Power System with Large Share of Renewable Energy Source and Role of Electric Vehicles in Increasing Power System Flexibility

TAIEX Regional Workshop on Renewable Energy Sources

organised in co-operation with Ministry of Civil Affairs of Bosnia and Herzegovina

Bihać, Bosnia and Herzegovina, 15 – 16 November 2018

Author: prof. **Željko TOMŠIĆ**, Ph.D.

University of Zagreb
Faculty of Electrical Engineering and Computing
Department of Power and Energy Systems

November 2018

Presentation outline

- INTRODUCTION
- ELECTRIC VEHICLES
- RENEWABLE ENERGY SOURCES
- ENERGY STORAGE TECHNOLOGIES
- METHODOLOGY FOR CASE STUDY
- TEST MODEL
- RESULTS

INTRODUCTION

- Fuel combustion in the transport sector significantly contributes to the total greenhouse gas emissions (GHG).
- In the European Union (EU) member states transport accounts for 33.1% of total final energy consumption, while the share of transport in total greenhouse gas emissions is 23%.
- Enabling electrification of the transport sector, as well as promoting electricity production based mainly on RES, would enable achieving EU's policy of low-carbon economy, which aims to reduce GHG by 80-95% by 2050.
- **EV**s provide the possibility of storing electricity, which opens new possibilities for integration of RES into the grid

INTRODUCTION

- In order to achieve set goals in reduction GHG emissions, it is paramount to change the way electricity is produced, distributed and consumed
- While **RES contributes to a decrease** of the environmental impact and to an increase in self-sustainability of national energy systems, many aspects of the power system are affected by the increased share of such sources.
- **Electric vehicles** and pumped-storage HPPs provide the possibility of storing electricity, which opens new opportunities for the integration of RES into the grid.

INTRODUCTION

- The priority for power system is **stability** – **equality** of **production and consumption** at any point of time.

- These two technologies (**EVs & RES**) can **profit from each other** because EV can provide capacity for energy storage produced from unpredictable OIEs with fast response at peak demand, while it is proved that OIE is the purest, cost-effective source of additional energy demanded by EV

The outline of the problem and methodology

- This presentation analyses the role that **large penetration of EVs** has on increasing the flexibility of a power system with a large share of renewable sources and example of the power system of the Republic of Croatia

RENEWABLE ENERGY SOURCES

- While **RES contributes to a decrease of the environmental impact** (especially GHG emissions) and to an increase in self-sustainability of national energy systems, many aspects of the power system are affected by the increased share of such sources.
- Forecast of **increased capacity** of variable renewables also requires **greater energy storage capacity and new technologies** to address grid-stability issues when renewable power sources replace thermal power stations.

RENEWABLE ENERGY SOURCES

- The need for energy storage technologies derives from the **basic characteristics of electricity; that in each moment consumption and production of electricity should be the same**.

RENEWABLE ENERGY SOURCES

- The i**ntegration of variable renewable energy sources** into energy systems is connected to the **system flexibility** as it is necessary to ensure balancing between demand and supply.
- **There are four main sources of flexibility in current power systems,**
  - **flexibility in generation units,**
  - **electricity storage,**
  - **interconnections and**
  - **demand side management.**

- Every of these **flexibility sources has technical and market potential in particular area**.

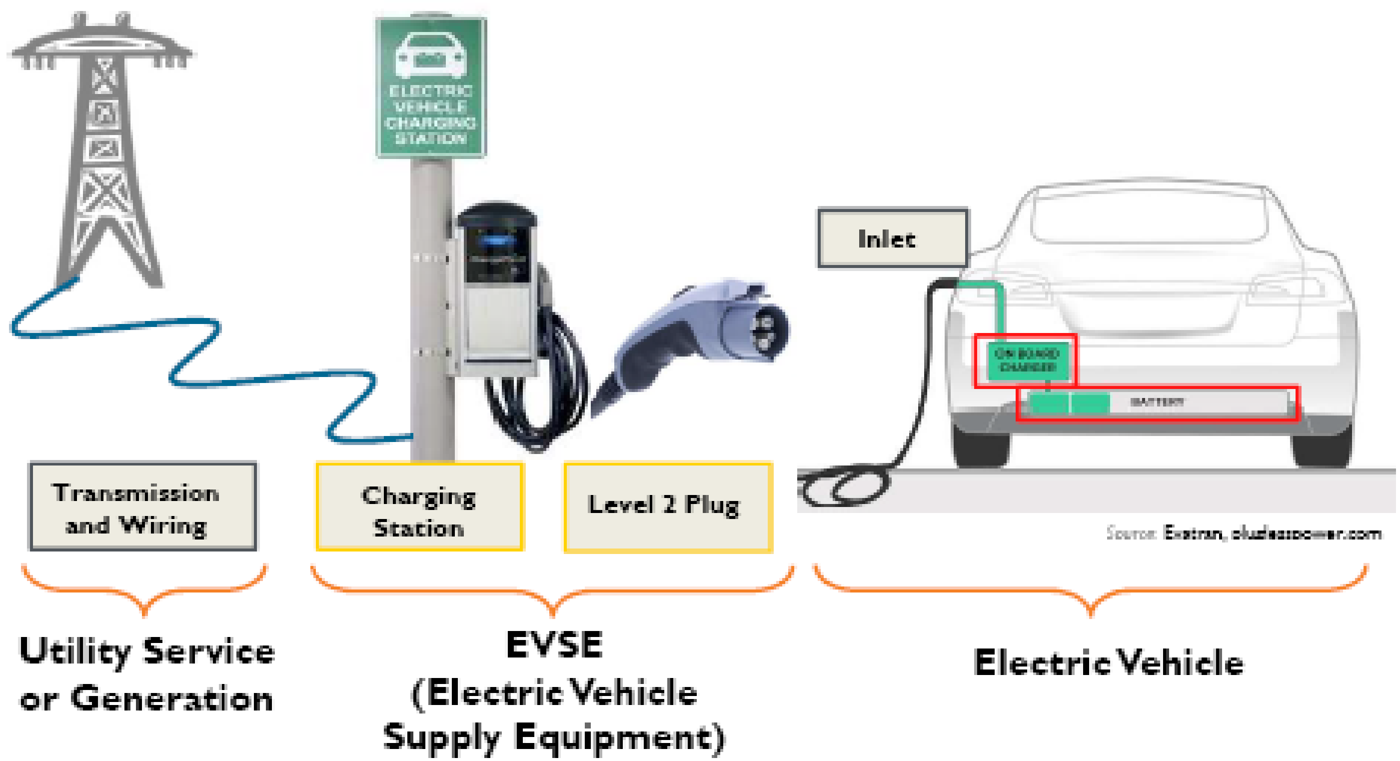
RENEWABLE ENERGY SOURCES

- In addition, with a high percentage of penetration of wind and PV in some regions, **there is excess energy, which is actually cost-free**.
- This surplus could be stored in **energy storage technologies** such as EVs or pumped storage HPPs and used later on and thus also reduce production costs.
- The unpredictability of wind has a negative impact on participation of wind power plant in the market - a reliable constant amount of electricity and the geographical distribution of wind power resources is typically uneven.

