the car owners must be at home during those hours and not use their cars.

In order to achieve this, we could imagine making use of remote working habits which have since the end of the pandemic strongly evolved.

In 2021 in Belgium, 41% of the total active population was working remotely at least one day a week. It is important to mention that not all jobs are compatible with remote working and thus connecting the car to the home grid. This percentage is nearly the highest ever excluding the period during the Covid pandemic when remote working was mandatory.

In 2017 17% of the active population was working from home at least one day a week, 22% in 2019 and 33% in 2020 before the pandemic started. In 2020 during the pandemic, this number was at its highest with 48% of the active population in Belgium working from home. When looking at the amounts of days working from home for people doing remote work, we can see on the graph that the majority of the employees are performing at least 3 workdays from home. Those figures are from 2020 before the pandemic, it is possible that since the pandemic those habits have changed. (FOD Mobiliteit en Vervoer, 2021)

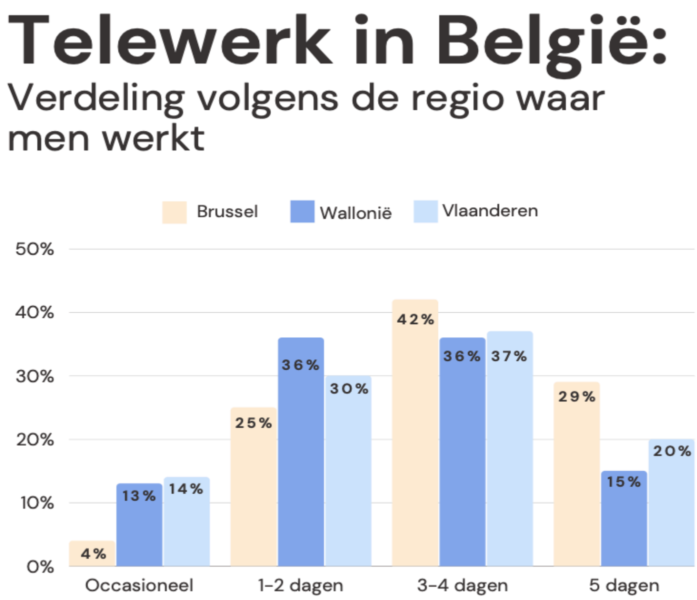

Figure 16: Remote Work in Belgium: Repartition depending on the Region (FOD Mobiliteit en Vervoer, 2021)

Based on those remote working habits in Belgium we can imagine that the solution could be based on this concept even more when we know that remote working is increasing.
We could rethink the way of remote working by motivating employees of working from home on sunny days to store the produced energy in their cars while working. Day-a-head meteorological previsions give the possibility to plan the days we are working from home some days ahead. With the flexibility and consent of the employer, this could be an optimal solution.
The governments could even motivate companies to follow this by giving subsidies or some tax decreases. The cost of those decreases might be covered by the overall savings they will allow (i.e., investments needed to increase the grid capacity).

It is also important to mention people who have an electric car which is not a company car. By diversifying the use of the car this would possibly make the investment more interesting while it would spread the costs of purchases on multiple uses of the car. This is even more relevant when we know that a car is stationary around 95% of the time. (Cf. Supra, p.19)

Both the willingness of authorities to encourage a functional mix within urban areas and the financial attractivity of the energy communities might strengthen the interest in using car batteries to store temporary excesses of electric production. For example, a factory using its solar production capacity during the week might be very interested in selling its energy to neighbours with EV cars without the cost of using the network during holidays or weekends.

ii. Discharging the Battery

When the battery is charged a new question is arising. What to do with the energy produced?

- The first idea could be of driving and consuming the produced energy while driving. However, not everyone is driving that much, and the energy could be used in another way as well.

- Another idea would be of leaving the car connected to the grid and thanks to the V2G technology use the stored technology to power the house consumption during the hours when there is low to no production with solar panels and as seen before those are the hours where the consumption is often at its peak. We know that the energy stored in the battery can largely sustain the consumption of an average household whit its storage capacity (Cf. Supra, p.53) this would mean that the battery would still have most of its battery charge when the charging cycle during the day would start again.

- We could as well imagine using the energy stored in the battery by releasing it on the general grid during peak consumption hours so that the energy produced during the day can be consumed as well by the people in the neighbourhood who do not necessarily dispose of such capacity. This would be done by just leaving the car connected to the home grid.

