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Electrical energy demand analysis of electric mobility in Slovenia

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Kurzfassung

Die Elektromobilitätszahlen in Slowenien steigen und Elektrofahrzeuge beginnen konventionelle Fahrzeuge mit Verbrennungsmotoren auf dem Fahrzeugmarkt zu ersetzen. Dies bringt mehrere Herausforderungen mit sich, wobei einer der ausschlaggebenden der Verbrauch an Energieversorgung, ist. Demnach ist das Ziel dieser Masterarbeit festzustellen, in was für einem Ausmaß Elektromobilität in Slowenien genutzt wird und wie der damit verbundene Energieverbrauch abgedeckt werden kann. Dabei soll erforscht werden wie hoch der Verbrauch in einem Jahrzehnt steigen kann, wobei erneuerbare Energiequellen als Forschungsgegenstand dienen sollen.

Die für diese Aufgabe verwendeten Daten stammen aus dem ganzjährigen Elektrofahrzeug Ladungsprofil, der auf Ladestationen von einem der slowenischen Ladeinfrastruktur-Anbieter basiert. Sie wurden mit Wetterdaten aus verschiedenen Quellen und Prognosen des slowenischen Übertragungsnetzbetreibers ergänzt. Auf Basis der Berechnungen wurde die gesamte Stromerzeugung und Stromverbrauch bis 2030 analysiert und dadurch der Gebrauch an Elektromobilität und die potenzielle elektrische Energieerzeugung, gewonnen aus erneuerbaren Energiequellen, veranschaulicht.

Wir haben herausgefunden, dass sich die Kluft zwischen der Erzeugung und dem Verbrauch elektrischer Energie in Slowenien in Zukunft vergrößern wird. Die Elektromobilität wird keine übermäßige Belastung aus der Sicht des Energieverbrauchs sein, aber es wird auf die zusätzliche Last auf das Stromnetz während der Stoßzeiten beitragen. Obwohl das Windpotential in Slowenien nicht reichlich vorhanden ist, wird es nicht ausreichend genutzt und bietet eine stetige Versorgung mit potenzieller Energie für die Nutzung. Die geplanten zusätzlichen Installationen von Produktionskapazitäten für die Nutzung von Solarenergie sind sinnvoll und ergänzen die gesamte elektrische Energieerzeugung in Slowenien angemessen. Daraus wird ersichtlich, dass der Stromverbrauch für Elektromobilität in Slowenien ohne einer intelligenten Lade- und Verbrauchssteuerung verwendet werden kann.

Abstract

Electric mobility numbers in Slovenia are on the rise and electric vehicles are beginning to replace conventional vehicles with internal combustion engines on the vehicle market. This poses several challenges. One of the most obvious ones is the increased consumption of electrical energy in the power grid. The aim of the master thesis was to determine how extensive is electric mobility consumption in Slovenia and how it could be covered. We were also interested in the extent to which it could grow in a decade. With regard to the coverage of consumption we focused on renewable energy sources, as they contribute most to the overall sustainability of electrical energy generation and transport.

The data used for this task were taken from the year-round sample of electric vehicle charges on charging stations of one of Slovenian charging infrastructure providers. They were supplemented with weather data from various suppliers and forecasts from the Slovenian transmission system operator. On the basis of the calculations, we created graphs of the forecast total electrical energy production and consumption in 2030 as well as consumption of electric mobility and potential production of electrical energy from renewable energy sources.

We found out that the gap between the electrical energy production and consumption in Slovenia will increase in the future. Electric mobility will not be an excessive burden from the point of view of energy consumption, but it will contribute to the additional load on the power grid during peak hours. Although the wind potential in Slovenia is not abundant, it is not sufficiently exploited and provides a steady supply of potential energy for use. The planned additional installations of production capacities for the use of solar energy are sensible and appropriately complement the total production of electricity in Slovenia. From the point of view of electrical energy consumption, electric mobility can be established in Slovenia without the necessary use of smart charging and consumption control methods.

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Introduction

Electric mobility is gaining on its significance every year. If a decade ago it seemed like a remote concept, today the multi-million global fleet of electric vehicles shows us that it is already an established vehicle type. Rapid technological development, especially in the field of batteries, has made their usage comparable to vehicles with internal combustion engines. Electric mobility certainly has its advantages, but like any new technology, it is also encountering some obstacles that it will have to overcome if it wants to establish itself and be maintained in the long run.

One of such obstacles is shift of the energy load from petroleum-based fuels to electricity. Electrical networks need to have balance between production and consumption and an increased load from electric mobility demands a proportional increase of production. Prediction of future loads is a very important aspect a grid operator must consider. Therefore, it is essential for them to try to understand an impact of a certain consumer group in the network and its potential growth. One such consumer group are electric vehicles.

Although the networks of different countries and areas are usually interconnected, countries and their network operators strive to maintain the best possible balance between consumption and production. Slovenia is no exception.

Slovenian goals in the field of sustainable mobility are ambitious. On 12 October 2017, the Government of the Republic of Slovenia adopted the Strategy for Market Development for the Establishment of Appropriate Infrastructure for Alternative Fuels in the Transport Sector in the Republic of Slovenia. The key goals of the strategy are to limit first registrations of passenger cars and light duty vehicles that emit more than 100 grams of CO_2 per kilometer from the year 2025 onwards and to no longer allow first registrations of petrol or diesel internal combustion vehicles with a total carbon footprint of a vehicle above 50 grams of CO_2 per kilometer from the year 2030 onwards. Today, only electric cars and plug-in hybrids achieve the carbon footprint limit of 50 grams of CO_2 per kilometer (Ministrstvo za infrastrukturo, 2017).

Stated document was made on the initiative of Directive 2014/94/EU of the European Parliament and of the Council on the deployment of alternative fuels infrastructure (The European Parliament and the Council, 2014). It demanded that the member states set targets for the use of publicly available chargers in the years 2020, 2025 and 2030 within the framework of their national political framework (International Energy Agency, 2019). There are several proposals and guidelines in the EU that directly or indirectly address the issue of electric mobility. They all call for substantial reductions in emissions and increases in energy efficiency. By the year 2030, 40 percent reductions in greenhouse gas production, 27 percent increase in electricity production from renewable sources, and a 27 percent increase in energy efficiency compared to the previous decade are expected

(International Energy Agency, 2019). All three are sensibly interconnected by electric mobility especially considering that the transport sector contributes nearly a quarter, 23 percent of the world's current production-related greenhouse gas emissions.

Electric mobility is therefore an integrated part of a larger, more sustainable, and responsible ecological behavior that developed world is trying to adopt. If no measures are taken globally, greenhouse gas emissions could increase by 20 percent by 2030, and even by 50 percent by 2050. One of the biggest fears in that sense is the average rise in world temperature. In 2015, the Paris Climate Conference (COP 21), organized by the United Nations, advocated, among other things, limiting the rise in global average temperature by less than 2 degrees Celsius by 2050. Such targets call for immediate action. According to the International Energy Agency (IEA), at least 20 percent of the world's vehicles on the roads should be on electric by 2030 if the set goals are to be achieved (International Energy Agency, 2019). According to IEA simulations, electric vehicles should account for 35 percent of global sales in 2030 (United Nations, 2015).

The issue of ecological balance throughout the life cycle of electric vehicles is also important. Electric mobility fulfills its mission as sustainable only if it is powered by renewable energy sources. It is characteristic of them that they have high fluctuations in the energy supply. Consequently, it is very important for electricity network operators and planners to understand what the future electric energy demand regarding electric mobility will be as the grid will be even harder to manage with renewable energy sources connected to it. Additional infrastructure will be required as well as investment and implementation of new technologies, such as smart grids.

The purpose of our master thesis is to determine the impact that the electromobility in Slovenia has on the electrical energy demand today and to predict its future growth. Thus, we could determine what measures will be needed to make electric mobility in Slovenia sustainable.

Our goal is to create a demand analysis of electric mobility in Slovenia. We want to determine what could be deduced from the charging data of the public charging stations of a particular company and analyze it. With the help of these analyses and considering growth trend, we want to predict the consumption of electric mobility in 2030. In order to satisfy rising electrical energy consumption, we need to cover it with additional production capacities. Given the above, renewable energy sources are the most suitable for this. In the master's thesis, we therefore want to show the potential production of electricity from renewable sources in a decade, in 2030.

We will use various methodological processes in our research. We will first review the documentation in the fields of sustainable transport and renewable energy sources in Slovenia. We will then analyze the charging data of electric vehicles from company Elevat’s charging stations in 2019. We will review and analyze data and forecasts from ENTSO-E and ELES, the Slovenian electrical network transmission system operator. We will analyze European Union’s and meteorological databases so that we can determine the expected profile of solar radiation and wind forces. We then want to compare the above data and draw logical conclusions regarding the development of electric mobility in Slovenia in the next decade. For calculations, we will help ourselves with MS Office and MatLab software.

Thesis will consist of a chapter on technologies, where we will briefly present the different types of vehicles, and the specifics of electric ones. It will be followed by a chapter on the growth of electric mobility in Slovenia. In the chapter on the electricity sector in Slovenia, we will present its main characteristics, current situation, and prospects. It is followed by a chapter on charging of electric vehicles. An important part of the master's thesis is also the chapter on ENTSO-E development scenarios and scenarios of Slovenian transmission system operator ELES. In the chapter on ecological perspective, we will present how ecological electric vehicles are and how much impact each phase of their life cycle has. The chapter on solar and wind energy will focus on the possibility of exploiting both in Slovenia in the future. In the following chapters, we will then look at the charging profiles of electric cars from company Elevat’s charging stations and generalize them to a larger, Slovenian scale. Based on this, we will show the potential consumption of electric vehicles in 2030 and compare it with electrical energy production, and especially with production from renewable energy sources. In the last chapter, we will also briefly present the possibilities offered by smart charging and then conclude the thesis.

1. Technologies

1.1. Types of automobile drives

Throughout the history many types of automobile drives have been developed. Electric drives are those, which can propel a vehicle independently at least for a certain period of time. Short description of different vehicle types is presented in a table 1.

Vehicle type	Drive energy source	Drive type	Characteristics
Conventional vehicles	Hydrocarbon based fuels (diesel, gasoline, biofuels)	Internal combustion engine (ICE) Otto engine	Established Otto gasoline engine, no electric drive
		Internal combustion engine (ICE) Diesel engine	Established diesel engine, without electric drive

Table 1: Types of automobile drives (Füßel, 2017)

Hybrid vehicles	Hydrocarbon based fuels (diesel, gasoline, biofuels) and / or electricity from the grid	Hybrid Electric Vehicles (HEV) Mild Hybrid	Recuperation ability, small electric motor, small battery
		Hybrid Electric Vehicles (HEV) Full Hybrid	Larger electric motor, larger battery, ability of self-propelled electric drive
		Plug-In Hybrid Electric Vehicles (PHEV) Plug-in Hybrid	Large internal combustion engine, external battery charging possible
		Range Extended Electric Vehicle (REEV)	Small internal combustion engine for battery charging, external battery charging possible
Electric vehicles	Electricity from the grid	Battery Electric Vehicle (BEV)	Only an electric motor, no internal combustion engine, external charging of the battery
		Fuel Cell Electric Vehicle (FCEV)	Hydrogen energy is converted to electrical energy, external battery charging is not possible

Table 1 (continued): Types of automobile drives (Füßel, 2017)

1.1.1. Conventional vehicles

These are vehicles that are powered by an internal combustion engine. The history of the internal combustion engine is long, and consequently several variants are known. The most established are certainly the gasoline engines and diesel engines which are both mature technologies. The engines consist of many components, which entails the high cost of their maintenance. The current vehicle fleet consists mainly of conventional vehicles. Vehicle producers offer different variants. Internal combustion engines are powered with fuel from petroleum products and consequently subject to price changes of them. During their usage, they produce CO_2 and other greenhouse gases which is an important argument in favor of the development of electric vehicles. Drivers are most accustomed to using conventional vehicles.

1.1.2. Hybrid vehicle

The word hybrid originates from the Greek and means a mixture or something of a dual origin. By definition, a hybrid vehicle contains at least two energy converters and two energy storage tanks. In most cases, we are talking about an internal combustion engine and an electric motor and a fuel tank and batteries. Usually, the internal combustion engine fuel is gasoline.

The basic principle of hybrid vehicles is to use a combination of different drives. Different types of engines respond differently at different speeds and in different conditions of use. Electric motors are more efficient in torque building and energy use and have the ability of regenerative braking, while the internal combustion engines are better at maintaining higher speeds. If the vehicle is capable of switching between the two powertrains, it can profitably benefit in energy efficiency and driving comfort and also has a potential reduce the release of harmful gases. When we load the internal combustion engine with a light load, its efficiency is low. Hybrid drives have an ability to variably load the internal combustion engine and at times when it would be inefficient use it to help the electric motor. Electric motor can store excess created energy in the batteries for later use. Similarly, we can load the internal combustion engine to the most efficient operating point, and then drive the vehicle in combination of both drives. As a result, such a combinated drive is more efficient than solely conventional ones because it allows better usage of energy (Karle, 2010).

Depending on the degree of hybridization, we distinguish half hybrids, of which are more types, and full hybrids. The established English terms for them are micro-, mild-, full- and plug-in hybrids. We divide them according to the power of the electric motor and the number of electrical functions. There is also a division between parallel, serial and combined hybrids, which is a breakdown by a different powertrain. For cars with alternative powertrains we often use the abbreviations such as HEV, BEV, REEV or EREV, PHEV, FCEV. These abbreviations describe what type of powertrain the vehicle has and what types of characteristics it has. In the following paragraphs we will briefly have a look at the characteristics of each type of hybrid vehicle.

1.1.3 Micro hybrids

Micro hybrids are vehicles that use a 'start-stop' system. This system allows the engine to be stopped automatically when idling. Micro hybrids are not true hybrid vehicles by definition as they do not rely on different energy converters and energy storage tanks.

1.1.4. Mild hybrids

This group includes vehicles with an internal combustion engine that is assisted by an electric motor. This enables the internal combustion engine to be switched off when the vehicle is idling, decelerating or standing and rapid restart if necessary. Mild hybrids often include a regenerative braking function or assist the internal combustion engine when accelerating, but do not have the ability to use purely electric propulsion. Such vehicles are more fuel efficient than exclusively internal combustion engine ran ones. However, they are not as effective as full hybrids (Wikipedia, Hybrid Vehicle, 2020).

1.1.5. Full hybrids

Full hybrids are vehicles that can be driven independently by any of the engines or their workings can be combined. The battery used to drive the electric motor has sufficient capacity to allow it to be used as a sole propulsion motor. Different types of drives make the vehicle more flexible. At this point, it makes sense to briefly divide the workings of diferrent vehicle types according to the type of their powertrain, that is, according the operation of parallel, serial and combined hybrid powertrains.

The parallel hybrid drivetrain uses both an electric motor and an internal combustion engine to move the vehicle. Regenerative braking is used as well, so there is no need for a battery as big as in the standard hybrids. When we have lesser need for power while driving, an electric motor can be used as a generator to charge the battery. Both powertrains are connected to the shaft, which provides high efficiency of transferring mechanical power into electrical and back. Such a powertrain design performs well when driving over long distances (Mastnak, 2018).

The serial hybrid drivetrain uses the electric motor as the main driving power source. Electric motor can either receive electricity directly from the battery pack or from a gasoline-powered generator. What amount of electricity will the electric motor receive from the generator or the battery is determined by the controller in the vehicle converter. The internal combustion engine is not directly connected to the drive shaft. Usually, the internal combustion engine smaller and has lower power, because it is primarily used to charge batteries and increase driving range of a vehicle. Regenerative braking is also used. Due to the favorable characteristics of the dominant electric motor, such vehicles are particularly useful for urban driving. Such vehicles have large batteries, which is reflected in their larger mass and higher price. Their cost of production is also higher, so such a drivetrain is usually used in ships or trains instead of passenger cars.

The combined hybrid drive combines both systems. When the parallel and series drives are merged, both drive units spin the wheels at the same time as is typical for the parallel drivetrain. There is also the possibility of shutting down the internal combustion engine. In this mode of operation the propulsion power is taken over by the electric motor, as is typical for a serial powertrain operation. The combined powertrain is therefore able to take advantage of the positive features of both types of drive - in urban driving, the system behaves like a serial hybrid, and at higher speeds we take advantage of the parallel drivetrain characteristics. Due to their flexibility, combined hybrid drivetrains are dominant in today's hybrids. The generator, larger battery and power distributor are to components to blame for the high prices of this type of vehicles (Mastnak, 2018).

1.1.6. Plug-In Hybrids

Plug-In Hybrids (PHEVs) are defined by two characteristics - they can be plugged into electrical grid and charged. Another feature of theris is the ability of the battery to power the entire drive system if needed. Connection hybrids also use a combination of an internal combustion engine and an electric motor. The drivetrain can be parallel or serial. Their biggest advantage is the ability to travel a certain distance without using an internal combustion engine. For the most part, the internal combustion engine only serves to aid when the vehicle is accelerating and at higher speeds. With advances in battery technology, their autonomous range is increasing, which contributes positively to the economy and efficiency of such vehicles.

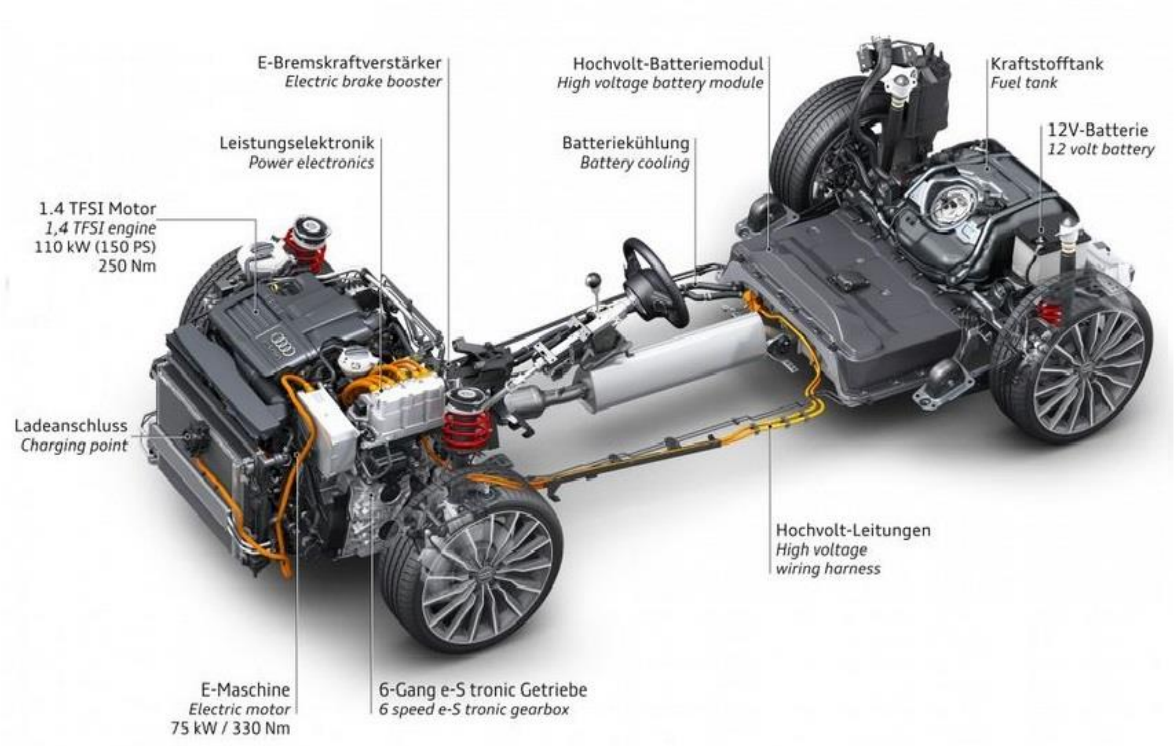


Figure 1: Hybrid vehicle drivetrain (Audi Technology Portal, 2020)

The figure 2 is showing a plug-in hybrid drivetrain. Both its internal combustion engine and its six-speed gearbox are mounted at the front of the vehicle, as well as the electronics with power electronics. We also have some space for a charging port located there. High voltage cables connect the batteries installed in the rear end of the vehicle with the components in the front. The fuel tank is also located at the rear.

1.1.7. Range extended electric vehicles

Range extended electric vehicles (REEVs) are based on previously mentioned drivetrains, with the most common ones being serial hybrids. The batteries of these vehicles are designed to be charged over the electrical grid. Such vehicles are powered by an electric motor, whilst a small internal combustion engine helps to charge the battery when it is almost empty. There are several possibilities of combining the two types of engines, but the internal combustion engine is only used for helping the electric motor in all cases. Range extended electric vehicles are therefore battery electric vehicles that have an extended driving range thanks to an additional internal combustion engine. However, such vehicles are in general subjected to the same characteristics as other electric vehicles (Mastnak, 2018).

1.1.8. Fuel cell electric vehicles

Fuel cell electric vehicles (FCEVs) are also worth mentioning here. They have a built-in electric motor that is powered by energy produced by fuel cells and can also be combined with battery power. Fuel cells use air-derived oxygen and compressed hydrogen for their operation. The final product of combustion of fuel cell fuels is water vapor, so such vehicles should be emission free. However, there are several problems that make such vehicles unpopular in the market. These problems are the storage and transport of hydrogen as an energy source, modest infrastructure and low energy efficiency in vehicles. As a result, fuel cell vehicles are widely criticized. However, technology in this area is still young and it may be that such vehicles will be more common in the future, as many studies are ongoing in this area (Wikipedia, Hybrid Vehicle, 2020).

1.1.9. Battery electric vehicles

When we talk about electric vehicles, we often mean battery electric vehicles (BEVs). These vehicles are powered solely by an electric drive. Such vehicle basically consists of three components: electric motor, battery and power electronics.

An electric motor in electric vehicles replaces the role of an internal combustion engine. This means that it must provide adequate torque and a wide range of motor rotations within its operation. From electric motors, we also expect the following features: high efficiency, sensitive speed and torque control, ability of recuperation, low weight, low volume, and a good price-performance ratio. They must be capable of operating in all driving conditions and under any load that the vehicle may find itself in (Karle, 2010). An important aspect of both the price and the performance specifications of the electric vehicle beside the battery are power electronics. They are used to properly control and regulate the electric motor. The proper functioning of the drive, as well as its efficiency and economy, depend on their operation. Ongoing research and improvement is underway in this area in order to make electric drives faster, more accurate, more robust and more efficient (Kampker, Vallée, & Schnettler, 2013).

1.2. Batteries

When it comes to electromobility, we cannot ignore the topic of batteries. Batteries are electrochemical energy storage devices in which energy is recharged, stored, and utilized as needed through electrochemical reactions (Kreyenberg, 2016). If the energy storage can be recharged by electrochemical conversion, we are talking about acumulators.

The acumulator battery is an indispensable component in conventional vehicles, its energy storage function is used when starting the vehicle and using electronic devices integrated into the vehicle when the engine is not running. It is not used for powering an engine however, since the primary source of energy for propulsion of conventional engines are conventional hydrocarbons, most often in form of gasoline or diesel fuel.

In electric vehicles, the main source of propulsion energy in electrical energy that is chemically stored in the battery. Battery technology is arguably the key to the development of electromobility. Knowledge in the field of electric motors and power electronics already has a certain tradition, while intensive research in the field of battery-powered vehicles and the storage of large quantities of energy has only recently become more popular. Today, many companies are investing heavily in battery development, as good technology in this area can mean success in many sectors, not just electric mobility.

An important factor here is also the battery price, that has lately been falling significantly, which is also the reason for the consequently more affordable prices of electric vehicles. The price of batteries today is about $ 176 per kWh of electrical energy; as early as 2025, the price is expected to halve to $ 87 per kWh, as stated by Bloomberg New Energy Finance (Bullard, 2019). In euros, this amounts to 160 € and 80 €, respectively. By comparison, the Chevrolet Bolt EV boasts istelf with 60 kWh battery, and the Tesla Model S with 100 kWh battery (Valdes-Dapena, 2019). Nissan’s model Leaf was introduced in 2010. It cost $ 35,000 with a range of 120 miles. The basic version of the Nissan Leaf in 2019 costs $ 29,000 and offers 270 miles of range. The price of this model is 27,590 €. There is also a more expensive version with a range of 370 kilometers, which is not available in Europe. Over the course of a single decade, the price of the Nissan Leaf has dropped by almost a fifth while his range has more than doubled. A similar thing happened with the prices and ranges of other EVs. Lowering of battery prices can thus mean potentially increasing the range of electric vehicles.

The usage of the battery as a primary source of propulsion energy in vehicles brings many innovations along. The most obvious is definitely battery charging. The electricity used to power the batteries of electric vehicles is produced from different energy sources in power plants. Electricity is supplied to the charging stations via the electrical grid. Therefore appropriate charging infrastructure is required for the day-to-day use of electric vehicles. Unlike the well-known and estabilished conventional gas stations intended for conventional vehicles, the charging infrastructure for electromobility in many places, especially outside settlements, does not yet provide adequate density. This brings us to the next issue of BEV - range. Until recently, this was the undoubtly most problematic aspect of using electric vehicles. Thanks to constant research and usage of new materials in battery technology, the ranges of better electric cars is now almost equivalent to those of conventional vehicles (Fußel, 2017).

Battery weight requires electric vehicle manufacturers to design these vehicles differently. Extra space is required for the batteries in the vehicle, additional body reinforcements need to be provided due to the extra weight of the vehicle, and the battery housings must be properly sealed, but still have to allow access of potential repairers. To maintain proper center of gravit of the vehicle, the batteries are either centrally mounted or slightly moved towards the rear of the vehicle. A lot of space is also occupied by elements of power electronics and electric motors. Extra space in the vehicle is available due to the absence of an internal combustion engine, fuel tank, gearbox and exhaust system. Chasis planning consists of design, selection of appropriate materials, and a series of tests to help engineers try to optimize a product so that it offers the best combination of desired characteristics (Fußel, 2017).

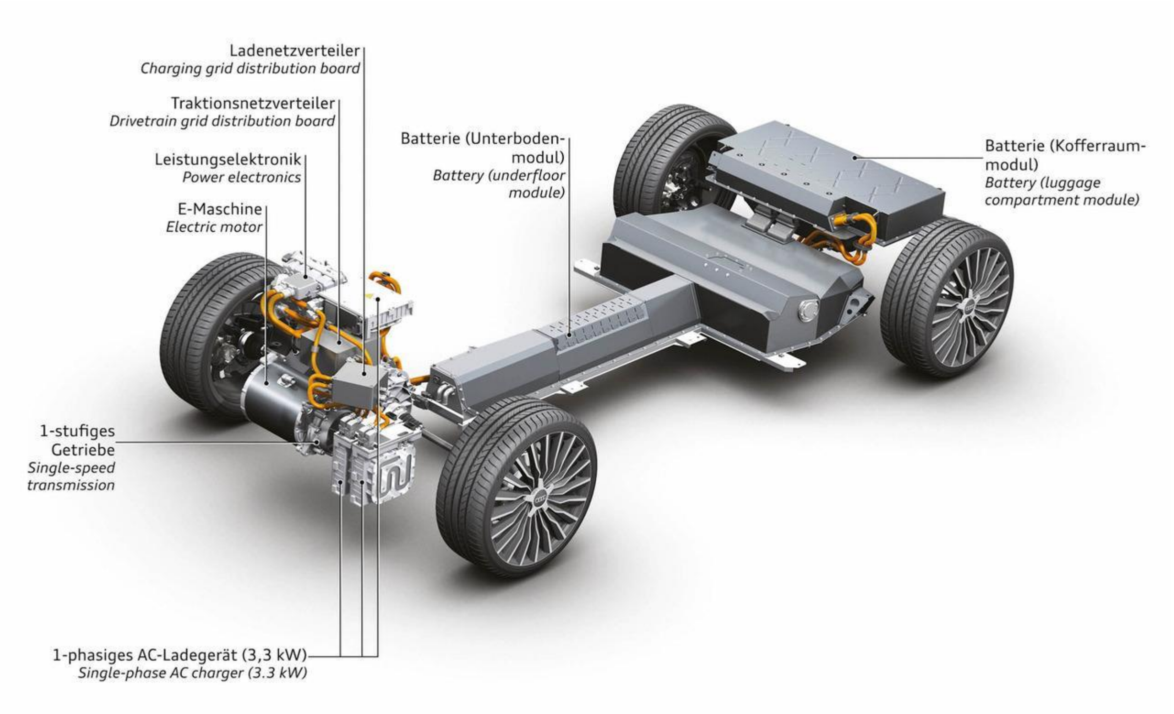


Figure 2: Electric vehicle drivetrain (Diagramchartwiki, 2018)

The figure 2 shows the electric drive of the vehicle. Above front axle we see an electric motor, power electronics, a one-speed gearbox and a charger. The battery modules are located centrally and in the back of the vehicle.

When the internal combustion engine is operating, excessive heat is released into the environment. In winter, this can be conveniently used for cabin heating. Electric motors do not heat up as much during operation and, as a result, the use of vehicle heating in winter results in significantly higher energy consumption of an electric vehicle. Like conventional vehicles, electric vehicles have an optimum operating temperature. The most appropriate environment for operating batteries is actually similar to the desired human. The cells in the batteries behave similarly to human cells, since in both electrolytic reactions take place.

It is still somewhat unclear to what extent the efficiency of electric vehicle batteries is depleting with their usage. In principle, the battery life can be divided into two parts: a calendar life that tells us how long the battery should last in case the battery would never be used, and the battery life is expressed in cycles, which tells us how many times the battery can be recharged and recharged.

Different types of batteries have become established in the field of battery technology. The most commonly used are the Li-Ion batteries. They are characterized by high voltage of their cells, high energy efficiency and low degree of self-discharging. Their problem are the high deviations of stability of the individual charge cycles, low charge and discharge currents, and the possibility of potential overcharging. Hybrid vehicles also use nickel metal hydride (NiMH) batteries. Such batteries have a lower energy density than Li-Ion batteries, but they are safer for use. Sodium-sulfur batteries have similar energy density as Li-ion batteries up to 200 Wh/kg and are very cheap to manufacture because of the use of sulfur. This technology posesses high heat losses occur during operation due to the required operating temperature of 250-300°C and can therefore only be used in systems with high performance requirements. Sodium nickel chloride batteries are also called "ZEBRA". They are inexpensive and have high energy density and are used in smaller vehicles (Fußel, 2017).

In the future, batteries will also play an important role in storing electrical energy produced from renewable sources.

1.3. Specific features of electric vehicles

We will briefly discuss how electric vehicles differ from conventional vehicles in the next section. So what are the benefits of using EVs?

- Electric drives are more energy efficient. The efficiency of electric motors can be more than 90%, which is significantly more than the 40% energy efficiency of internal combustion engines. Electric drives are also distinguished by the possibility of regenerative braking. This is the ability of the engine to act as a generator when braking, so that it can transfer some of the braking energy back to the energy storage - battery. Regenerative braking effectively helps to extend the range of electric vehicles, saving between 8% and 25% of the total energy consumed when driving a vehicle. In principle, the torque generated by regenerative engine braking alone is not high enough to completely brake the vehicle, so electric cars also need a conventional braking system. The success of regenerative braking is conditioned, among other things, by the state of charge and the temperature of the battery (Varocky, 2011). The efficiency and ability of regenerative braking also depends on the type of electric motor. Regenerative braking therefore maintains a certain amount of propulsion energy, which successfully helps to improve range and reduce consumption and pollution. It is also important to emphasize that the electric motor, due to its relatively simple construction design, wears slower and requires no or much less maintenance compared to a gasoline or diesel engine (Karle, 2010).
- Electric drives are locally free of greenhouse gas emissions. This means that they do not produce greenhouse gas emissions through the exhaust while driving. With electric vehicles, pollution occurs in power generation at power plants, that is, before it actually reaches the vehicle. It should be noted that BEVs do not pollute the air at the local level, but, like conventional cars, they still pollute the air with fine particles that are generated by braking or lifting road dust. With ICE ran vehicles, most pollution occurs while driving, ie when the fuel is combusted in the engine.
- Electric drives develop high torque even at lower rpm and cover a wide speed range. What are the power and torque of the engine? In physics, torque is defined as a vector product between crank and force, and in practice we express with torque how much force a motor can produce when rotating. The product of engine torque and speed is power. From the power of the engine we can learn how fast the engine can

produce the work. The work produced is reflected in the acceleration and speed capabilities of the motor vehicle. In practice, we want as much power and torque as possible and as light an engine and therwfore vehicle as possible. The electric motor is capable of producing such a high torque already at zero rpm that the vehicle can easily accelerate right from the standstill. Only a single-speed gearbox is required to set the speed. Internal combustion engines up to a certain idle rpms cannot develop the proper torque for propelling. For this reason, when accelerating from the standstill in such vehicles, the difference between a low wheel rpm speed and a higher engine rpm speed must be compensated by a clutch. This leads to increased fuel consumption and increased wear on mechanical parts. In a diesel engine, the torque rises slowly to its maximum depending on the rpm, and then starts to fall, so that it would not overload the engine. In order to maintain torque in the desired range, in the case of internal combustion engines, we must be able to change the gear ratio, ie the gearbox. As a consequence, the electric drive is, in this aspect, more powerful and has correspondingly high initial accelerations. Electric motors therefore allow for comfortable, dynamic driving at high torque without the need for gear changes.

- Due to lesser initial acceleration effort, electric drives have a different power consumption than conventional ones - they consume less in urban driving conditions, and more at higher speeds, e.g. on the highway. The picture for internal combustion engines is reversed - higher urban consumption and lower open road consumption. Better acceleration and a shorter reaction time when accelerating an electric vehicle in the city traffic are also beneficial for the use of electric motors in city driving. These features also help reducing urban congestions and, consequently, reduce pollution.
- Electric drives are quiet. The silence of electric drive compared to internal combustion engines means a slightly quieter environment for the driver and passengers. Even less noise outside the vehicle, especially at low and medium speeds, contributes to the quality of life of city inhabitants and other road users. In an urban environment, low noise levels can cause pedestrians and cyclists to notice an electric vehicle too late or even overlook it. For their safety, solutions are being developed such as e.g. the use of artificially generated warning sounds.
- Electric vehicles have simpler components and are easier to control and regulate. With comparable performance, the electric motor is lighter and more compact than the internal combustion engine and largely maintenance-free. Electric motors are easier to control electrically, even switching between forward and reverse driving is done electronically without a manual transmission. However, due to the high voltages and currents that need to be monitored, electric drives require more complex control electronics than conventional vehicles (Karle, 2010). In addition to the gearbox and the clutch in the electric drive, some other car parts have become obsolete such as fuel tank and fuel pump, oil tank, catalytic converter, exhaust system, starter, alternator ...

What are the disadvantages of electric mobility?

- Electric vehicles have a high price. The reason for it is largely the battery. The electric motor and power electronics have a price comparable to an internal combustion engine. Although battery prices are steadily declining, they still represent a significant downside to electric vehicles.

- Electric vehicles have a limited range and longer battery life. For the drivers, the biggest difference between BEV and ICE drives is their different usage frame. Probably the most obvious difference is the energy recharging or refueling. Charging electric vehicle batteries takes significantly more time than filling the fuel tank for the internal combustion engine driving needs. The charging infrastructure for the needs of electromobility is in many places, especially outside settlements, not yet densely arranged enough for comfortable driving experience. Current battery technologies of electric vehicles do not necessarily guarantee the equivalent driving range to that of internal combustion vehicles full fuel tank. The length of a battery charging process is also a significant difference. Filling the right amount of fuel into the tank of a conventional vehicle is not an extremely time-consuming task and even in the worst-case scenario it only takes a few minutes. It takes at least 15 minutes to charge an electric vehicle on a rapid charger.

2. Electric vehicles in Slovenia

There has been a major shift in the transport sector in the recent years. At the end of the year 2017, 1,117,935 passenger cars, 780 electric vehicles and 3,042 hybrid electric vehicles were registered in Slovenia (Ministrstvo za infrastrukturo, 2017). Awareness of the environmental burdens caused by traffic as well as the Dieselgate affair have accelerated the introduction of electric vehicles, which are expected to contribute to reducing harmful greenhouse gas emissions.

The scenarios were determined mainly using the document Strategija na področju razvoja trga za vzpostavitev ustrezne infrastrukture v zvezi z alternativnimi gorivi v prometnem sektorju v RS (Strategy for the Development of the Market for the Establishment of an Appropriate Infrastructure in the Transport Sector in the Republic of Slovenia). The document is used as a basis for determining the future share of individual vehicles by their propulsion energy type.

In the passenger car segment, the introduction of electric vehicles is the most intense since they already allow for a solid reach and a relatively affordable price. Plug-in hybrids will also be important during the transitional period. Among alternative energy products, gas fuels are also growing more important in this segment.

In the segment of road goods vehicles and road passenger transport, the situation is slightly different. In the case of short-distance transport, the proportion of electric vehicles will be significant. In this segment we can also see a significant increase in the share of vehicles on compressed natural gas (CNG), especially in mass urban passenger transport. For long distance transport, i.e. between EU countries and neighboring countries, however, battery-powered electric vehicles will not be suitable for some time due to the low energy density of the batteries, high charging powers and long charging times. In this segment, a gradual transition to liquefied natural gas (LNG) is probable in the near future. Gradual introduction of fuel cells that use hydrogen as a source of propulsion energy and, alternatively, natural gas is also possible. Hybrid technology is not particularly suitable for long-haul transportation, as the higher mass and technological complexity of the vehicle does not outweigh the savings. Diesel engines will still play an important role, more frequently using biodiesel to be in line with strategy (ELES, 2019).

The optimal scenario of the proposed Strategija na področju razvoja trga za vzpostavitev ustrezne infrastrukture v zvezi z alternativnimi gorivi v prometnem sektorju v RS foresees an increase in the share of passenger cars with alternative fuels or alternative propulsion in the entire Slovenian car fleet by 2030 to 20%. This will only be possible through the intensive implementation of the proposed measures. The scenario assumes that in 2030 every second newly registered car in Slovenia should be electric with 33% share of BEV, and 17% share of PHEV. By achieving the set goals in accordance with the optimal scenario, Slovenia would fulfill its commitments in the field of transport. Intensive scenario would make Slovenia one of the leading countries in the field of green mobility. The intensive scenario foresees a higher (37%) share of passenger cars with alternative fuels and carbon-free cars in the vehicle fleet by 2030, and an 81% share of newly registered such types of vehicles, with 79% being electric cars and 2% hydrogen cars (Ministrstvo za infrastrukturo, 2017).