Types of Electric Vehicles

	Hybrid	Plug-in Hybrid	Battery	Fuel Cell
Drive Source(s)	Internal combustion engine Electric motor	Internal combustion engine Electric motor	Electric motor	Electric motor
Battery Size	1-2 kWh	4-20 kWh	20-100 kWh	None
Electric Power Source	Regenerative braking	Outside electric power (plug-in) Engine Regenerative braking	Outside electric power (plug-in)	H_2 Hydrogen gas combines with oxygen to produce electricity, which runs a motor

Electric Vehicle Charging Infrastructure



Electric vehicles (EVs)

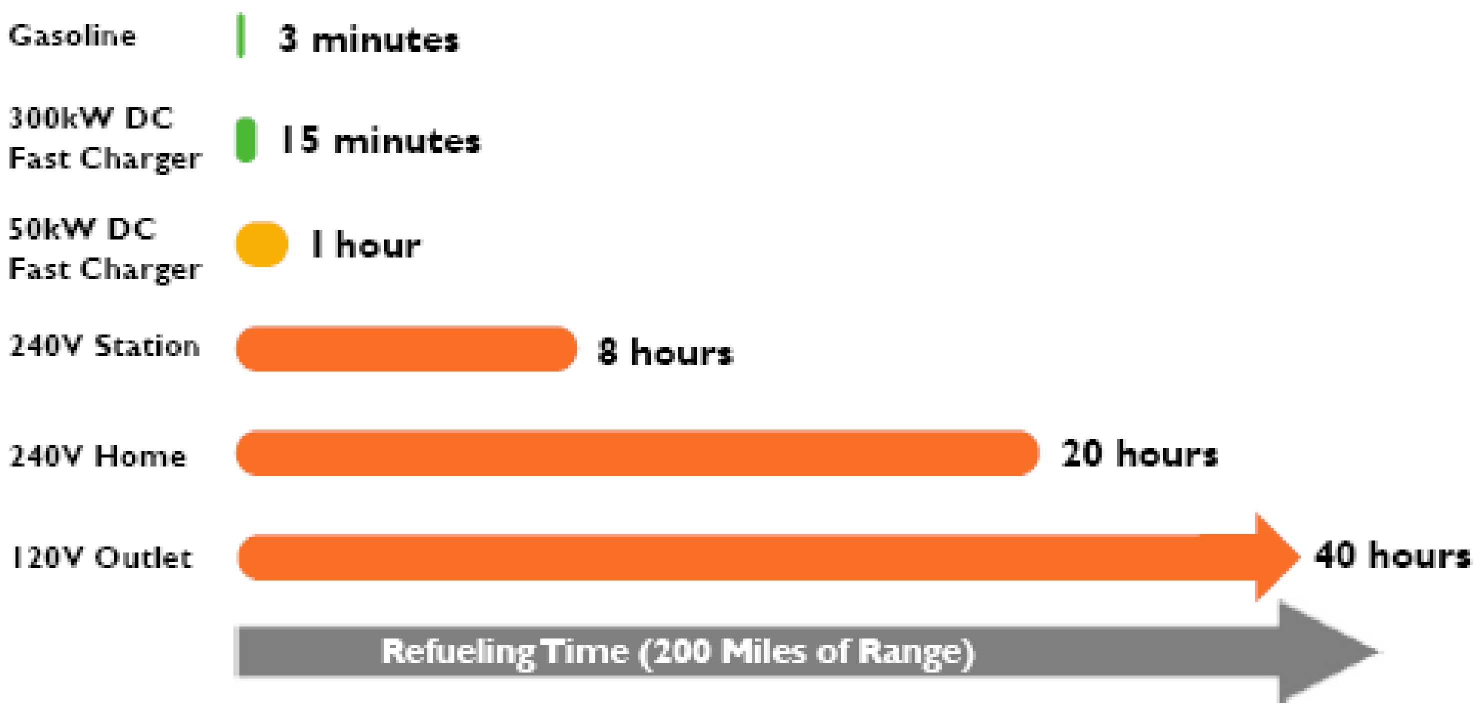
- **Electric vehicles** are powered by an electric motor which is powered by a battery or other power source.
- EVs can be divided into few types
- In this analysis, only the **battery electric vehicles** are modelled
- EVs **charging equipment** changes the time needed to charge a fully depleted battery.
  - **Level I** equipment provides charging through a 120 V alternating-current (AC) plug
  - **Level II** equipment offers charging through a 240 V, AC
  - **Level III** equipment with CHAdeMO technology, also commonly known as DC fast charging, charges through a 480V, direct-current (DC) plug

Electric vehicle charging levels/types

	Level 1	Level 2	DC Fast Charging
Circuit	Standard outlet 120V, 15-20 A	Dedicated circuit 240V, 30-40 A	Dedicated circuit 480V, 125 A
EVSE	Regular GFI outlet, available everywhere	Charging station (electrician)	Charging station (electrician)
Cord set	Included with car, 3 prong w/ J1772	After-market, cord w/ J1772	After-market, multiple standards
Power	1.44 kW	3.3-6.6 kW	50 kW
Time	12-24 hours	4-8 hours	30 minutes
Charge time	3 to 5 miles per hour charge	10 to 25 miles per hour charge	200 miles per hour charge
Cost	None	$1.5k-$5k + install	$10k-$30k + install
Best for…	LSEVs PHEVs <20 mile	BEVs PHEVs >20 mile	Fast Charge BEVs PHEVs >20 mile



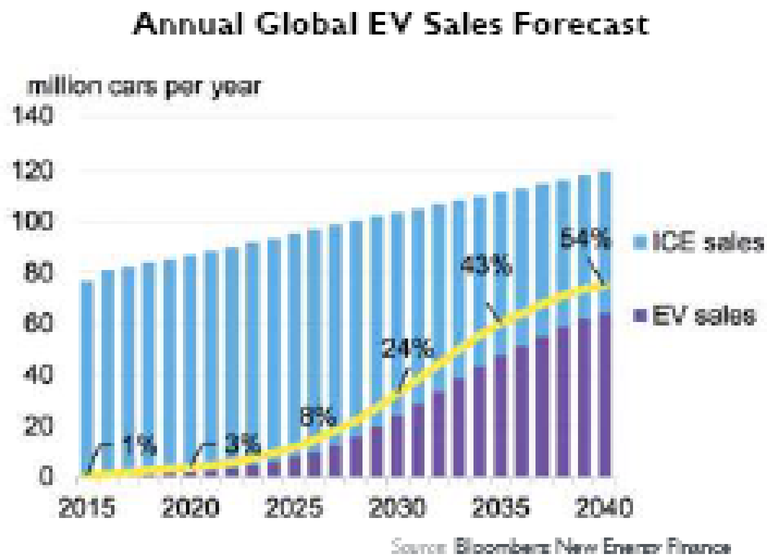
Improving the EV charging experience

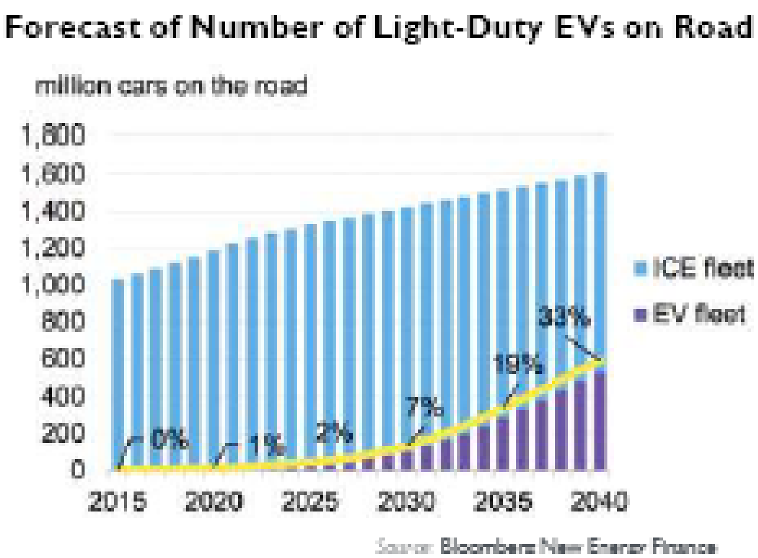


Expected charging times by charging level

	Level 1	Level 2	DC Fast Charge
Charge power	1.5 kW	6.6 kW	20-120 kW
Range/charge hr.	4 mi/hr	22 mi/hr	140-330 mi/hr
Toyota Prius Prime *(4.4 kWh)*	4 hours	1 hour	Not available
Chevy Volt *(16 kWh)*	12 hours	3 hours	Not available
BMW i3 *(22 kWh)*	15 hours	4 hours	24 kW (80% in **30 min**)
Nissan Leaf *(32 kWh)*	16 hours	5 hours	50 kW (80% in **20 min**)
Chevy Bolt *(60 kWh)*	40 hours	10 hours	50 kW (80% in **60 min**)
Tesla Model S85 *(90 kWh)*	60 hours	15 hours	120 kW (80% in **40 min**)