- Finally, an idea that could be interesting would be moving the car to high-consumption or high-energy storage facility locations when the battery is full. Those locations could be merged with free access to coworking spaces to motivate people to bring the energy they produced and sell it. During the survey, we asked if bringing the energy produced at home and stored in the batteries of the car would be a problem for the users. 75% answered they wouldn't mind bringing the produced energy to such facilities or consumption points. When asking them which third-party location would seem a good place to bring the stored energy a lot of them answered places like supermarkets, shopping malls, or similar consumption locations.

However, some other interesting locations were also mentioned like:

- Using it to charge a neighbour’s car.
- Bring it to a second residence, camping, or hotel.
  Those locations are mostly located far from the house which is the production location. This means the energy stored would be completely or mostly used to get to this place. Therefore, this proposition is seen as irrelevant.

The main idea here would be to sell the energy to third parties of the grid. When asking the population who answered the survey most of them would appreciate or think they would maybe appreciate selling this surplus of energy. This is even more relevant when we in a previous question asked if they were satisfied with the reinjection rate their energy provider was providing them. On this question, more than half of the people who answered (60%) were not satisfied.
This is interesting because it shows us the potential interest of people to be able to decide to whom they want to sell their surplus of production.

Those third parties could be various, some of the locations mentioned by the respondents like the camping, hotels, etc. Those are located too far away from the production location and all the energy produced will probably already be consumed to arrive at the final destination.
Using it to power neighbours’ consumption points, those could be various and go from powering the general consumption of the house to charging the car from a neighbour. This could be an idea when the neighbour doesn’t have a solar installation but has an electric car. In this case, the technology used is not Vehicle to grid but vehicle-to-vehicle. This technology however is not ready now and still has to be developed further mainly due to the fact all car brands are not using the same charging technologies so an interaction between different brands could be problematic. However, in the future, this could be a good option.

The most relevant discharging points which were also mentioned by the respondents are locations such as supermarkets, shopping centres, etc. Those locations could be good discharging points while a lot of people are coming at least once a week to those locations (mainly the supermarket). While the car is being discharged the user can benefit from the facilities located nearby.
We could also imagine the combination of those discharging locations with co-working spaces where people would come when their car is fully charged. When their car is being discharged and in exchange for a small percentage of the reselling price those users could benefit from the infrastructures provided in the coworking space for free. Those infrastructures could provide a proper

workspace (desk, second screen, WIFI, etc.) but also secondary advantages such as free coffee and water, a gym or even a janitorial service.
In order to make it also attractive for people not working or not able to work nearby those discharging points, the attraction points (supermarkets for example) could offer them reduced prices in the shop. Those discounts would be given if the users are bringing the electricity at the moments when the locations need the energy for example when the electricity of the grid is at a high price.

The duration of discharging is depending on multiple factors such as the size of the car battery and its charging level; The power output which is depending on both the car output and the output capacity of the (dis-)charging infrastructure.

This discharging process based on the factors here above will strongly vary from time to time and from vehicle to vehicle and could take a few dozen minutes to several hours.

Next, it is important to think about where the energy would go. We thought already about locations to bring the different users together and use only one big infrastructure but if the energy is just reinjected on the grid without any energy management behind it would not advance us.
Different options are feasible.

- A first option could be reinjecting it directly on the grid at the location where the cars are discharged. This option is as mentioned already before, not ideal while we are just relocating the issue to another geographical location. We could imagine motivating the users to discharge their cars at these locations only at peak consumption periods, but this is not always feasible for the users while those periods (Cf. Supra, p.48) are periods where they are mostly home.

- Another idea could be using the energy directly at the location where the cars are discharged. Supermarkets for example are big energy consumers due to the multiple fridges and freezers which are powered on continuously to maintain the products at the right temperature. We could easily imagine other locations with high electricity consumption industries where the discharged energy could be used directly when discharged. However, this brings us again to the same problem where the discharging and thus the possible use of this energy will not take place at the moment when it is mainly needed. During these periods the car will be back home with its user. (Cf. Supra, p.48)

- For some years now a lot of research is made about super batteries and battery parks. Belgium is one of the leading countries regarding this technology with some battery parks already installed and some of the largest in the world under construction. In Antwerp for example the company Nyrstar started the construction of a super battery. This battery will be one of the largest in Europe. Its size will be equivalent to 24 shipping containers. The 25 MW battery will thanks to its capacity be able to power some 100.000 households during an hour. The main objective of this battery would be to improve the stability of the electricity grid in the area by storing electricity when the demand is low and releasing it when there is high demand. (Carter, 2022)
  Such a battery could be a feasible option with a reduced storage capacity compared to the one mentioned here above. We could imagine installing a super battery on the discharging location which would store the energy released by the cars connected to the infrastructure. During these periods the battery will charge itself and during periods with high energy needs the battery would discharge itself and inject the energy to the infrastructures located nearby which are needing this energy or even on the grid.