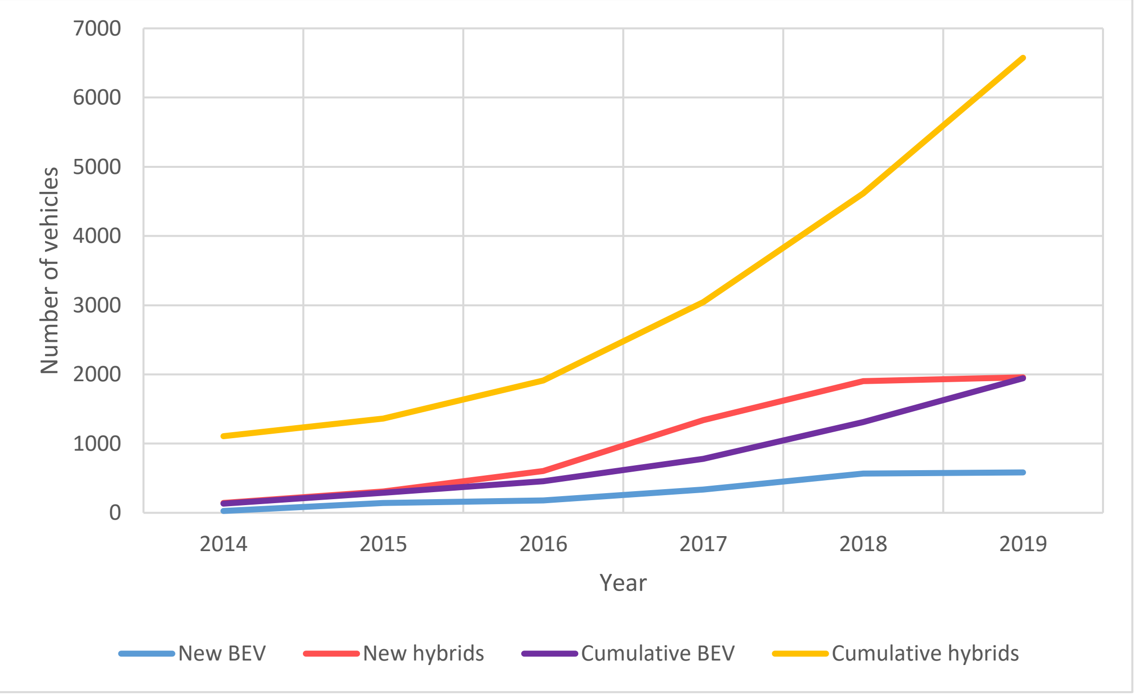


Figure 3: Growth of electric mobility in Slovenia between the years 2014 and 2019 (SURS, 2020)

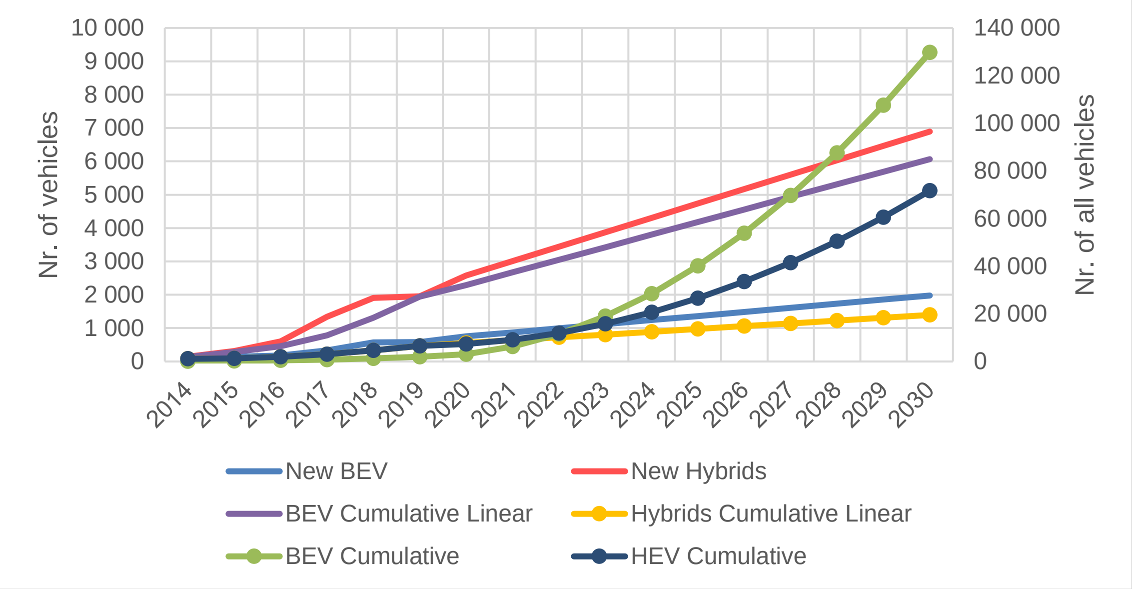


Figure 4: Electric vehicle growth trend projections (Ministrstvo za infrastrukturo, 2017); (SURS, 2020)

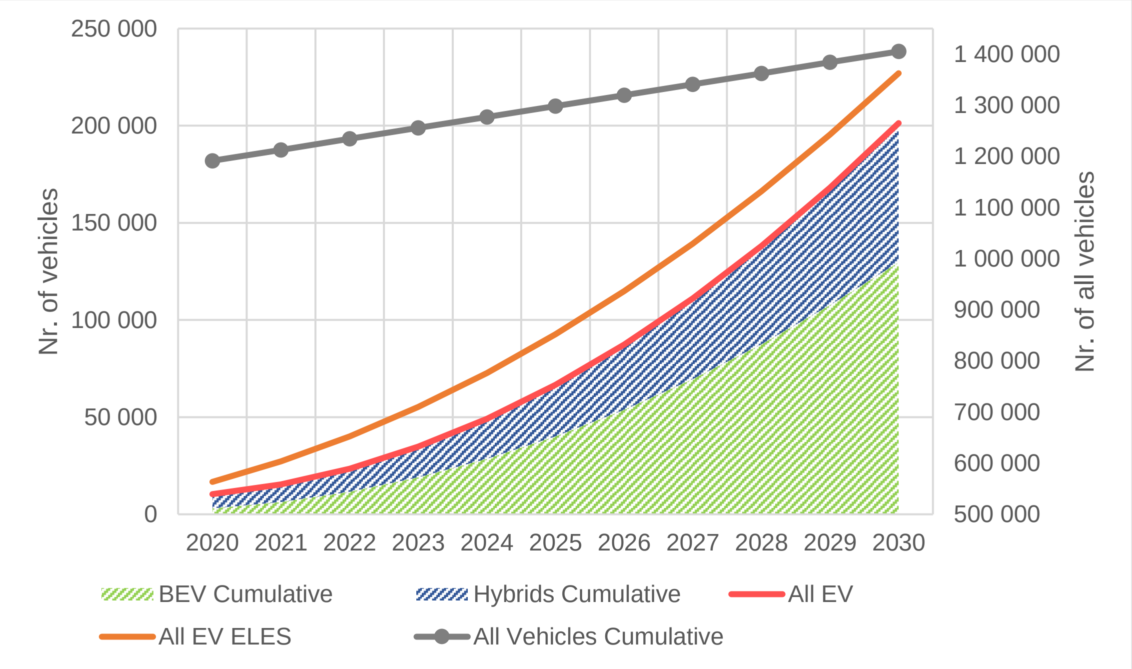


Figure 5: Extended electric vehicle growth trend projections (Ministrstvo za infrastrukturo, 2017); (SURS, 2020)

3. Electrical energy sector in Slovenia

3.1. Ownership division

Electricity production in Slovenia is divided into two pillars. The largest in terms of electricity produced is the group Holding slovenske elektrarne (Holding Group of

Slovenian Power Plants or HSE), which combines thermal power plants and hydro power plants. It represents the first energy pillar in the Slovenian wholesale market. Its share of total Slovenian electrical energy production is 56,6% with 7.119 GWh in 2018. The second energy pillar is represented by GEN energija (GEN Energy) group which combines a Slovenian owned part of a nuclear power plant, hydro power plants and a gas powerplant. GEN energija produces 29,5% of total Slovenian electrical energy production with 3.703 GWh (Agencija za energijo, 2019). Other producers are smaller, they operate both on the transmission network as well as on the distribution network.

3.2. Transmission System Operator and Distribution System Operator

Company ELES d.o.o. is a transmission system operator and is 100% state-owned. It operates the transmission networks of voltage levels of 400kV, 220kV and 110kV. Takeover points between the transmission and distribution networks are usually on the 110kV network or in the respective distribution transformer stations. In them, electricity is transformed to voltage levels of 35kV, 20kV or 10kV, which represent the voltage levels of the medium voltage distribution network, that ends with the transformer stations that supply voltage of voltage level of 230/400V to a low voltage level network to which most customers are connected. Other customers are connected either to the medium voltage level network, or to the 110kV network in cases of larger and largest clients.

The company SODO d.o.o. is the operator of the distribution system. It provides public utility services of an electricity distribution operator on the basis of the granted concession. On the basis of a contract for lease of the electricity distribution infrastructure and provision of services, the following companies carry out the distribution activities of the company: Elektro Ljubljana d.d., Elektro Maribor d.d. , Elektro Celje d.d., Elektro Gorenjska d.d., and Elektro Primorska d.d.

Most of the 110 kV network is owned by ELES, and a smaller part, mainly the power lines to the distribution transformer stations, are owned by the distribution companies. The 110 kV voltage level sets transmission and distribution networks apart.

Electricity distribution and transmission activities are network activities, which are natural monopoly activities and are therefore subject to regulation implemented in Slovenia by the Agencija za energijo (Energy Agency), which was established in 2001. This includes, i. a, the economic regulation of the activities of the distribution system operator. The network charge is set separately for the transmission and the distribution network for a regulatory period of three years. Customers connected to the network pay the price for using the network in addition to consumed electricity itself. Such limited pricing is a broader term than network charge and covers both network charges for the transmission as well as distribution network and accessories for the operation of the system (Vojsk, 2016).

3.3. Development

The development of the electricity grid is based on the ten-year development plans for the transmission and distribution system of electricity, which the electricity operators must produce every other year and obtain the consent of the minister responsible for energy. The plans must be developmentally coordinated and take into account national strategic orientations in the field of energy. When designing electric operators, they use the prescribed uniform methodology, which considers long-term consumption forecasts, analyzes of expected operating states, level of reliability of power supply to users, economic analysis and also the possible locations of new production sources.

The starting point for network planning in the system operator's development plan is to analyze the situation in the transmission system. Based on the input data for the forecast of electricity and power consumption, the system operator should make an analysis of the variant consumption forecasts, also consider the methodologies of the European Association of System Operators (ENTSO-E) and its own assessment of future economic development. The development plan must include an analysis of the coverage of consumption by production resources and the adequacy of production resources, as well as an analysis to assess the needs for transmission capacities, which are the basis for defining the timing of planned investments and their financial evaluation. In the development plan, the distribution operator must analyze the period of the previous development plan, perform an analysis of forecasts of electricity and electricity consumption, and prepare an investment plan for electricity distribution infrastructure for the entire country, which must also be financially evaluated.

In the development plans for the period 2017-2026, the operators plan to invest in the electricity infrastructure worth 504 million euros into the transmission system and 1291 million euros into the distribution system (Agencija za energijo, 2019).

3.4. Energy flow

In 2018 15.003 GWh of electric energy was taken over into transmission and distribution network, which is 19 GWh more than in the year 2017 (Agencija za energijo, 2019). Takeover of electricity generated from renewable sources amounted to 5,177 GWh, which rose up for 698 GWh in comparison to previous year, the takeover from fossil fuel power plants contributed 4343 GWh, which is 196 GWh less than in the year 2017. Transmission network took over 5483 GWh of electricity from the Krško nuclear power plant, which is 483 GWh less than a year earlier.

In 2018, a total of 1050 GWh of electricity from production was taken into the distribution system (including closed-loop distribution systems).

Taking into the account half of the production of the Krško Nuclear Power Plant, domestic production of 12,262 GWh of electricity was contributed to the Slovenian electricity system. Consumption of final customers, including system losses, amounted to 14,501

GWh of electricity. In Slovenia, in 2018, domestic production covered 84.6% of final customers' electricity consumption. A total of 373.3 MW of new generation capacity was included in the Slovenian electricity system, while the production capacity of 250.7 MW was discontinued. The major change was the result of the complete shutdown of Unit 4 at Šoštanj Thermal Power Plant (248 MW) and the resumption of operation of Unit 5 at the same power plant (305 MW). In addition, a new 53 MW gas generating unit at the Brestanica Thermal Power Plant was put into operation. A further 7.6 MW of solar power plants and 0.9 MW of new hydropower plants were connected to the distribution system in 2018, and a total of 6.7 MW of fossil fuel cogeneration facilities were newly connected to closed distribution systems (Agencija za energijo, 2019).

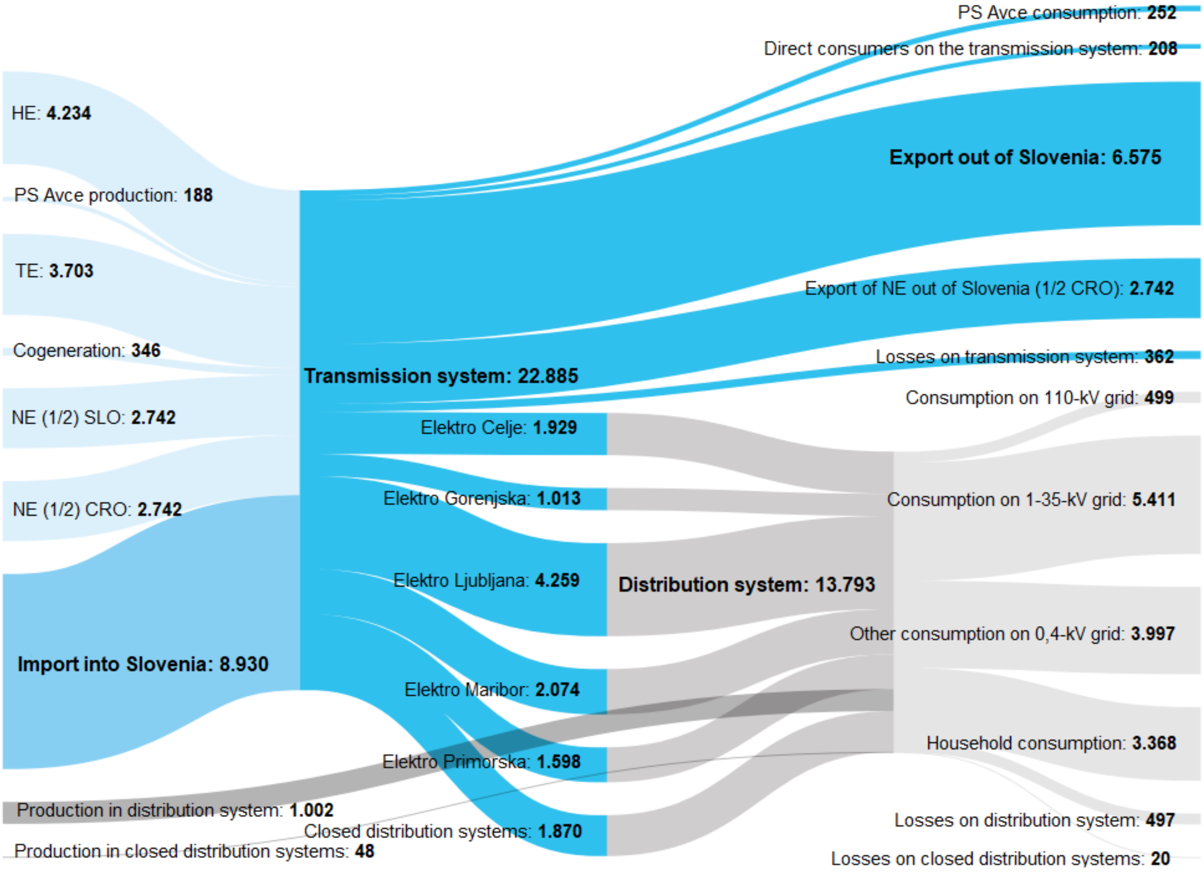


Figure 6: A flow chart of production and consumption of electric energy in Slovenian transmission and distribution system in the year 2018 in GWh. Quantities of energy are taken from the balances of electric operators based on physical flows (Agencija za energijo, 2019)

3.4.1. Larger producers

There were nine companies operating on the Slovenian electricity market in the year 2018 that have production facilities with an installed capacity exceeding 10 MW. Production companies in Slovenia differ in the way they produce electricity and the primary source of production. The companies which produce electricity from hydro power plants are: Dravske elektrarne Maribor (DEM), Hidroelektrarne na spodnji Savi (HESS), Soške elektrarne Nova Gorica (SENG), and Savske elektrarne Ljubljana (SEL).

Termoelektrarna Šoštanj (TEŠ) produces electricity in a coal-fired power plant.

Termoelektrarna Brestanica (TEB) and HSE – Energetska družba Trbovlje (HSE ED Trbovlje) produce electricity from liquid and gaseous fuels.

Nuklearna elektrarna Krško (NEK) produces electricity in a nuclear power plant.

Javno podjetje Energetika Ljubljana (JPEL) generates electricity and heat in the process of coal cogeneration.

Some of listed companies also include solar power plants, smaller hydropower plants and CHP plants as a minority share in their production portfolio. The companies DEM, SENG, HSE ED Trbovlje and TEŠ operate within the first energy pillar group of Holding slovenske elektrarne (HSE). Companies SEL, TEB in accordance with the international agreement between Slovenia and Croatia, 50% of the Krško Nuclear Power Plant, operate within GEN energija group. At the same time, the GEN energija group is a 51% owner of HESS and the rest of the company belongs to the HSE Group. JPEL is 100% owned by Javni holding Ljubljana (Public Holding Ljubljana).

Primary sources for production of electrical energy in Slovenia in the years 2017 and 2018 are listed in the table below. Renewable energy sources (RES) are divided between water, wind, sun and biomass, however it should be noted that water is far the most important factor of the listed ones.

Year	2017		2018	
	Energy (GWh)	Share (%)	Energy (GWh)	Share (%)
Fossil fuels	4.539	30,3	4.343	28,9
Nuclear fuel	5.966	39,8	5.483	36,6
RES water	4.048	27,0	4.783	31,9
RES wind	5,72		6,02	
RES sun	250	1,7	225	1,5
RES biomass	175	1,2	162	1,1
RES total	4.479	29,9	5.177	34,5
Total production	14.984	100	15.003	100

Table 2: Primary sources for production of electrical energy in Slovenia in 2017 and 2018 (Agencija za energijo, 2019)

As it is displayed in the table 2, fossil fuel power plants contributed contributed 28.9% to total production and Krško Nuclear Power Plant provided 36.6% of all electricity produced. Under the agreement between Slovenia and Croatia, half of the production of the Krško NPP belongs to Croatia, which reduces the share of the Krško NPP in actual Slovenian electricity production.

Jedrska elektrarna Krško (Krško Nuclear Power Plant, abbreviated as NEK) is the only Slovenian nuclear power plant. It has been in commercial operation from 1983. NEK is equipped with a Westinghouse pressurized light water reactor, which generates 2,000 MW of thermal power. The nominal capacity of the plant is 696 MW. The maximum capacity is 676 MW, the fuel is enriched uranium. It is connected to the 400 kV grid, which supplies electricity to consumer centers in Slovenia and Croatia (Wikipedia, 2020).

NEK was built based on a self-governing agreement between the former Yugoslav republics of the SR Slovenia and the SR Croatia, each investing half of the funds. The plant was originally planned to operate until the year 2023 but based on the good condition of the reactor vessel and the findings of the nuclear industry on the lifetime of reactors, it extended the planned closure to the year 2043. Agreement on some controversial issues that have accumulated during the operation of the nuclear power plant, especially after the independence of the Croatia and Slovenia was covered by an international agreement signed by the representatives of both governments on December 19, 2001.The National Assembly of the Republic of Slovenia ratified the treaty and entered into force in March 2003. The agreement stipulates that both partners share the produced electrical energy. NEK operates on a non-profit basis. Electricity production costs are covered by the two partners.

Thanks to its operating characteristics, NEK covers the base load all year round. In addition, as a reliable source of active and reactive power, it is an important base for the power supply system as part of the European Network of Transmission System Operators for Electricity (ENTSO-E). It is an important factor in stabilizing critical operating and voltage conditions, especially during major transients within the ENTSO-E.

The operation of the power plant between two outages is called the fuel cycle. During an outage, part of the spent fuel is replaced by fresh fuel, preventive overhauls of equipment are carried out and parts are replaced, the integrity of the material is checked, monitoring tests are carried out and corrective action is taken if necessary (Nuklearna Elektrarna Krško, 2020). Such overhauls are performed at NEK regularly every 18 months and last about a month. At such times, the power plant is shut down and does not generate electrical energy.

In 2017 and 2018, NEK produced 5,966 and 5,483 GWh of electricity, half of which (2,983 and 2,742 GWh) for the Slovenian market.

The Termoelektrarna Šoštanj (Šoštanj Thermal Power Plant, abbreviated as TEŠ) is Slovenia's largest thermal power plant. With an installed capacity of 779 MW, it on average generates one third of the country's electrical energy and covers more than half of their consumption needs during the crisis situations. The average annual electricity produced ranges between 3,500 and 3,800 GWh. Its energy production also covers the thermal needs of the surrounding areas. The average annual production of heat for district heating in the Šalek valley is between 400 and 450 GWh. For limited annual electricity and heat production, they use between 3.4 and 4.2 million tons of coal and about 60 million Sm^3 of natural gas.

The agreement for the construction of the first unit of the Šoštanj thermal power plant was already adopted in back in 1946. In 1956, the construction of two units was completed, each with a capacity of 30 MW. In 1960, a 75 MW unit 3 was built and in 1973 a 275 MW unit 4 started to produce electricity. In 1978, in accordance with the growing energy needs of the region, 345 MW of Unit 5 was put into operation. The total installed capacity of TEŠ thus increased to 755 MW and represented at that time the largest electric power facility in Slovenia.

The decision to build 600 MW Unit 6 was made in 2004, which from an ecological point of view, meant the continuation of ecological remediation, which began with great concern for the environment back in 1983. The purpose of Unit 6 was to gradually replace technologically outdated and economically unprofitable units 1, 2, 3, and 4. Unit 6 consumes about 30 percent less coal for the same amount of energy produced and with the same amount of energy produced, 30 percent less CO_2 than with the other units of TEŠ is emitted. The construction of the replacement Unit 6, which began its pilot operation in June 2015, reduced the level of environmental pollution, improved the quality and energy efficiency, and enabled the plant to comply with international best available technology standards. Other units were gradually shut down - unit 1 in 2010, unit 2 in 2008, unit 3 in 2014, unit 4 in 2018. Unit 5 was gradually restored and updated and in 2018 it started producing electricity again at 305 MW after being shut down for three years. Two 42 MW gas units also operate at TEŠ. In 2017 and 2018, TEŠ produced 3,909 and 3,698 GWh of electrical energy (Termoelektrarna Šoštanj, 2020).

Important rivers for electrical energy production in Slovenia are Drava, Sava and Soča. Hydro power plants on the river Drava have threshold power of 587 MW, and in 2017 and 2018 they delivered 2,312 and 2,913 GWh of electricity to the grid, respectively. Drava has characteristics of the high mountain rivers with the highest flow of water in the late spring and early summer, while the lowest flow can be expected in the winter. In terms of the size of the periodic mean annual flow, Drava is Slovenian most watery river; the flow below the confluence with the river Pesnica exceeds 320 m_3/s (Čehić, 2007). It has 8 hydroelectric power plants, the largest of which is 136 MW hydro power plant Zlatoličje (Dravske Elektrarne Maribor, 2020).

Hydro power plants on the river Sava have a threshold power of 276 MW, and in 2017 and 2018 they delivered 745 and 942 GWh of electricity to the grid, respectively. Sava is a middle mountains river with two typical flow peaks (in spring and in autumn). It is the longest river in Slovenia. It has 8 larger and several smaller hydropower plants.

Hydroelectric power plants on the Soča River have a threshold power of 137 MW, excluding Avče pumped storage power plant, and in 2017 and 2018 they delivered 396 and 378 GWh of electricity to the grid, respectively. The Avče pumped storage power plant has a power of 185 MW and a production capacity of 180 MW; in 2017 and 2018, it produced 271 and 188 GWh of electricity while in its production regime, respectively. The Soča River is a coastal river, as it has the highest flow during the period of winter rain and spring snowmelt in the Alpine region. It has 5 large power plants.

In total, in 2017 and 2018, Slovenian hydropower plants delivered 3,725 and 4,421 GWh of electrical energy to the transmission system. Smaller power plants delivered 323 and 362 GWh of electrical energy to the distribution network in 2017 and 2018, respectively (ELES, 2019).

The share of electrical energy produced from hydropower and other renewable energy sources varies from year to year according to hydrological and other conditions, as well as to the volume of investments in the construction of production units for the use of renewable sources. In 2018, the share of renewable sources amounted to 34.5% of all electrical energy produced in Slovenia, which is almost five percentage points more than in the year before, which largely coincides with water energy usage (Agencija za energijo, 2019).

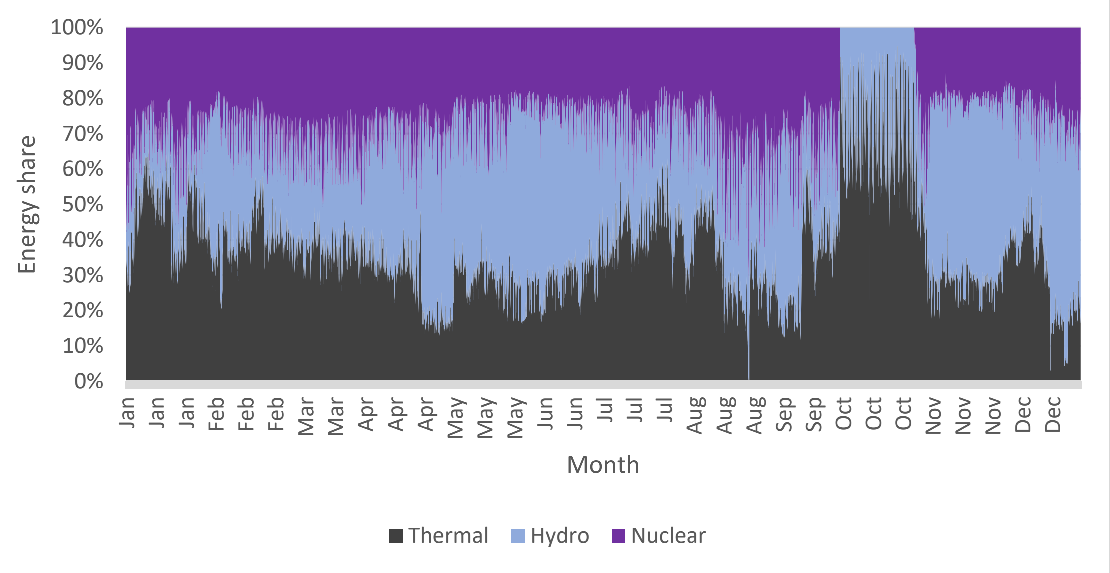


Figure 7: Primary sources for production of electrical energy in Slovenia in the year 2019 (ELES, 2020)

Figure 7 is showing primary production sources of electrical energy in Slovenia in the year 2019. As it can be seen, Krško nuclear power plant was put out of production in October and underwent a regular overhaul, which is scheduled after every 18 months of usage. It lasted for almost a month and included changes in fuel, various inspections, maintenance work and updates (Nuklearna Elektrarna Krško, 2020). Production facilities in Šoštanj thermal plant were recently expanded in 2018. On July 6, 2018, Unit 4 unit was shut down due to wear and tear and ecological, economic and technological unacceptability. On August 16, 2018 Unit 5 started to produce electricity again. It did not operate in the previous three years, and after its ecological rehabilitation and obtaining all permits, it was again synchronized to the grid. The installed capacity of Unit 5 is 305 MW, and in 2018 it produced 385.1 MWh of electricity. Unit 4 production in 2018 was 491.6 MWh (Termoelektrarna Šoštanj, 2020).

The electrical energy production from scattered production sources connected to the distribution network is becoming increasingly important. These are mainly small hydropower plants, solar power plants, biogas power plants and industrial facilities for cogeneration of heat and electricity. Compared to 2017, the generation of electricity from scattered sources increased by 7.5%, mainly due to increased electricity production from small hydropower plants and fossil fuels cogeneration (Agencija za energijo, 2019).

3.4.2. Support schemes

In the year 2018, 937.9 GWh of electricity was generated from power plants integrated into the support scheme. The support scheme is intended to promote the production of electricity from renewable sources (RES) and in the efficient cogeneration of heat and electricity (CHP). The amount of electricity produced from these power plants has been declining since 2016. Production at solar, biogas and biomass plants declined slightly on an annual basis, while production at hydro, wind and CHP plants increased. Compared to 2017, biogas production decreased the most, by 11.5%, with hydroelectric production having the highest growth in 2018 with 14.9%. The overall balance of production of the power plants included in the support scheme is negative compared to 2017. In 2018, these power plants produced 0.7% less electricity than in the previous year.

3.4.3. Renewable energy sources

The use of renewable energy sources in Slovenia is bound by the national goals imposed on the country by its membership of the European Union. By 2020, Slovenia must achieve a 25% share of RES in final gross energy use, out of which a 10% share in transport sector. When designing a country's energy and environmental policies, it is important to consider that RES, in addition to being a state commitment, is also an opportunity for technological and economic development.

The Nacionalni energijski in podnebni načrt (National Energetic and Environmental Plan) sets the target value for the year 2030 at at least 27% of renewable energy sources in final energy consumption. With the successful implementation of all planned policies and measures by the year 2030, the following can be achieved: 43% RES share in the electricity sector, 21% RES share in transport. Until the year 2030, the usage of RES should rise for 3.890 GWh from the year 2017, of which 2,223 GWh will be from the increase of production of electrical energy from RES, 1,841 GWh from the consumption of biofuels in transport and the use of heat from RES will be reduced by 488 GWh. Final energy usage will decrease by 3.247 GWh in the same period (electrical energy consumption will increase by 1,246 GWh, transport use by 253 GWh, and energy consumption for heating and cooling will decrease by 4,746 GWh) (Vlada Republike Slovenije, 2020).

The share of RES in final gross energy consumption in Slovenia reached 58.7 TWh in 2017, stood at 21.5% and 12.6 TWh in 2017, respectively. This represents the total share of RES energy in the final gross energy consumption of all three energy sectors - transport, heating and cooling and electricity. This share would need to be increased by 3.5% by 2020. In order to reach the target, the greatest progress would be needed in transport sector, where the target 10% share, on which Slovenia does not have full influence, is lagging behind for 7.8%. In the heating and cooling sector, the sectoral share of RES defined in the current Renewable Energy Action Plan 2010-2020 was exceeded by 2.4% already in 2017. Slovenia is also lagging behind in the electricity sector share by 6.9 percentage points. Given the progress made over the past twelve years, which is smaller than the 2020 target, and the lengthy procedures involved in putting large energy installations into place, a target share by 2020 will be difficult to achieve. The estimated share of RES in gross final energy consumption in 2018 is 21.8%, which is 0.3 of a percentage point higher than in 2017 (Agencija za energijo, 2019).

3.4.4. Future development

In the next ten years, various investments into electrical energy production are planned in Slovenia. An additional pumped storage power plant is planned in the Drava river basin, as well as additional hydropower plants on the Sava, Soča and Mura rivers. Electrical energy production in thermal power plants will be decreasing because of omission of some worn out capacities. A negative electrical energy production balance is foreseen (ELES, 2019). Particularly difficult in that aspect are dry years, which greatly increase the potential import of electricity. Additional investment in wind energy has long been promised, but it is usually stuck in implementation. Next decade may be more favorable for wind power. By acting responsibly, Slovenia could achieve 100 MW of installed wind power, which would potentially bring more than 200 GWh of electrical energy per year (Markelj, Vončina, & Miklavčič, 2019). Solar power investments are also planned. In every way, their share of energy produced will be negligible compared to other sources of electrical energy production.

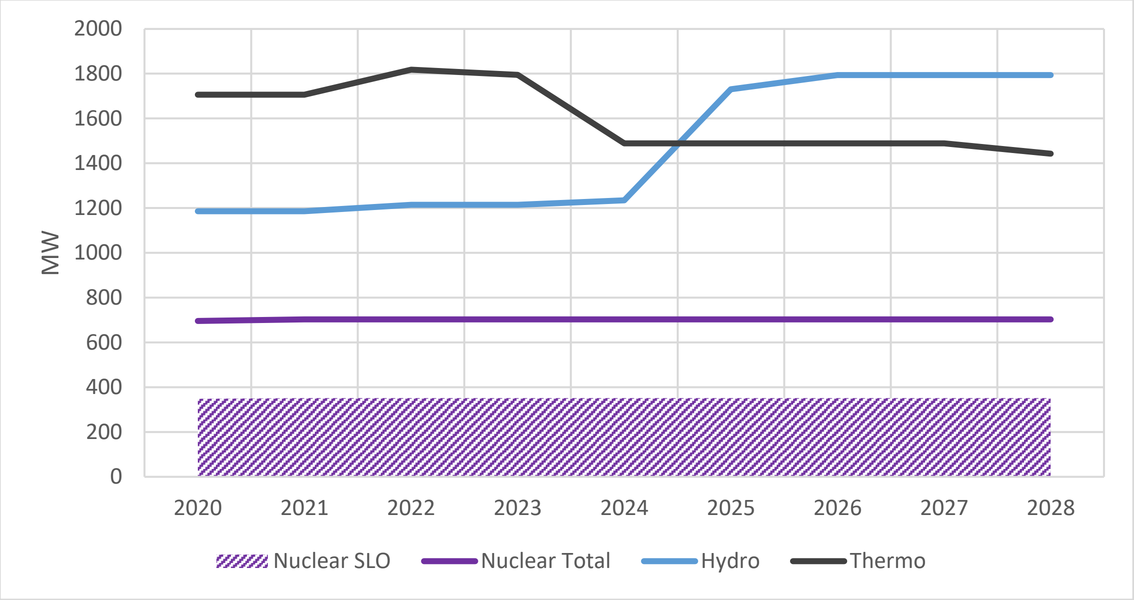


Figure 8: Electrical energy production units projection in the next decade (ELES,2017)

3.4.5. Consumption of electrical energy

Total electrical energy consumption in Slovenia in the year 2018 amounted to 14,616 GWh or 13,736 GWh without considering losses in transmission and distribution networks. Compared to the year 2017, total electrical energy consumption has increased for 58 GWh or 0.4%. Business consumption on the transmission system consists of three direct customers, which consumed 93 GWh of electrical energy, and 115 GWh of electrical energy was exported to Italy from the Vrtojba and Sežana distribution transformer stations. Customers in closed loop distribution systems consumed 1902 GWh of electricity. The Avče pumped storage power plant used 252 GWh for pumping water, which is 113 GWh less than in 2017. The losses in the transmission and distribution system amounted to 880 GWh of electrical energy, including losses due to transit, import and export of electrical energy.

Consumption of business and household customers on the distribution network was 1.8% higher in comparison to 2017, amounting to 11,374 GWh. Household customers consumed 3,368 GWh in 2018, a 1.2% increase from a year earlier. However, the consumption of business customers on the distribution network in 2018 amounted to 8006 GWh, which is 2.1% more than in 2017.

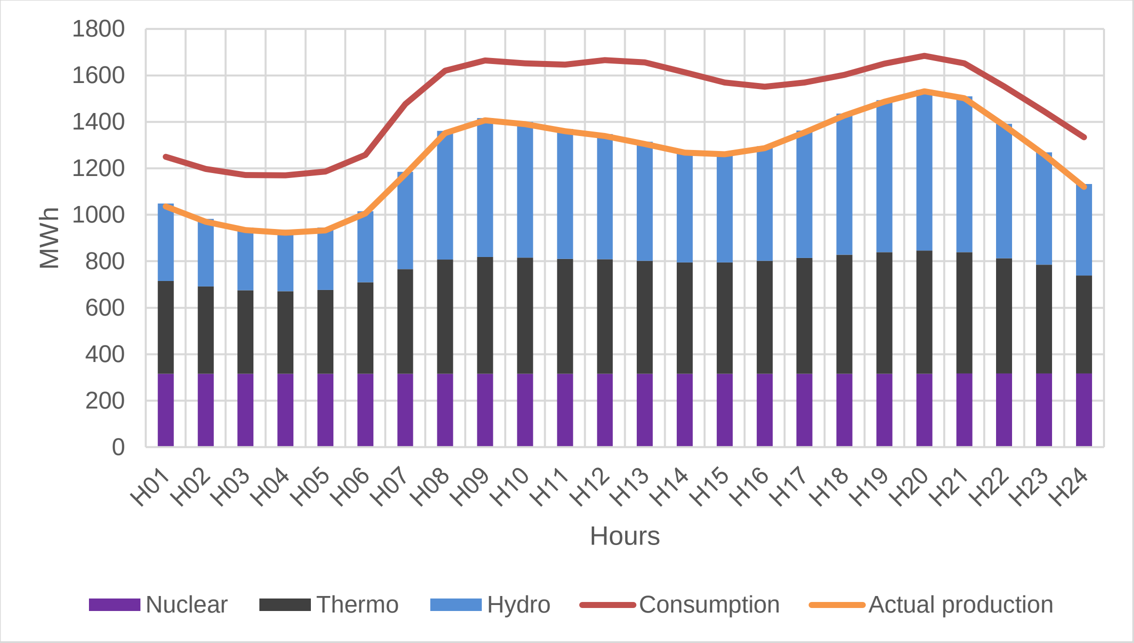


Figure 9: Average hourly electrical energy production and consumption in 2019 (ELES, 2020)

The maximum hourly load of the transmission system was 2228 MW, which is 97 MW more than in 2017. It was reached on March 1, 2018 in the 13th hour block (between 12 and 13 p.m.). Consumption of electricity, including losses in the system and considering that half of the Krško nuclear power plants production belongs to Croatia, was not fully covered by production sources in the territory of Slovenia. The coverage of Slovenian consumption by domestic production was approximately 84.6%. Total exporting transmission of electricity abroad through the transmission and distribution systems amounted to 9317 GWh, with 2742 GWh representing Croatian half of the nuclear electrical energy production. Therefore, net exports from Slovenia amounted to 6575 GWh and imports to 8930 GWh of electricity. Figure 9 is showing average hourly electrical energy production and consumption in the 2019, where we can see the discrepancy between both well. We can also see that the variable consumption can largely be covered through hydro power plants.

At the end of 2018, 955,925 final consumers were connected to Slovenian electricity system. Compared to 2017, their number increased by 5668, or 0.6%. In 2018, 689 business and 20 household customers were connected to the distribution system with a production capacity in their indoor installation. In the self-sufficiency system, 69 business and 2138 household customers were connected to the distribution system. The proportion of customers with two-rate metering also increased, who can adjust their consumption and increase it at a time of lower tariff, thereby reducing the cost of electricity supply. Thus, customers can take advantage of lower tariff times between 10pm and 6am, and on weekends and public holidays, with added control equipment, which is an additional incentive to save money. On the other hand, the number of household customers with a single-tariff measurement constantly decreases.

3.4.6. State of transmission and distribution network

The transmission network is a high-voltage power network, consisting of three voltage levels in Slovenia, namely 400, 220 and 110 kV voltage level. At the end of 2017, the total length of Slovenian 400 kV transmission lines was 669 km, 220 kV transmission lines 328 km, and the total length of 110 kV transmission lines was 2,723 km, of which 1,886 km were owned by ELES. Four different types of transformer substations with 400/110 kV, 400/220 kV, 220/110 kV and 110/35 kV transformations are set up in the Slovenian transmission network.

According to expert assessments of the life of the power elements prepared within the CIGRE WG 37-27 Working Group (Aging of the system), which predict life expectancies of different types of equipment (for switches between 40 and 43 years, transformers between 35 and 42 years, electrical equipment of transmission lines between 40 and 50 years, cables from 40 to 45 years and somewhat lower ratings for other elements). Slovenian transmission lines at 110 and 220 kV voltage levels are older, while 400 kV ones are slightly younger. The oldest 220 kV transmission line was built in 1963, the youngest in 1972 and most between 1967 and 1969. In the year 2020, all 220 kV transmission lines will be over 50 years old, except for the 220 kV line Šoštanj-Podlog.

The age of the remaining elements varies within the age range. ELES regularly renews and performs the necessary reconstructions of high-voltage power lines. Careful maintenance, necessary repairs and reconstructions allow ELES to reach the full life of the entire transmission line, up to 100 years. In the upcoming period after the year 2025, ELES will also focus its activities on the renewal of the transmission network at 220 kV and 400 kV voltage levels, which will also be one of the important activities of the development plans in the future. Transformers in the Slovenian network are also older (especially the ones at 110 kV voltage level), as many as 13 of them are older than 40 years and four are older than 30 years. The oldest transformers at the 220 kV voltage level are at Cirkovce substation, and at the 110 kV voltage level the oldest ones are at Divača and Pekre substations. It should be noted that the life of the transformers depends mainly on the degree of aging of the insulation, which depends on the temperature of the warmest part of the winding or on the load on the transformer. In recent years, ELES has established transformer monitoring that enables the determination of the remaining technical lifetime of power transformers based on the residual mechanical strength of paper insulation in transformers. By the end of 2020, the end of life expectancy of six transformers can be expected, and by 2030 they will be followed by five additional ones. ELES therefore pays close attention to the introduction of measures to extend life expectancy (e.g. optimization of the operation of refrigeration systems) where this is physically feasible and economically justifiable. Otherwise, ELES is planning a wave of replacements for existing transformers, which is also reflected in their development plan (ELES, 2019).

An increase of electric mobility could potentially cause problems in distribution network. Of particular concern is the age of some elements of the distribution network, particularly of overhead transmission lines and transformers. Especially problematic are medium voltage levels, where 49% of 20 kV lines and 85% of 10 kV lines have already exceed their intended service life. Recently, concrete transformer stations, transformer stations on concrete poles and prefabricated sheet metal transformer stations are being built. The oldest ones are tower transformer stations, of which 91% already exceed the intended service life. Fortunately, many of them can be reconstructed and repaired. A bigger problem is the age of distribution transformers. The most problematic are the 35/20(10) kV transformers, followed by the 20/0.4 kV transformers, of which 31% exceeds the estimated useful life (over 30 years) and the 10/0.4 kV transformers, of which 76% exceed estimated useful life. More than 12% of all transformers are older than 40 years. The age structure of transformers has been improving as they have been actively replaced for some time (SODO, 2018).