Forecasts for large growth in EV market through 2040





- Predicts an "inflection point" in late 2020s, where EVs reach cost parity with internal combustion engine vehicles (ICEVs)
- BEVs will begin to comprise majority of EV sales after 2025

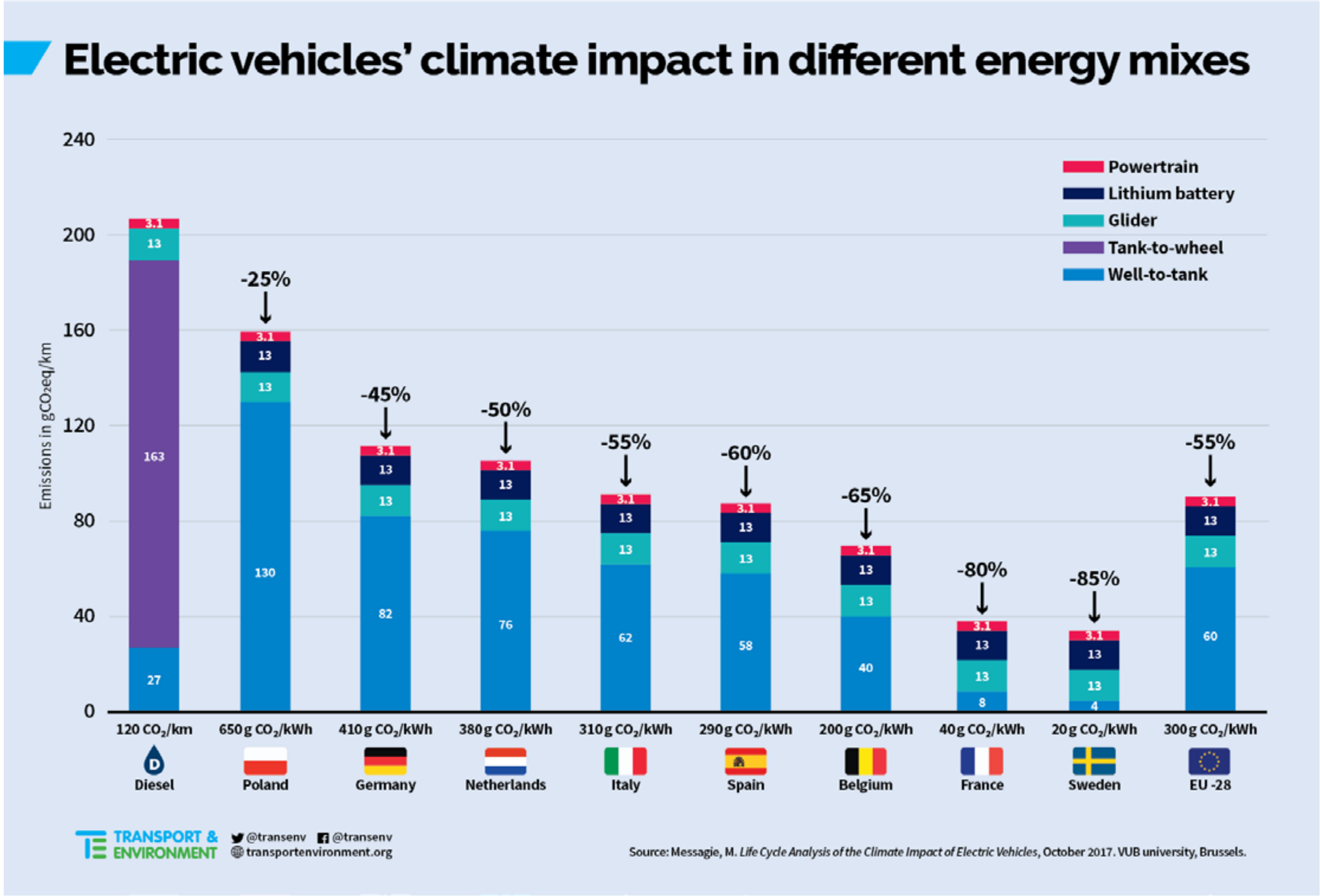
Electric vehicles (EVs)

- When connected to the grid, **EV can operate in four different ways:**
  - **Grid-to-Vehicle** (G2V) when the battery of an EV is charged directly from the grid,
  - **Grid-to-Vehicle Half** (G2V/2) when the battery does not charge but would otherwise be charged, thus EV is helping the system by providing up-regulation,
  - **Vehicle-to-grid** (V2G) when the battery is discharged, providing the appropriate reserve, and
  - **Vehicle-to-Vehicle** (V2V) when instead of taking the electricity from the grid, one EV discharges the battery giving the electricity to another connected EV whose battery is then being charged.
  - In this analysis, only the **battery electric vehicles** are modelled

Are electric vehicles cleaner? The evidence points firmly in one direction

- The environmental benefits of electric cars are **under intense scrutiny** with news articles on this a regular feature in most EU countries.
- So, **do electric cars reduce** car CO_2 emissions or do they just shift the problem elsewhere?
- For this we use lifecycle analysis.
- The most critical factor is the carbon intensity of **electricity used to power and build the vehicle.**

Electricity used to power EVs



Are Electric Vehicles Finally Taking Off?

- Electric vehicles are poised to take off.
- It’s no longer a question of whether electric vehicles – or EVs – will arrive, it’s how:

  How big of a role will EVs play, how soon and how clean will they be?

- Popularizing EVs will depend on tackling **key challenges**!

Popularizing EVs key challenges

1. Bringing down the cost of batteries

- Battery packs account for a third of the upfront cost of full EVs.
- Driving these costs down expands the number of EV models that are price-competitive with conventional vehicles.
- There is tremendous progress here.
  - The **price of lithium ion batteries dropped 73%** between 2010 and 2016, according to research firm Bloomberg New Energy Finance.
  - Numerous analyses point to battery costs of $100 per kilowatt hour (kWh) as the mark where full EVs become as affordable as traditional cars.
  - General Motors' battery costs are $145 per kWh, and the company expects that number to drop under $100 per kWh by 2021.

Popularizing EVs key challenges

2. Ramping up automaker investment for new, improved models

- Automakers are bringing electric cars and trucks to market with ever-better batteries and driving range.
  - Ford Motor Co.’s plan to double its investments in EVs to $11 billion is just the latest example.
- Globally, automakers have announced investments of more than $90 billion in EVs.
- Growth will continue over the next year
- The time it takes to recharge will need to be improved, too.
  - Helpfully, efforts are underway to deploy a next generation of fast-charging stations capable of adding 250 miles in a 15-minute fuel stop.

Popularizing EVs key challenges

3. Making charging stations more widely available

- People are more likely to invest in plug-in cars once they feel confident they'll always find a place to recharge their batteries away from home, and fast.
- **In fact, the availability of public charging infrastructure is a leading factor in EV adoption.**
- While the vast majority of charging occurs at home, public charging stations enable EV drivers to take extended trips.
- They also facilitate EV ownership by households reliant on on-street parking.
- To get the most out of EVs, we need more renewable energy on the electric grid and drivers who charge vehicles when the grid is its cleanest. States play a vital role.

* *A new report out by the California Energy Commission estimates that between 229,000 to 279,000 electric charging stations will be required by 2025 in order to reach the state's target of five million EVs on its roads by 2030.*

Popularizing EVs key challenges

4. Shifting to clean energy for charging

- To get the most out of EVs, we **need more renewable energy on the electric grid** and drivers who charge vehicles **when the grid is its cleanest**.
- States play a vital role.
- *By encouraging customers to charge EVs at times when renewable energy is readily available and affordable, New York is ensuring that EVs will benefit the grid and the environment.*

Popularizing EVs key challenges

5. Strengthening and extending emission standards

- Well-designed emission standards are critical to scaling clean vehicle solutions, such as EVs.
- With the certainty of long-term standards in place, manufacturers invest.
- This dynamic can be seen across the globe, as policy measures from China to California are driving EV investments.