- Finally, an option which could be imagined is joining this discharging location with a charging location. The energy brought by the users with their cars would be used by the users coming to charge their cars. This could even be connected with a super battery to make it possible for people to load their car on the discharged energy even when nobody is discharging. However, this option could be a problem due to the fact not a lot of people are charging on the go or in public charging locations. Most users are using those charging facilities only when they are on a long journey and need to charge their car to arrive at their destination. This was confirmed in the results of our survey. Where we saw that most of the time people were charging their cars at home, followed by charging the car at their office. (Appendix 3)

It is clear here that creating local discharging hubs would be an optimal solution to manage the discharging process of electric cars. However, it is important to make those discharging hubs attractive to go to. In the different points here above, we are mentioning some interesting locations to combine those discharging hubs with like supermarkets, shopping centres, coworking spaces, etc. It is possible to imagine multiple locations being combined with the discharging points. The most important point is that it allows the users to stay long enough and to combine this with another activity so that besides the financial attraction of reselling their surplus electricity there is another motivation to come and unload their vehicle somewhere else than at home.

Recommendations for future research

Attraction Pool Business Plan for Discharging Locations

We have seen in the last chapter of this thesis that a good idea to discharge the energy produced at home and stored in the batteries of an electric car would be the creation of discharging hubs. At those discharging hubs the car owners will be able to discharge their cars in return for financial retribution.

Next, it is important to motivate the users to come to those discharging hubs. We mentioned some ideas for combinations of activities to motivate users to come to those locations. We could imagine combining it with supermarkets or consumption locations where people are coming multiple times a week. We could also imagine joining those discharging points with coworking spaces. We saw thanks to the survey that at the moment around 75% of the electric cars (mostly in Belgium) are leased/company cars this means that the interest in coworking spaces for this public could be very high. (Appendix 3)

Combining this, as mentioned in the last chapter, with a super battery would offer the possibility to grid managers to benefit from a stored energy capacity releasable instantly in case of high demand peaks.

We could also imagine rethinking the usage of fuel stations which will tend to disappear. Transforming those already existing locations in attraction pools could be a good switch of usage.

It could be therefore interesting to perform a proper business plan as well as a financial analysis to see if the project is viable in the short and long term.

Battery Owned by the Energy Provider.

An idea that we did not mention in this thesis but which by some experts could be a good alternative would be that the battery of the electric car is owned by the energy provider or the grid operator. In exchange for being allowed to remotely manage it, the consumer would have to keep it connected to the grid during periods fixed by the provider.

This would offer the provider storage buffers to mitigate the different peaks.

Moreover, if we look at the consumer's side, batteries owned by the energy provider would significantly lower the purchase costs of an electric car.

Production and Use of Hydrogen

We saw during the first part of this thesis that one of the possibilities of storing the surplus of production is the production of hydrogen. This hydrogen can be retransformed into electricity but the energy losses due to these successive transformations are important. We saw that one of the promising uses of hydrogen is to use it in the transport sector. Some solutions are already on the market for example cars, public transport and trucks, other research is still done but with promising results and effects on the environment. This is for example the case in the maritime and aviation sector.

Due to this, finding great usage possibilities of this hydrogen and finding good production methods would be a good thematic for future research.

Limitations and Future Challenges

This thesis is the first step in order to analyse how to mitigate energy peaks by increasing the storage and transportability of energy produced by renewable energy production methods. In the recommendation for future research, we mentioned some ideas which could be good points to further develop the problematic. In order to go further those points would be good starting points together with this thesis to start with.

At the moment the V2G technology is not well developed, only a few car brands have already the technology on some of their models and this technology is yet not well developed in Belgium and more broadly in Europe. This is mostly due to regulations that must be put in place to be sure the technology is safe for the grid and the end users.

Moreover, to be able to use this solution to try to avoid as much as possible to lose energy as well as production and consumption peaks, the user needs to have both solar panels and an electric car. Even if this is strongly increasing for the past years we have seen through scientific reviews and in our surveys that this is not the case. In our survey, only 24 respondents out of a total of 82 have both an electric car and solar panels. (Appendix 3) Next to the interaction between the car and the solar panels, it is also necessary to have infrastructures to discharge the car. As we have seen it is possible to imagine multiple solutions to do so but the proper rules and procedures must be fixed as well as building the necessary infrastructures in case it is needed.