The weakest link are the medium voltage networks. SODO plans to invest in new medium voltage power lines due to the poor condition of the power supply equipment and increased peak power demand. By building new transformer stations, they are trying to eliminate poor voltage conditions and respond to the increased need for electrical power. In order to prevent interruptions in supply, operation of medium-voltage networks will focus on detection, control and automation, operation and cabling. The most important reason when investing into a low-voltage network is the low voltage supply quality and increased need for electrical energy (SODO, 2018). The current grid is designed for an average household consumption of 1.5 kW, and today's energy needs of households are three to four times higher (Milač, 2019). A high proportion of EV recharges will take place at home, which will further increase households' energy needs. Document Strategija na področju razvoja trga za vzpostavitev ustrezne infrastrukture v zvezi z alternativnimi gorivi v prometnem sektorju v RS (Strategy for the Development of the Market for the Establishment of an Appropriate Infrastructure in the Transport Sector in the Republic of Slovenia) predicts network reinforcements in low voltage and middle voltage level networks (Ministrstvo za infrastrukturo, 2017).

Kekec analyzed the impact of electric vehicles on the distribution network in Slovenia (Kekec, 2019). He analyzed four scenarios: the non-EV scenario and the scenarios with EV shares of 25%, 50% and 100%. He found that when an EV was purchased into a household, household electricity consumption would increase by 75%. Today's networks would find it difficult to withstand 25% electromobility, and scenarios with 50% and 100% electromobility would probably be too ambitious. In their case, distribution lines would be overloaded and the material prematurely aged. Because they are designed for a particular voltage level and consumption, an increase in transformer size would also be required. Even under 100% load, the distribution network model did not collapse, but under such conditions the grid would not be able to operate in the long run (Kekec, 2019).

4. Charging of electric vehicles

Just as vehicles with internal combustion engines need petroleum products for their operation, electric vehicles require electricity. There are different types of battery charging for electric vehicles: conductive charging, inductive charging, changing vehicle batteries etc. The usual form of charging is conductive charging, which in practice means plugging the plug into the socket of the electric vehicle and charging the battery. Different power levels of concuctive charging are being used. The most common one is home charging, the owner plugs an EV into the grid through a single-phase socket (schucko plug), which are used in homes for energizing household appliances. Charging an electric vehicle on a single-phase outlet takes between 6 and 8 hours, usually by EV owners who are using it overnight. For the purpose of EV charging, some users choose to mount a special wallbox, but apart from minor adjustments to home wiring, the introduction of home charging does not require much effort from EV users. Although accessible to everyone, this type of conductive charging takes the longest to fully charge an electric vehicle battery. Home charging is the cheapest and the simplest form of EV charging (Usmani, in drugi, 2015).

Charging an EV while parking away from home mostly is mostly done by a higher power level of conductive charging. Vehicle is being charged on a charging station specifically designed for EV charging. Different types of charging service providers exist, such as privately owned charging stations, but these can often be publicly available. Therefore we usually speak of public charging stations. Usually, user identification is required for the electrical current to start flowing after the charging station is connected to the vehicle, which serves both as control of accessing the charging station and as control of consumption of electrical energy for the purposes of data collection and later adequate billing of the usage of charging service. Public charging can be slower or faster, and vehicle owners would the meantime, often linger in nearby facilities, be it a workplace, a shopping mall, or a public transport stop. Usually the stronger (more powerful) the charging station is, the faster will the vehicle be charged. An important factor to consider when talking about charging speed is also the fulness of the vehicle battery as they are being charged slowly during the lower and upper boundaries of the battery capacity (Schoch, 2018). The more powerful three-phase EV charging stations need around 3 hours to fully charge an electric vehicle. The higher the power consumed at the charging point, the greater the load on the network.

Fast charging stations are often set along the highways. They use direct current at high power to speed up the charging process. That allows EV users to stop for a shorter period than they would have to for a normal charging speed. In this sense fast charging stations try to emulate an established process of filling a tank of gasoline on a station. Vehicles could be charged enough in 10-20 minutes to be able to travel around 100 km.

Standardization is very important in the field of EV batteries and chargers. It is currently lacking in the field of batteries and it is somewhat more defined in chargers. US SAE International defines different charge levels according to the power of the charging station. The International Electrotechnical Commission also defines different charging methods according to the standard (IEC 62196) according to the charging speed. Depending on the complexity of the charger and its power, it differentiates between four different types. The standardization trend seeks to unify the equipment used in the North American, European and Asian markets (Wikipedia, Charging station, 2020).

A brief overview is provided in the table 3:

Method	Type	Maximum current	Charging power	Charging time
Slow charging, suitable for smaller EVs	AC	(3 x) 16A	3,7 kW (11 kW when 3-Phase charging)	11-12 h
Slow charging, suitable for larger EVs	AC	(3 x) 32 A	7,4 kW (22 kW when 3-Phase charging)	3-8 h
Medium speed charging	AC	(3 x) 32 A (up to 63 A)	7,4 kW (22 kW when 3-Phase charging) maximum 43,5 kW	3-8 h
Fast charging	DC	400 A	20 kW – 150 kW	10-20 min

Table 3: The IEC 62196 - Conductive charging standard on plugs, socket-outlets, vehicle couplers and vehicles defines several charging methods or modes (Polnilne postaje, 2020)

Directive 2014/94/EU uses following definitions:

- Normal charging point is a charging point that allows the transmission of electrical energy to an electric vehicle with a power of less than or equal to 22 kW, except for devices with a power of less than or equal to 3.7 kW, which are installed in private households or whose original purpose is not charging of electric vehicles and which are not accessible to the public.
- High power charging point is a charging point that allows the transmission of electrical energy to an electric vehicle with a power greater than 22 kW (The European Parliament and the Council, 2014).

Conductive charging is related to different types of charging stations that have evolved in the recent years and they differ not only in the type of current and charging power but also in the type of plugs and protocols they use.

In addition to inductive charging, there is also the possibility of inductive charging or charging via a magnetic field, without a physical connection. Along with a high investment, the problem with inductive charging is also its low charging efficiency. It may become a suitable option in the future. However, it may already be appropriate for specific cases of small commercial vehicles, such as small vehicles for the transport of semi-finished products in factories. A big advantage of inductive charging in the future is that vehicles in this mode could theoretically be charged while driving. A similar technology for charging vehicles while driving has long existed in conductive charging. For example, trams and trains that are in constant contact with the electricity grid. They are charged via rails or from the top via pantographs. Another simple form of EV battery charging is to replace the batteries and recharge them externally. It has been found out that for now the operation of fast battery replacement centers would be too expensive (Cimerman, 2020).

4.1. Charging stations in Slovenia

Number of charging stations in Slovenia is growing together with vehicle count. European Alternative Fuels Observatory is estimating 671 public charging stations in 2020. This number is almost certainly an underestimation. Slovenian electricity industry magazine Naš stik lists between 1.300 and 1.400 of them (Ambrožič, 2020). Calculations in our thesis were based on 1.100 public charging stations.

In March 2020, the Ministry of Infrastructure started evidencing the e-charging infrastructure, which is taking place within the EU project IDACS (ID and Data Collection for Sustainable Fuels in Europe). By the middle of 2022, a national access point, a web portal with data on each e-charging point, should be established.

The number of charging stations in Slovenia has been steadily increasing in recent years, as can be seen from the figure 10.

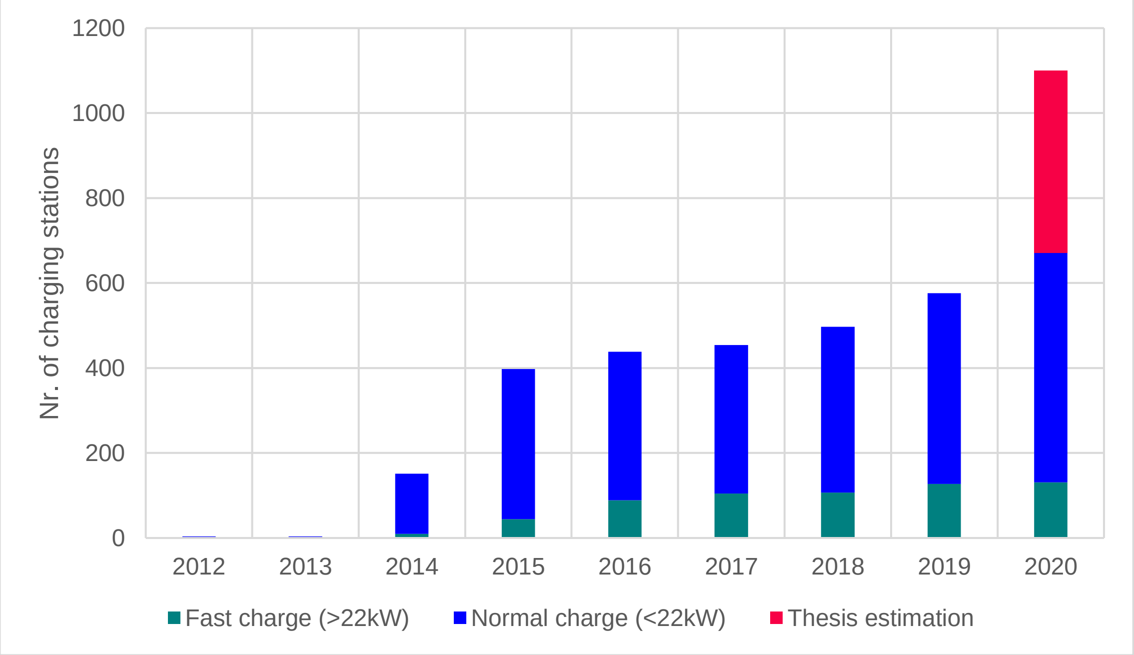


Figure 10: Number of public charging stations for electric vehicles in Slovenia and estimation (European Alternative Fuels Observatory, 2020)

The number of fast charging stations in the year 2019 is reported to be 131 (European Alternative Fuels Observatory, 2020). They are mostly represented along the highways, which is not surprising, given that Slovenian highways are a part of strategically important EU TEN-T highway network (Ministrstvo za infrastrukturo, 2017).

In 2016, the share of public charging stations was reported to be 60% (Ministrstvo za infrastrukturo, 2017). The largest share of privately-owned charging stations was represented by slow charging, low-powered charging stations (less than 3,7 kW). If we examine the data on more developed countries in the field of electric mobility in Europe, such as Norway and the Netherlands, we see that a very high proportion of vehicle charges are done at home and at work, followed by slow publicly available charging stations. A 2016 Norwegian study by the Institute of Transport Economics found that 59 percent of battery electric vehicle (BEV) owners and 74 percent of plug-in hybrid vehicle (PHEV) owners mostly charge their cars at home (Fingenbaum & Kolbensvendt, 2016). Norway is the most developed market in the world in the field of electric mobility. The rate of urbanization in Norway in 2017 was 81.87 percent (Statista, 2020)and is considerably higher than Slovenian, lying at 54.27 percent (Statista, 2020). As a result, charging EVs within one's own household will probably be even more popular in Slovenia. Therefore, thesis estimates 80% of charges to be done at home, within the household. Global EV Outlook also predicts 60 percent of charges in 2030 will be slow. Given this data, Slovenia will probably need to pay a lot of attention to changing the habits of private users and stimulate them into desired behaviors which would suit the transmission system operator. How many users could be influenced and to what extent is difficult to determine.

Public charging stations in Slovenia are represented by various providers, some of them like e.g. Elektro Ljubljana are electrical energy distribution companies, others like e.g. Petrol are energy companies. The biggest providers are Elektro Ljubljana, Petrol, Dravske Elektrarne Maribor, Elektro Maribor, Elektro Gorenjska, Elektro Celje, Elektro Primorska. There are also privately-owned charging stations, which are publicly accessible (Divjak, 2018).

According to Ministry of Infrastructure (Ministrstvo za infrastrukturo, 2017) Strategy for the Development of the Market for the Establishment of an Appropriate Infrastructure in the Transport Sector in the Republic of Slovenia‘s optimal scenario, Slovenia is going to require 1.200 public charging stations altogether in the year 2020, 7.000 in the year 2025 and 22.300 in the year 2030 to satisfy its electrical vehicle fleet’s needs.

5. Scenarios, ENTSO-E goals

ENTSO-E, the European Network of Transmission System Operators for Electricity, represents 42 electricity transmission system operators (TSOs) from 35 countries across Europe. ENTSO-E was established and given legal mandates by the EU’s Third Legislative Package for the Internal Energy Market in 2009, and was given legal powers to further liberalize the gas and electricity markets in the EU. The role of transmission system operators has evolved significantly with the Third Energy Package. With the unbundling and liberalization of the energy market, TSOs have become the meeting point for the various players to interact in the market. The members of the ENTSO-E share the common objective of creating and ensuring the optimal functioning of the internal energy market and supporting the ambitious European energy and climate change agenda. One of the important issues on today's agenda is the integration of a high share of renewable energy into the European energy system, the development of a consistent flexibility and a much more customer-oriented approach than in the past (ENTSO-E, 2020).

The ENTSO-E is committed to developing the most appropriate responses to the challenge of a changing energy system while maintaining security of supply. Innovation, a market-oriented approach, customer orientation, focus on stakeholders, security of supply, flexibility and regional cooperation are key to the ENTSO-E's agenda (ENTSO-E, 2020).

Scenarios ENTSO-E provide an overview of possible European energy futures. They have been prepared as realistic and technically sound, based on a forward-looking policy, but at the same time they are ambitious and aim to reduce emissions by 80 to 95% in line with the EU's 2050 targets.(ENTSO-E, 2017). National transmission system operators create their own scenarios that correspond the ones suggested from ENTSO-E.

Slovenian TSO ELES based their predictions on ENTSO-E scenarios from the year 2018. These are following scenarios: Distributed Generation, Sustainable Transition, Global Climate Action and European Commission Scenario EUCO 30. The scenarios have been updated for the year 2020 and are now called National Trends, Global Ambition and Distributed Energy scenarios (ENTSO-E, 2019).

Distributed Generation scenario (DG) focuses on prosumers. It represents a more decentralized development with a focus on end-user technologies. Smart technology and dual-fuel devices such as hybrid heat pumps allow consumers to switch energy according to market conditions. Electric vehicles see their highest market penetration with PV and batteries, which are widely used in buildings. These developments mean that there is a high degree of responsiveness on the demand side. Biomethane growth is strong as the links to distribution systems using local raw materials are increasing.

Sustainable Transition scenario (ST) aims to achieve a rapid and economically sustainable CO_2 reduction by replacing hard coal and lignite with gas in the electricity sector. Gas also displaces part of the oil consumption in heavy transport and shipping. The electrification of heat and transport is developing more slowly than in other scenarios. In this scenario, the achievement of the EU target (80-95% CO_2 reduction by 2050) requires rapid development in the 2040s, which must be achieved through increased technological adoption or development.

Global Climate Action (GCA) stands for a global effort towards complete decarbonization. The focus is on large scale renewable energies and even on nuclear energy in the energy sector. Residential and commercial heating systems are becoming more electrified, leading to a steady decline in demand for gas in this sector. The decarbonisation of transport is being achieved by an increase in both electric and gas vehicles. Energy efficiency measures affect all sectors. Electricity to gas production sees its strongest development within this scenario.

European Commission Scenario EUCO 30 was a core policy scenario that was created using the model PRIMES and the EU Reference Scenario 2016 as a starting point. The scenario models the achievement of the climate and energy targets for 2030 as agreed by European Council in 2014 but includes an energy efficiency target of 30%. It was prepared by a consortium led by E3Mlab, hosted at the National Technical University of Athens (NTUA), and including the International Institute for Applied System Analysis (IIASA). On the basis of the evaluation of European Commision, although no scenario allowed a direct comparison, Global Climate Action was found to be the most representative in terms of the parameters defining the scenario. However, the different methods used to derive the scenarios may lead to differences in continuity between this scenario and the scenarios developed internally. The ENTSOs will continue to work with European Commision to ensure overall consistency within the Scenario Report (ENTSO-E, 2017).

Scenarios for future electricity consumption and load on the Slovenian transmission network are designed to take into account as much requirements set out of ENTSO-E TYNDP as possible and also the scenarios from the Energijski concept Slovenije (Energy Concept of Slovenia) draft. The scenarios used in this development plan vary depending on the different parameters, i.e. rates of future economic activity, energy prices, integration rates of RES production, development of technical and technological parameters, efficiency, efficient use. Slovenian TSO ELES developed four development scenarios in which the ENTSO-E and Energijski koncept Slovenije orientations are reasonably linked (ELES, 2019).

Scenario 1 (Sc1) envisions lower growth in economic development and developments in pursuing of energy policy goals, but the results seek to approach the objectives of the Energijski koncept Slovenije. The demand for electrical energy is further increased by the extensive use of heat pumps. In the transport sector, consumption of petroleum products replaced by natural gas is moderately reduced. The deployment of electric mobility and gas fuels in Scenario 1 is estimated in terms of actual technical and financial electrical energy sources on the level of distribution network is very limited (ELES, 2019).

Scenario 2 (Sc2) predicts lower economic development growth. It considers the EU-wide targets set for the year 2030. The demand for electrical energy is further increased by the extensive use of heat pumps. It considers reduction of consumption of petroleum products in transport by gradually replacing them with natural gas, but unlike the Sc1, this scenario is more ambitious and considers the higher growth of electric vehicles. The long-term vision, which spans over a decade, considers the construction of new nuclear production in Slovenia. Sc2 goals match the ones of the ENTSO-E Distributed Generation scenario (ENTSO-E, 2017).

Scenario 3 (Sc3) predicts higher economic development growth. It includes policies and measures adopted at an EU level and in Slovenia by 1 September 2016, meaning that the legislation is strictly applied and that there is no doubt about its implementation. Sc3 is therefore designed to bring the results closer to the objectives of the Energijski koncept Slovenije. As a result of a higher GDP growth, traffic intensity is also rising, with a very high growth in natural gas consumption in transport. The Sc3 matches the objectives of the ENTSO-E Sustainable Transition scenario (ENTSO-E, 2017). In the thesis we focused on that scenario and have expanded it to match our vision of possible renewable sources energy production in 2030.

Scenario 4 (Sc4) anticipates the EU-wide targets set for the 2030 policies. It is assumed that for the achievement of the 80% EU-wide emission reduction target by the year 2050, compared to the year 1990, the production of electrical energy will require 100% national renewable energy coverage by the year 2050. Policies to promote the continued uptake of renewable energy are being implemented, creating a more attractive environment for its usage. Sc4 considers more favorable macroeconomic conditions and therefore an increasing number of heat pumps. As a result, the intensity of traffic is also increasing, in which the deployment of e-mobility is the most intensive. The Sc4 matches the objectives of the ENTSO-E Global Climate Action scenario (ENTSO-E, 2017).

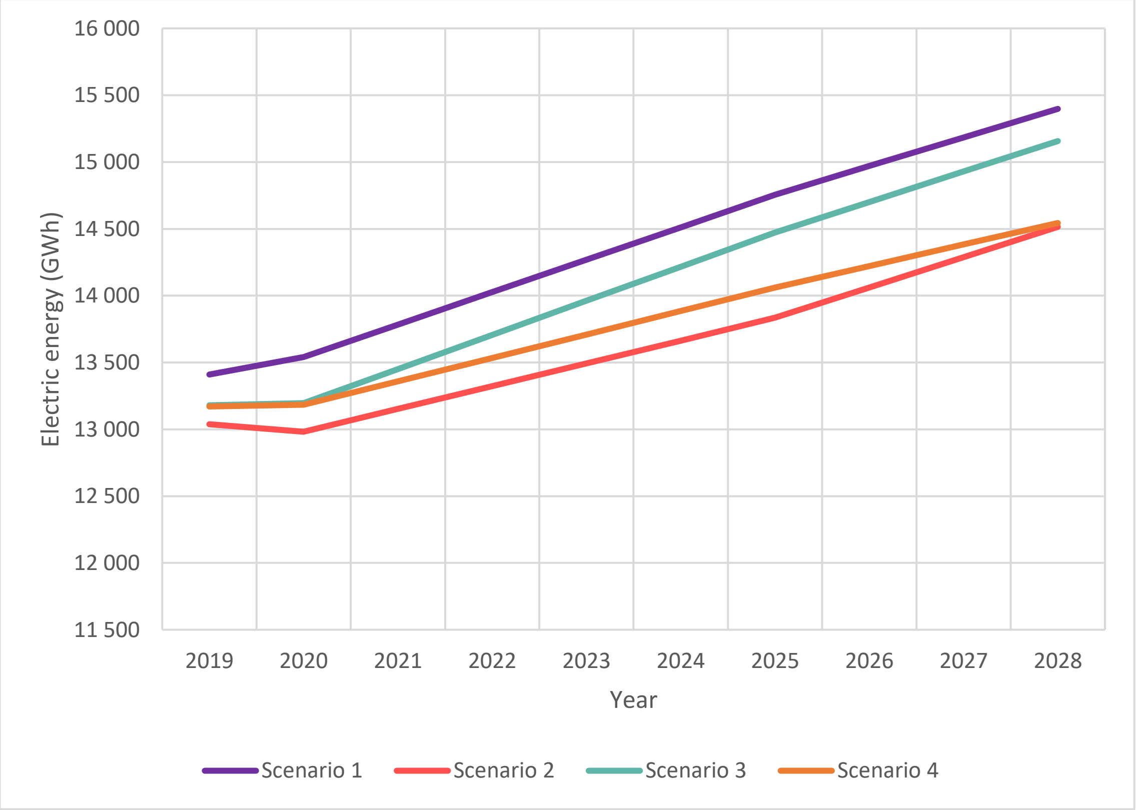


Figure 11: Forecast of electricity demand in Slovenian transmission network by the year 2028 according to different scenarios (ELES, 2019)

Considering the scenarios presented, a large spread of EVs is expected, which can pose a major challenge for the operation of the electrical energy system. To prevent negative impacts and reduce the necessary financial investments, Slovenia must prepare for the upcoming situation in a timely and gradual manner. This is not only the case for the electrical energy system, but also for Slovenian companies, which will have to adapt quickly if they are to remain competitive. At the same time, new conditions are enabling the arrival of new high-tech start-ups. The ENTSO-E scenarios foresee rapid EV growth in all scenarios, the highest being in the DG scenario where high economic growth is anticipated, which gives the society more resources to invest in new technologies. The lowest EV growth is expected under the ST scenario, which is projected to have moderate economic growth and low gas prices, which in turn means more vehicles using gas as a fuel. Nearly one million EVs were registered in Europe at the end of 2017. Despite the small EV numbers in Slovenia and elsewhere in Europe, EV growth is exponential. Therefore, achieving the goals or projections will be extremely dependent on the policies of the countries of the future (ELES, 2019).

According to all ENTSO-E scenarios, Slovenia also has high electrical energy consumption growth. Predicted consumption growth between the years 2020 and 2025 is 11.2%. Between the years 2020 and 2030 predicted consumption growth is 16.6% according to the EUCO scenario, 23.5% according to the ST scenario and 31.1% according to the DG scenario. ELES scenarios predict the consumption growth between 8.8% and 11.7% between the years 2020 and 2025, and between 16,8% and 24,4% between the years 2025 and 2030.

6. Life-cycle analysis of electric mobility

The question of its ecological nature has a great influence on the prevalence and acceptance of electric mobility. Therefore, this chapter will focus on its ecological perspective.

The easiest way to present ecological challenges is systematically. If we show only the consumption of the vehicle during its usage time, we ignore a large portion of the actual impact the vehicle has on the environment. Life cycle analysis (abbreviated LCA) helps us to understand the ecological aspect of electric mobility. It is even more accurate when it takes into the account the principles of circular economy. In doing so, we consider all stages of the vehicle life, from its production, usage and end of usage life, considering destruction and preferably reusage or. recycling. The concept of the circular economy encompasses influences and solutions through entire social system. Within a traditional linear economy, products are made, used and then discarded, while a circular economy tries to maintain the highest possible value of materials and products for as long as possible. As a result, the need for new materials and energy is reduced.

6.1. Raw material extraction and vehicle production stage

The first phase of the BEV life cycle includes two parts - the extraction of raw materials and the production of vehicles. These two phases are severely limited to the countries where both activities take place. The vehicle usage phase and the reuse and recycling phase are more important for Slovenia. Therefore, we presented both works in a common chapter and combined them into a common phase.

From an ecological perspective many aspects are important: the structure of vehicle, the best possible usage of materials, consideration of the negative impacts of the automotive industry on nature. The production of BEVs requires more copper, nickel, and some key raw materials from rare earth elements than the production of conventional vehicles. The extraction of copper, nickel, and other critical raw materials for BEVs has a negative impact on the environment, as it involves intensive use of raw materials, the risk of spillage of toxic materials into water bodies and soil pollution. Obtaining these materials is an energy-intensive process. Energy savings are also key to reduce a harmful impact of electric mobility on the environment. If in the production of BEVs we strive to reduce the weight of vehicles and use carbon fiber and aluminum for the body of vehicles, this further increases energy consumed while producing such components. In order to maximize the range of vehicles, the use of lighter materials in vehicles is often emphasized. This can reduce consumption while the vehicle is in use, but at the cost of negative environmental impacts during production and more difficult recycling of materials. To reduce energy consumption within the entire life cycle of a vehicle, a very important factor to consider is the potential mileage of the vehicle. The larger the distance the vehicle covers in its lifetime, the lower the relative energy invested in production in comparison to the entire usage period. The total distance that will be traveled by the vehicle is indisputably related to the design of the vehicle. If the vehicle is durable enough and maintenance is not demanding, we can hope for its longer service life. Many of EVs, unfortunately, are still not specifically designed according to its propulsion, but are based on ICE vehicle models. This results in less used battery space, greater wear of mechanical parts due to higher weight, poorer driving characteristics, etc. (European Environment Agency, 2018).

Despite their name, not all Rare Earth Elements are rare in the Earth's crust. Nevertheless, their availability is limited to only a few geographical areas, which adds risk and cost to their use. From the imports/exports and production point of view, China is by far the most important global player, providing 70% of the world's supply of critical raw materials (abbreviated CRM), including many important ones used in electric mobility. As a result, China has a strong monopoly in the field of BEVs production, which can be problematic for other players in the field of electric mobility (European Environment Agency, 2018). In China's hands thus lies the potential to reduce the intensity of usage of rare and non-renewable materials in EVs production and great bargaining power (King, 2018). This means that important decisions regarding life cycle and the ecological impact of EVs will often be taken outside the US and EU legislative frameworks.

A positive aspect of the highly concentrated Asian influence in battery production is the possibility of them taking advantage of economies of scale. In the production of EVs, the production capacities can be used to the maximum and thus the average energy consumption required to produce a single vehicle or battery is reduced.

In addition to reducing the usage of rare and non-renewable materials in EVs production, the use of different, alternative materials will also be important. Such materials would have the same or better performance than the materials in current use, while representing a lesser burden on the environment. The production and usage of these represents an opportunity and solution for the production of BEVs in Europe, where there is a shortage of rare materials, and the usage of alternatives would also make an important contribution to reducing global consumption of rare earth materials (European Environment Agency, 2018).

When designing EVs, the most important component that determines their impact on the environment is their battery. The production of batteries is the main culprit for air pollution and the generation of greenhouse gases in the production stage of EVs, which is, as already mentioned, a very energy-intensive process. Its optimization is therefore crucial. Proper design of batteries and vehicles would allow for reduced input of raw materials and the usage of alternatives from the very beginning of the process. Use of recycled materials instead of newly acquired ones, reduction of waste materials and choice of the type of batteries with the lowest possible environmental impact are challenges that EV manufacturers face. Appropriate standardization for batteries will also need to be introduced and considered, which would make handling with them easier in the following phases.

Most BEVs use one of several different types of Li-ion batteries, which differ in the material from which the cathode is made. Li-ion batteries provide high energy densities that are key for vehicle reach. Higher energy density in principle means that less material is needed for a certain vehicle range, which means fewer negative effects on the environment for a certain vehicle. Longer battery life also relatively reduces the negative environmental impacts of battery production, as this means larger distances driven with a certain EV (European Environment Agency, 2018). The development of Li-ion batteries has significantly contributed to the practicality of BEVs and consumer interest in them, due to their high energy density and durability compared to previous battery technologies. $LiFePO_4$ batteries have the lowest potential environmental impact due to their longer life. LiNMC batteries have the lowest negative impacts while in production. $LiFePO_4$ batteries unfortunately have a relatively low energy density and are mostly used in hybrid vehicles (Battery University, 2019).

Consumer expectations regarding the range of EVs will be key to the further development of battery technologies. Larger and heavier batteries allow for more energy storage and thus better vehicle range, making it easier for the user to drive longer distances and reducing range anxiety (Melliger, Van Vliet, & Liimatainen, 2018). Unfortunately, larger amounts of raw materials and energy are needed to produce larger batteries. Their higher weight also requires more energy per kilometer driven. Battery size in higher-end vehicles is typically about 3,4 times larger than in smaller cars, but the range of larger vehicles is on average only 2,3 times larger due to the extra weight (European Environment Agency, 2018). Unfortunately, by increasing the number of batteries in vehicles we proportionally increase the negative environmental impact of vehicle production. Negative environmental impacts would be reduced if trends or consumer preferences in the automotive industry would be changing into the direction of more moderate vehicle ranges and smaller batteries. Sufficient density of the charging network and times required to charge the vehicles will also be important factors influencing the users' expectations regarding the range of the vehicles. As electric mobility becomes more prevalent, users may become more accustomed to patterns of behavior associated with more frequent charging, and this will also reduce worries about low battery and insufficient range. Further research in battery technology could help reduce the negative environmental impacts while maintaining comparable EV ranges.

The main sources of air pollution in the production stage of BEVs are emissions of SO_2, NO_x, particulate matter and other pollutants caused by energy consumption in the production of components and vehicle construction. The entire BEV production process is expected to generate approximately 1,5 to 2,5 times more NO_x, SO_2 and particulate emissions than the production of vehicles with ICE (Rangaraju, De Vroey, Messagie, Mertens, & Van Mierlo, 2015).

Despite the high energy requirements of the production stage, most energy is consumed in the vehicle usage stage. However, when we can provide energy used in the usage phase from renewables, vehicle production stage accounts up to 75% of greenhouse gas emissions throughout their whole life cycle, partly because the energy production of battery-producing countries is mostly high-carbon intensive. Viewed in the context of current European electrical energy production mix, the battery production phase contributes to around 30% of life-cycle emissions. During the production stage of batteries, between 35 and 50% of all greenhouse gas emissions are caused by electrical energy consumption (European Environment Agency, 2018).

The share of electricity produced from renewable sources is expected to increase sharply in China by 2025, which is good news for reducing the carbon footprint in EVs production. Increasing the usage of electrical energy from renewable sources in production stage, as well as in other phases of the EV life cycle, is key to their contribution to a cleaner environment (Huo, Cai, Zhang, Liu, & He, 2015).

During this stage of the electric mobility life cycle, Slovenia does not have a particular decision-making power. Active participation in the formulation of EU regulations and the promotion of positive guidelines are important for favorable further development. Users of EVs can support quality manufacturers by buying and using well-designed vehicles that have a long lifespan, are compatible with our roads and charging system, and can be recycled. More can be done in the stages of usage, reuse and recycling.

6.2. Usage stage

During the usage stage, BEVs do not produce greenhouse gas emissions through the exhaust. These are generated during the production of electrical energy, which is consumed during this phase while driving the vehicle. Calculated per kilometer, BEV emissions are generally lower than for conventional cars with ICE, due to better energy efficiency and the use of less carbon intensive electrical energy sources.

Pollution associated with EVs is influenced by various factors, the most important ones being the production sources of electrical energy, vehicle characteristics, driving style and location, and vehicle charging patterns.

Differences in pollution between BEVs and conventional vehicles in the usage phase are most clearly presented through the process of energy generation from fuel to its consumption while driving the vehicle, also known as wheel-to-tank analysis. In BEVs, most air pollution occurs while producing electrical energy in power plants, that is, before it reaches the vehicle. We must not forget that while BEVs do not pollute the air with exhaust gases at the local level, but they, like conventional vehicles still pollute the air with fine particles that are formed while braking or lifting dust from the road. In vehicles with ICE, most of the pollution occurs while driving, when the fuel burns in the engine. Emissions from the ICEs can have unpleasant consequences for local air quality and the environment and are also a major reason for changes in mobility. BEVs promise a shift in the production of emissions from the urban environment to the countryside, which means lesser exposure of a larger number of people to pollution, but this shift has more negative consequences in the extra urban environment or more precisely in the vicinity of power plants. Due to a different form of pollution, both forms of mobility are difficult to compare even in the usage stage.

Most life-cycle analyzes consider BEVs emissions from energy source to energy consumption within Europe as lower than those of conventional vehicles with ICE. Final intra-EU emissions from electricity production are estimated to be between 47% and 58% lower in BEVs than in conventional cars in this area. Range extended hybrids (REEVs) and plug-in hybrids (PHEVs) are also expected to have lower emissions by 48% and 36%, respectively. BEVs can convert between 70% and 90% of the energy stored in batteries into motion. The maximum theoretical efficiency of vehicles with the ICE is only 40%, while the actual efficiency while driving is between 10% and 15%. The better efficiency of EV results from the more efficient operation of individual parts of the powertrain and the ability of regenerative braking, which can recover between 10% and 20% of energy consumed, depending on driving style and driving conditions. The estimated life of the EV is somewhere between 150,000 kilometers and 200,000 kilometers driven (European Environment Agency, 2018). Obviously large difference between these two values poses a problem in estimating energy consumption in the usage stage. In any case the break-even point, where EVs outperform conventional ICE cars in terms of lower greenhouse gas emissions is between 44,000 kilometers to 70,000 kilometers (European Environment Agency, 2018).

The production of electrical energy for charging BEVs batteries pollutes the air with SO_2 and NO_x while fine particles are also formed during driving. Emissions of SO_2, NO_x and particulate matter from electrical energy production per kilometer in the EU in the year 2013 were similar for BEVs and petrol-powered vehicles and slightly higher than for diesel-powered vehicles. The reason for that is a relatively high share of electrical energy produced in the EU from coal. The situation varies from country to country to local mix of electrical energy generation. In the cases of some regions in China and the USA, it has been found that emissions of SO_2, NO_x and fine particles in BEVs can be up to two, three or even four times higher than in the ICE ran vehicles when a very high proportion of electricity is produced from coal. It is also true that updating technologies can significantly reduce harmful effects. In Belgium, a 2011 study showed that their local emissions of SO_2 and NO_x produced by BEVs are much lower than by the vehicles with ICE. It is important to note that nuclear power generation in Belgium accounts for 60%, and the next most represented form of electricity generation is gas. In different countries within the EU, different values of greenhouse gas emissions are generated while producing electrical energy required for the use of EVs. The lowest values of CO_2 per kilometer of distance traveled by EV are in Sweden with 9 gCO_2/km, where nuclear power and hydropower predominate, and the highest in Latvia with 234 gCO_2/km, where they mostly import high-carbon-intensive electrical energy from neighboring Russia. In Slovenia, these values are around 65 gCO_2/km (Moro & Lonza, 2017) as shown in the figure 12. The carbon footprint of EU electrical energy production mix is likely to decline in the future, as reductions in coal use and more renewables are planned. The carbon footprint of average electrical energy production per kilowatt of energy produced in the EU is projected to decrease from 300 gCO_2/kWh in 2015 to 200 gCO_2/kWh in 2030 and to 80 gCO_2/kWh in 2050. For EVs this means a reduction in greenhouse gas production from the current 60 gCO_2/km to 40 gCO_2/km in 2030 and to 16 gCO_2/km in 2050, representing an overall reduction of 73% (European Environment Agency, 2018). However, it is difficult with an average carbon footprint to really describe what carbon footprint the usage of EV has at a given moment, because we do not take into account what combination of energy sources is used to produce electrical energy at that given moment in time. The combination of electrical energy generation is not independent of demand, and additional energy demand can lead to an increase in greenhouse gas emissions and air pollution depending on the type of electrical energy generation mix used at that time to meet the increased demand. Charging EVs at a time when the supply of electrical energy from renewable sources exceeds demand (e.g. at noon when enough solar energy is available) helps to lower the footprint of greenhouse gas emissions and lower air pollution. Charging BEVs in the evening, when we have peak electrical energy consumption in the network, usually also means higher greenhouse gas emissions, as carbon-intensive electrical energy generation sources are often used to cover demand. If we want to reduce greenhouse gas emissions during EVs usage stage, we need to encourage the integration of low-carbon electrical energy sources into the grid and reduce demand at the time of peak electricity demand. Smart charging will play an important role here in the future. In addition, we can contribute to greater efficiency in the use of produced energy by e.g. strengthening the network infrastructure, reducing demand (e.g. using vehicles with smaller batteries, which are charged earlier and need less power) etc.

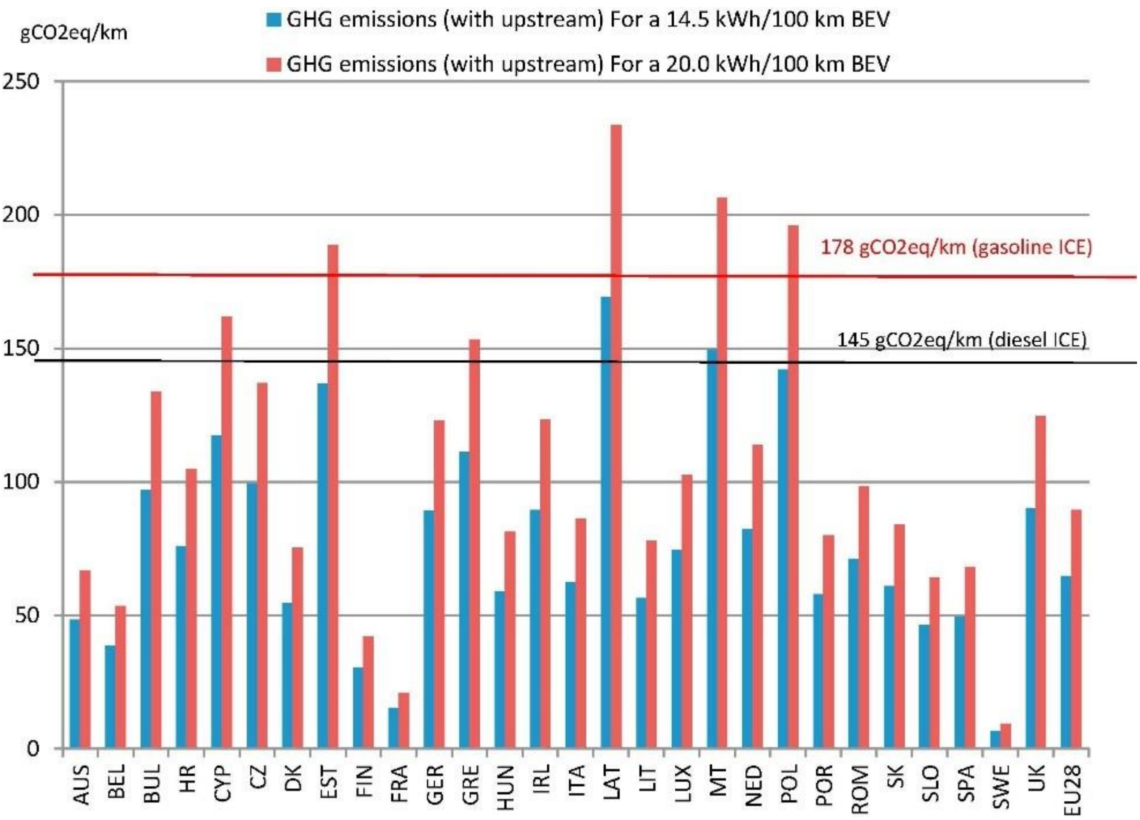


Figure 12: CO2 emission values per km of distance driven by EV according to different sources of electrical energy production in different EU countries (Moro & Lonza, 2017)

The energy efficiency of EVs largely depends on the location and style of driving, the use of air conditioning or. heating and the size and weight of the vehicle. A key factor influencing EV energy consumption is the extent to which the potential for regenerative braking can be exploited. This is most effective in moderate deceleration and downhill driving. With jerky braking of the vehicle, less energy can be recovered, and mechanical brakes, that we also know from conventional vehicles, are also used intensively at such time. Regenerative braking also has a much higher potential for energy savings when driving smoothly and economically. Unlike conventional vehicles, EVs energy consumption within cities is often even lower than when driving out-of-town. There is also an important difference in the source of energy for heating the interior of the vehicle - unlike conventional vehicles with ICE, where excess energy from the engine can be used for heating, BEVs must use energy from the battery for heating. When cabin and glass heating is required in winter conditions, the difference in the energy efficiency advantage of BEVs over conventional vehicles is reduced. Energy consumption is also strongly determined by the mass and size of the EV. Heavier and larger vehicles use more energy when driving uphill, and they also have more air resistance than lighter and smaller vehicles. In Slovenia, it will be necessary to promote favorable opportunities for the economical use of EVs. A quality and well-thought-out road network and coordinated traffic contribute a lot to the economy of transport. Another important factor is the tolerance and culture of drivers, which has a strong influence on the smooth flow of traffic, especially in cities.