Charging electric vehicles: the challenges ahead

- The most challenging and disruptive changes lie within the electricity system.
- The issues, divided into four sections:
  - **The Electricity Mix**
  - **Distribution Networks**
  - **Fast Charging**
  - **Autonomous Vehicles**

The electricity mix and price signals

- At a macro level, the overall increase in electricity demand due to EVs is likely to be just a few %, often less than 10%.
- On the one hand that doesn't sound a lot.
- Nevertheless it's still a significant chunk of **new power generation capacity** (or an increased utilisation of existing capacity).
- More significant than average changes in demand, will be ***when* these changes occur – and how they fit with changing supply**.
  - in **summer** there is likely to be *excess* **energy available** in the middle of a sunny day, due to large solar capacity.
  - **Will EVs be able** to soak up that excess?
  - in **cool northern climates** demand is already **greatest in the winter**.
  - The **additional demand from EVs** may be enhanced in the winter too, as a result of their reduced efficiencies in cold weather: meaning **more charging is needed** to achieve the same mileage
  - There will also be times of plentiful or excess energy due to wind, it's impossible to model the impact based on any regular schedule. Price-taking here would need to be a much more ad-hoc, automated response.

Distribution networks and demand diversity

- If everyone on your street decided to **switch on their electric oven at the same time**, a fuse at the local substation would likely go “pop”.
- Everyone would find themselves in the dark (with those electric oven owners limited to eating salad).
- *In other words, **grid capacity** is already sized around demand diversity, rather than scaled to accommodate synchronised maximum demands.*
- *This approach **keeps costs down by avoiding sizing infrastructure** to meet very, very unlikely scenarios.*
- *It isn’t aggregated energy that matters here, **it’s power demand at any specific moment in time.***
  - And **EVs, especially future ones with faster chargers, are bigger draws on power than electric ovens**!

Distribution networks

- One UK analysis concluded that in a town with a population of 6,800, just 900 EVs entering the system could lead to brownouts (through a drop in the voltage of supply).
  - At a more local level, a pilot project showed problems when just *five* 3.5 kW chargers were connected to a network cluster (with 134 dwellings) and charged at the same time.
  - That project concluded that 32% of UK low voltage circuits (312,000 in total) would require reinforcing if 40% – 70% of customers had EV's with 3.5 kW chargers (i.e. very slow ones, with 7kW now becoming the norm).

Fast chargers and “filling stations”

- **Home-based charging** – and it certainly seems reasonable to assume that, unless unable to, most EV owners would like to have a charger at home.
- Nevertheless, distribution constraints mean that unless they are prepared to pay for the privilege of higher power, this **charger will likely remain *slow***.
- Yet there is clearly lots of interest in *fast* charging, (350kW being the highest).
- Fast-charging could be key in overcoming anxieties around range.
- Bear in mind that **ten 350 kW chargers** would require an **infrastructure capable of handling 3.5 MW**.

Fully-autonomous EVs

- The impact of fully-autonomous EVs is one which promises to be significant at all levels within the electricity system, both macro and local.
- One key question concerns overall energy use: Will AEVs increase or decrease driven miles?
- There are a lot of variables that feed into answering that question.
  - *How many AEVs will simply replace private vehicle ownership on a one-to-one basis?*
  - *How many will be shared AEVs (SAEVs), whereby a single car replaces several privately owned ones, through car sharing or "Mobility as a Service" (MaaS) schemes?*
  - *In either case, will the AEV experience prove so pleasant that more journeys are made, perhaps even reducing demand for public (mass) transport?*
  - *Or will route-sharing and efficiency algorithms, plus other SAEV fleet management software* ***get people from place to place with less overall driven miles****?*

Digitalization

- **Digitalization** is an integral part of the present energy system, and an important instrument for the energy transition.
- **Improved control systems,** for example, driven by data from embedded sensors across the entire energy system — from generation through transmission and distribution and in endusers' plants and machinery — are **critical to enabling the energy transition we have envisioned**.
- **The power system is in the midst of digitalization**; an example being **demand-response**, where cost based rules may benefit both the thrifty consumer, as well as society which will see less need for upsizing the grid as electricity demand increases.

Digitalization

- Digitalization also allows for **higher asset utilization, improved energy efficiency, and the ability to implement new business models**.
- Digitalization’s impact is **spread throughout the energy system**, and its influence will grow with increasing application of advanced computational approaches such as machine learning.

EVs in Case study Croatia

EV modeling - Covered Issues

- Number of EVs
- Load profile
- Batery capacity and charge power
- Avalilable capacity for V2G
- Additional flexibility provided by EVs – examples

METHODOLOGY

- The **PLEXOS software tool** has been used for the purpose of analysis in this paper.
- Modelling in PLEXOS can be carried out using deterministic or stochastic techniques that aim to **minimize an objective function** to the modelled cost of electricity dispatch and to a **number of constraints**, including availability and operational characteristics of generating plants, licensing environmental limits, fuel costs, and operator/transmission constraints.
- The simulation of the solution is based on the MIP mathematical programming technique - mixed integer programming.

Test Model – Power System of The Republic of Croatia

- In the model, the low-carbon scenario of strong transition was taken into account, and all the data is used according to MZOIP: Bijela knjiga (White book of Low carbon Development Strategy).

Installed power [MW]	*2015*	*2030*	*2040*	*2050*
TOTAL	**4 786**	**8 434**	**10 718**	**12 643**
Nuclear power plant	348	348	348	500
Gas-fired power plant	1.140	1.745	2.630	3.080
Coal-fired power plant	330	210	0	0
Gas-fired power plant with CCS	0	0	550	550
Heating oil-fired power plant	320	0	0	0
Hydroelectric power plants	2.095	2.567	3.107	3.107
Wind power plant	420	**1.887**	**2.227**	**3.259**
Solar power plant	48	**1.300**	**1.400**	**1.667**
Biomass power plant	28	94	140	150
Biogas power plant	21	100	128	136
Geothermal power plant	0	44	48	54
Small hydroelectric power plant	36	140	140	140

Electricity consumption

- The **hourly electricity consumption** was estimated and created for up to the **year 2050**, based on the hourly load profile from 2015, with a proportional annual increase in energy consumption.
- Due to the higher anticipated consumption of electricity in industry and services and the electrification of transport, the **average growth rate** of electricity consumption is estimated to **1.2 % per annum** from 2014 to 2030, and **1.7 %** growth from 2030 to 2050.
- Consumption should be by 70.1% higher in 2050 than in 2014.