Regarding the fact that this problem is rather recent, a lot of research is still done which is thus not yet available. To this end, quantitative research was conducted to support and add credibility to the different sources found online. However, photovoltaic installations and electric cars are as we have seen quite expensive and thus yet not a lot of people have already those in their possession or even both. To this end, it is important to use this data with caution.

Overall, when analysing this subject, a lot of information was found regarding the technology, its limits and how it could be beneficial for the grid. However, there is still a lot of work to do before it could be massively implemented as a solution to mitigate the production peaks which are resulting in energy losses as well as consumption peaks.

Conclusions

We have seen in the first part of this thesis that for some years now energy prices have been extremely volatile. Those fluctuations had different causes starting from the unbalance between demand and growth linked to an economy in continuous growth, the growing desire from political leaders to get much more green energy production and finally geopolitical events impacting the energy supply and its price.
Those fluctuations are motivating both professional and private customers to search for alternative solutions to reduce their energy costs or at least to prevent unexpected expenses.
We examined some of the solutions available including photovoltaic installations. However, photovoltaic installations can cause intermittency on the grid. This issue is also encountered by other renewable energy production methods like wind energy. This is due to the instability of those energy production methods. Indeed, those methods are depending on factors which are beyond human control like wind or sunshine.
Additionally, if we look at the production trends analysed in the previous chapters, we can see that the production peaks are not corresponding with the consumption. The consumption peaks, on the other hand, are mainly occurring when households are getting home and during extreme weather conditions (cold- and heat waves). Moreover, the production peaks with solar panels, on the other hand, are occurring on a daily base during daylight hours.
A significant amount of research has been completed to solve issues around sunlight discordance. Such research aims to aid users with photovoltaic installations in avoiding wasting the excess energy they have produced through the maximisation of their own energy consumption.

The first section of this thesis demonstrates that many energy storage options exist to increase the self-consumption variable.
Those solutions can be subdivided into four main categories:

- Mechanical storage with hydraulic storage, kinetic energy storage, and compression storage.
- Electromechanical storage: includes storage by producing hydrogen, electromechanical batteries and finally circulating batteries.
- Electromagnetic storage, where a magnetic field is produced by the supplied energy.
- Thermal storage, which takes advantage of the heat generated by the electricity surplus to restore it later.

We compared the different solutions and concluded that they were not all ideal. Some solutions were requiring a lot of space to install (i.e., hydraulic storage), or were too expensive. Others were more energy flow management solutions than storage solutions (i.e., kinetic energy storage). Considering this we focused on the most suitable solutions which were batteries and hydrogen production. However, regarding hydrogen production, we quickly saw with concrete examples from the present that it could be of great use for the transport sector. To this end, we analysed the use of batteries in combination with the V2G technology.

For many years now batteries have been used in electric vehicles. These batteries store the energy capable of moving a vehicle several hundred kilometres at a time before needing to recharge.

Compared to the average home battery on the market, electric vehicle batteries can be more than five times larger. In addition, the batteries of electric vehicles are often not used up to their full capacity. And as we have seen electric vehicles are not used a lot during the day and thus could be possibly connected to the grid 95% of the time which allows a lot of possibilities for usage.

With this in mind, the V2G technology was analysed. This is where a vehicle would be charged during the day using the energy generated by solar panels, storing that energy, before being either reinjected onto the grid or used in other installations – as analysed in the final chapter of this thesis.

Regarding the charging period of the car, we saw it would be necessary to rethink our mobility since cars are mostly situated away from properties equipped with solar panels during production hours. In this thesis, we imagined an optimisation of the remote working days by those days when the sunshine is high. This would only work if this were encouraged by the employers and the governments.

As for the discharge, some ideas were mentioned such as bringing the energy to attraction pools and discharging the car batteries there. Those attraction pools could be placed across multiple locations, like coworking spaces, supermarkets, or shopping centres. We also saw it would be beneficial to combine it with a super battery to reinject the energy brought at the periods where it is necessary.

To conclude, V2G technology could validate our hypothesis which is “Increase in storage and transportability of electricity produced by renewable production methods would mitigate energy peaks.”. However, this would only be working by considering and implementing the different points described above.

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