Road transport within Europe is the largest source of both air and sound pollution. Prolonged exposure to road noise is associated with a wide range of health problems and adverse effects on the heart, blood vessels and metabolism. Traffic noise is a combination of vehicle drive sounds, road sounds and aerodynamics. How intense any of these factors is depends heavily on the speed of the vehicle and the structure of the road. At lower speeds, electric motors are about 10dB quieter than the ICE, and their pitch is also higher and gets lost sooner with increasing distance. At higher speeds, the sound of wheels on the road and the sound of passing air begin to predominate. Here, the noise levels of the two types of vehicles are virtually indistinguishable. From this point of view, BEVs definitely have an advantage where there is a lot of slow and stagnant traffic, i.e. in cities. Unfortunately, a significant difference in this aspect would require the replacement of a large proportion of vehicles, as replacing 2% of the vehicle fleet of conventional vehicles with BEVs would reduce traffic noise by only about 0.1 dB in the urban environment (Campello-Vicente, Peral-Orts, Campillo-Davo, & Velasco-Sanchez, 2017). There is also promise of potentially equipping the EVs with audible signals so that pedestrians would not overlook them. Such a policy would most likely nullify the potential of EVs in reducing traffic noise pollution.

It is also important to consider how EVs are used compared to conventional vehicles in terms of driving frequency and distance traveled during the year, and for what trips we use them. The market share of EVs and PHEVs in the EU has grown in recent years from 0.01% of registrations in 2010 to 1.5% of new registrations in 2017. Due to such a sharp jump, we often lack data on how EVs are actually used and what habits their users have. According to research, from the vehicle range point of view most trips with conventional cars could be done with EV. A small number of studies that have analyzed the behavior of new EV drivers hint at a potential increase in car usage (European Environment Agency, 2018). Such studies suggest that the BEVs are often purchased as a secondary car in the household and then often used for most trips. Unfortunately, there are between 10% and 20% of trips that are replaced by BEVs that could be done either by bike or on foot. Local initiatives to promote electric mobility, such as free parking, toll exemptions and the possibility of public charging, may also be partly to blame for that effect. The drivers of this phenomenon are also the attempts to justify the investment into an EV and the enthusiasm for a new form of technology. Some of these effects will most likely start to fade as EVs become more common. In order for electric mobility to play a sustainable role, we must encourage the development and use of public transport and other green forms of driving and create a favorable environment for them. Rational use of vehicles will always be relevant, as we do not want to further increase the presence of cars on the roads, as this clearly harms the environment. We need to consider the opportunities offered by new business models in the field of mobility, such as car sharing.

6.3. Reuse and recycling stage

The reuse and recycling stage has the least impact within the entire life cycle. However, it still plays an important role in reducing negative environmental impacts throughout the life cycle. From the circular economy point of view, the reuse of batteries, especially for energy storage, has a high potential to reduce negative short- and medium-term environmental impacts, while also helping to develop the production of energy from renewable sources. Recycling makes it possible to improve resource efficiency and the availability of raw materials. Improving waste management and higher efficiency through increased reuse and recycling rates can reduce the high toxicological impact associated with the intensive use of elemental metals such as copper and nickel.

Reuse and recycling of EVs is of little use in the EU since the number of such vehicles on the roads is still low. As a result, there has been little initiative so far to develop the infrastructure and procedures needed to reuse and recycle parts. However, by the year 2025, there are estimated to be between 40 and 70 million BEVs on world roads. Changes will be needed to deal with them in the final stage of the life cycle in the future (International Energy Agency, 2019).

Reuse is the process by which a final component of a life-cycle component is used for the same purpose for which it was manufactured. It can be direct when used in new EVs or it can be used to store energy within different requirements, e.g. to support the electrical grid. Reusing EV batteries extends battery life and removes the need for additional end-of-life procedures.

Remanufacture and functionalization involve the processing of materials into a usable form for either the same or a different function.

Recovery involves the recovery of metals and metal compounds, inorganic materials and components used to reduce pollution.

Recycling means the recovery of waste materials, either for the original or for another purpose.

The 2000/53/EC of the European Parliament and of the Council on End-of-Life Vehicles Directive requires vehicle manufacturers to take greater responsibility for their vehicles and components after the usage stage. It thus imposes a responsibility on car manufacturers to either reclaim their products for reuse or recycling, or to delegate this responsibility to a third party. By 2015, at least 95% of vehicles are supposed to be reused and remanufactured, and at least 85% of vehicles should be reused and recycled (The European Parliament and the Council of the European Union, 2000).

The process of recycling the vehicle begins with the deregistration of the vehicle and its handover. The vehicle is then disassembled. At this point, components containing environmentally hazardous materials (batteries, refrigerants) and components with potential for recycling and reuse (engines, tires, bumpers) are collected separately.

Vehicle bodies are cut. Cut materials are divided into ferrous and non-ferrous materials. The key differences in the recycling process of BEVs and conventional vehicles are in their composition. EVs contain several lighter and more powerful engines and a large battery or multiple battery packs. They usually contain four times more rare earth materials than diesel or petrol vehicles of similar size (European Environment Agency, 2018).

The main economic guideline in battery recycling is the value of metals in batteries. In terms of price, the most valuable materials are cobalt and nickel. Other metals, such as copper and iron, are also recycled within current industrial processes. Research suggests that the future focus should be on the removal of Rare Earth Elements either before cutting or during the processing of cut residues. Recycling of Li-ion batteries is currently rare for several reasons: low energy volumes of batteries that would reach the final stage of use, modest knowledge in battery design, and the lack of appropriate labeling of battery packs and cells. Li-ion batteries have a lifespan equivalent to the expected life of the vehicle (8-10 years) and can later be used for energy storage systems. Therefore, it is not expected to increase the number of batteries in the last stage of the life cycle for at least another decade. Until then, larger capacities for their recycling are expected to be established. Until the need for battery recycling increases, there is still enough time at the local level to encourage the acquisition of knowledge in this area. Current battery recycling processes mostly involve a combination of different approaches such as mechanical separation, pyrometallurgical and hydrometallurgical processes. Different separation pathways are suitable for different materials, require different material and energy inputs, and achieve different results. According to current findings, pyrometallurgical processes will be useful for larger amounts of recycling, and hydrometallurgical for smaller ones. The key to developing such plants will be understanding how to effectively extract rare earth elements from batteries in the last life cycle, as there is currently no industrial recycling process to extract rare earths elements from EV batteries. Future increase in the usage of composite materials could make recycling even more challenging (European Environment Agency, 2018).

As the growth trend of electric mobility continues, by the year 2030 the share of BEVs is expected to be between 3.9% and 13% of newly registered vehicles, and the share of PHEVs between 6.7% and 22.1% of newly registered vehicles EU wide. Assuming an average vehicle life of 10 years, this would mean that in the year 2021, 9,000 EVs in the EU will need end-of-life processing. That number is expected to grow to 200,000 vehicles by 2027. Despite knowing future dangers such as e.g. uncertainty in the demand for lithium and its availability, it is difficult to estimate the actual required production volumes of lithium, as we do not know exactly what quantities will be used to produce one battery, we do not know the prevalence of EV in the future vehicle fleet and future recycling rates (European Environment Agency, 2018).

Increased demand for BEVs will consequently also raise the need for rare earths elements such as neodymium and dysprosium. Trends and demand forecasts for individual rare earth elements are limited. However, demand can increase sharply - demand for neodymium and praseodymium could rise from 1.000 tons per year in 2015 to 11.000 tons in 2025 (European Environment Agency, 2018).

One third of the cobalt needed should be obtained from recycling in 2021. That still means two-thirds of the element would be delivered from new excavations if we cannot find an alternative.

Lithium stocks are unlikely to be depleted any time soon, but supplies may come under pressure as popular lithium extraction from brine is a slow process that cannot respond so quickly to growing market needs. These examples show how important the future availability of materials will be and that this is a challenge that covers almost all stages of a vehicle's life.

Recycling of certain materials will definitely be necessary at some point in time, which adds useful value to the waste. For materials that cannot be recycled, it will be necessary to arrange the necessary landfills.

Batteries usually reach the end of their life in EVs after about 8 to 10 years or 150.000 to 160.000 km if their capacity is less than 80% of the original capacity. However, there are some ways to reuse batteries in vehicles, e.g. due to premature breakdowns, traffic accidents and in older vehicles where the battery has been replaced once and the second battery is still unused (Casals, García, Aguesse, & Iturrondobeitia, 2017).

Direct battery reuse is currently the only process at the end of the life of EVs where the material goes directly to the Li-ion battery market. Such an approach causes the least harmful impact on the environment because the materials do not need to be recycled. Compared to other recycling technologies, there is also a much lower amount of waste material, as only a small amount of polymer components need to be removed. However, direct reuse of batteries is limited to those with sufficient capacity.

Cascade battery reuse means using them in different and less demanding environments. This avoids the burden of producing new battery packs. Using them in this way has economic advantages as the market value of used batteries is maintained and the cost of buying new batteries is avoided. Used EV batteries, with their lasting utility value, certainly offer an important opportunity within the recycling economy, especially as part of energy storage systems. They could be used to store energy for private consumers and to store renewable energy sources. One of the main environmental benefits of cascading reuse could be to support the integration of renewable energy sources into the grid. The storage of volatile energy sources enables and facilitates the harmonization of supply and demand. The use of EV batteries in renewable energy storage systems could extend battery life by 72% and lead to a 42% reduction in greenhouse gas emissions per kilometer of EV driven. However, more research will be needed in the future on cascading reuse of EV batteries. Such use could also have indirect environmental benefits as the development of the used battery market could reduce EV costs. It will be particularly important to understand the degradation rate of battery components if we are to better assess the potential for the most efficient reuse (Casals, García, Aguesse, &

Iturrondobeitia, 2017). In the local areas, opportunities for the use of recycled batteries in the power sector could be explored.

Recycling used Li-ion batteries from EVs is a relatively new approach to handling them and is not yet very widespread at present. This process involves restoring the active cathode and anode materials back to their original state for their reuse in new Li-ion battery cells. This results in a complete loop in which high-value materials are processed for use into new batteries, and other materials are returned for recycling. Certain cathode and anode materials remain almost fully functional, even though the rest of the battery cell has degraded to the point where replacement is required. Within such a system, we produce smaller amounts of waste. This has environmental benefits that are known throughout the EV life cycle, especially in the initial stages, as we reduce the need and use of untreated materials, similar to direct reuse (European Environment Agency, 2018).

Recycling Li-ion batteries is also demanding due to the lack of standardization. Battery versions vary depending on the material used, the design, the location of the battery, and the shape of the battery pack. Full standardization is probably not possible; however, basic standardization would greatly help the recycling process in terms of time and complexity. An example are the lifting lugs, which would be mounted on batteries as part of the standard equipment, which would allow the use of standardized lifting equipment in the recycling of batteries.

Studies examining the continued use of EV batteries are currently limited in terms of the conclusions they can make. Their problem is mainly in the lack of reliable data (European Environment Agency, 2018).

The last stage of the EV life cycle plays several important roles in the sustainability of electric mobility: it reduces the need for newly acquired raw materials and thus reduces the negative impacts of mining and production, it reduces or delays waste disposal and moves towards a sustainable and circular economy through reuse or recycling of batteries and battery components. Further research and development will be needed to increase the sustainability and efficiency of end-of-life processes. Consistent standardization will be important to encourage reuse and recycling at a wider level. We need to test battery reuse possibilities and other options at the end of use. We need to develop systems to extract rare earth elements from magnets. Even in the terminology used in the field of EVs, it will be necessary to take a more standardized approach, which will make it easier to define problems and possible solutions. At the local level, the last stage also offers many entrepreneurial opportunities. Encouraging and financing development and research in this field can help to establish an appropriate base of knowledge and build appropriate infrastructure with which Slovenian companies could become an important player in the field of materials management. In the field of electric mobility, due to the lack of raw materials and size, it is more difficult to establish ourselves as a vehicle manufacturer, while the field of reuse and recycling is still open, at least for now.

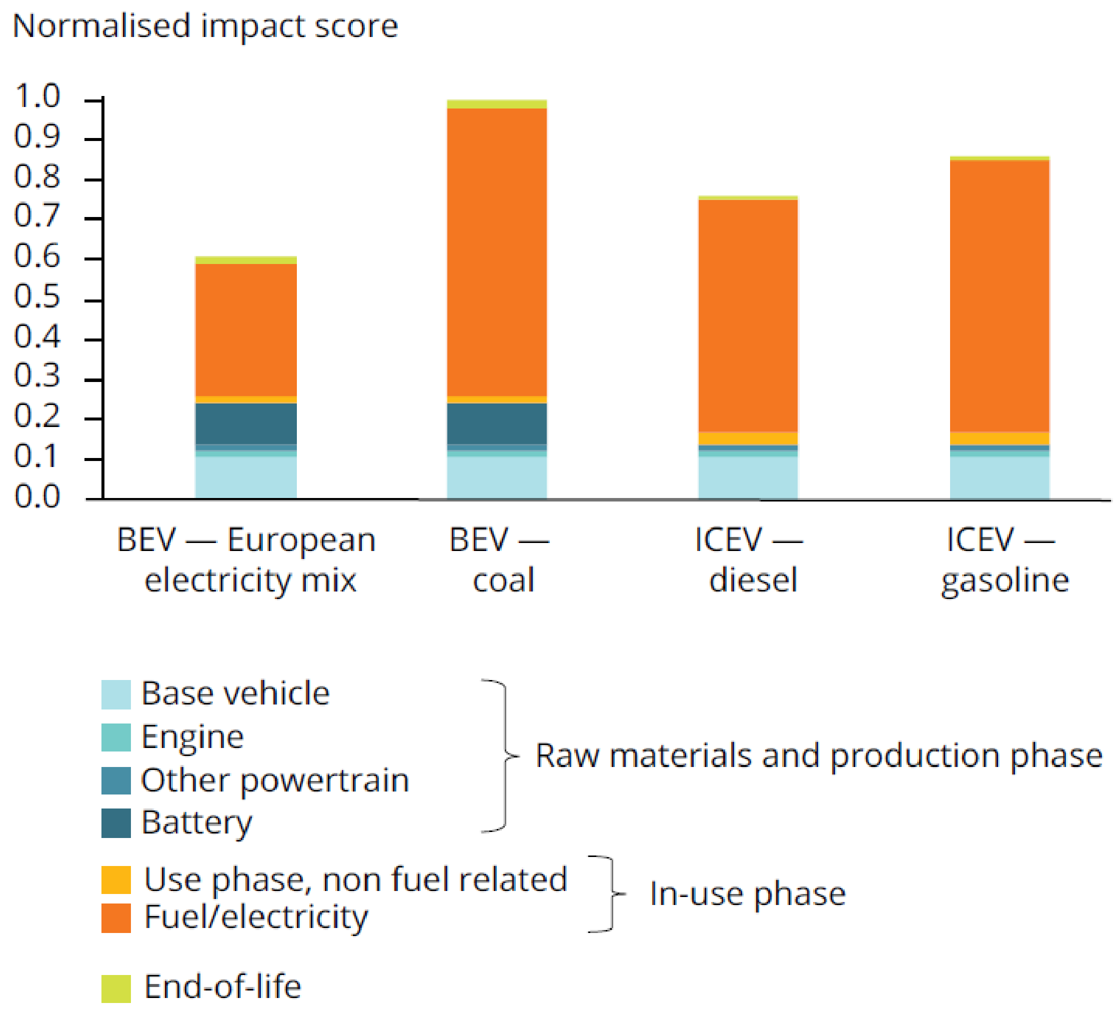


Figure 13: Comparison of climate impacts of electric vehicles and conventional vehicles according to different stages of the vehicle life cycle (European Environment Agency, 2018)

7. Solar and wind potential in Slovenia

In accordance with the findings from the previous chapter, we can conclude that it makes the most sense to use renewable energy sources for charging of electric vehicles. As the Slovenian hydro potential has already been concretely exhausted, Slovenian energy sector will have to look at possibilities of obtaining energy from the sun and wind.

Let's start with the possibility of harnessing wind energy. In some places Slovenia is exposed to steady and solid winds, but these areas often coincide with Natura 2000 sites. Natura 2000 is the largest coordinated network of protected areas in the world. It provides a refuge for the most valuable and threatened species and habitats in Europe. It covers 18% of the EU's land area and more than 8% of its marine territory in all 27 EU countries. The network aims to ensure the long-term survival of Europe's most valuable and threatened species and habitats, which are listed at both Birds Directive and Habitats Directive. It is not a system of strict protected areas from which all human activities would be excluded, and its approach focuses on people working with nature, not against it (European Commission, 2020).

Nevertheless, the EU member states must ensure that the sites are managed in an ecologically and economically sustainable manner. In the case of wind energy, this means that no interference with nature is made.

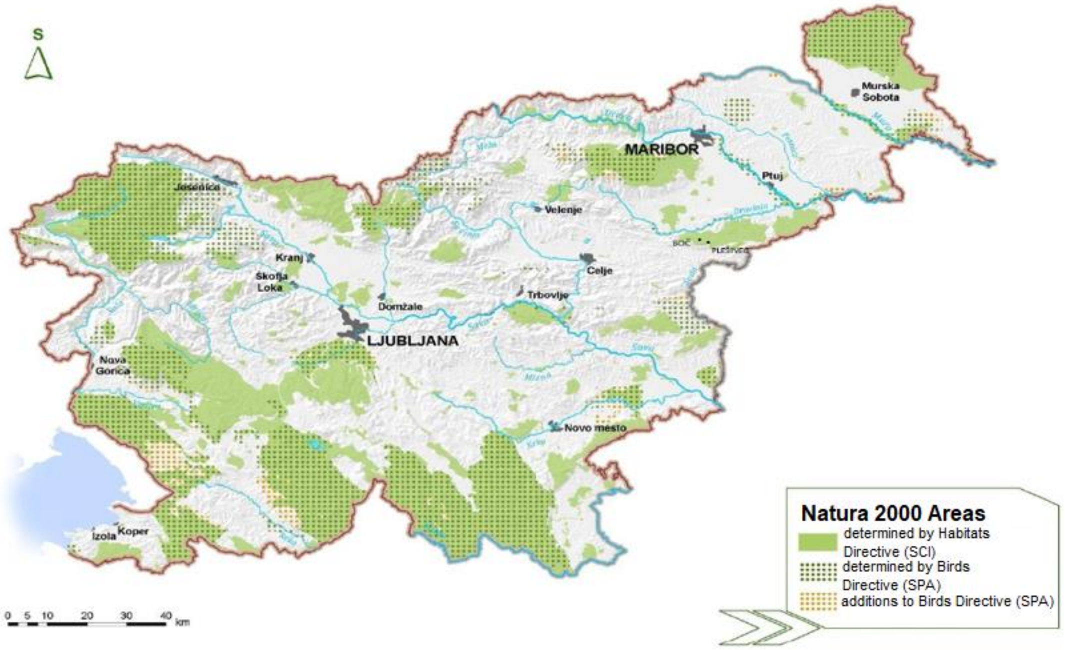


Figure 14: Natura 2000 areas in Slovenia (Čoh, 2013)

The figure 14 is showing scale of Natura 2000 areas on the map of Slovenia. Green and dotted areas are areas belonging to Natura 2000, with green areas showing areas determined by Habitats directive and dotted ones showing areas determined by Birds directive.

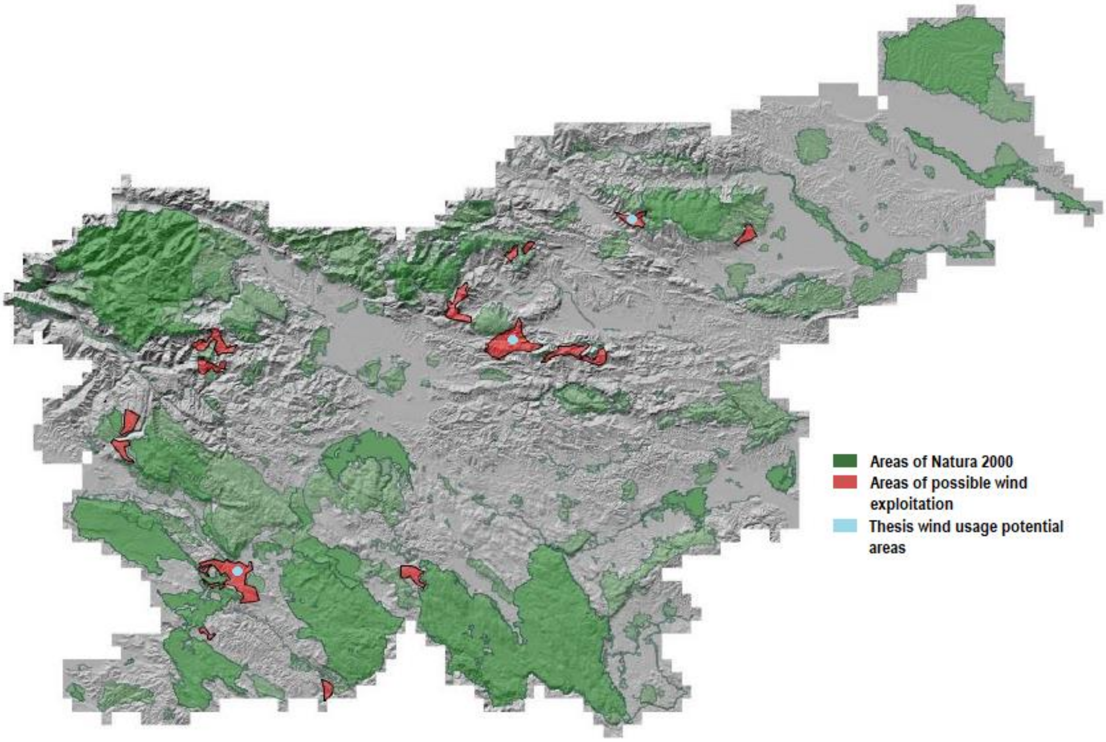


Figure 15: Areas suitable for wind energy exploitation (Makarić, 2014)

The figure 15 is showing areas of possible wind exploitation. They are marked with red color. Green areas belong to Natura 2000. To be able to determine the wind potential for the needs of the thesis, we placed the windmills in areas with blue dots.

Only 3,3 megawatts of power are installed that delivered 6,1 gigawatt hours of energy in 2019 (Agencija za energijo, 2019). This ranks Slovenian wind production on the European Union’s tail. Due to political divisions, lengthy procedures for obtaining energy permits and pressure from conservationists, despite the various planned capacities in the past, only a few turbines were built (Pavlin, 2017). The largest of installed wind turbines is an Enercon E-82 turbine, installed near Dolenja Vas in Primorska region, close to southwestern blue dot marked on the map. Enercon still markets this type of turbine, which is designed for medium speed winds. Therefore, we decided to use this type of turbine as the default in the thesis calculations.

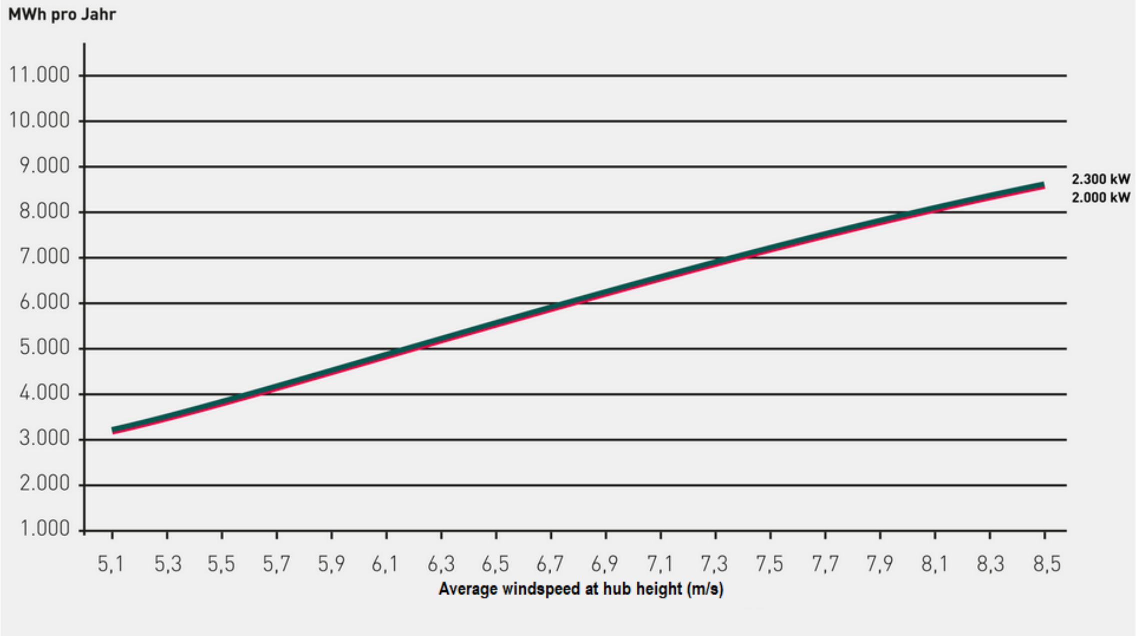


Figure 16: Annual energy yield of Enercon E-82 E2 wind turbine (Enercon, 2020)

The figure 16 shows an approximate annual energy yield of Enercon E-82 E2 wind turbine. Wind power is calculated with following equation:

$$P = \pi r^2 v^3 \rho \eta \tag{1}$$

where R stands for radius, v for wind speed, ρ for air density and η for the efficiency factor, which tells how much wind that blows through the airblades gets converted into wind power. Using data from Danish Wind Industry Association for wind speeds at higher altitude (Danish Wind Industry Association, 2020) and weather data from Slovenian meteorological organization ARSO (ARSO, 2020) along with wind turbine graph from figure 16 we were able to determine how much wind energy we could expect to gain from installing particular production capacities along Slovenia.

The locations we selected for calculations are under Nanos (the southwesternest blue point), Trojane Limovce (the middle blue point) and Šmartno Pohorje (the northeasternest blue point). We opted for a total of 150 wind turbines and distributed them evenly across all three locations. We displayed the results along with solar energy potential in figure 19, figure 20, figure 21 and figure 22.

The Slovenian TSO ELES expects a higher share of electrical energy obtained from the sun in the future. The share of installed solar energy capacities is increasing from year to year and this trend is expected to continue, only its intensity is variable according to different scenarios.

The highest solar intensity in Slovenia is observed in the coastal region, Primorska and and on the sunny hills of Bizeljsko. Most hours of sunshine, even over 800 hours, are also detected in the Primorska region, the rest of Slovenia is evenly irradiated between 740 and 800 hours and the least radiance is in the Alpine world, between 600 and 700 hours, in some places even less.

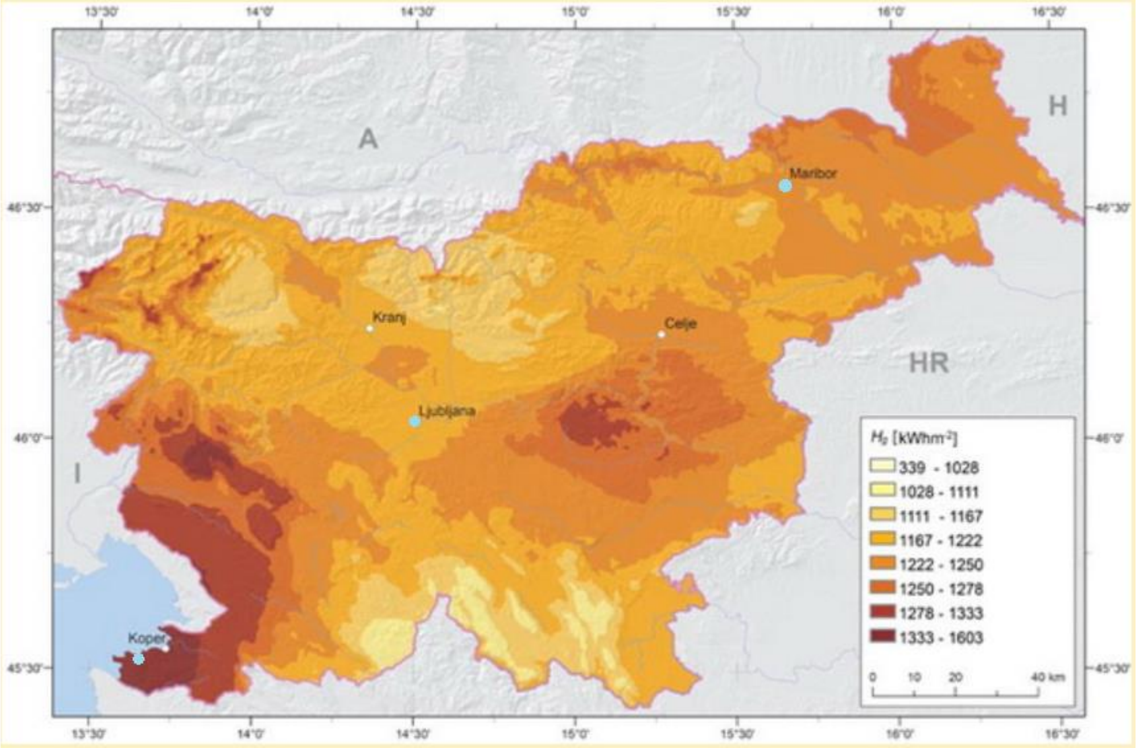


Figure 17: Map of solar irradiance intensity in Slovenia (Univerza v Ljubljani, 2020)

The figure 17 shows map of solar intensity in Slovenia. Darker colors mean stronger irradiance, lighter coincide with softer irradiance.

The figure 18 shows the monthly length of solar radiation and the associated operating hours of solar cells at different locations. The yellow color shows the average operating hours of Slovenian solar power plants. Unsurprisingly, Portorož, a town on the Slovenian coast, stands out, marked with red color.

Currently installed solar power production capacities are 275,9 MW and they produced 269,8 GWh of electrical energy in 2019 (Agencija za energijo, 2020). Different scenarios predict various volumes of energy produced in 2030. Energy concept of Slovenia scenario predicts 400 MW of production units, an 45% increase of capacity. ENTSO-E Distributed Generation scenario predicts 775 MW of installed power (181% increase), ENTSO-E Sustainable Transition scenario predicts 500 MW of installed power (81% increase) and ENTSO-E Global Climate Action scenario predicts 1400 MW of installed power (407% increase) (ELES, 2019). According to literature review cited in document about potential on solar power plants on the roofs of Slovenian buildings, various development scenarios list between 554 GWh and 1460 GWh of energy produced in 2030 (Kovač, Urbančič, & Staničić, 2018). Their reference scenario is at 554 GWh, very similar to ENTSO-E Sustainable Transition scenario.

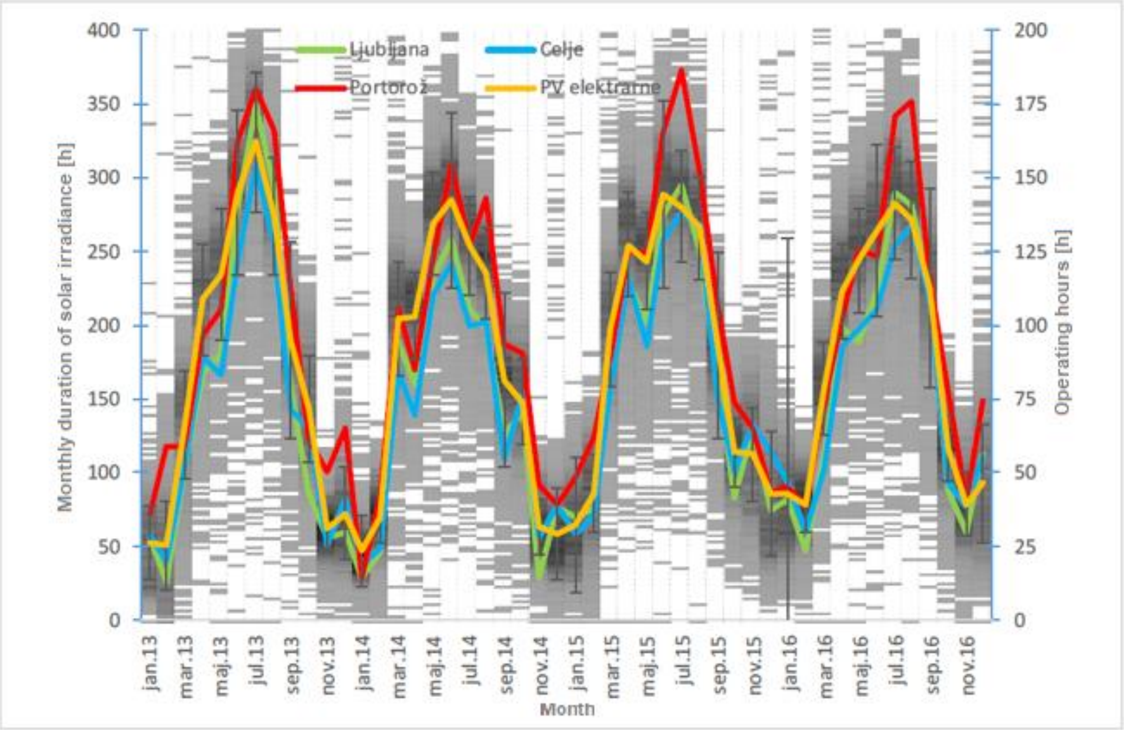


Figure 18: Monthly duration of solar intensity in different spots (Kovač, Urbančič, & Staničić, 2018)

The thesis predicts that the production of solar energy in Slovenia in 2030 will be similar to the ENTSO-E scenario of Sustainable Transition, therefore in the range of 500 MW of installed power. The volume of production was generalized to three locations: Ljubljana, Maribor and Koper. Ljubljana and Maribor lie in an area with 740 – 780 hours of solar irradiation yearly, while Koper gets around 820 – 860 hours of solar irradiation yearly (TOPSOL, 2019). Solar intensity is between 1,167-1,222 kWhm^2 in Ljubljana, between 1,222-1250 kWhm^2 in Maribor and between 1,333-1,603 kWhm^2 in Koper (Univerza v Ljubljani, 2020). For help with exact irradiation of a particular area, we used a tool Photovoltaic Geographical Information System (PVGIS) provided by EU. We assumed 15 kW power units, 14% system losses and optimized slope and azimuth. We divided the production quarterly, so that we could observe how the length of the day and solar intensity affect potential solar production. The results are shown it the figure 19, figure 20, figure 21, and figure 22 together with potential wind production.