EV modelling

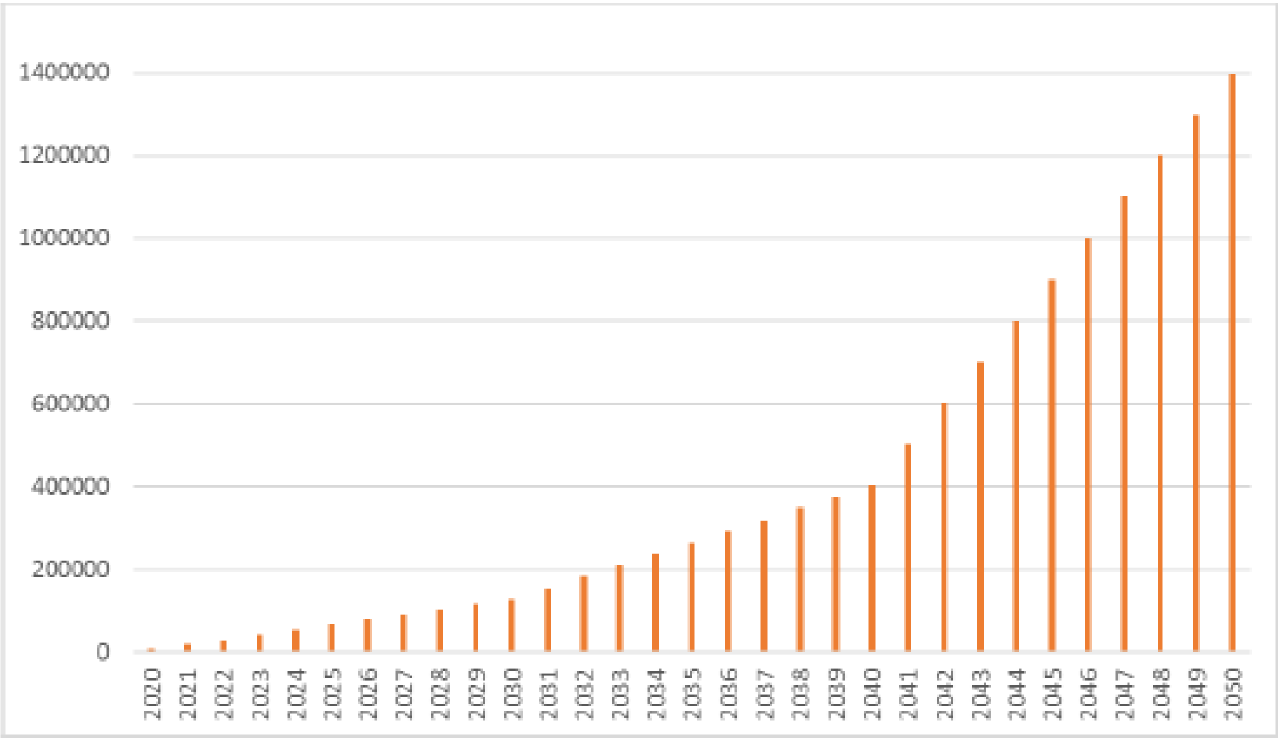
- **Battery electric vehicles (BEV) with vehicle-to-grid (V2G)** technology were modelled
- The total number of EVs penetrating each year from 2020 to 2050 was divided into 20 EV objects, which represent a set of EVs with corresponding annual capacity growth.
- The amount of EVs connected to the grid by **2030** is set to be **150,000**, i.e. **4%** of the total number of vehicles in 2030, **and by 2050 a total of 1.5 million EVs** or 75% of the total number of vehicles
- It was necessary to set the maximum power that each vehicle has at a given time during the day

EV modelling

- **Hourly diagrams**, made for working days and weekends or holidays, describe the movement of cars for each group of EVs object, i.e. their **consumption or production**
- Furthermore, in order to successfully model the separation of EVs from the network, it was necessary to **model the limitation related to their production**.
- In other words, the available capacity of each battery must be **greater** than or equal to the **maximum power used by the EV** at every hour of the day, so that there is a potential for EV to deliver power to the network and thus serve as an energy source.

*charger 3,5 kW	*storage 50 kWh
*1,4 mil cars 2050	

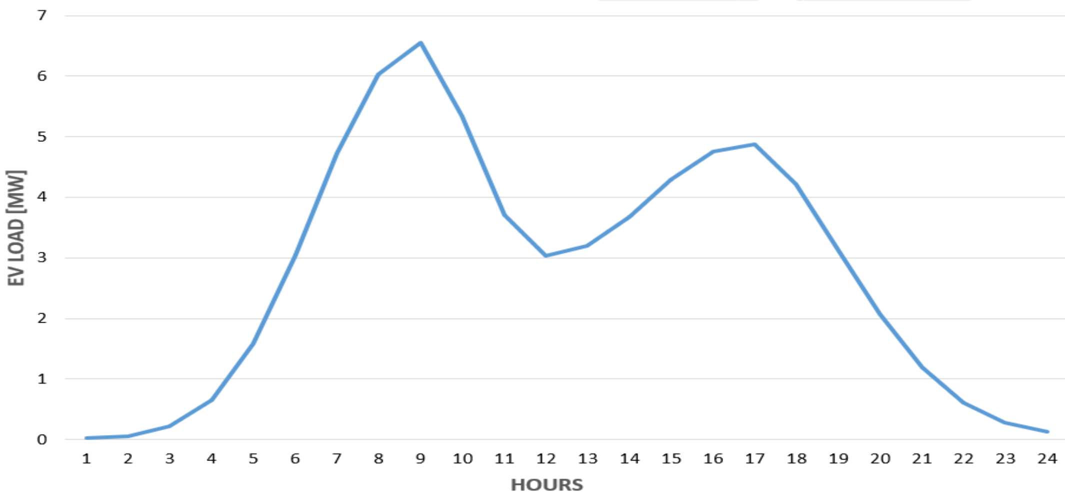
Predicted number of EVs



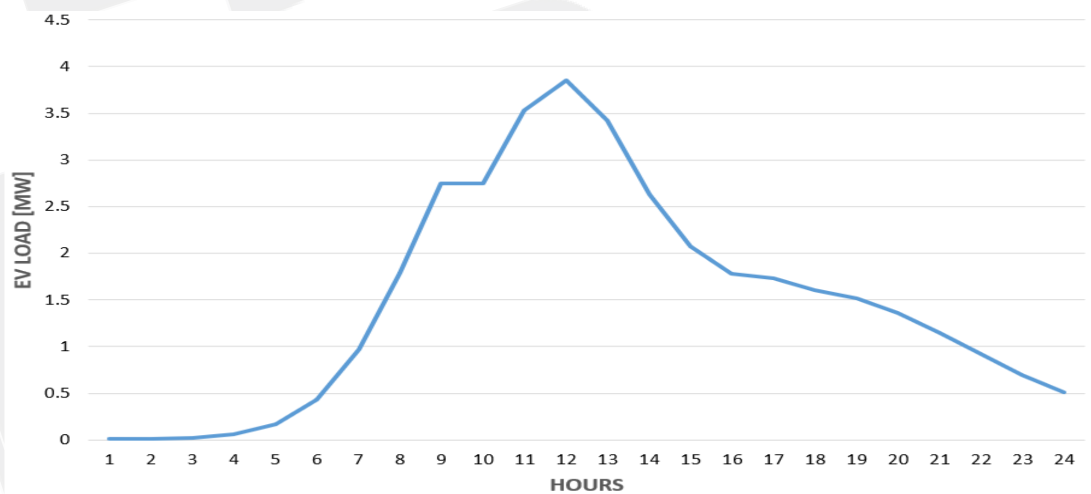
- Target: 1,4 million by 2050.