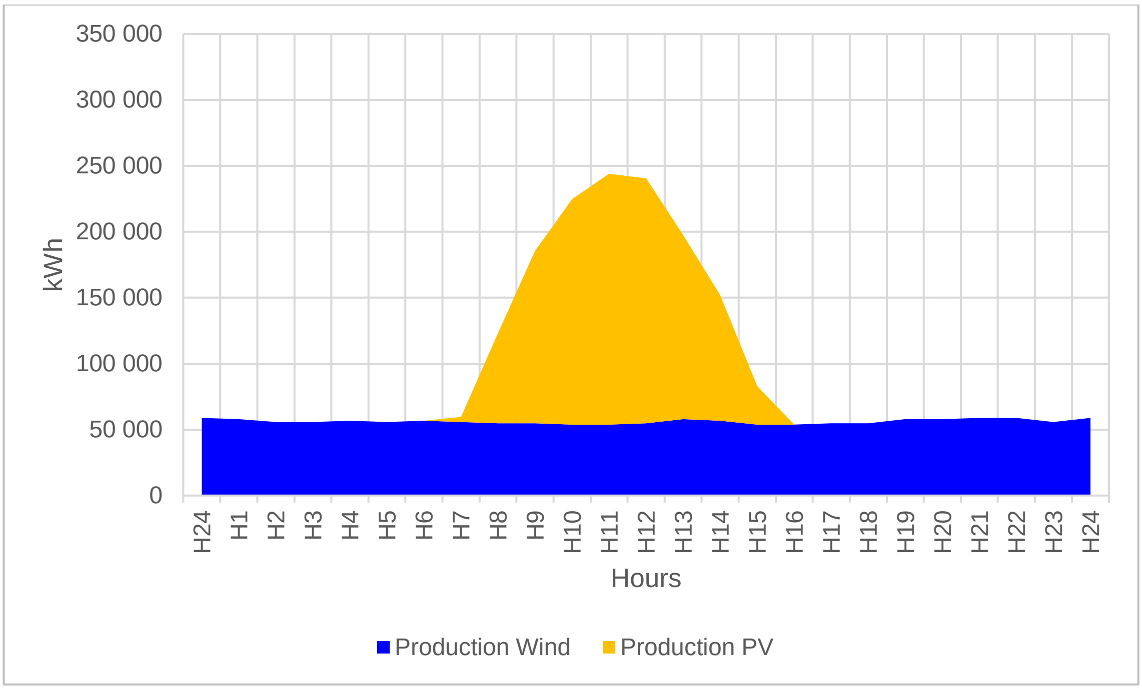


Figure 19: Potential daily solar and wind energy production in the first quarter of 2030

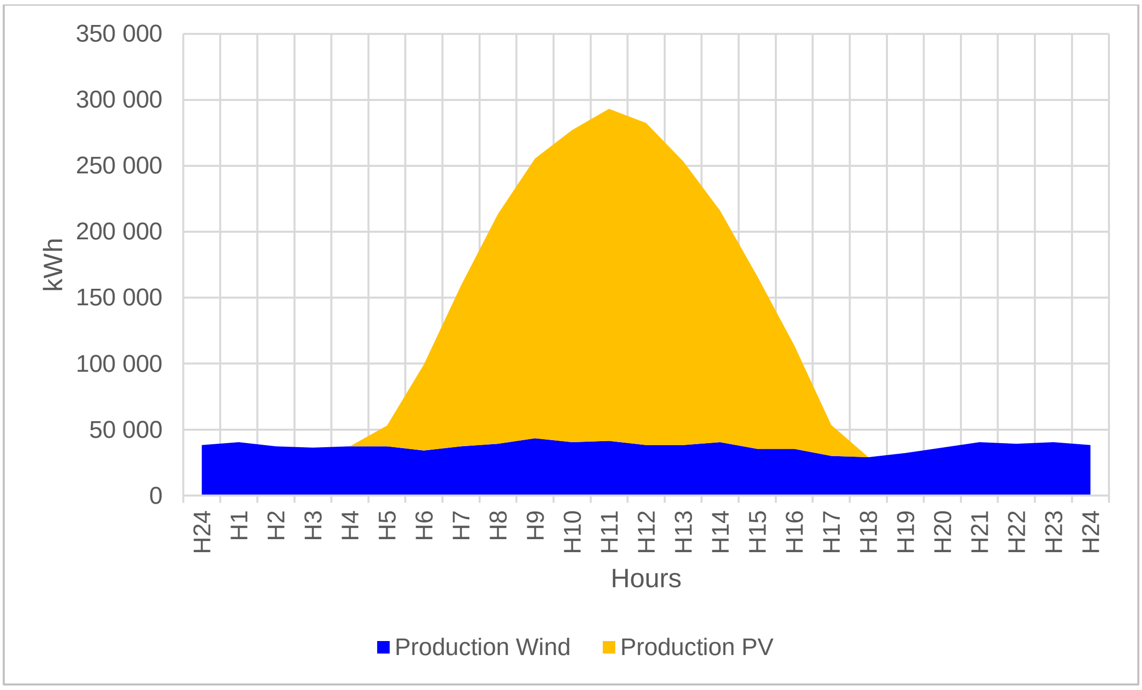


Figure 20: Potential daily solar and wind energy production in the second quarter of 2030

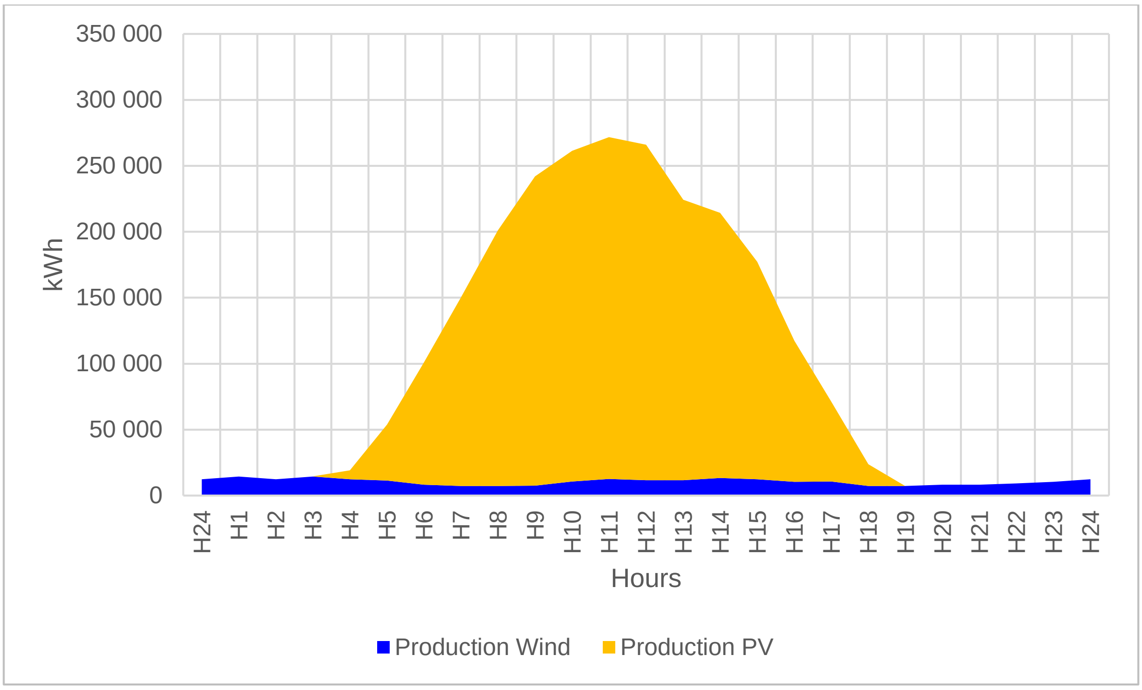


Figure 21: Potential daily solar and wind energy production in the third quarter of 2030

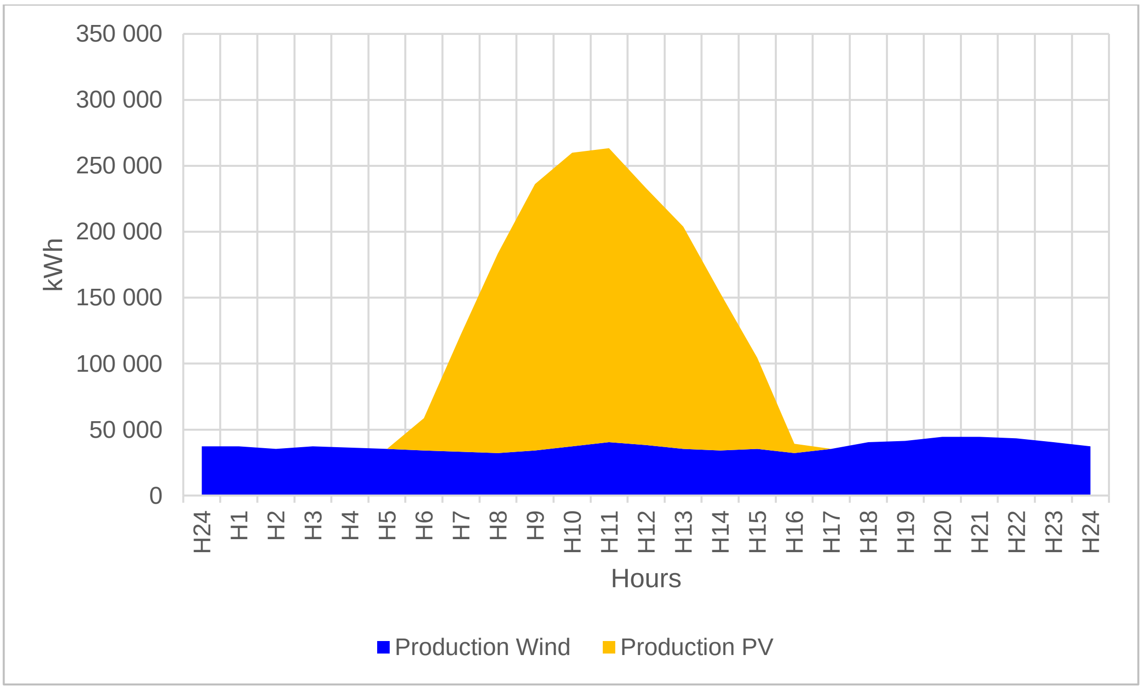


Figure 22: Potential daily solar and wind energy production in the fourth quarter of 2030

The graphs show the potential energy produced from the sun and wind in 2030. The wind is marked in blue and the sun in yellow. Although wind is unevenly distributed across selected regions, total wind energy production profile is very even. Most wind is present in the winter months, so it is not surprising that most wind power is produced in the first quarter. The second and fourth quarter still produce moderate amounts of wind energy, but third, summer quarter is problematic it is very starved in terms of wind potential. The reverse is the picture of solar energy potential. The first quarter is the poorest, both in terms of short days and in terms of the intensity of energy production at a given time. It is followed by the fourth quarter with slightly higher solar irradiance intensity and on average longer days, and the second quarter with even stronger sun and even longer days. The most energy is produced in the third quarter. Interestingly, in the afternoon the curve does not fall as steeply as it grows in the morning, this is most likely due to the afternoon heat storms. Given the even distribution of the wind, it seems that the wind would be suitable for covering an additional demand, which in our case is electric mobility. Solar energy has a favorable contribution to daily energy consumption, but it would be very beneficial if it could be stored at least to cover a possible evening peak of electrical energy demand.

8. Charging patterns of electric vehicles in Slovenia

8.1. Charging patterns of company Elevat charging stations

For our starting point we will use the data from the charging stations of the company Elevat, one of the providers of the public charging infrastructure in Slovenia. They offer 283 charging spots, 82 of which are slow charging ones, 163 of them are on 10-20 kW AC level, 34 of them are on higher than 20 kW AC level. They also offer 4 fast charging DC stations. We have tracked the charging profiles on their charging stations in the year 2019.

In 2019, the charging stations of the company Elevat were used 12.578 times, during which they consumed 134.930 kWh of electrical energy, averaging 369 kWh daily and 15,4 kWh hourly. Cumulative time spent charging was 21036 hours, 4 minutes, and 13 seconds. This means that a charging spot was on average used for 1 hour, 40 minutes and 21 seconds.

Several slow charging stations have been added throughout 2019. In order to scale Elevat charging station demand onto cumulative demand of Slovenian charging stations, we only considered charging stations above slow charging, 3,6 kW level. Total number of the ones considered is therefore 201. They consumed 127.308 kWh of of electrical energy, averaging 348,6 kWh daily and 14,5 kWh hourly.

We displayed all charging events in 2019 on a figure 23, which shows at what times the charging stations have been in use and energy consumed on an average timespan.

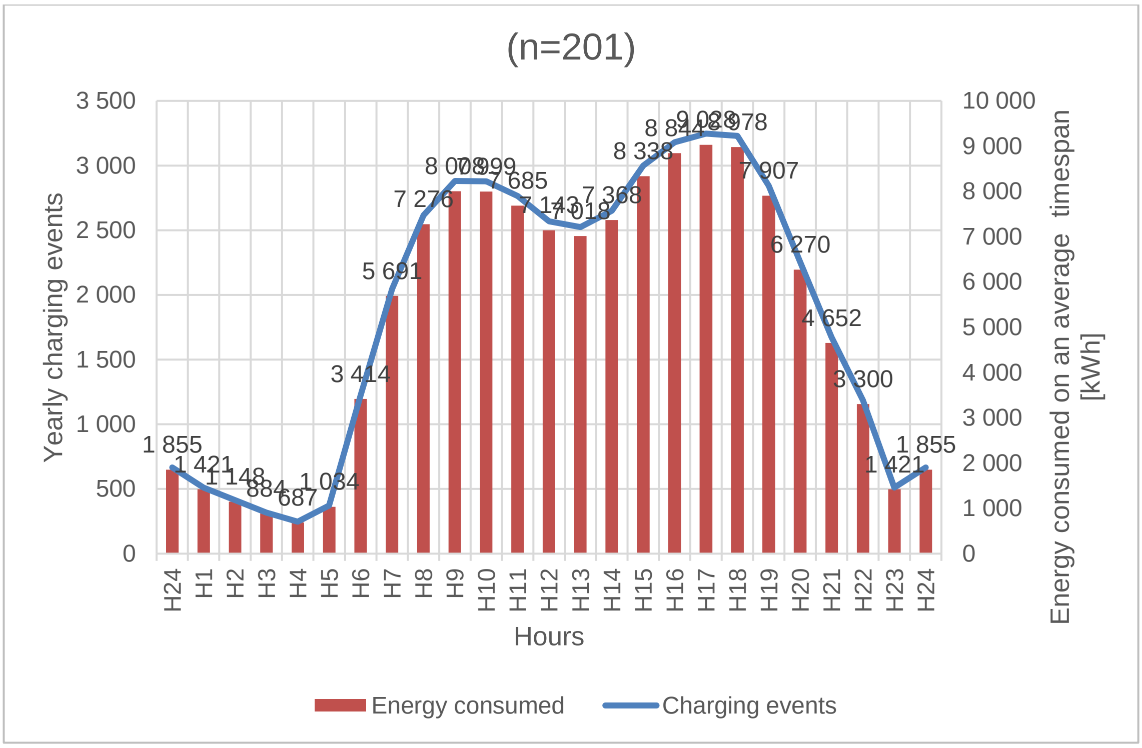


Figure 23: Cumulative charging profile on charging stations of a company Elevat 2019 (Elevat, 2020)

As we can see, their charging stations are mostly being used during the daytime, with curve beginning to rise early in the morning hours and reaching first of two peaks at around 9 a.m. During the midday, the intensity of charging stations usage somewhat falls and than steadily climbs to reach its highest peak at around 6 p.m. After that it considerably declines until the late evening. Except for a small increase of charging intensity at midnight, the usage slowly declines until the early morning hours.

In order to determine how the electric vehicles energy demand is distributed regionally, we divided the charging data into three different regional groups or clusters, Ljubljana cluster, Maribor cluster and outskirts cluster, which includes all charging stations that are considerably far away from both cities (more than 30 kilometers). In Ljubljana cluster 4.214 charges took place, with a total duration of 6.908 hours 55 minutes and 28 seconds, consuming 37.883 kW of electrical energy. In Maribor cluster 4.231 charges took place, with a total duration of 8.127 hours 53 minutes and 50 seconds, consuming 51.381 kW of electrical energy. In the outskirts 3.785 charges took place, with a total duration of 5.929 hours 54 minutes and 14 seconds, consuming 45.599 kW of electrical energy. Around 70 hours and 66 kW of electrical energy remained unallocated – they were intended for testing equipment. The longer and more intensive use of charging stations in the Maribor area is noticeable, especially because the charging stations in its cluster were used comparably to the charging stations in both other clusters, particularly in the Ljubljana cluster. A possible explanation for that phenomenon is a lower density of public charging infrastructure in Maribor area, which may be causing electric vehicle owners to leave their cars to charge on the charging spots longer whereas electric vehicle owners in Ljubljana have more charging options and can switch charging spots if they have to run errands elsewhere. The arrangement of charging points can be seen from Slovenian electric vehicle charging providers maps such as polni.si, gremonaelektriko.si and onecharge.eu.

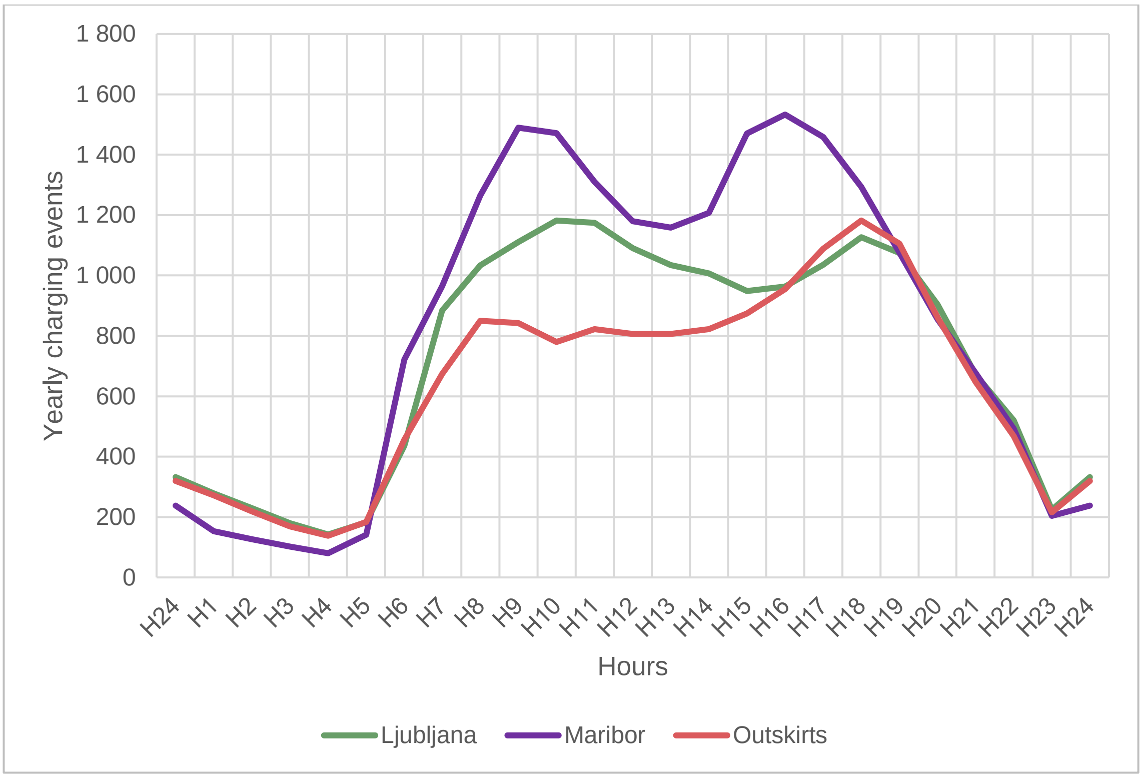


Figure 24: Regionally divided charging profile on all charging stations of a company Elevat in the year 2019 (Elevat, 2020)

Figure 24 is showing the division of the regionally divided charging profiles on the charging stations. All three curves start steadily climbing in the early morning hours and have an almost identical slope while declining from the afternoon peak. Their pattern of usage at night is also similar, with charging stations in Maribor being somewhat less used than charging stations in other two clusters. The biggest differences between the three are in their daytime usage pattern. Charging stations in Maribor have the most highlighted two peaks in usage – the first one occurs around 9 a.m. and the second one occurs at 4 p.m. Between them is a visible decline of usage at midday. Second peak occurs earlier than the afternoon peaks of both other clusters. However, as it declines, its slope is identical to the ones of Ljubljana and outskirts clusters. The charging spots in the Ljubljana area are used quite evenly during the daytime, they reach two small peaks at 10 a.m. and 6 p.m. and experience a small usage decline in the afternoon hours. Charging spots in the outskirts experience a slightly different usage pattern – they do not have a late morning peak but still climb quite steadily until around 8 a.m., after that their rise is slower and increases only late in the afternoon when it reaches its peak at 6 p.m. It is hard to provide an argument why is the charging pattern in Maribor different than in Ljubljana. It may be that for the same reason as for longer usage time and higher power consumption at charging stations the electric vehicle users in Maribor are simply not able to charge at some locations they frequent during the midday – while having lunch and running errands, therefore they excessively charge during the morning and afternoon hours and leave a gap between them. Usage pattern of the outskirts cluster is easier to explain – charging stations in these areas are more frequently used during the afternoon, after jobs and activities in the cities are completed and electric vehicle users gather at leisure activities at local centers of living.

We were also interested in a comparison between the intensity of use of charging stations during the working days and on weekends. According to SURS a single Slovenian resident travels 7.200 km in one year on average. The residents performed 3.2 trips per day, which took them 76 minutes in total, the average length of one trip was 13 kilometers. Their working day trips differ from the non-working day trips: on working days the residents of Slovenia performed 3.3 trips on average, and on non-working days 2.7 trips. A single trip was about 12 kilometers long on a working day, and about 17 kilometers long on a non-working day. On a working day, about 75 minutes were spent on all trips, while on a non-working day 78 minutes were spent. On working days most trips started between 7 and 8 am, and between 3 and 4 pm. On non-working days, most trips started between 10 and 11 am (SURS, 2018). Trips are displayed in a figure 25 provided by SURS.

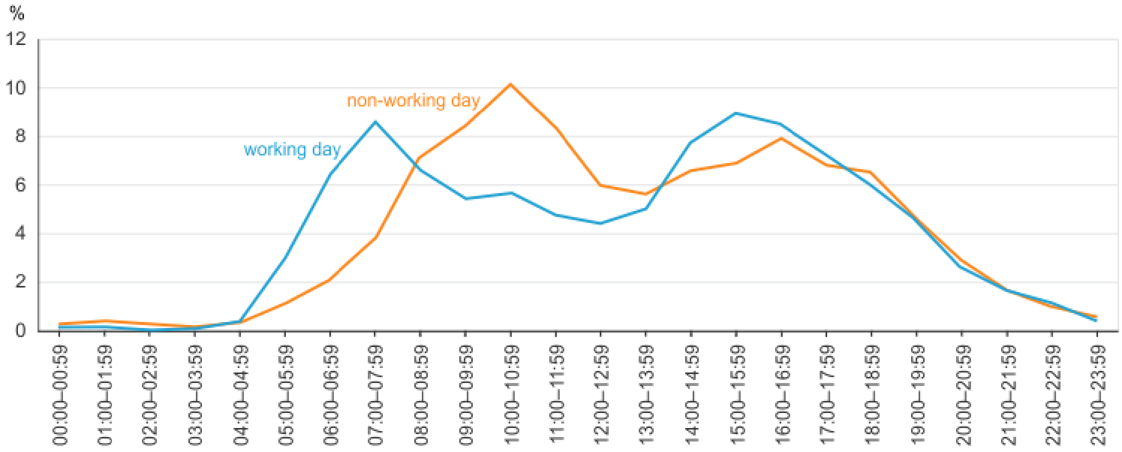


Figure 25: Trips on working and non-working days by hour of their beginning in Slovenia in the year 2017 (SURS, 2018)

Similarly to SURS' graph, we displayed the frequency of charging station usage during different hours on working days and non-working days.

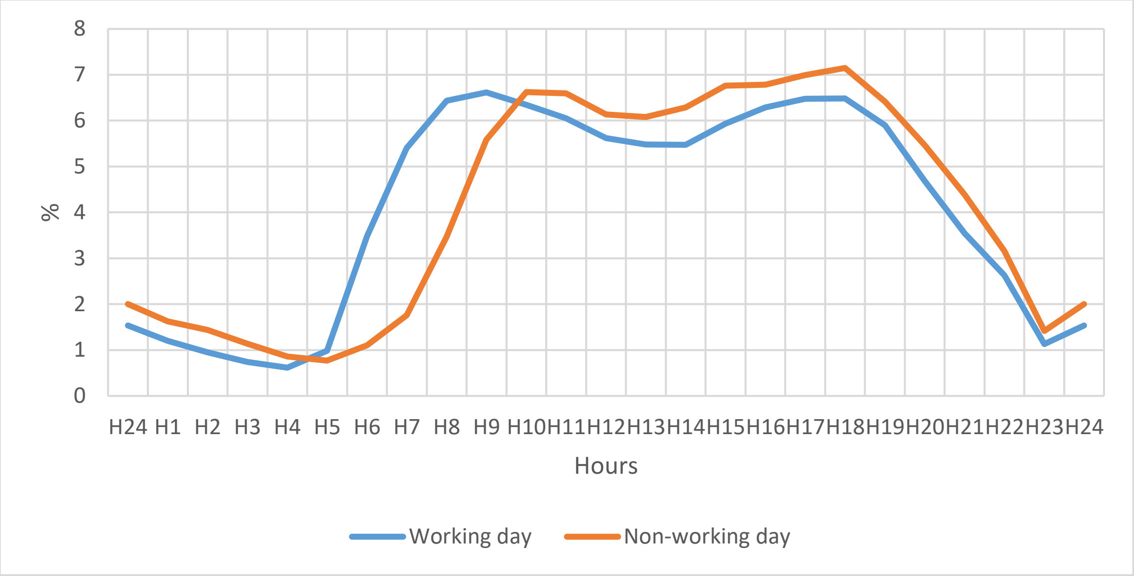


Figure 26: Frequency of working and non-working day usage on Elevat charging stations (Elevat, 2020)

We can observe the correlation and differences of daily Slovenian car trips graph and share of charging events on the public charging spots graph. Similarity between both graphs is the initial increase in trips as well as charging events. It can be said that the charging events start later during the weekend as they do during the workweek, which corresponds to intensity of trips during this time span. During the midday, the intensity of trips as well as charging events encounters a small fall. However, the one with charging station events is much flatter. An important fact to consider is that SURS' data is counting only beginnings of trips, while charging events are counted whenever the electric vehicle is charging itself on a station during that hour. Workday usage of charging stations is also very similar to trip intensity in a sense of both having a second peak in the afternoon. The non-working day trips have a very unexpressed second peak in comparison to the first, morning one, but charging event intensity does not really fall, it even rises a little in comparison to morning intensity. This shows a difference between the habits of an average car user and an EV user. It is hard to explain however, why there is still significant amount of charging events done in the afternoon of non-working days by the EV users.

8.2. Electrical energy demand of Slovenian charging stations in 2019

After we made sure that the data of the company Elevat are appropriate, we decided to generalize it to the total consumption of Slovenian electric mobility in order to get a broader overview of energy requirements. In doing so, we considered the number of charges and their length, as well as the energy consumption and scaled them from 201 charging stations to 1100 charging stations. These larger values were then redistributed again between new, larger number of charging stations and events. If we show the result in a figure 27, we get the following:

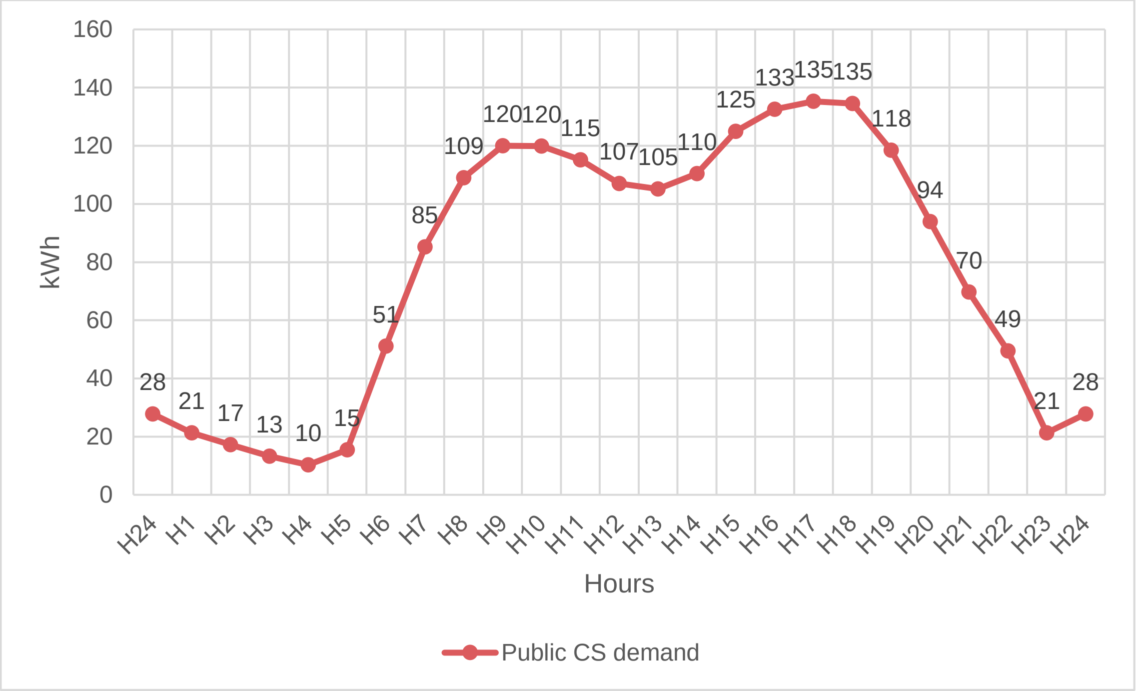


Figure 27: Total average daily Slovenian charging station demand

To accurately display changes of electric mobility demand throughout the year, we also displayed it quarterly, so how much energy is consumed by Slovenian electric mobility in a particular quarter. More charges have been made earlier in the morning and later in the afternoon in the second and third quarter, which is probably because of longer periods of daylight. Higher intensity of charging at night can be seen in the last quarter, which might be due to the fact that some vehicles were left on the charging stations over night to charge.

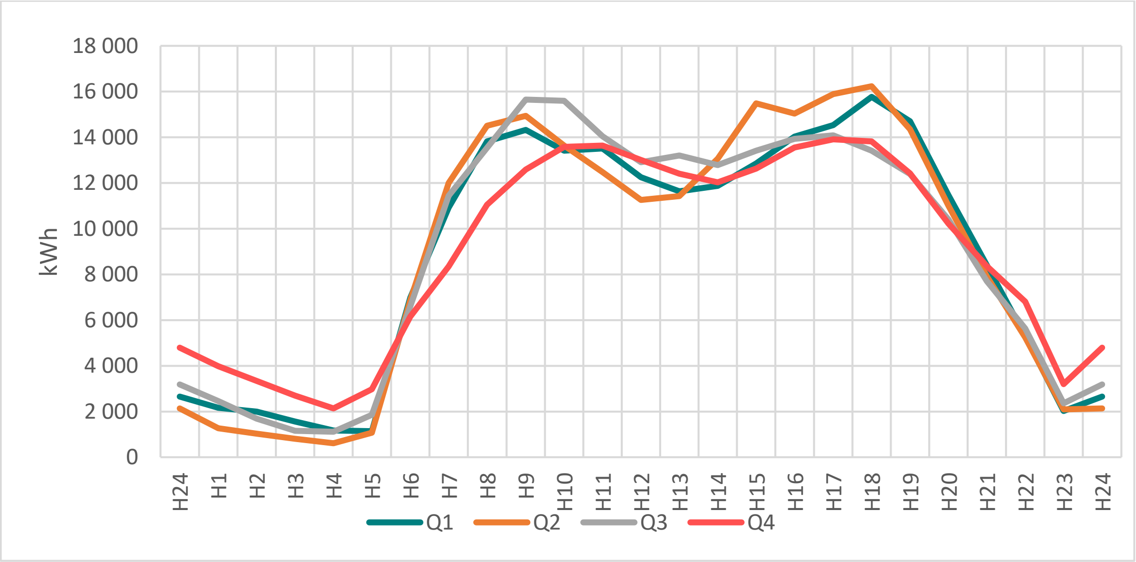


Figure 28: Quarterly consumption of electrical energy on Slovenian charging stations

The assessment of the total demand of electric mobility for electricity, however, includes more than just charging at charging stations. Unfortunately, it is much more difficult to extract data for individual tasks consumption patterns of a particular household. As a result, we unfortunately had to estimate the electric mobility charging consumption within the household. In doing so, we used data from document Learning from Norwegian battery electric and plug-in hybrid vehicle users (Fingenbaum & Kolbensvendt, 2016) as well as (Anderson, Lin, Newing, Bahaj, & James, 2017) and (Gouveia, Seixas, & Mestre, 2017). We estimate that connecting of electric vehicles to charge will not differ majorly in time from the current pattern of household consumption and usage of other appliances, except perhaps at night. Regarding the amount of energy consumed, we assumed that 80% of all charging of electric vehicles takes place at home, within households, according to the previously mentioned logic (Fingenbaum & Kolbensvendt, 2016) by the lower degree of urbanization in Slovenia.

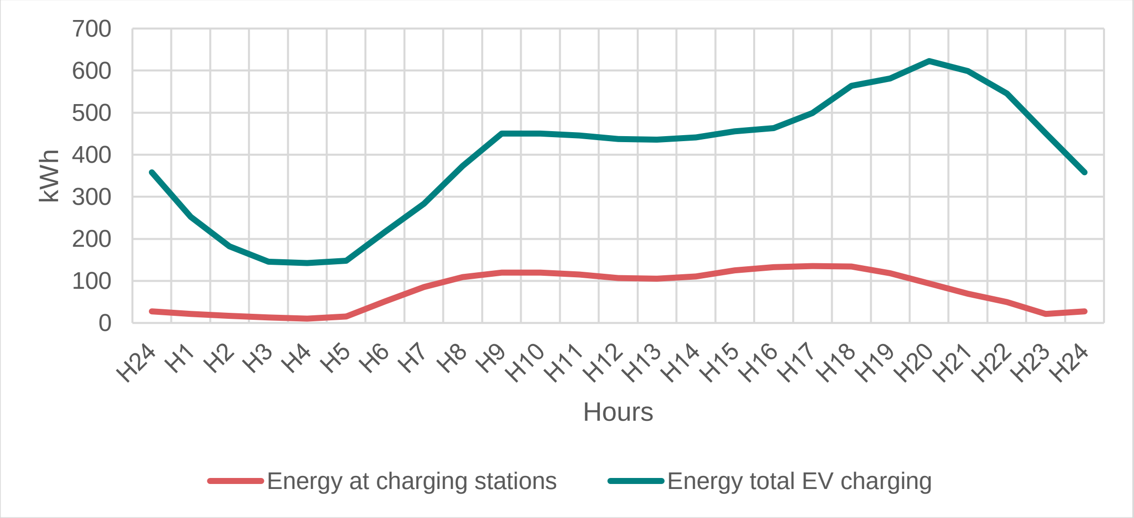


Figure 29: Total average hourly charging demand including household charging

Total consumption is shown in the figure 29. The graph of overall consumption is flatter than conventional energy consumption in households, which is positive from the point of view of adjusting energy production to match the demand. A negative aspect is the additional load in the peak evening hours, at 18 or 19.

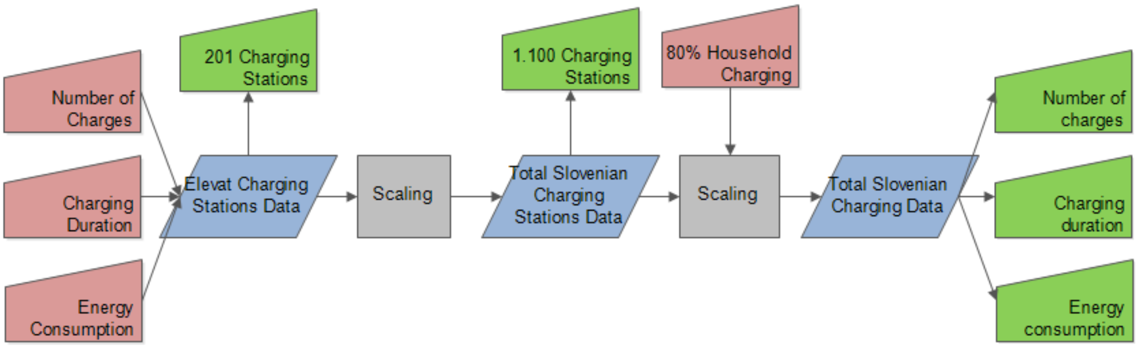


Figure 30: Flow chart of total Slovenian charging data in 2019 calculations

Based on the loads from 2019 and with help of transmission system operator scenarios, we will describe projected consumption in 2030 in the next section.

9. Prognosis of production and consumption in 2030

Taking into account the data from chapter 2, figure 4, ie ELES's data on network consumption, we generalized the 2019 consumption to the total consumption in 2030. Based on the ENTSO-E scenarios, we developed a thesis scenario which is similar to the Sustainable Transition scenario in terms of exploitation of solar potential and and predicts higher wind energy utilization, with 150 wind turbines installed. It represents the highest feasible proportion of wind energy production in 2030. Such scenarion would therefore be probable and optimal for electric vehicle demand. Electric mobility consumption is shown as an addition to total consumption. In doing so, we took into account the consumption as calculated through the Elevat charging stations, but for a comparison we also displayed a more exteme electric mobility demand ELES scenario based not on energy consumption of electric mobility but vehicle kilometers driven.

For the number of electric vehicles in 2030, we considered the optimal scenario of the Ministry of Infrastructure with 129.690 battery electric vehicles and 71.644 hybrid vehicles (Ministrstvo za infrastrukturo, 2017). An extreme scenario foresees ELES' estimated number of electric vehicles in 2030 with 227.000.

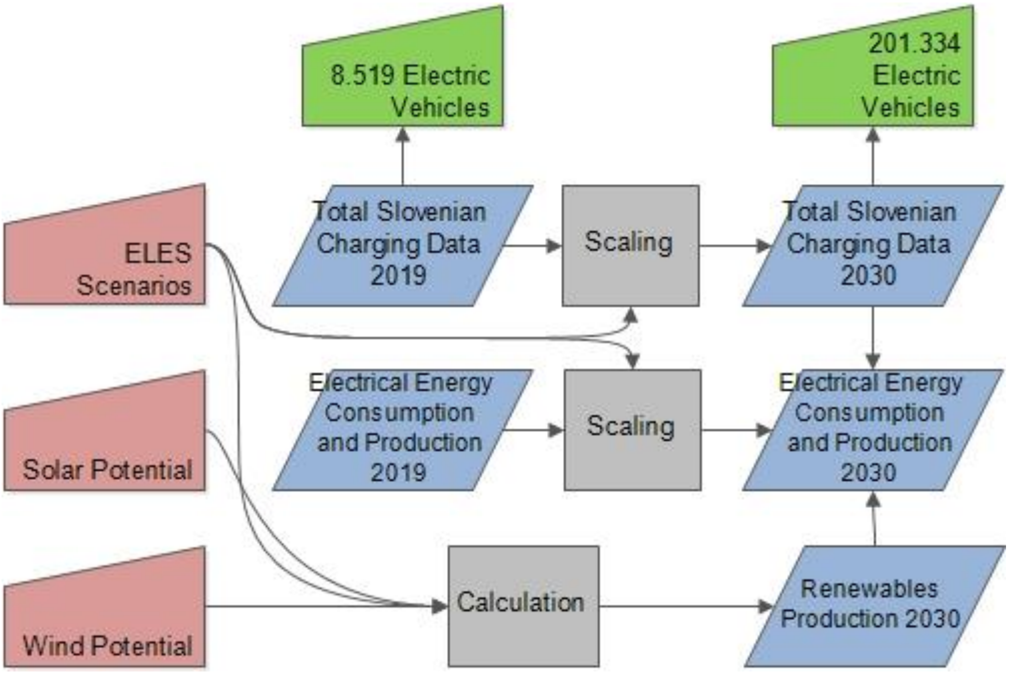


Figure 31: Flow chart of total Slovenian electrical energy consumption and production in 2030 calculations

Using this process, we created the following displays of consumption and production: figure 23, figure 24, figure 25, and figure 26.

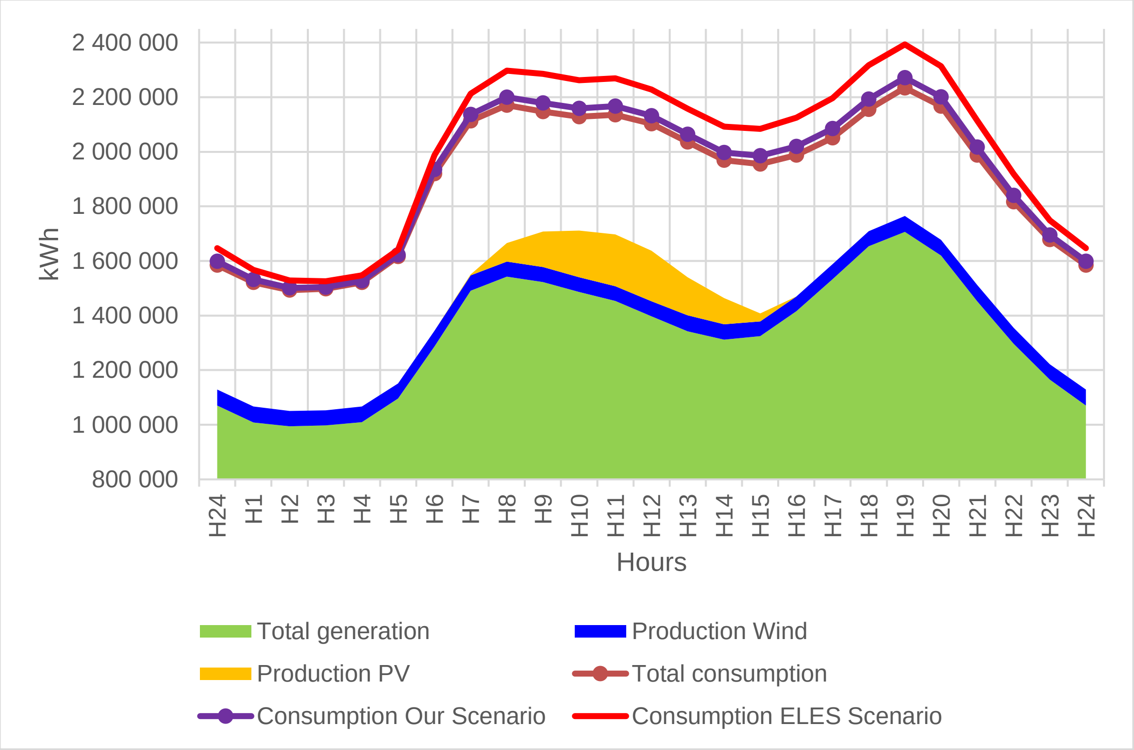


Figure 32: Total consumption and generation of electrical energy in the first quarter of 2030 according to thesis scenario (ELES, 2019); (Elevat, 2020); (ENTSO-E, 2019)

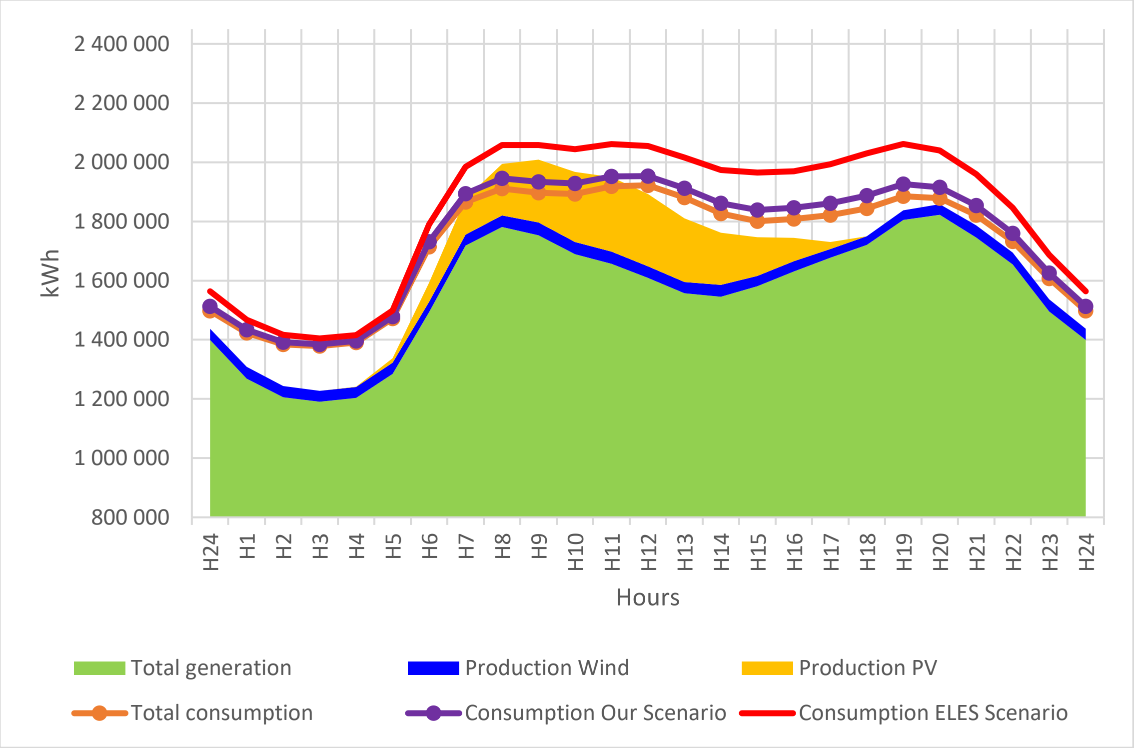


Figure 33: Total consumption and generation of electrical energy in the second quarter of 2030 according to thesis scenario (ELES, 2019); (Elevat, 2020); (ENTSO-E, 2019)

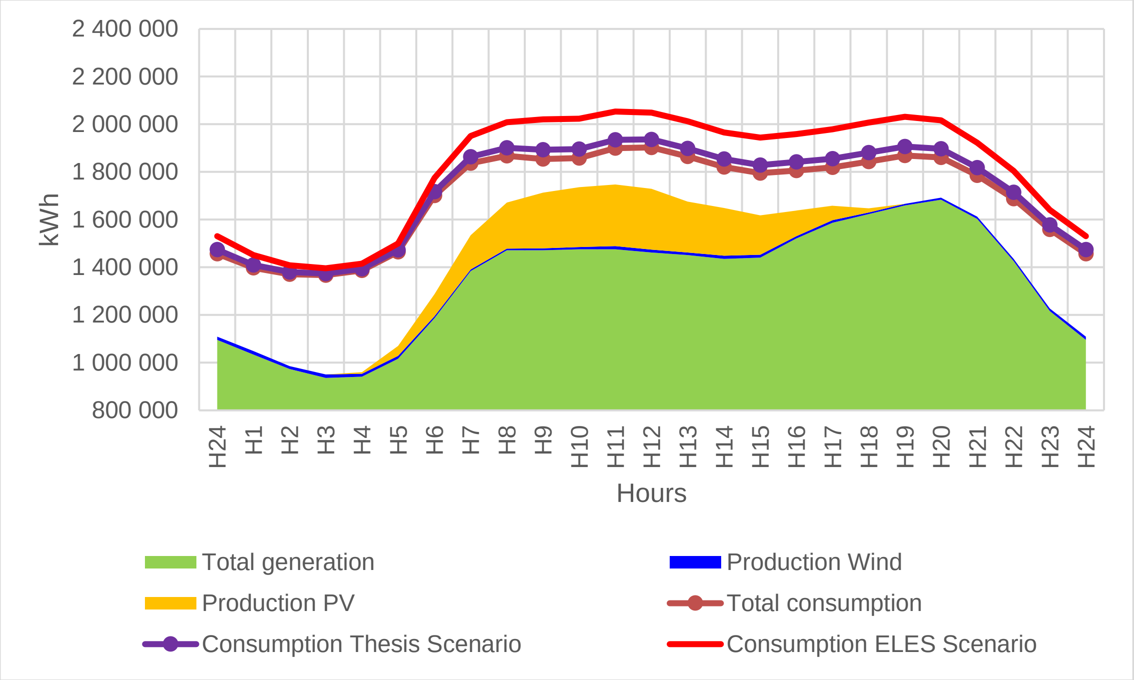


Figure 34: Total consumption and generation of electrical energy in the third quarter of 2030 according to thesis scenario (ELES, 2019); (Elevat, 2020); (ENTSO-E, 2019)

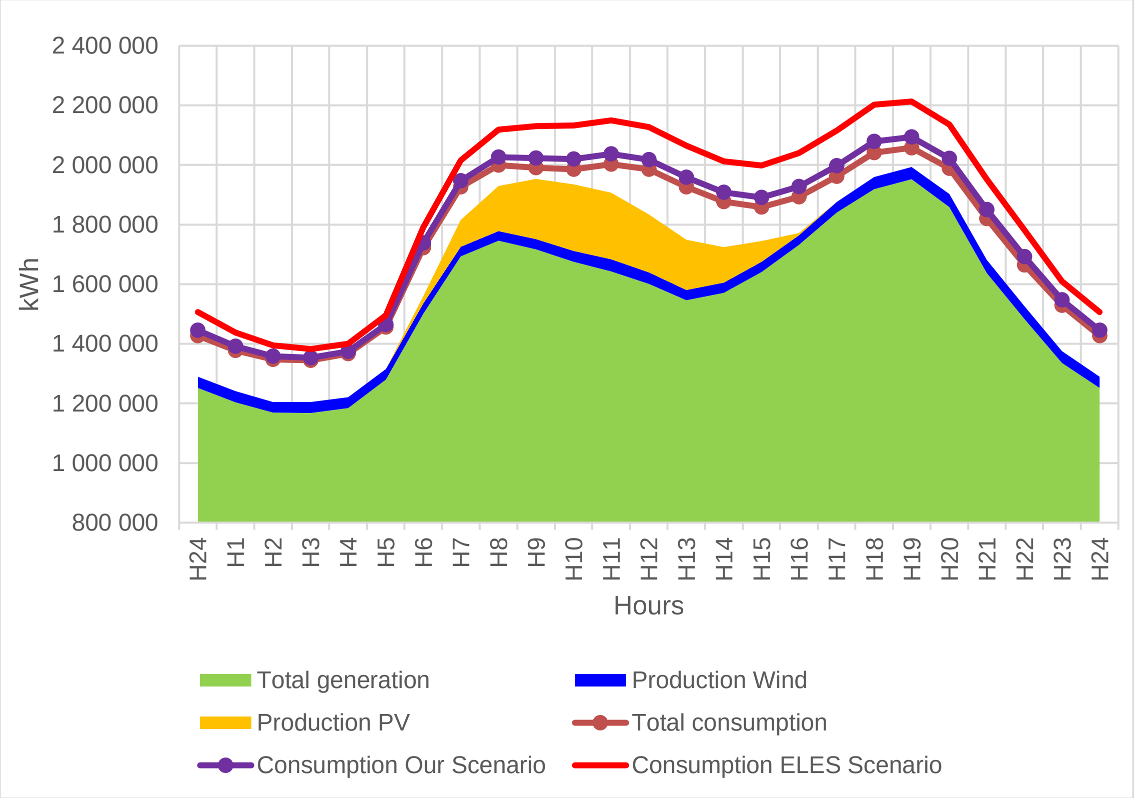


Figure 35: Total consumption and generation of electrical energy in the fourth quarter of 2030 according to thesis scenario (ELES, 2019); (Elevat, 2020); (ENTSO-E, 2019)

The lines on the graphs mark consumption. Total consumption is expanded with either thesis scenario in violet or more extreme transmission system operator ELES scenario in red. Energy generation is marked with area plot in green color and expanded with wind production in blue and solar production in yellow.

The most problematic time of the year according to such scenario would be the first quarter, where a really large difference between total production and consumption of electric energy is visible. Although there is a lot of wind present, we do not have enough solar energy to cover a very high total demand caused by heating needs. It is important to mention, although it is not visible from the graph, that this is also the time of lower river flow and so hydropower does not have an above-average contribution to production.

More promising is the second quarter where a smaller gap between consumption and generation is present. Heating needs of the population are lower, river flows are at their highest and the discrepancy between production and consumption is smaller. With an additional wind and solar energy, the thesis scenario is able to cover parts of energy consumption of calculated scenario and to significantly reduce Slovenia's import dependence in the field of electrical energy on the entire curve.

In the third quarter we have a low total consumption and very low wind production. Total production is also lower, and we therefore have some discrepancy between total production and consumption. Solar production distributes itself very evenly along other production sources which is good for managing the network.

The fourth quarter is similar to second quarter in terms of wind production, hydro energy production is also lower. Total consumption is again higher because of heating needs. Solar production does not cover the consumption, but the gap between consumption and production is not too large.

In general, the graphs show that both wind energy, which is evenly distributed throughout the day, and solar energy, which fills the morning peak, are favorably interacting with the balance of energy in the Slovenian electricity network. According to our findings, apart from increasing the share of mentioned renewables excessive change in electricity mix would not be necessary in order to easily to cover total energy consumption with an additional electric mobility demand.

10. Charging strategies of electric vehicles to reduce network load

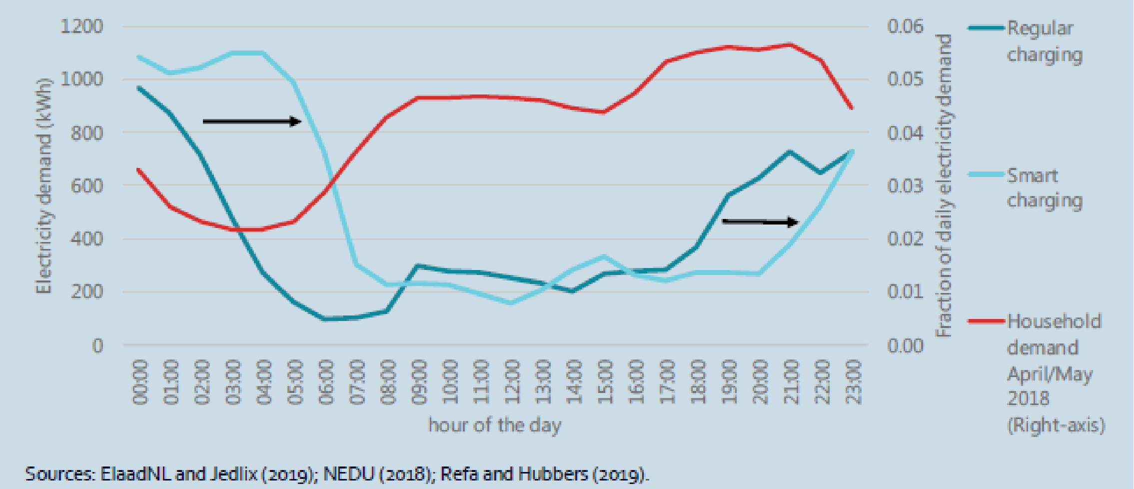
Although we have found out that along with the proposed increase in charging capacity and the increase in electrical production from the sun and wind in the next decade, there would not be necessary to overly adapt the network, we will briefly describe the possible measures which will facilitate the possibility to integrate a larger share of electric mobility into the grid.

Controlled electric vehicle charging is the method that is most often mentioned in connection with the allocation of energy needed for electric mobility. Controlled electric vehicle charging offers the use of demand side response, which provides various solutions to the problem of high load on the power system (International Energy Agency, 2019). The most important ones are:

- Reducing the load on the electrical system by reshaping the electrical energy demand pattern; it is therefore a matter of encouraging the charging of electric vehicles during periods when there is less demand in the network (International Energy Agency, 2019).
- Electric vehicles can supply energy to the power system if necessary. Electric vehicle batteries enable a very fast and accurate response to control signals; they can also stretch demand over longer periods of time. These capabilities enable electric vehicles to offer demand side response and participate in electricity markets at different times. This is an important advantage of electric vehicles over other sources of demand side response (International Energy Agency, 2019)
- Electric vehicle batteries can store electrical energy that can also be used for purposes other than powering the vehicle. Technologies such as "vehicle-to-grid" (V2G), along with other "vehicle-to-everything" (V2X) technologies, enable electric vehicles to act energy storage facilities for buildings or power network and thus maintain the stability of the system. The usage of these properties can have a very positive effect on the quality and stability of the network at the local and wider level (International Energy Agency, 2019)

In the very short time scale, electric vehicles can help ensure the stability of the system (voltage, transient and frequency stability) at high proportions of variable (unstable) production, in the short time scale they can regulate more frequent, faster and less predictable changes in the supply/demand balance. In the medium term, they could alleviate longer periods of surplus or deficit of electrical energy due to e.g. specific weather conditions in renewable energy production and in the long term they could balance seasonal availability of variable energy production from renewable energy sources with their energy demands (International Energy Agency, 2019). In thesis case, the renewable energy sources falling under these frameworks of balancing seasonal availability are energy production from sun and wind.

One of the ways to influence the demand of electric mobility is to shift its charges to the nighttime. In order to achieve that, the charging aggregator in the Netherlands has helped himself by changing electricity prices at different times and thus stimulated charging outside of peak times. The figure 36 shows the influence of the response of the change in price signals on the change in the charging pattern.



Sources: ElaadNL and Jedlix (2019); NEDU (2018); Refa and Hubbers (2019).

Figure 36: Change of smart charging pattern of electric vehicles in accordance to different price signals (International Energy Agency, 2019)

Figure 36 displays how the charging pattern adjusted itself when the aggregator leased the amount of electrical energy for 1.000 charges and distributed the charges of electric vehicles in accordance with the demand of households or the price of electricity in the market. Red color indicates household demand, dark blue the usual charging pattern, and light blue the smart charging, aggregated pattern. Compared to the average household electrical energy consumption, smart charging is redirected to times with lower energy demand. On a national scale, between 30 and 50 percent of charging sessions in the Netherlands take place in the evening peak hours (between 16:00 and 20:00), while cars are on average parked at charging spots approximately four times longer than the required charging time, allowing the actual charging time to be adjusted, until the driver moves its vehicle (International Energy Agency, 2019). This kind of charging is not expected to affect the final charge of the battery, as confirmed by several studies including (Hu, You, Lind, & Østergaard, 2014). In this study, among other things, experiments were performed on what form of smart charging would work best. As the best solution, they proposed a combination of direct control of energy consumption of electric vehicles and its adjustment according to the price of electricity. An important factor in the adjustment is also the voltage level in the network (Hu, You, Lind, & Østergaard, 2014). A similar smart charging option is also predicted by Slovenian transmission system operator ELES in more distant future.

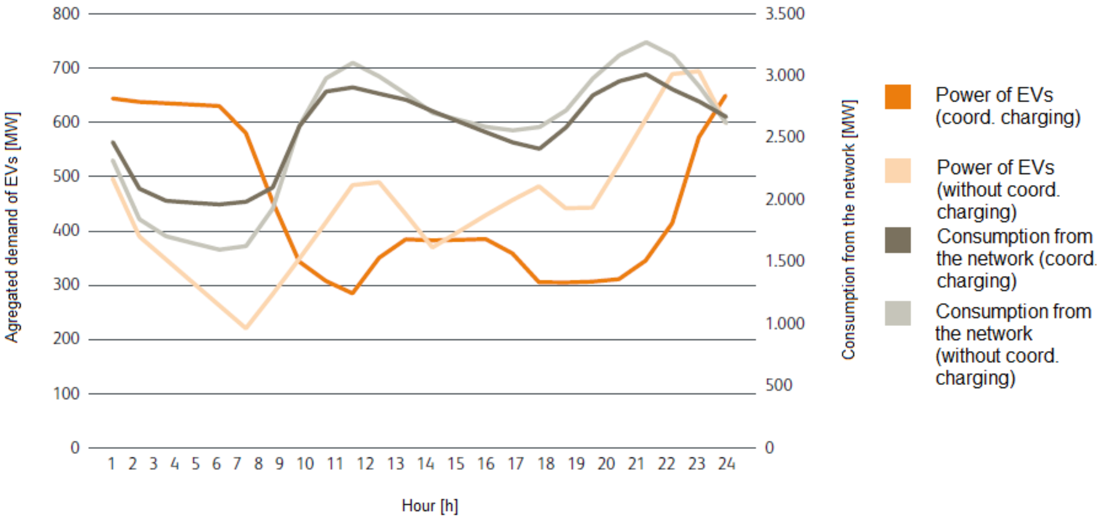


Figure 37: The impact of different charging strategies for electric vehicles on the daily electricity consumption diagram in 2050 (ELES, 2019)

On ELES' figure 37 we also see that sharp jumps in electricity consumption in the grid are smoothed out, and both the power of electric vehicles (orange) and their consumption (grey) draw a smoother curve.

Apart from the possibility for the user of an electric vehicle to manage the charging of his vehicle on his own, the development of smart charging offers several possibilities. Today, the OCPP (Open Charge Point Protocol) communication protocol is used at most charging points; it is intended for the communication of the charging station with the central control system. The company that developed the protocol has developed a new one, OSCP (Open Smart Charging Protocol). This will be more suitable for integrating electric vehicles into smart grids and among other things, it enables charging in accordance with the 24-hour forecast of the electrical energy level in the network (Open Charge Alliance, 2019). The development of the mentioned and similar ways of communication of the charging system will enable easier participation of all actors within the electricity markets. Companies for the transmission and production of electrical energy could cooperate with the owners of such fast or publicly available charging stations as well as private ones and coordinating different charging powers at different times. Certainly, coordination between the involved parties will require some effort. (Hu, You, Lind, & Østergaard, 2014) mention not only the term aggregator but also the term fleet operator. Fleet operators would take care of coordination between electric mobility users, charging stations and network operators. Given the amount of information he would have available and given the amount of his authorization, he could manage the charging of electric vehicles batteries to a considerable extent. Coordination could be based on network occupancy, the price of services, the needs of electric vehicle users and energy producers, and so on. It would therefore be a new market player in the electricity market, playing an important role in reducing network congestion and integrating electric vehicles into the electricity markets (Hu, You, Lind, & Østergaard, 2014). Different levels of possible integration of electric vehicles into the grid are described in the table 4. The state of technology in Slovenia currently does not allow a higher level of integration than the one described in the 1st level.

Electric vehicles grid integration levels	Description	Regulatory and market requirements
Grid-compliant charging	Phase where electric vehicles are connected to the grid for their charging needs, but smart charging is not yet applied.	Electric vehicles comply with the local requirements and regulations. The charging power is below the thresholds prescribed by grid operators.
Level 1 – Controlled charging	Charging power and time are controlled remotely by various management systems, either the user or by the energy management system at home.	Dynamic electricity pricing levels are needed to incentivize charging behavior.
Level 2 – Aggregated controlled charging	A charging profile is negotiated based on various drivers (monetary drivers or grid constraints), and responses are controlled and bundled by aggregators without direct individual user interaction.	Aggregators need to be authorised as market players. The wholesale balancing and capacity markets (where applicable) need to be open to incentivise aggregated demand-side resources.
Level 3 – Bidirectional charging	Electric vehicles can also feed electricity back to the grid and home. This allows for the use of electric vehicles as a distributed electricity storage mechanism, and enhances the attractiveness for electric vehicles as a frequency response measure.	Pricing of flexibility services needs to exceed the increased cost for the electric vehicle owner of bi-directional charging. Bidirectional charging requirements may be included in the standardization of electric vehicles supply equipment and electric vehicles.
Level 4 – Aggregated bidirectional charging	The enhanced flexibility capacities of electric vehicles are managed by aggregators to be able to compete in the flexibility market with larger capacities.	Aggregators need to be allowed as a market player, benefits from bidirectional flexibility should be rewarded through electricity market dynamics.

Table 4: Grid integration levels of electric vehicles and regulatory and market requirements (International Energy Agency, 2019)

We should not neglect the development of small electricity producers (prosumers) either. The term prosumer refers to a user who generates electrical energy in their home environment and has a possibility to store excess energy for future consumption or sell it to other interested potential customers within the smart grid. A significant proportion of users of electric mobility could, in the case of the installation of their own production capacities, largely cover their electricity needs. Their production capacities could also be managed by an aggregator. This is another way to reduce network congestion. Time will tell how the development in the field of smart charging will really take place in the future.

Conclusion

Electric mobility is gaining ground both globally and in Slovenia. As a member of the European Union, Slovenia follows its directives and guidelines in this area as well. Trends tend to limit the use of vehicles with internal combustion engines, reduce greenhouse gas emissions, and produce and store electricity produced from renewable sources. Therefore, it makes sense to show electric mobility in combination renewable energy sources, especially if we want electric mobility to be a cleaner alternative to the environment.

For completely accurate results, we would need a better insight into the charging structure of electric vehicles within households. There are different computational approaches that do not give the same results with a large amount of energy. At times it was difficult to obtain statistical data, as some are not publicly available and are used solely by analysis services. However, our calculations shed light on the issue of the impact of the increase in electric mobility on the network, and point to the fact that electric mobility is far from being the biggest challenge for power networks and are is a part of several future challenges.

In this context, we found out in the thesis that Slovenia is not self-sufficient in terms of production of electrical energy and that the difference between the production from primary sources of electrical energy and overall consumption will continue to increase and Slovenia will continue to import a significant share of electrical energy in 2030. Therefore, the use of so far less exploited renewable energy sources such as solar and wind power is increasingly important.

We focused on solar and wind potential. Findings indicate that solar capacities in Slovenia are not yet exhausted and have the possibility to produce large quantities of electrical energy to help cover both the electric vehicle and total electrical energy demand. Although wind potential in Slovenia is low, it offers considerable steadiness. It is a fact that wind power is underused and could partially cover electric vehicles energy demand. Because of its steadiness it may make sense for Slovenian government to reconsider investing into it.

Given the projected growth of electromobility, we do not anticipate that its charging intensity would have a significant impact on energy shortages in the grid by 2030 but will nevertheless add to consumption during peak hours. It would make sense to relieve the intensity of consumption at these times and in order to do that electric vehicle users should be stimulated accordingly.

In the future, electric vehicles will be able to contribute to reducing the load on the power system through controlled and smart charging. Already today, unused production capacities could be used at nighttime. In any case, the active introduction of electric mobility into the power network is a new business opportunity for small electrical energy producers as well as for energy companies and their coordinators. New grid investments should help provide a functional environment for the use of electric mobility. The introduction of new technologies will bring both obstacles and new solutions in the long run but for now, electric mobility in Slovenia can grow without major concerns.

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Annex

a) Scenario 1 figures

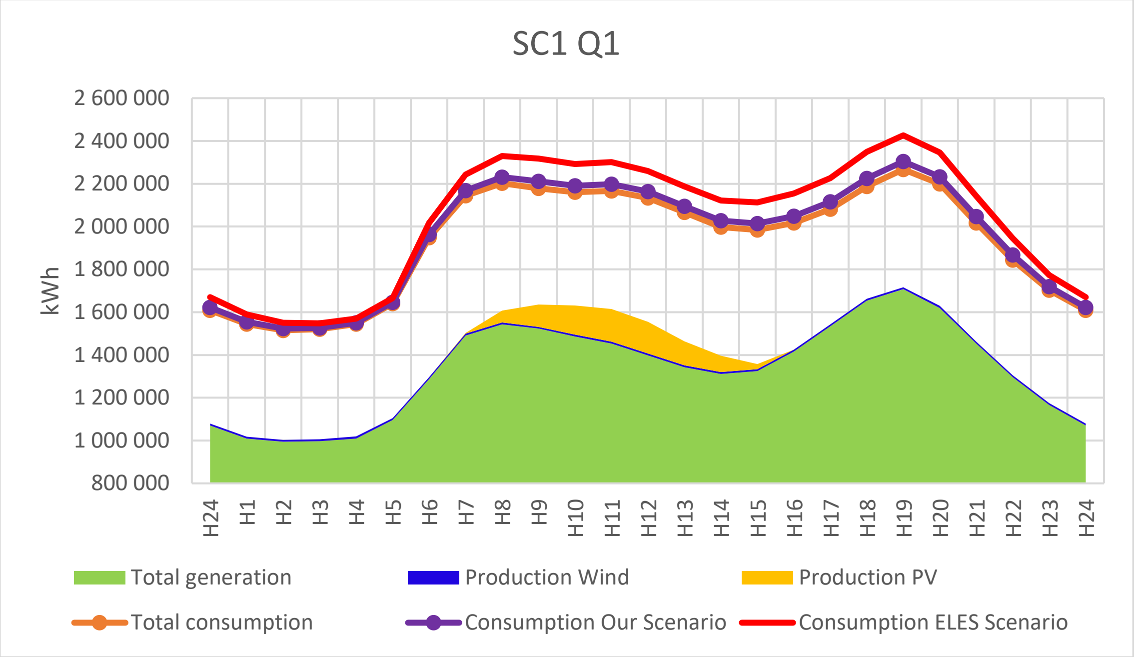


Figure 38: Total consumption and generation of electrical energy in the first quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

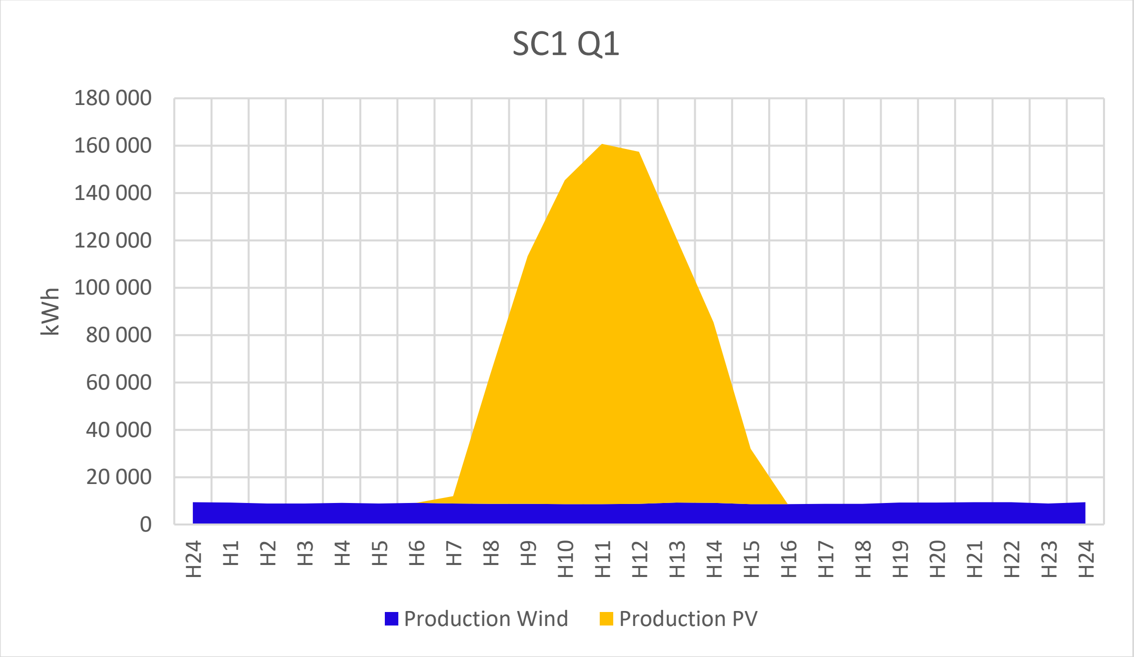
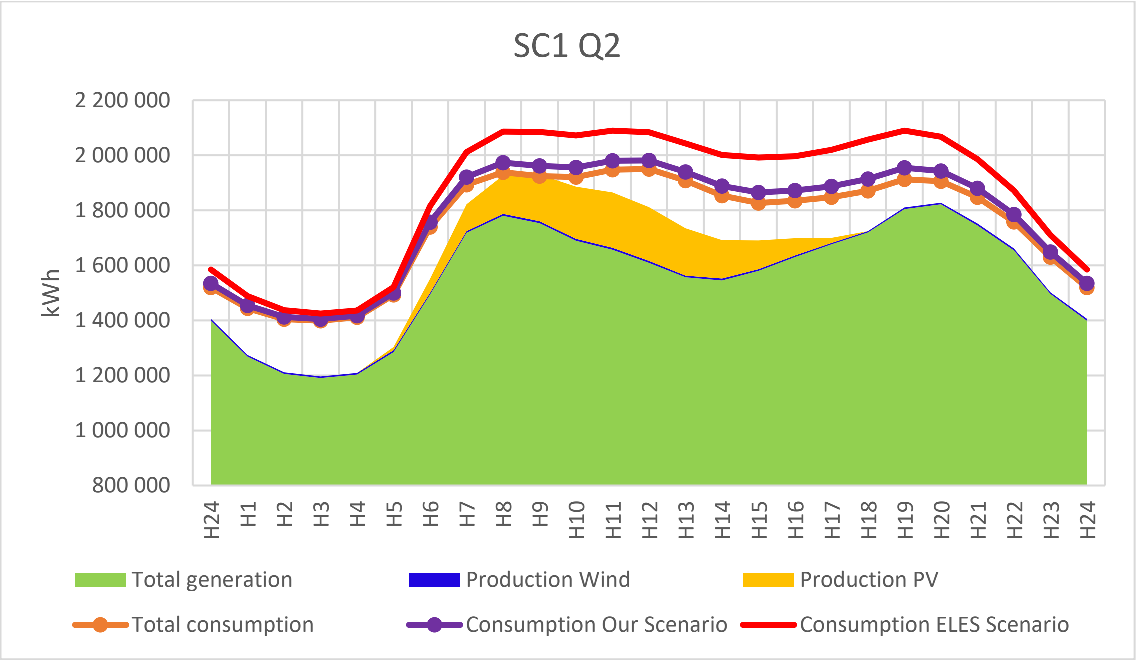


Figure 39: Potential daily solar and wind energy production in the first quarter of 2030 according to Energy concept of Slovenia scenario (SC1)



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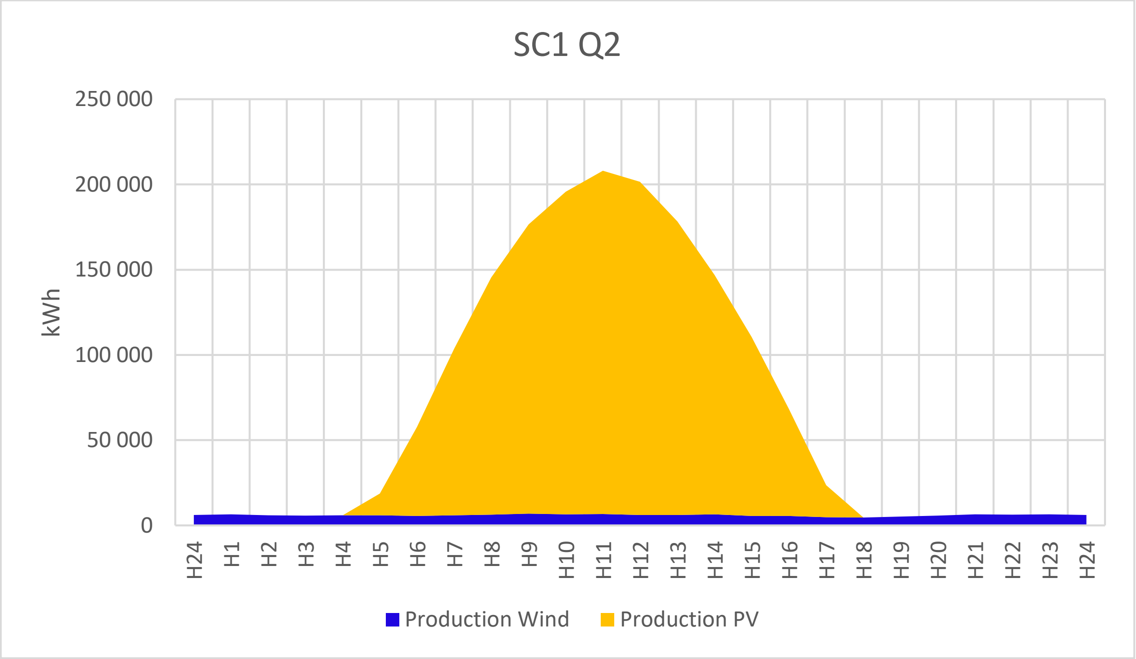

Figure 41: Potential daily solar and wind energy production in the second quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

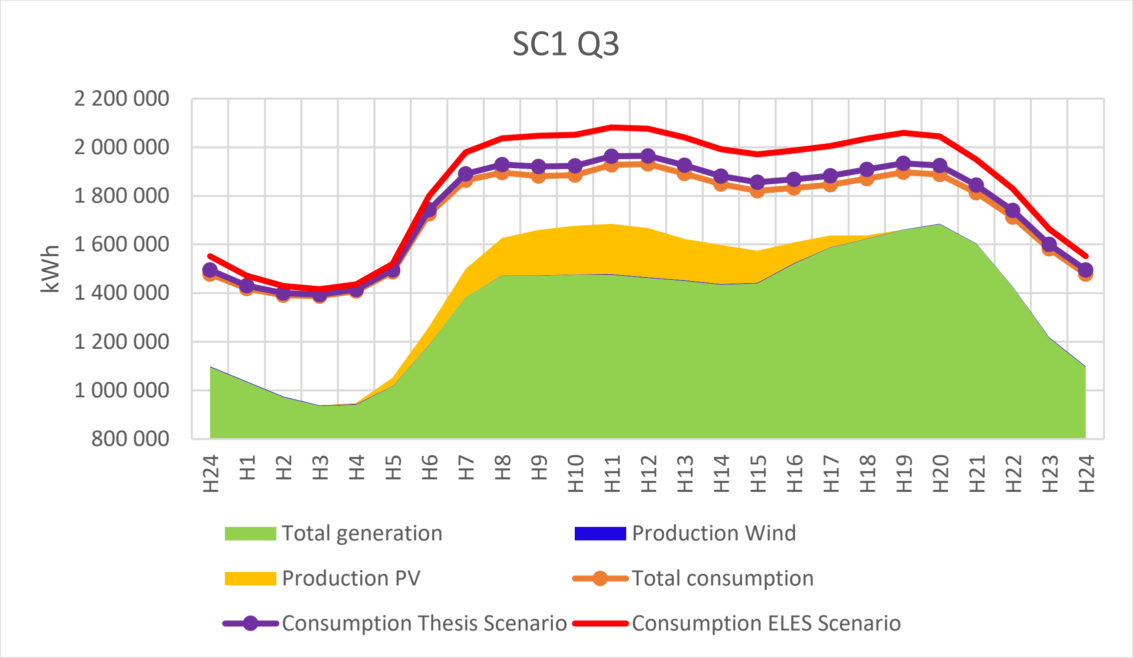

Figure 42: Total consumption and generation of electrical energy in the third quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

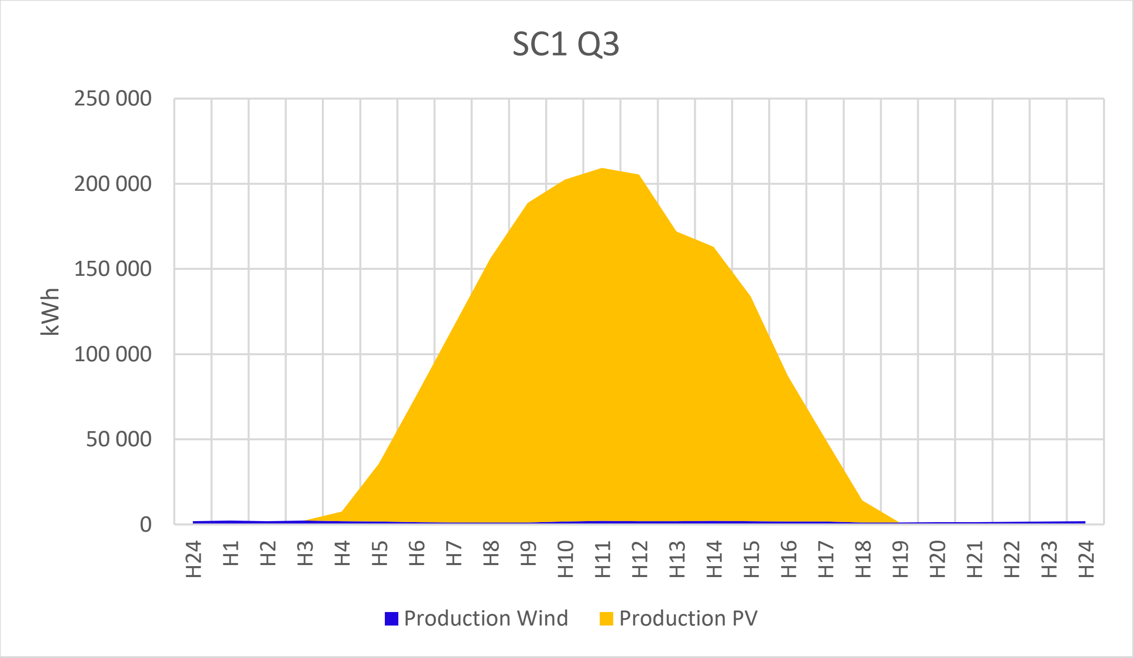

Figure 43: Potential daily solar and wind energy production in the third quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

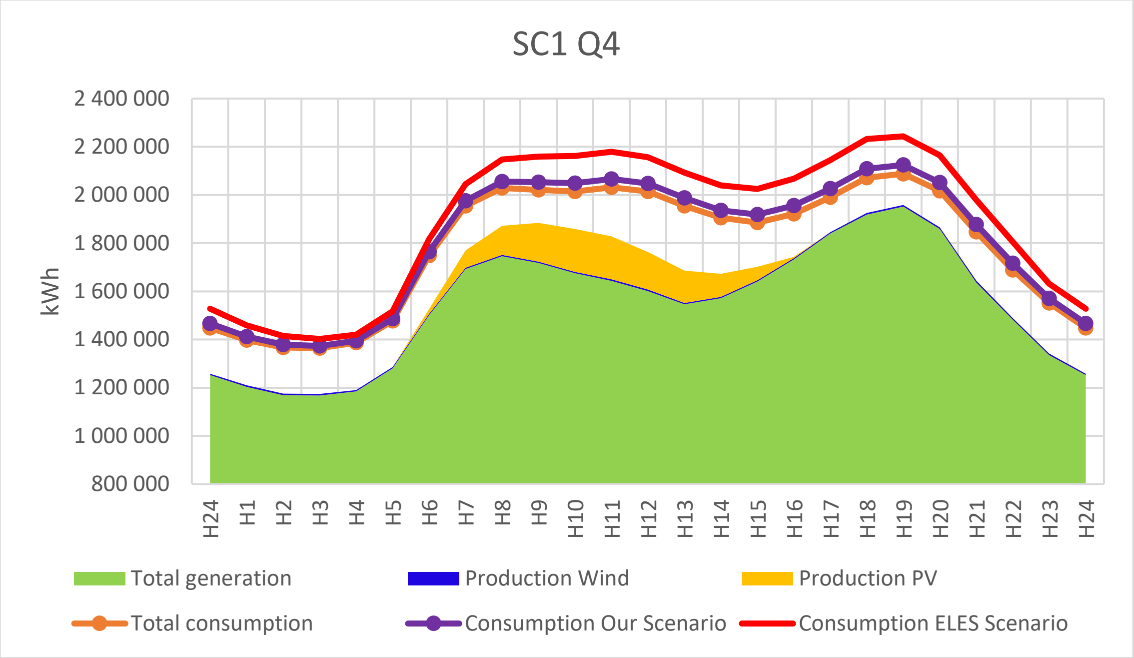

Figure 44: Total consumption and generation of electrical energy in the fourth quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