Hourly profile of energy consumption of a group of EVs

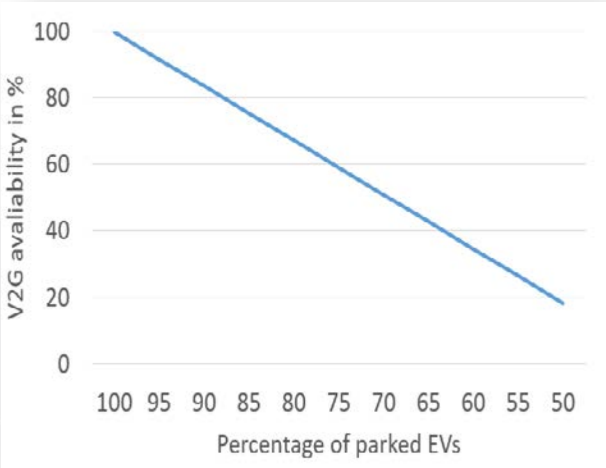
working day



weekends and holidays



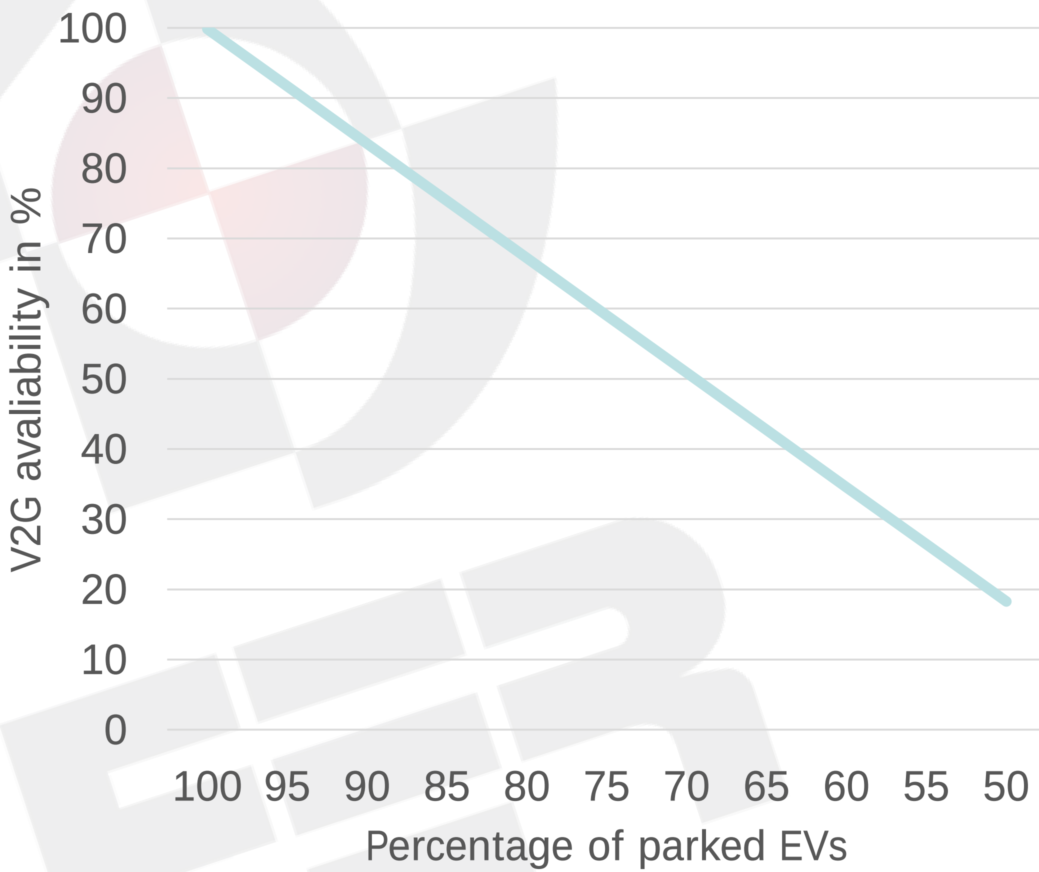
Available V2G capacity



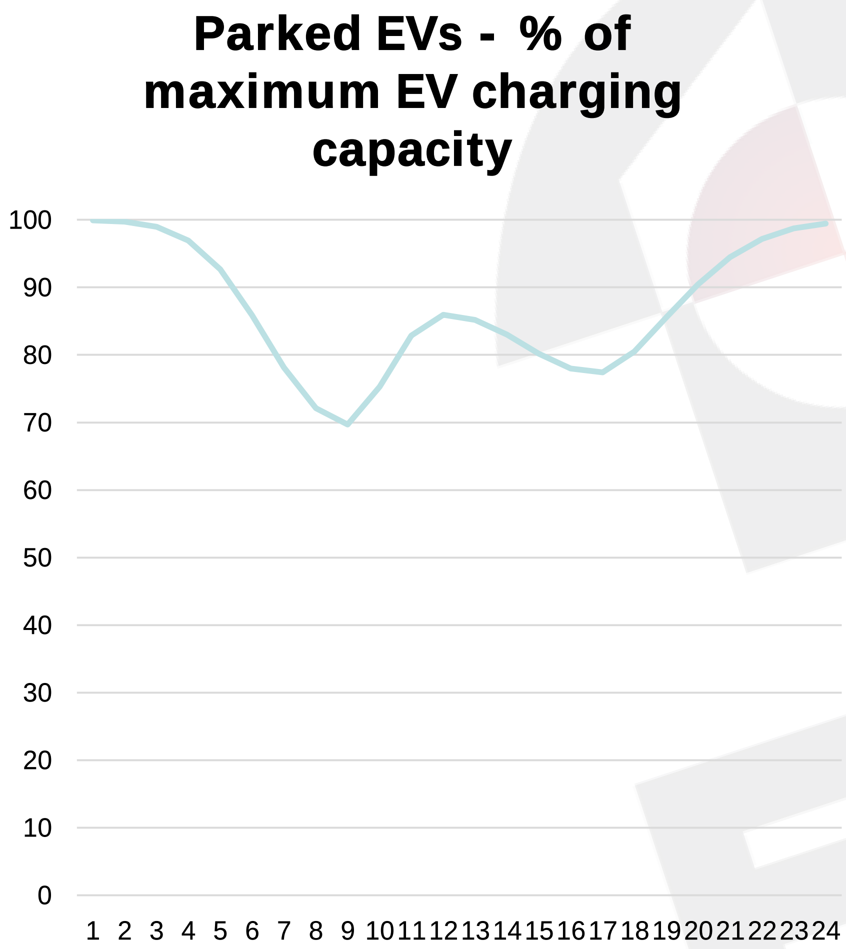
- Depends on:
  - Number of **parked** EVs (not moving)
  - Number of parked EVs on parking places with **adequate assets**
- Availability of parked EV capacity
- Approach and **assumptions**:
  - During night hours most of parked EVs are also available for V2G
  - During peak traffic hours avaliability of parked EVs for V2G is lowest
  - Availability for V2G is **inversly proportional** to number of moving EVs

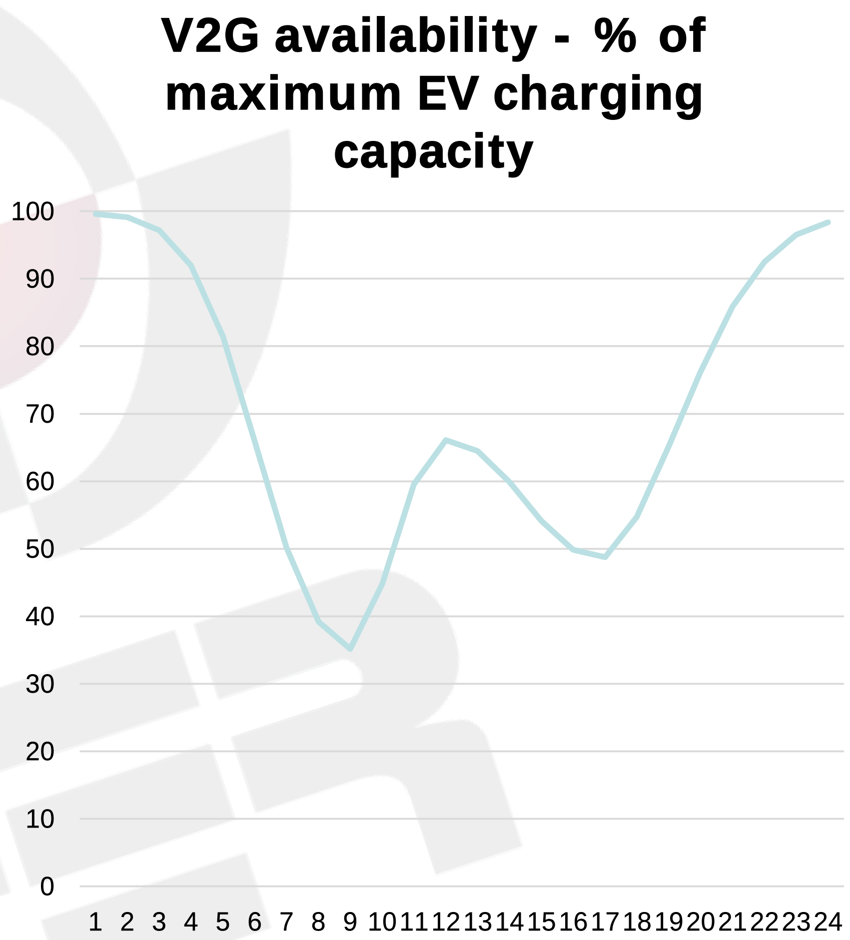
V2G availability function

- If all EVs are parked availability is 100 %
- During peak trafic hours availability is 50 %
- It is assumed that at least 70% of EVs are always parked