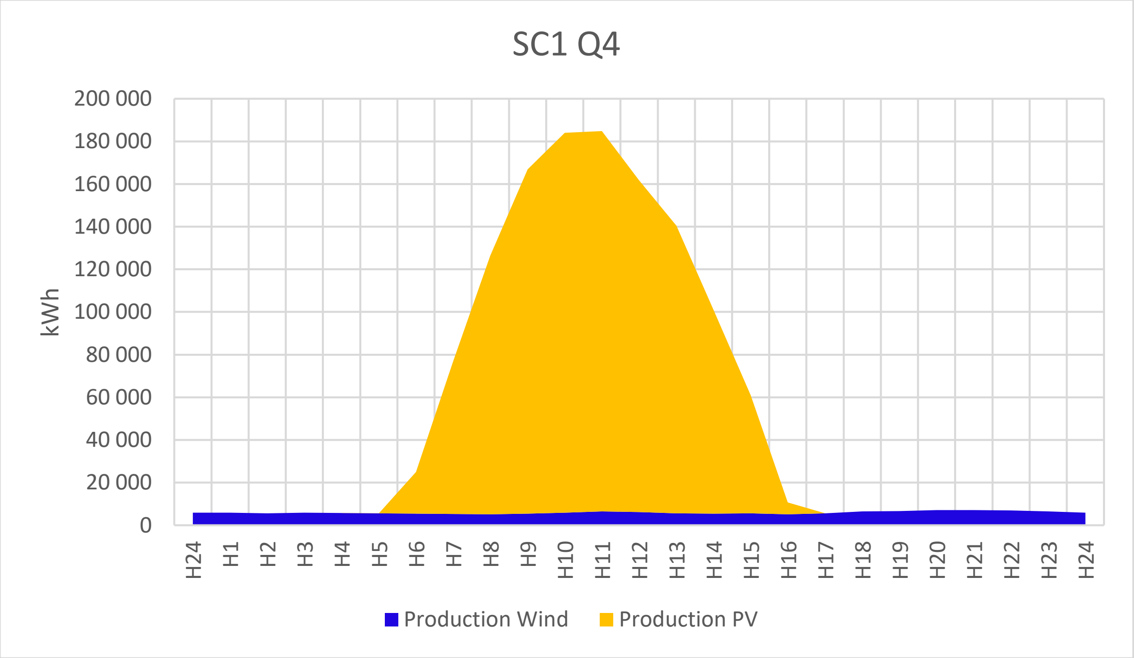

Figure 45: Potential daily solar and wind energy production in the fourth quarter of 2030 according to Energy concept of Slovenia scenario (SC1)

b) Scenario 1 150 Wind Turbines

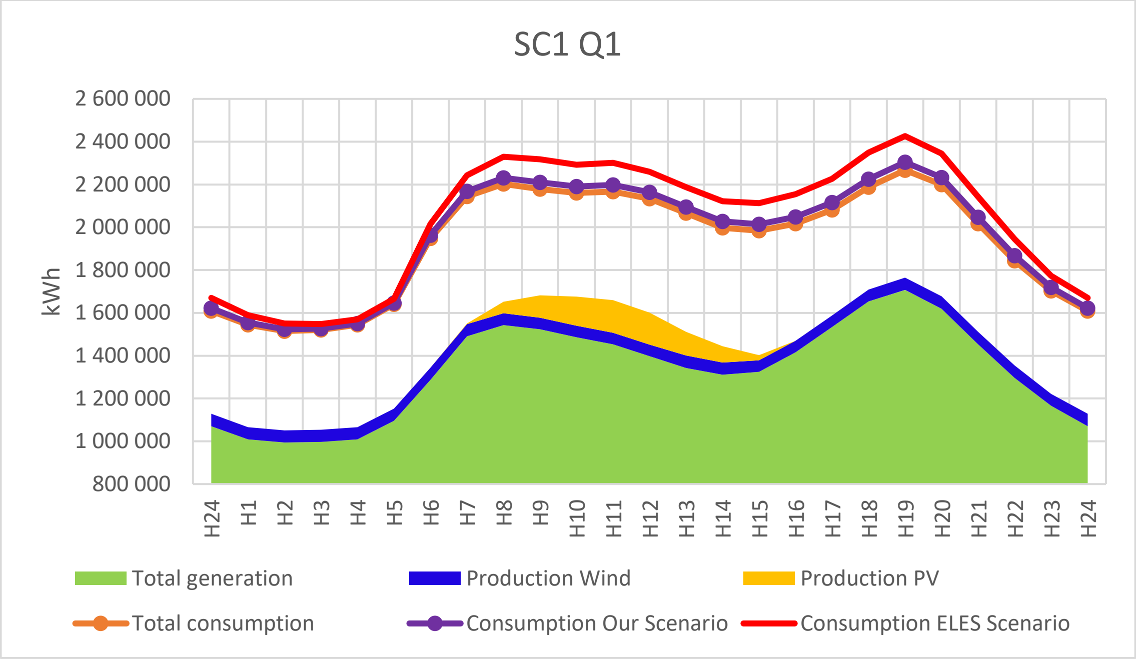

Figure 46: Total consumption and generation of electrical energy in the first quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

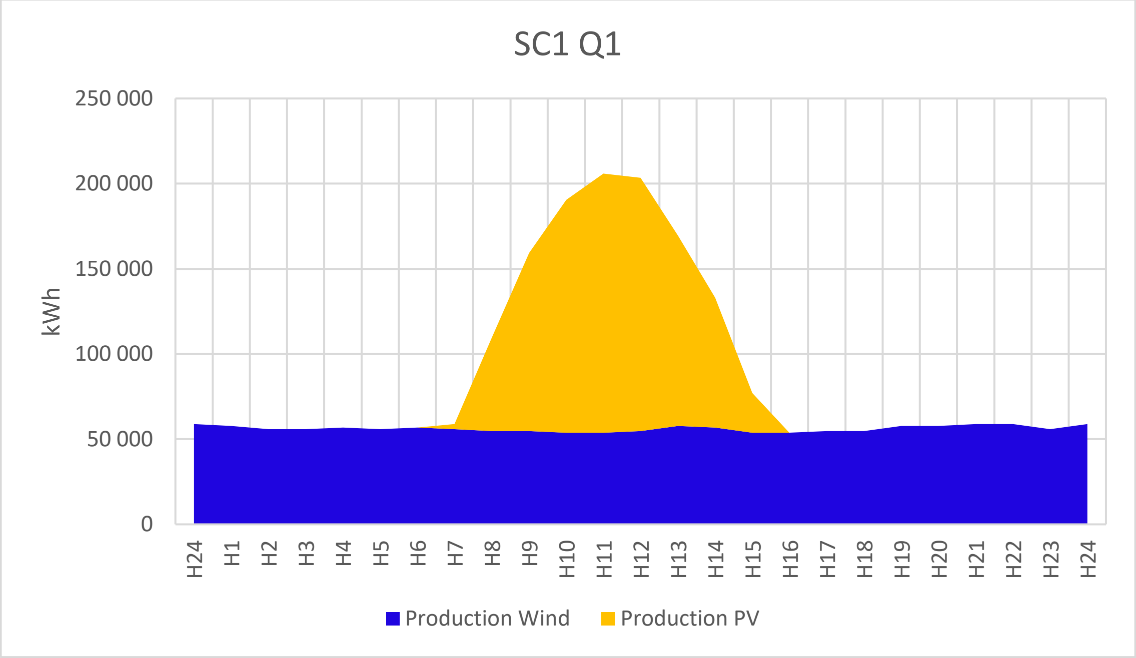

Figure 47: Potential daily solar and wind energy production in the first quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

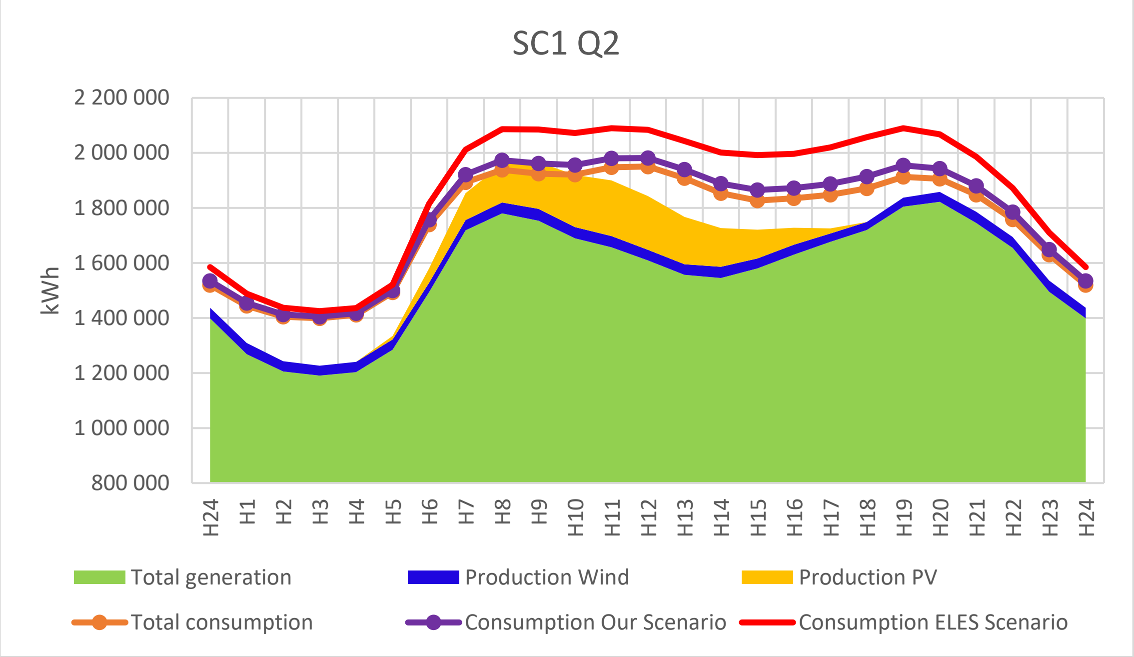

Figure 48: Total consumption and generation of electrical energy in the second quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

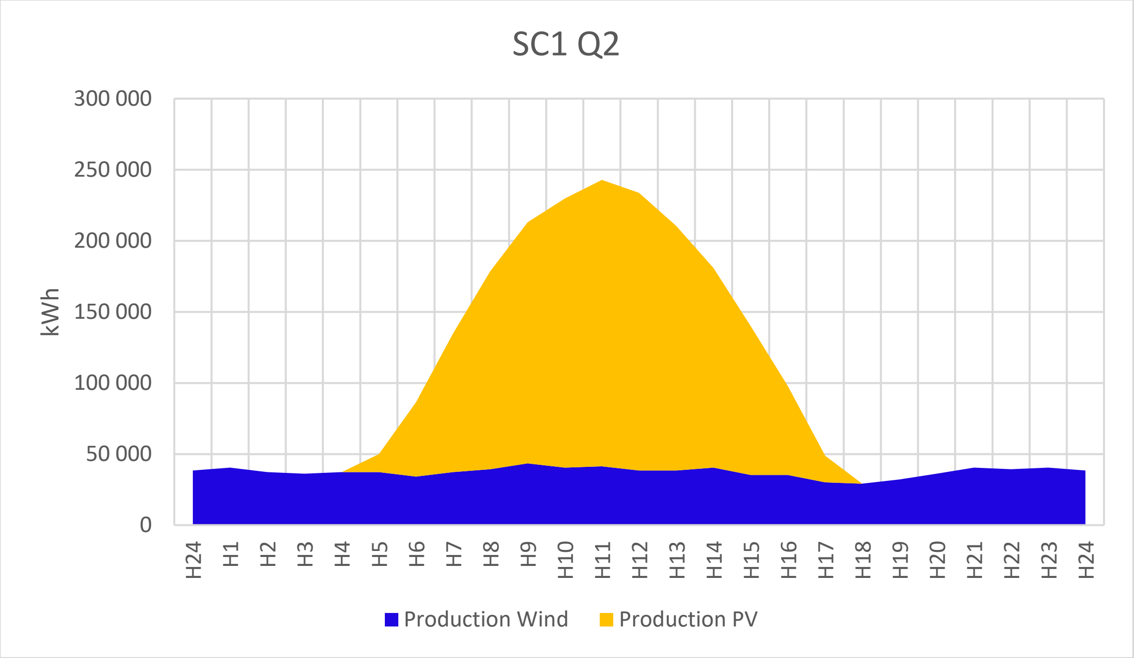

Figure 49: Potential daily solar and wind energy production in the second quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

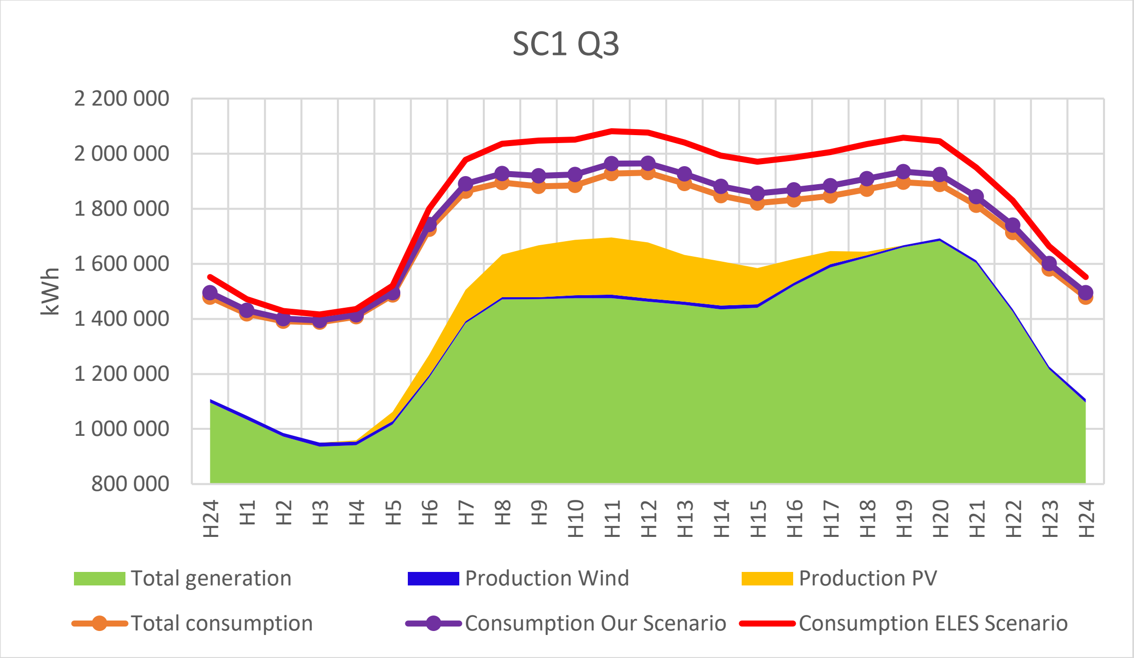

Figure 50: Total consumption and generation of electrical energy in the third quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

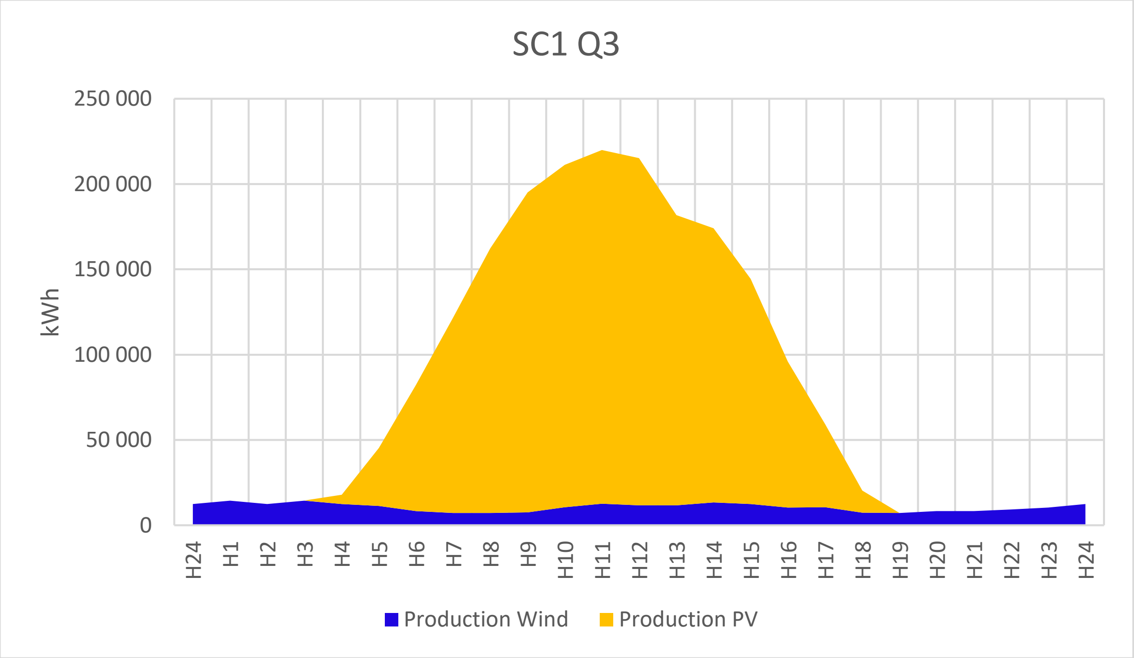

Figure 51: Potential daily solar and wind energy production in the third quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

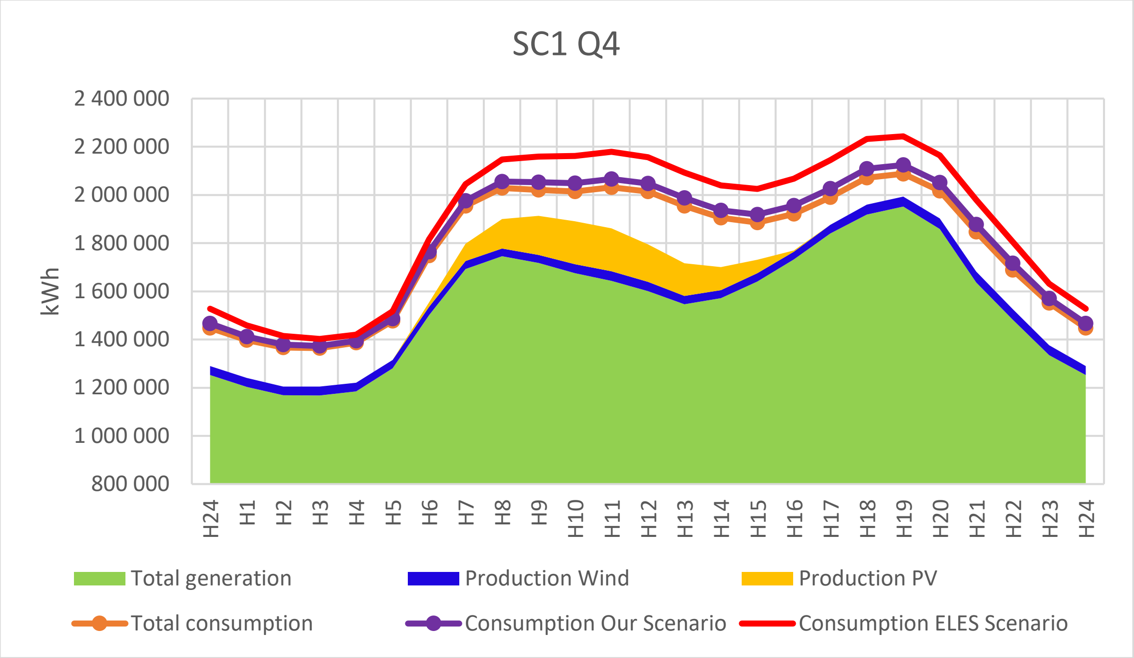

Figure 52: Potential daily solar and wind energy production in the third quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

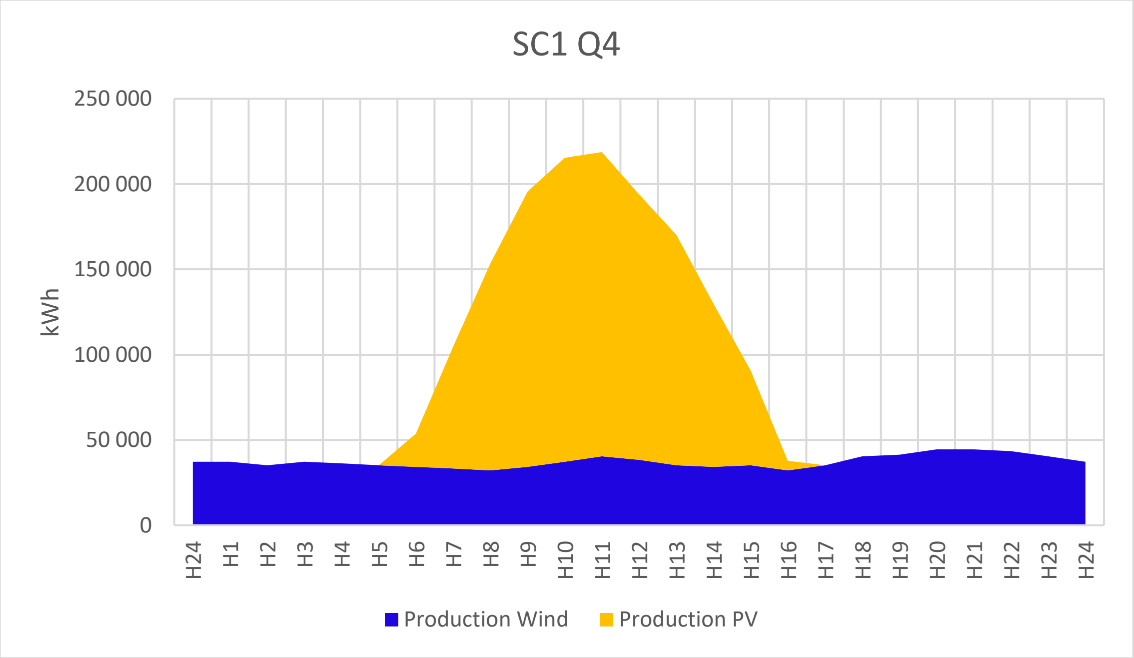

Figure 53: Potential daily solar and wind energy production in the fourth quarter of 2030 according to extended Energy concept of Slovenia scenario (SC1)

c) Scenario 2

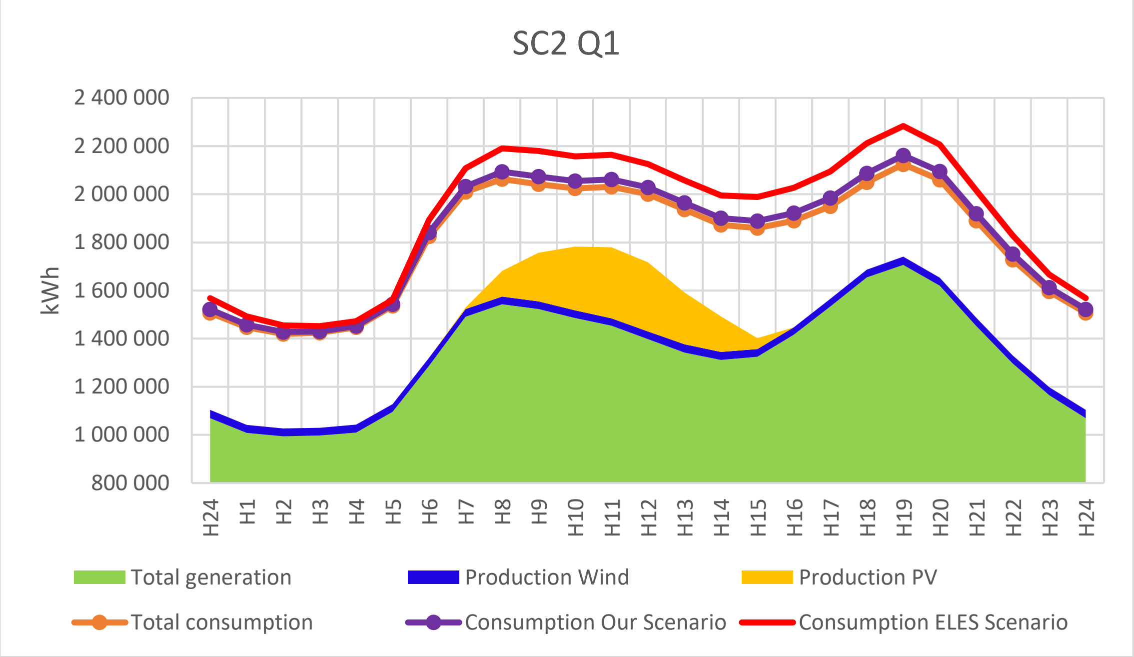

Figure 54: Total consumption and generation of electrical energy in the first quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

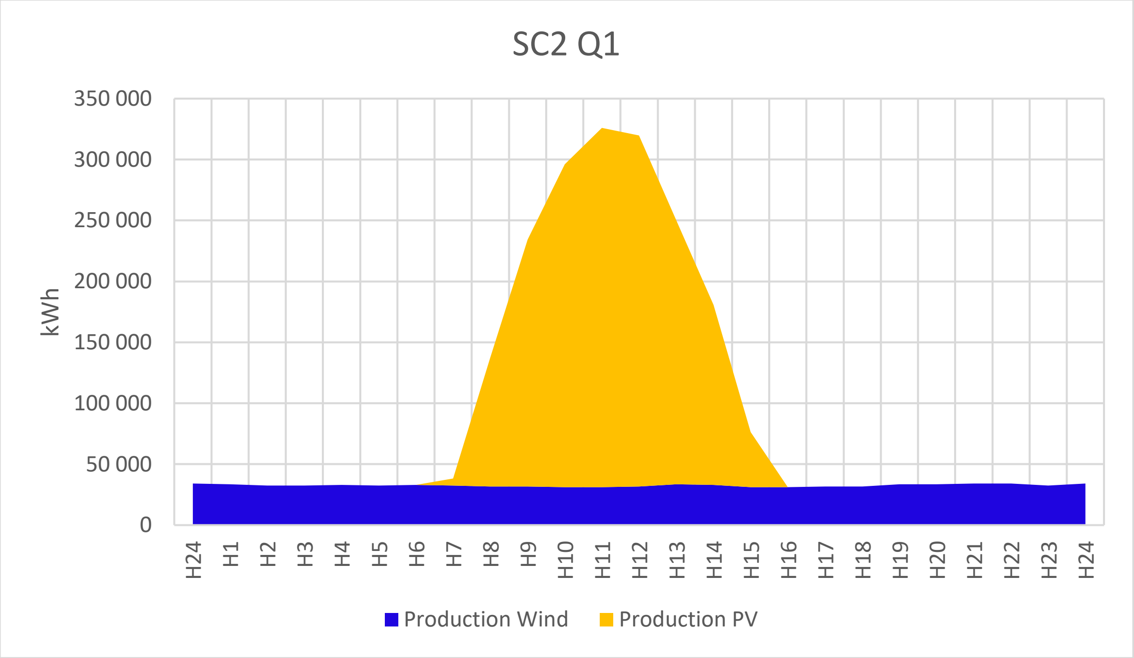

Figure 55: Potential daily solar and wind energy production in the first quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

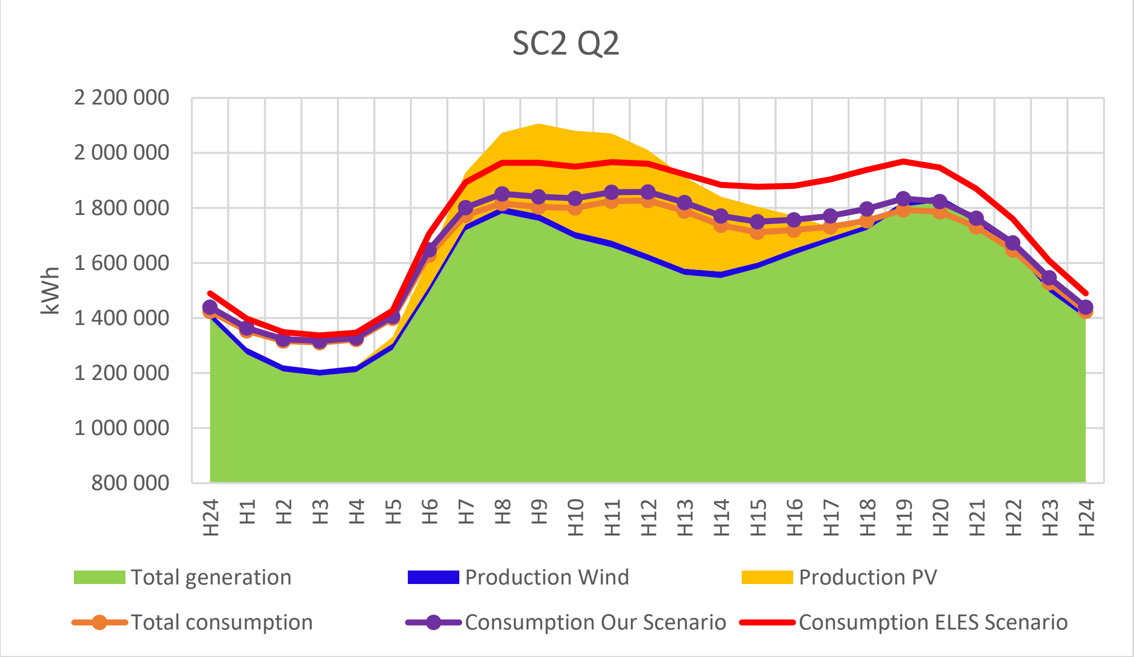

Figure 56: Total consumption and generation of electrical energy in the second quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

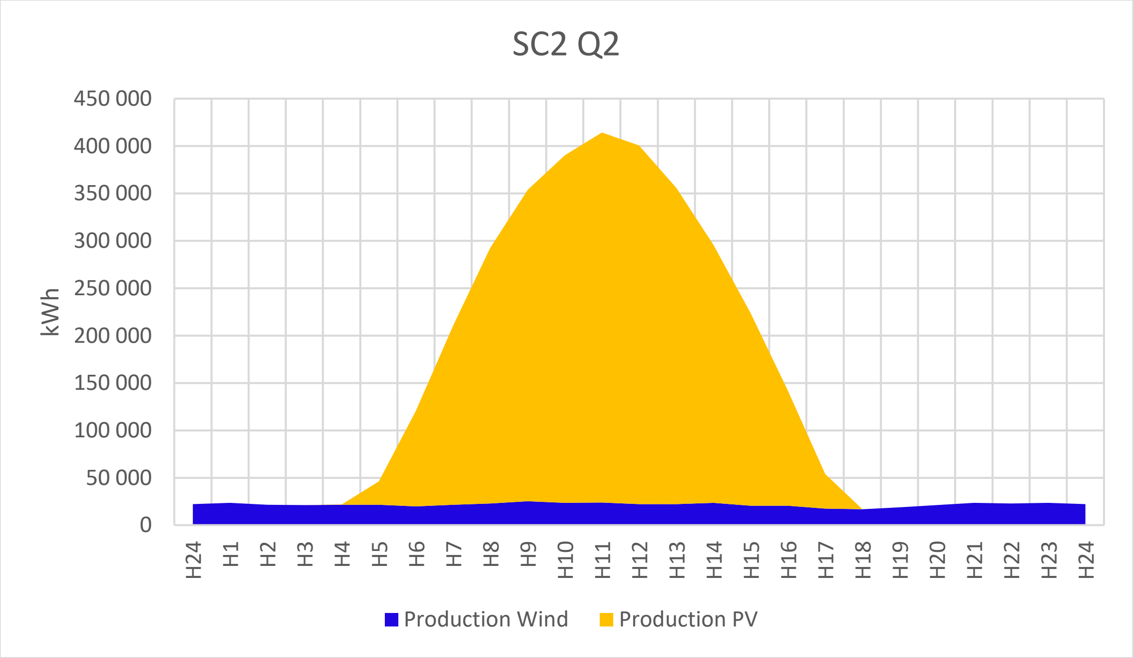

Figure 57: Potential daily solar and wind energy production in the second quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

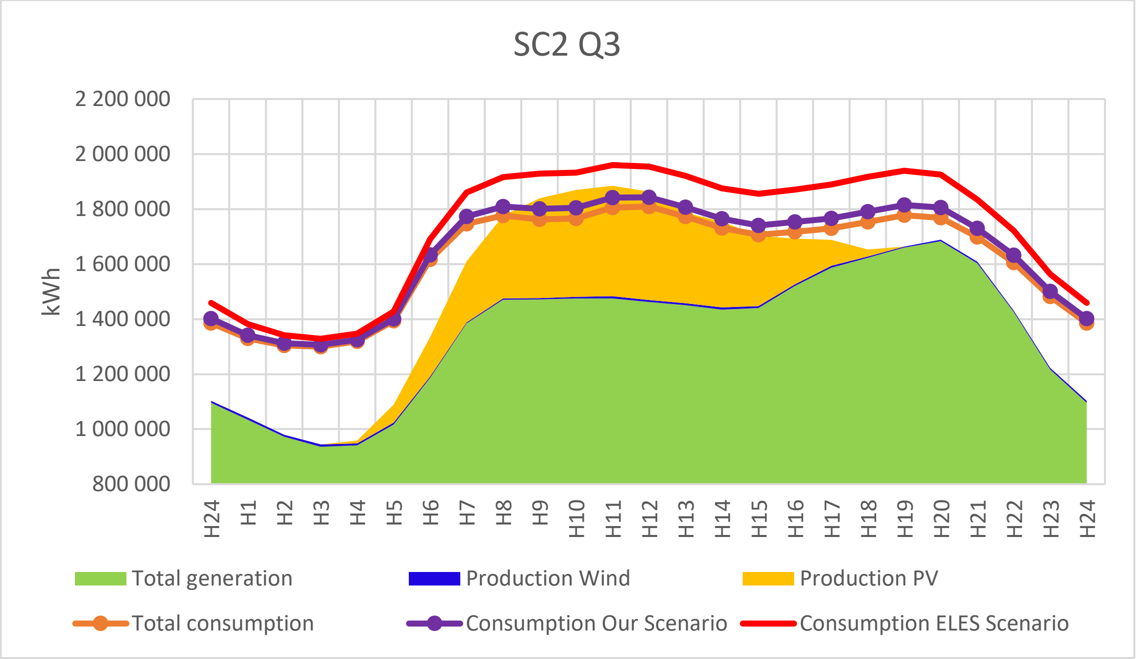

Figure 58: Total consumption and generation of electrical energy in the third quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

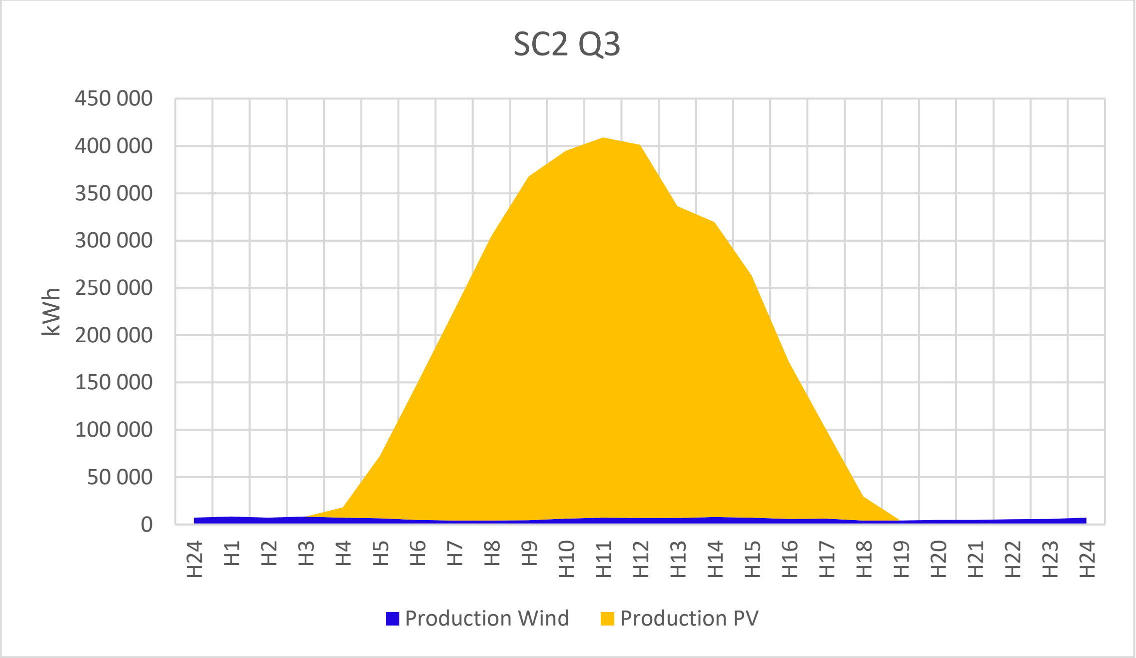

Figure 59: Potential daily solar and wind energy production in the third quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

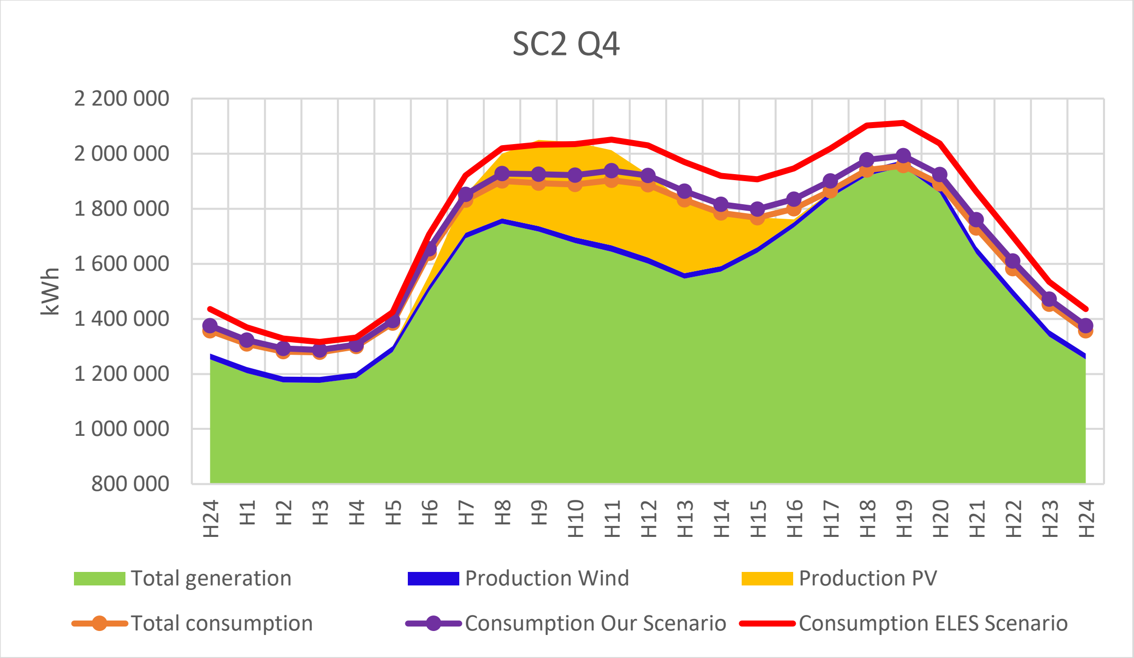

Figure 60: Total consumption and generation of electrical energy in the fourth quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

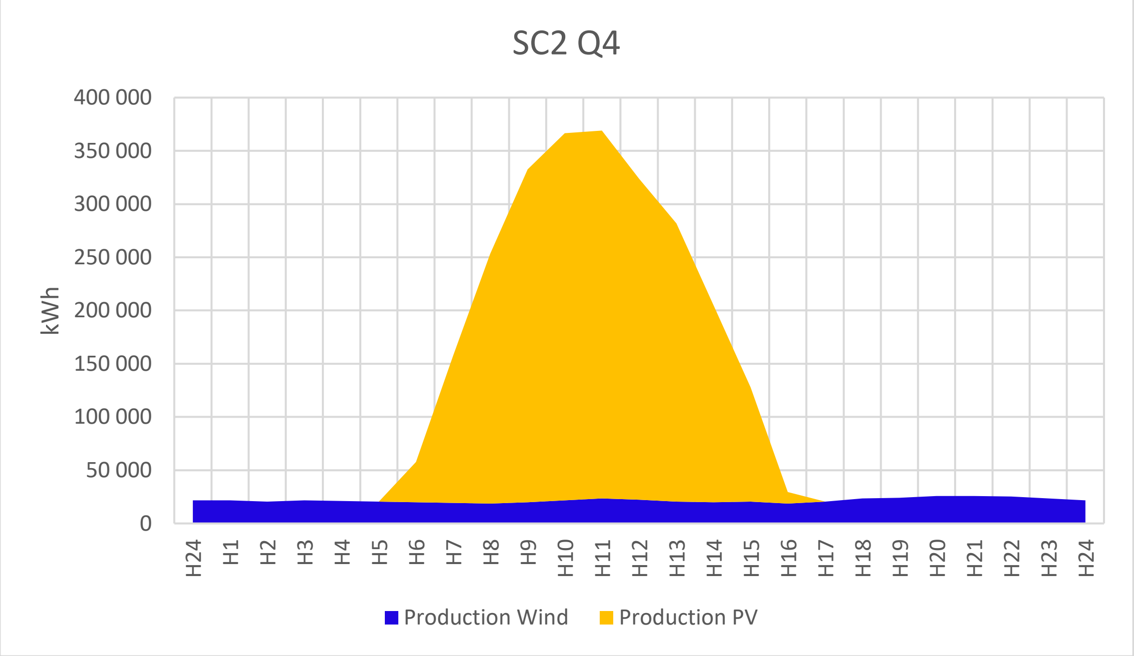

Figure 61: Potential daily solar and wind energy production in the fourth quarter of 2030 according to ENTSO-E Distributed Generation scenario (SC2)

d) Scenario 3

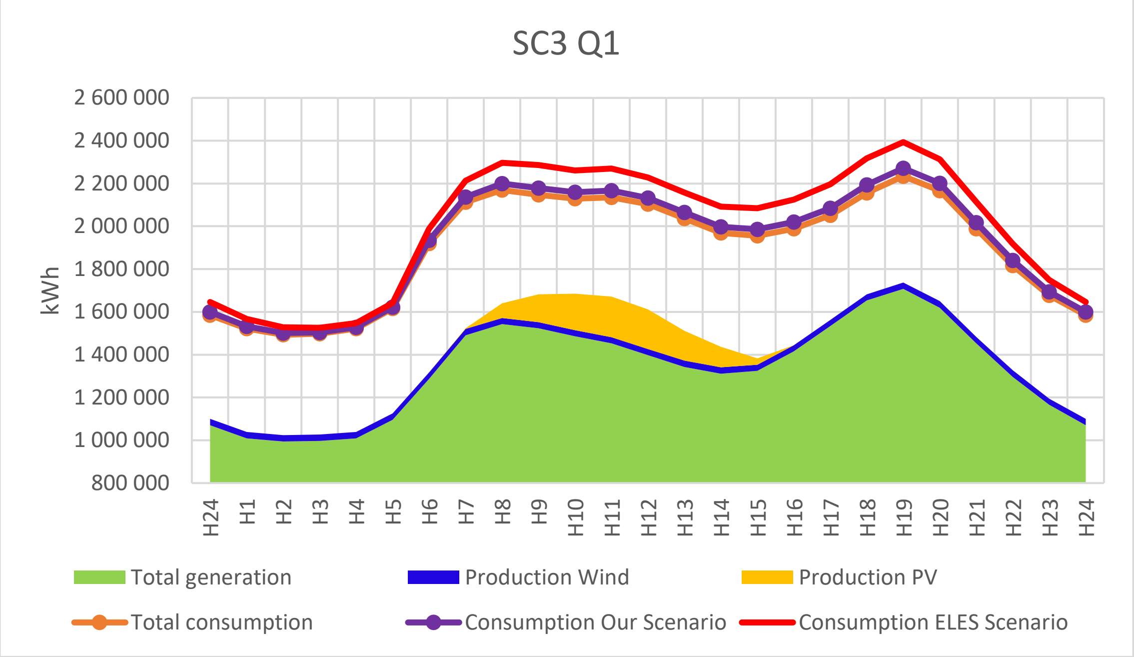

Figure 62: Total consumption and generation of electrical energy in the first quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