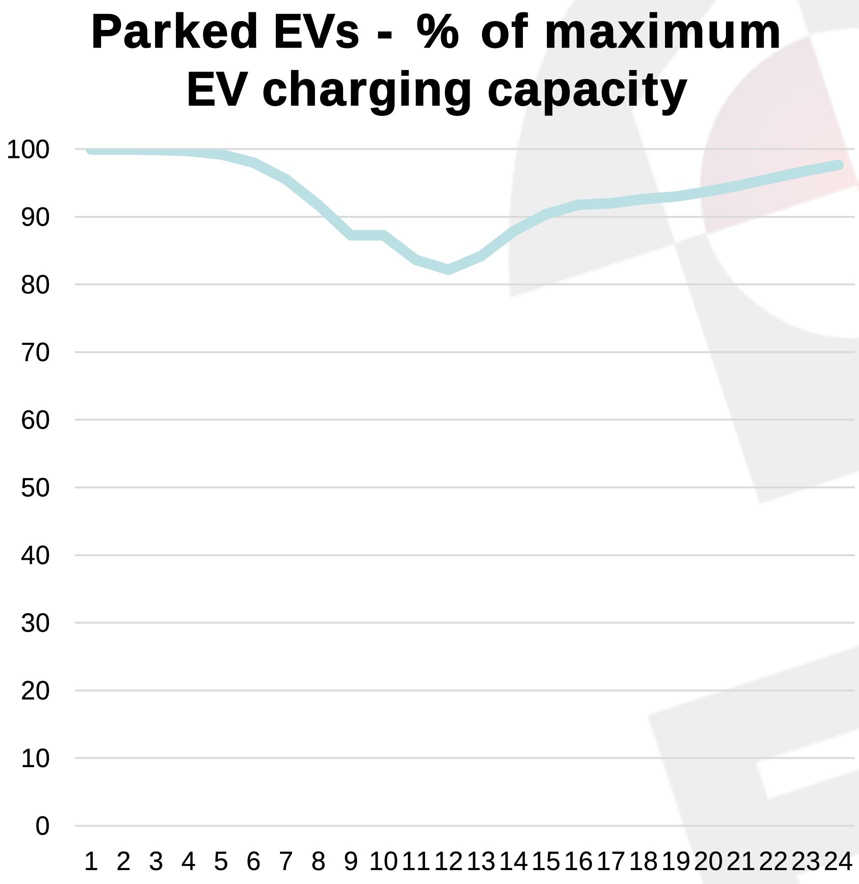


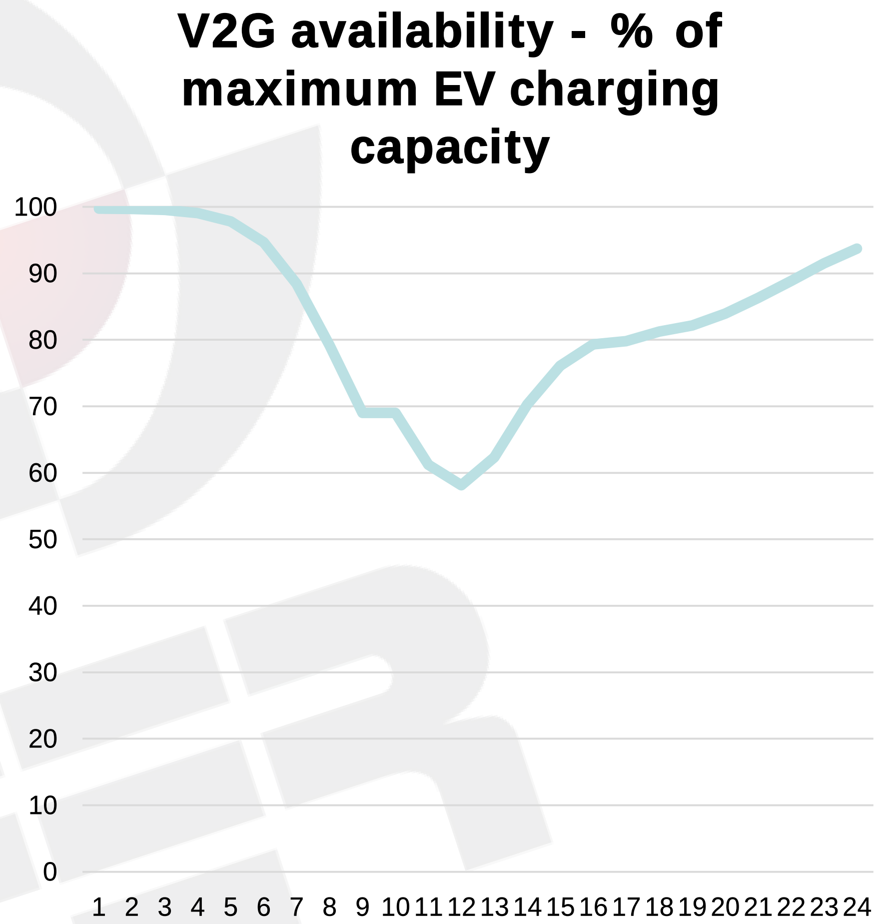
Hourly profile of maximum power of a group of EVs V2G availability – week day





Hourly profile of maximum power of a group of EVs V2G availability – weekend day





Wind and PV power plants modelling

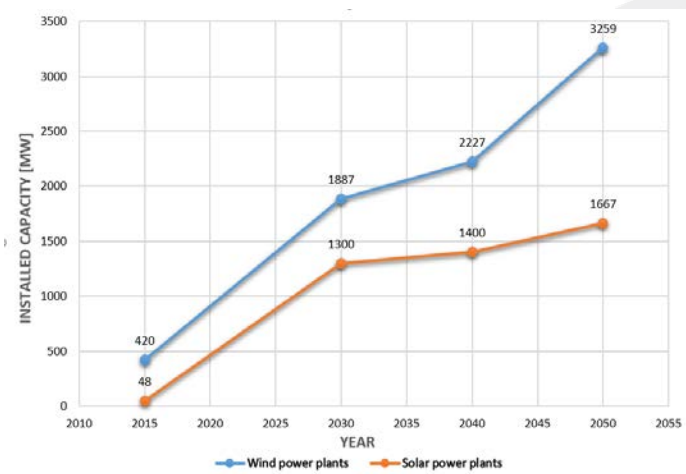
- Wind power plants modelling
  - The anticipated entry of new production units into the grid and the existing installed wind power plants capacity in the period up to the year 2050 were modelled.
  - Current and future production units were divided into **nodes by the geographic** position on the 'South Adriatic', 'Middle Adriatic' and 'North Adriatic'.
  - For each area, based on **the existing measurements** and data from 2015 and forecasts, an **hourly chart of wind farm production is determined by year 2050**
- PV power plants modelling
  - The modelled existing solar power plants and the anticipated production units are distributed in the model hubs according to their geographical position to 'Inland', 'Primorje' and 'Dalmatia'.
  - For each area, the **hourly production diagram is defined** based on the measurements collected for the base year 2015