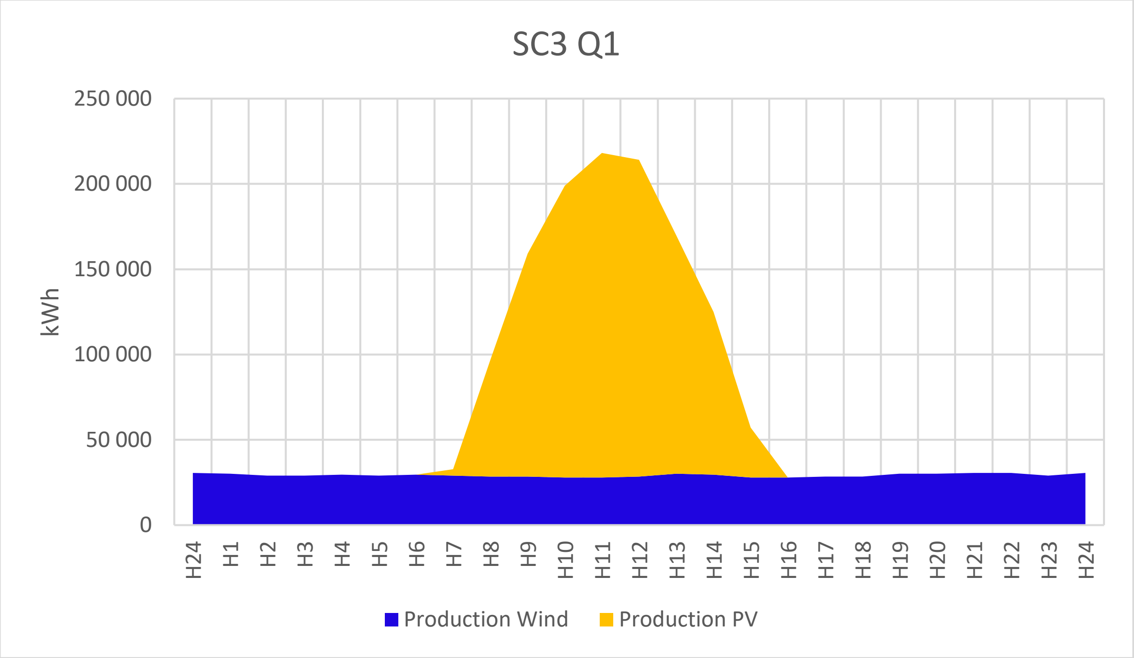

Figure 63: Potential daily solar and wind energy production in the first quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

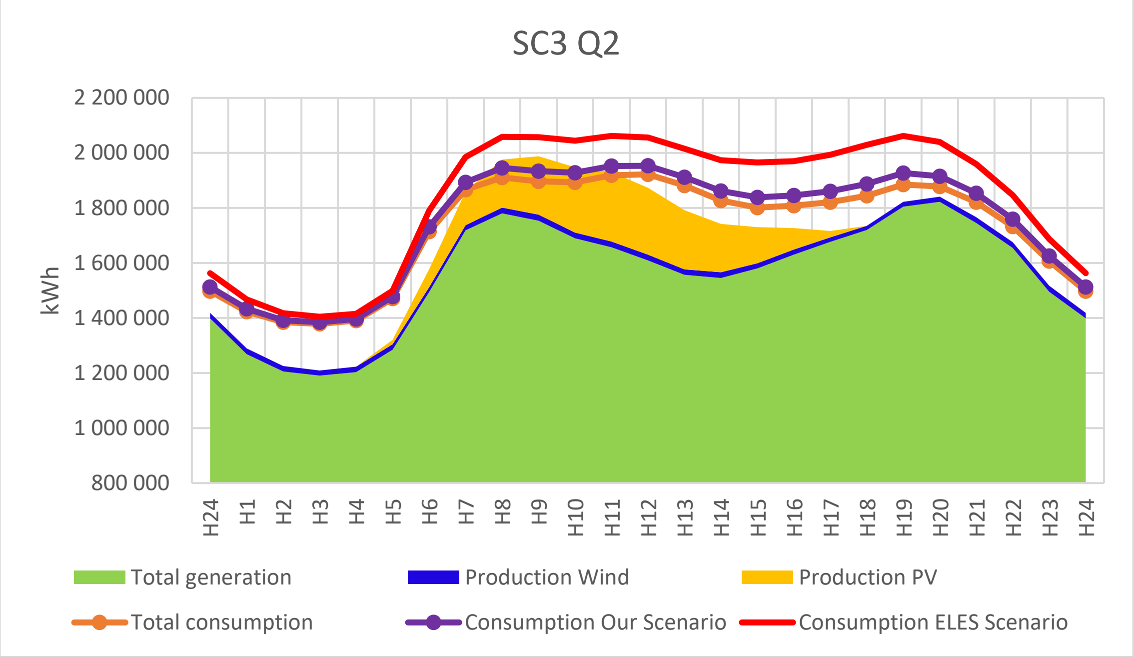

Figure 64: Total consumption and generation of electrical energy in the second quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

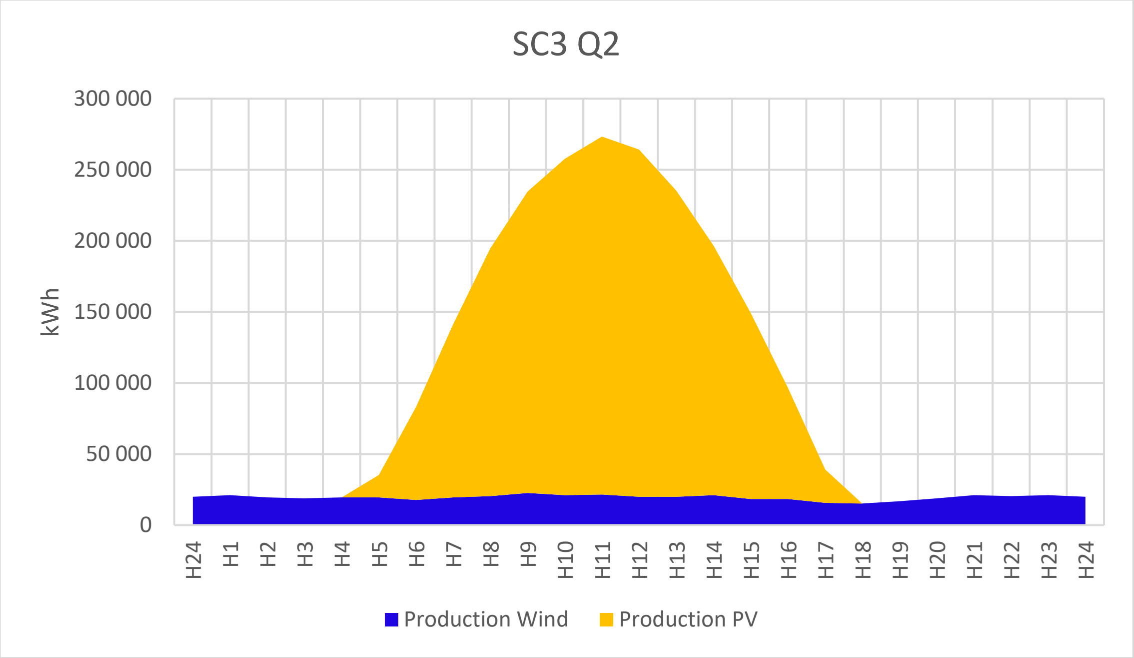

Figure 65: Potential daily solar and wind energy production in the second quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

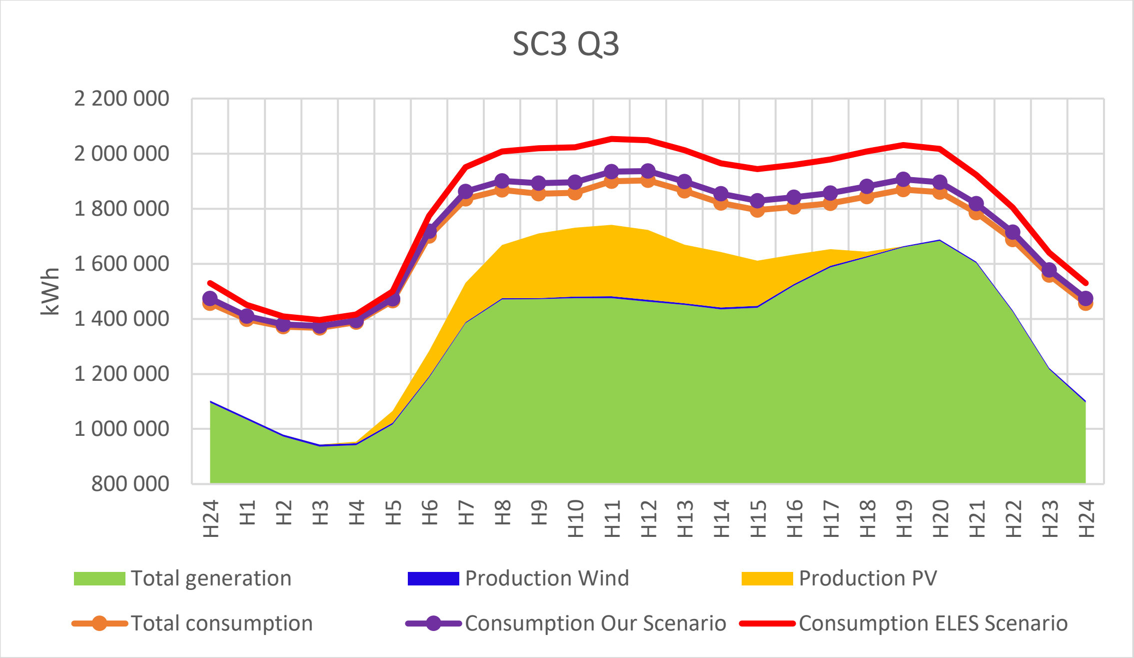

Figure 66: Total consumption and generation of electrical energy in the third quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

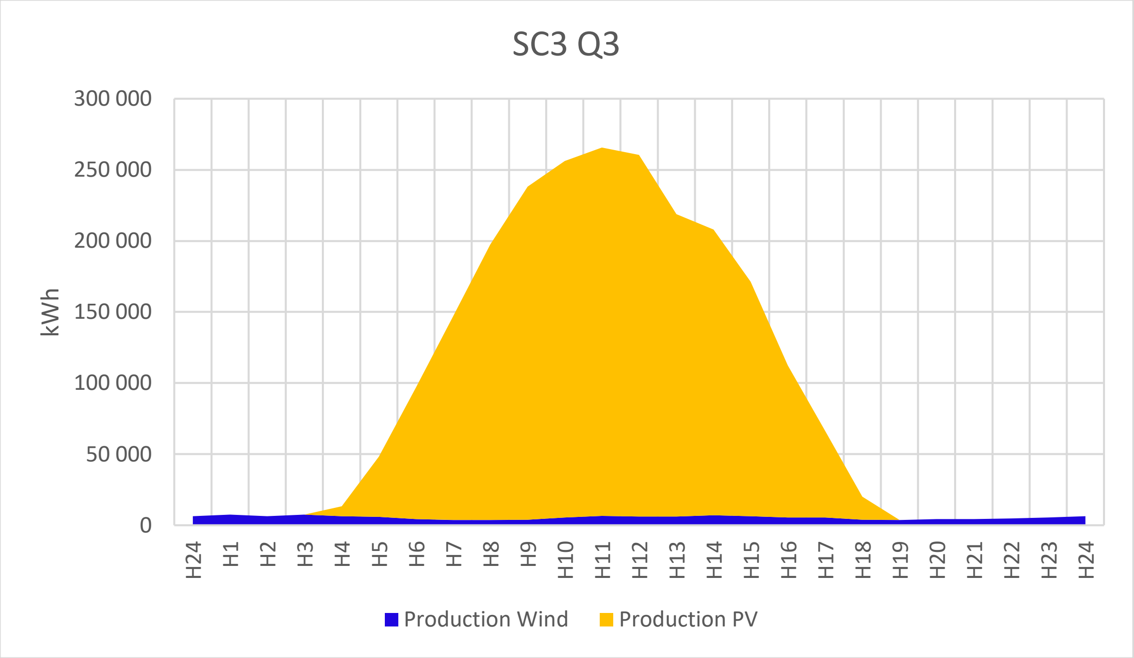

Figure 67: Potential daily solar and wind energy production in the third quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

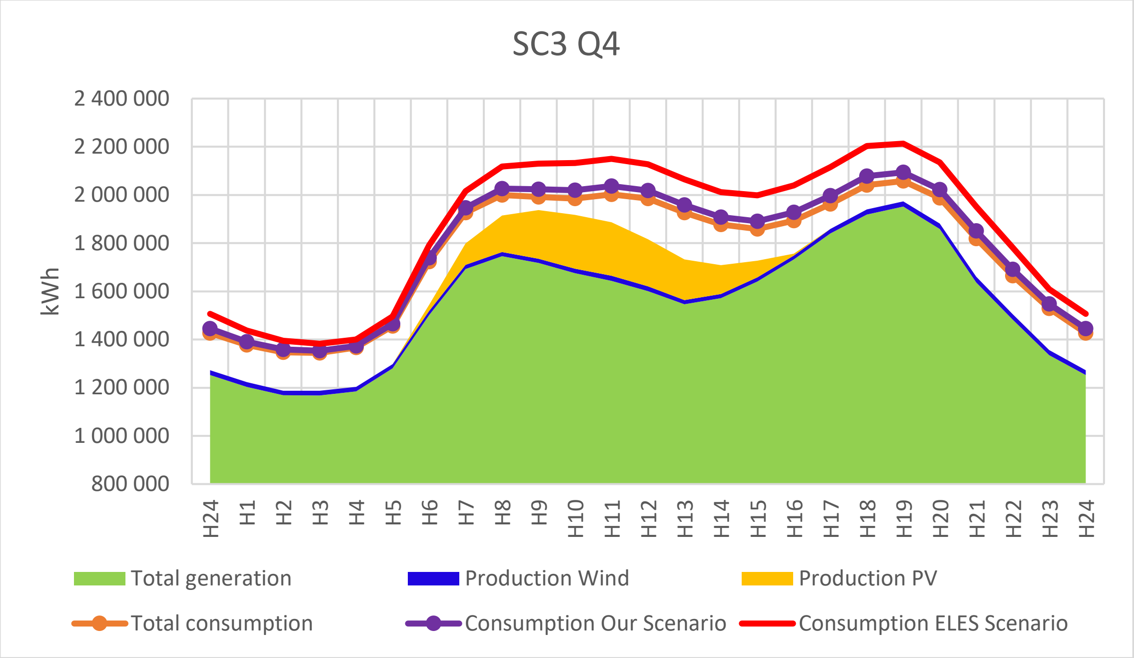

Figure 68: Total consumption and generation of electrical energy in the fourth quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

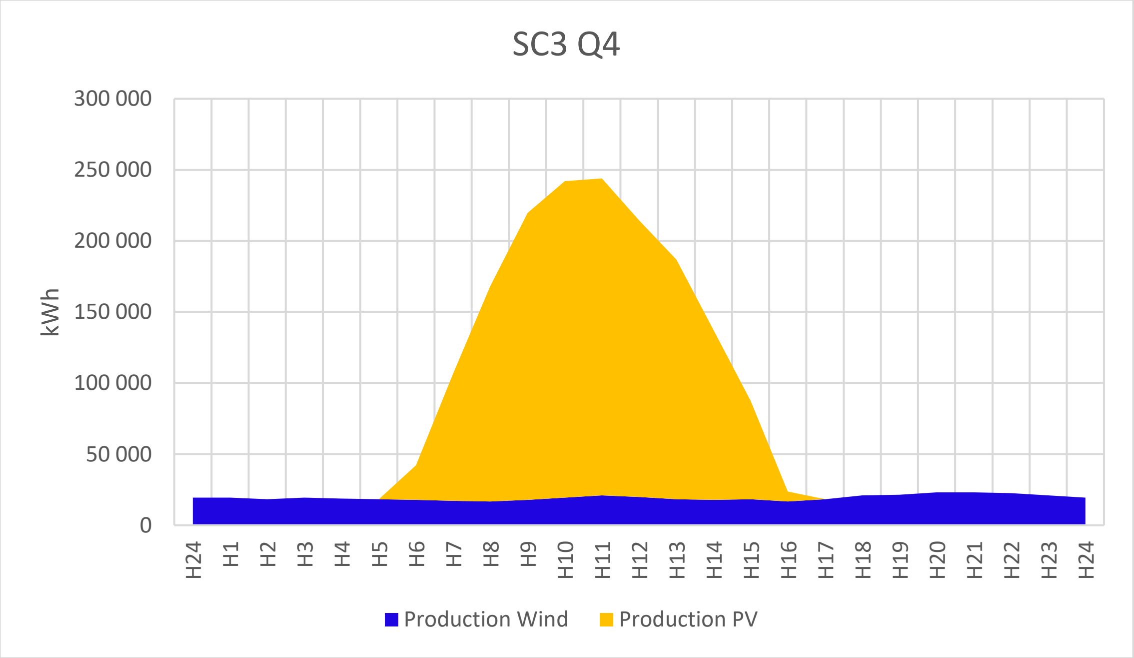

Figure 69: Potential daily solar and wind energy production in the fourth quarter of 2030 according to ENTSO-E Sustainable Transition scenario (SC3)

e) Scenario 4

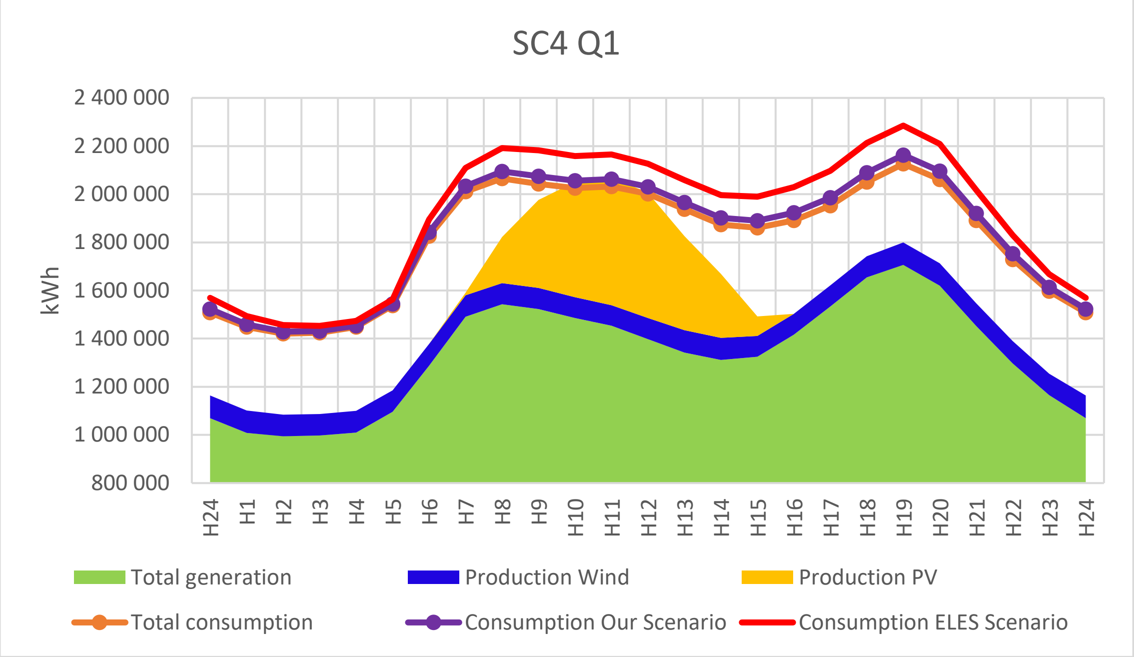

Figure 70: Total consumption and generation of electrical energy in the first quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

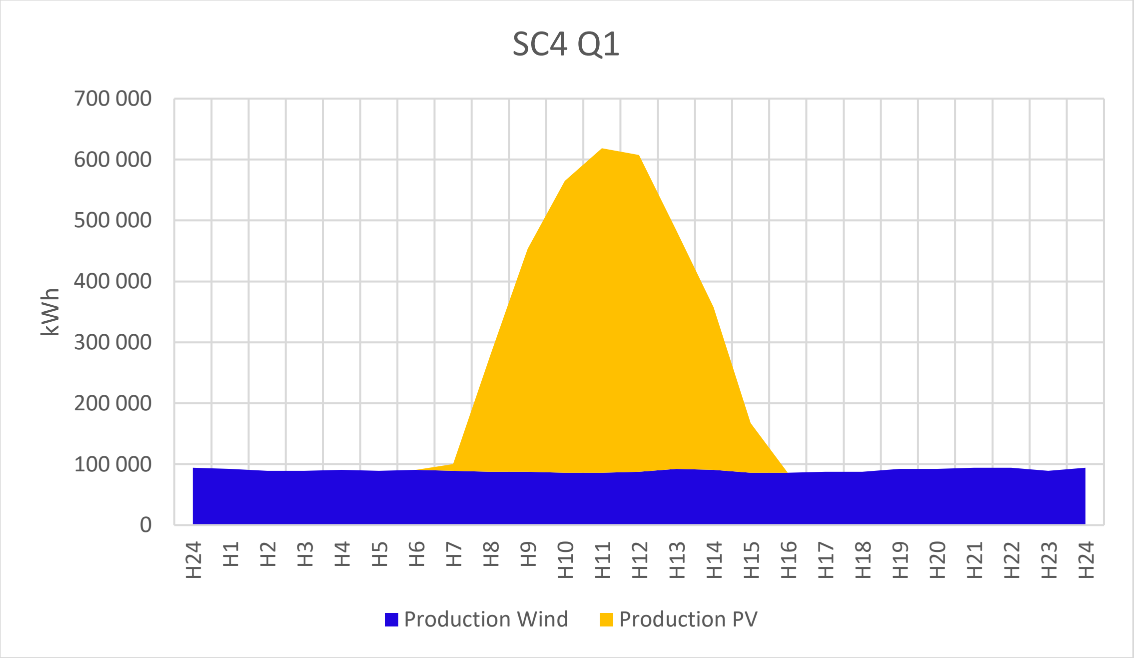

Figure 71: Potential daily solar and wind energy production in the first quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

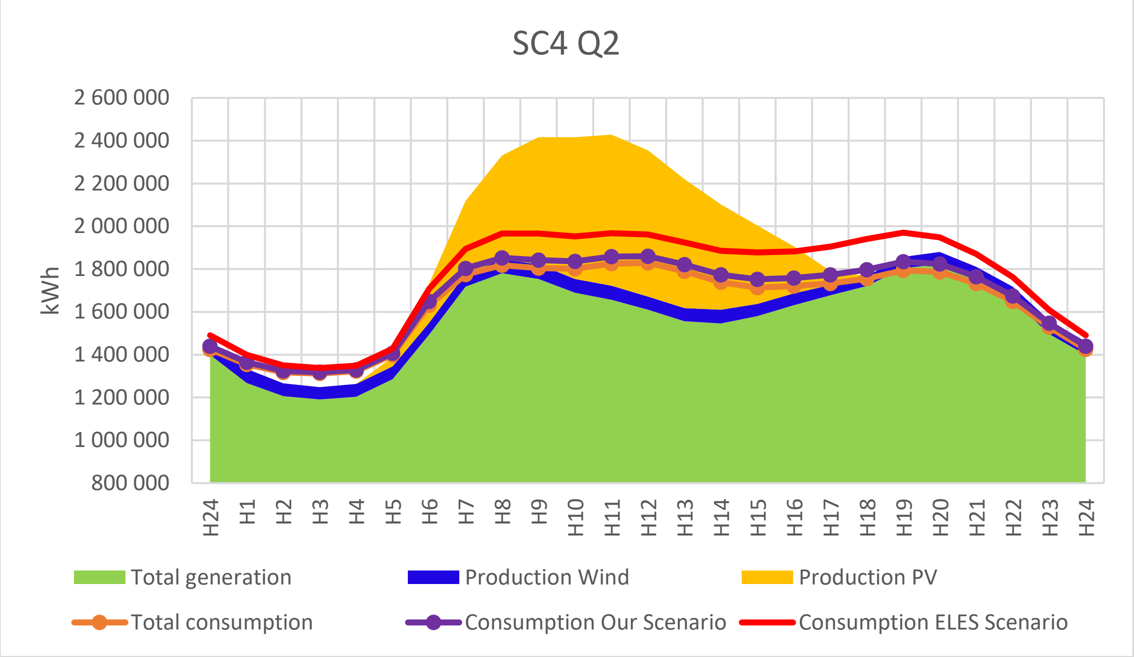

Figure 72: Total consumption and generation of electrical energy in the second quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

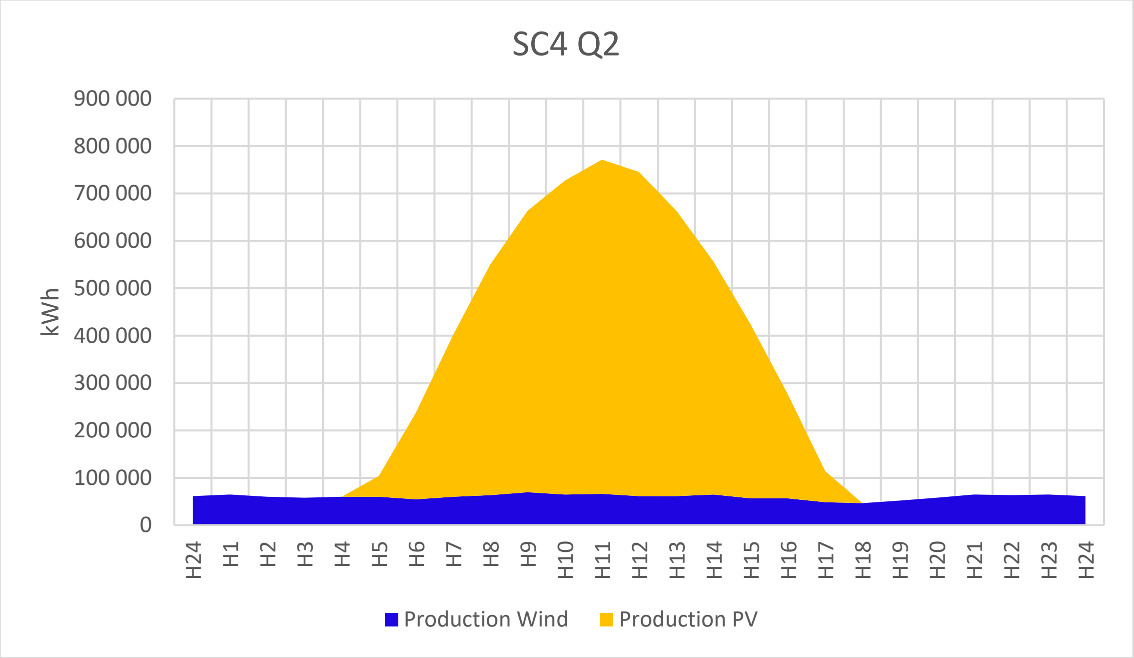

Figure 73: Potential daily solar and wind energy production in the second quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

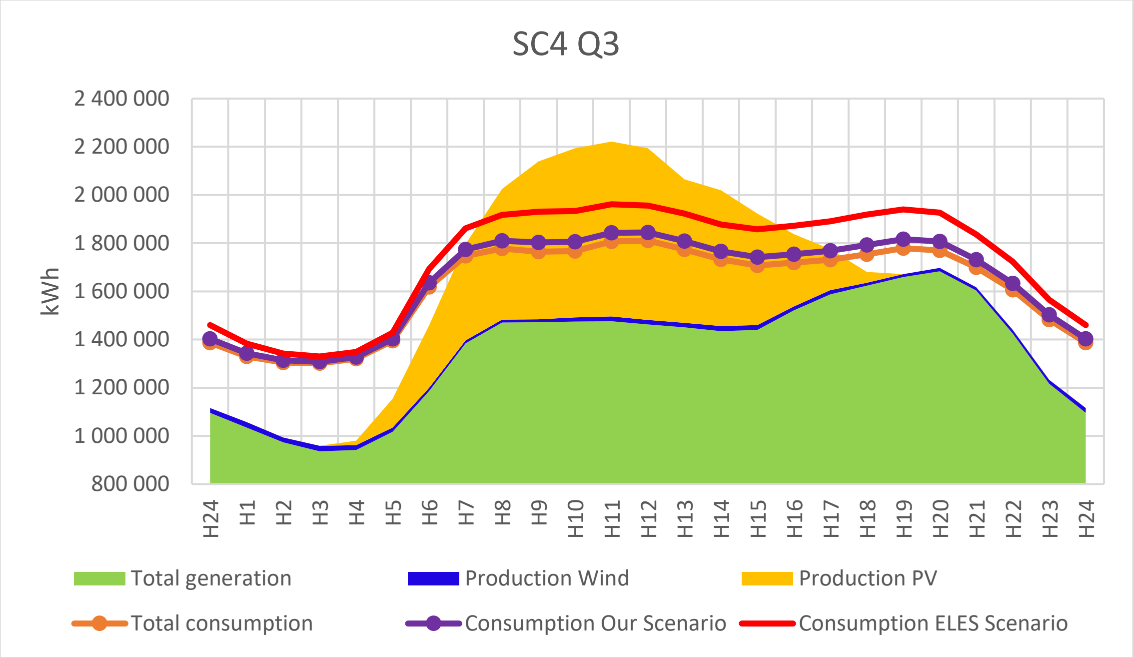

Figure 74: Total consumption and generation of electrical energy in the third quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

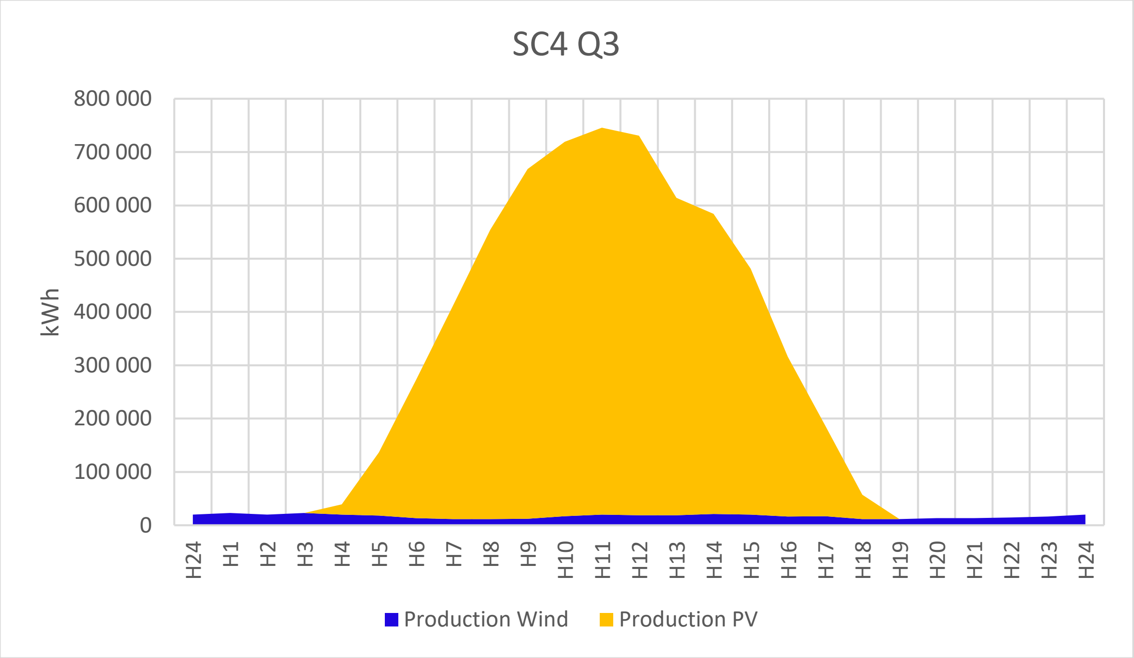

Figure 75: Potential daily solar and wind energy production in the third quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

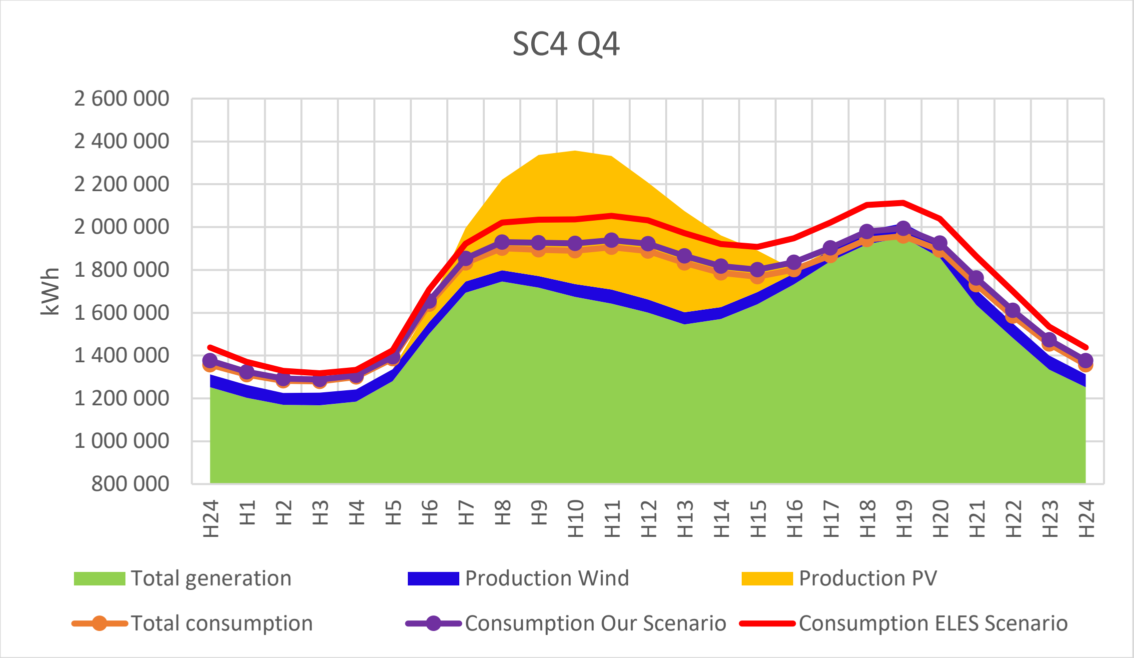

Figure 76: Total consumption and generation of electrical energy in the fourth quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

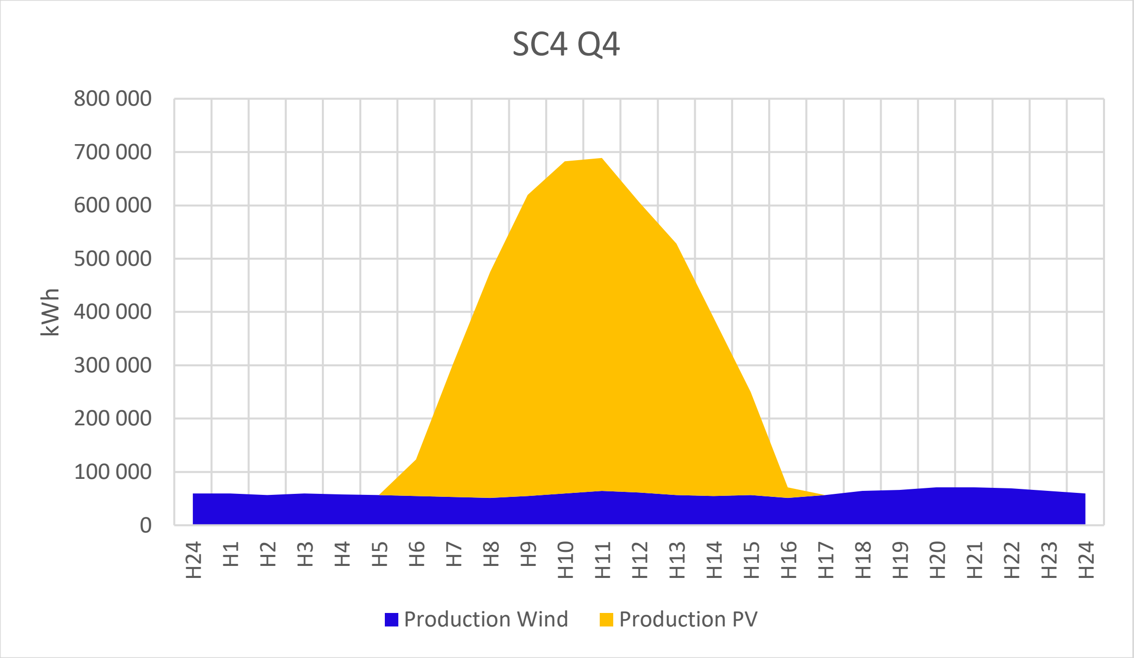

Figure 77: Potential daily solar and wind energy production in the fourth quarter of 2030 according to ENTSO-E Global Climate Action scenario (SC4)

Abbreviations

AC	Alternating Current
BEV	Battery Electric Vehicle
CHP	Cogeneration of heat and electricity
CNG	Compressed Natural Gas
CRM	Critical Raw Materials
DC	Direct Current
DEM	Dravske Elektrarne Maribor (Hydropower plants on River Drava)
DG	Distributed Generation
ELES	Slovenian Transmission System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GCA	Global Climate Action
HESS	Hidroelektrarne na Spodnji Savi (Hydropower plants on River Sava)
HEV	Hybrid Electric Vehicle
HSE	Holding Slovenske Elektrarne (Holding of Slovenian Power Plants)
ICE	Internal Combustion Engine
IEA	International Energy Agency
JPEL	Javno Podjetje Energetika Ljubljana (Public Company Energetika Ljubljana)
LCA	Life Cycle Analysis
LNG	Liquified Natural Gas
NEK	Nuklearna Elektrarna Krško (Nuclear Power Plant Krško)
PHEV	Plug-In Hybrid
REEV	Range Extended Electric Vehicle
RES	Renewable Energy Sources
SEL	Savske Elektrarne Ljubljana (Hydropower plants on River Sava)
SENG	Soške Elektrarne Nova Gorica (Hydropower plants on River Soča)
SODO	Slovenian Distribution System Operator
ST	Sustainable Transition
SURS	Statistični Urad Republike Slovenije (Slovenian Statistical Office)
TEB	Termoelektrarna Brestanica (Thermal Power Plant Šoštanj)
TEŠ	Termoelektrarna Šoštanj (Thermal Power Plant Šoštanj)
TSO	Transmission System Operator
US	United States
V2G	Vehicle-To-Grid
V2X	Vehicle-To-Everything