RESULTS

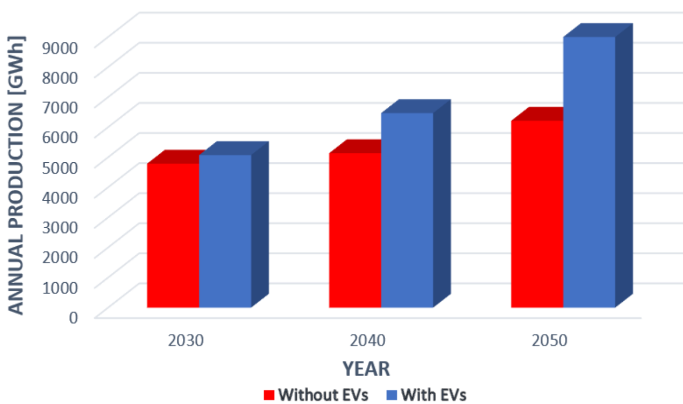
Model of the Republic Croatia

- The test model of the Republic Croatia was created
- **Several scenarios** have been created to help manipulate input data for the purposes of analysis.
- Two main scenarios were observed and analysed, **one without EVs and pumped-storage HPPs and one with EVs and pumped-storage HPPs**
- Impact on system flexibility can be examined by looking at **how much EVs and their quantity affect the production of certain power plants**, so that the shortage or surplus production caused by intermittent production from RES is covered.
- In addition, the production of RES changes depending on whether EVs are or are not connected to the power system and whether the pumped-storage HPPs are constructed or not.

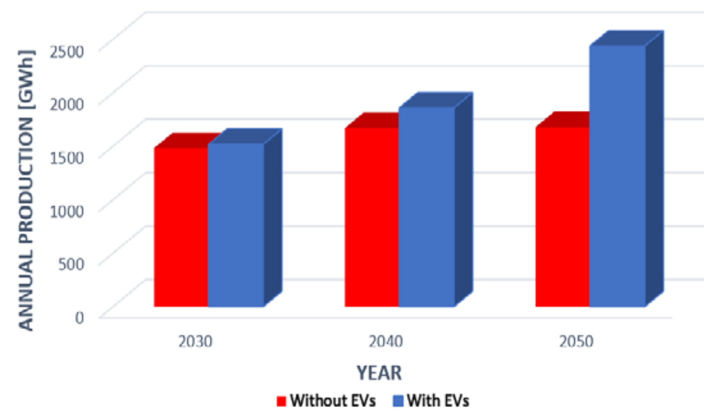
Increase in the installed capacity of wind and solar power plants



Increase in the installed capacity of wind and solar power plants



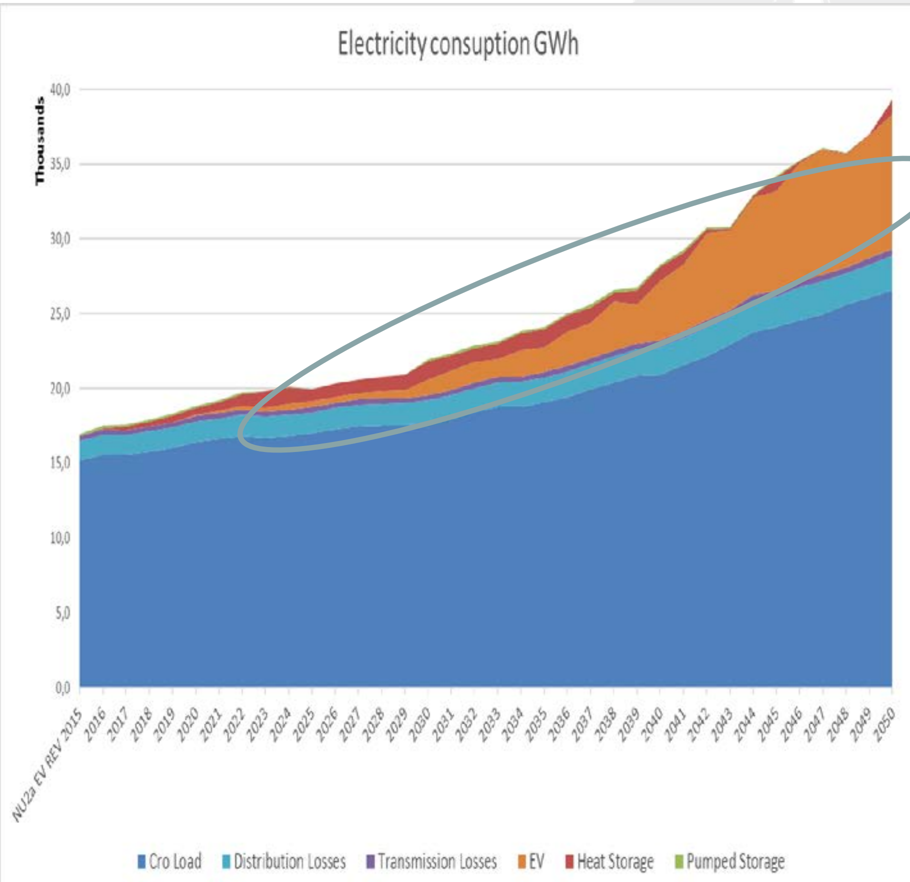
Annual production from wind power plants for both scenarios



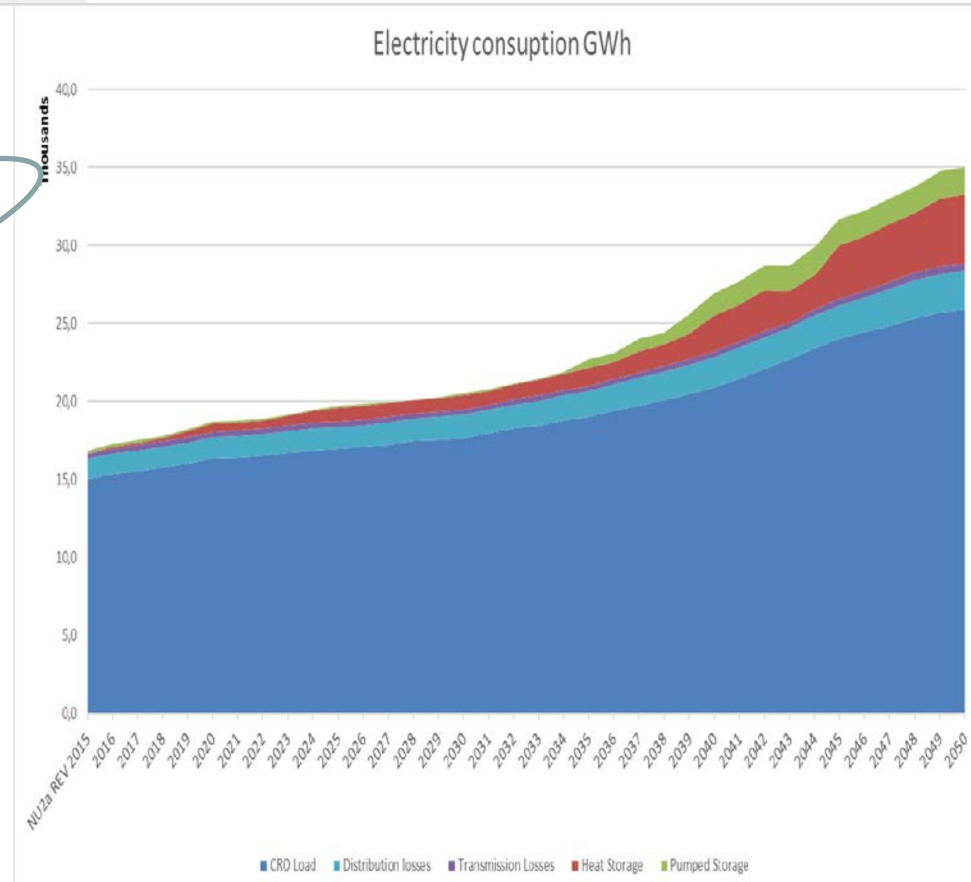
Annual production from solar power plants for both scenarios

Results with & without EVs modeled electricity consumption

with EVs

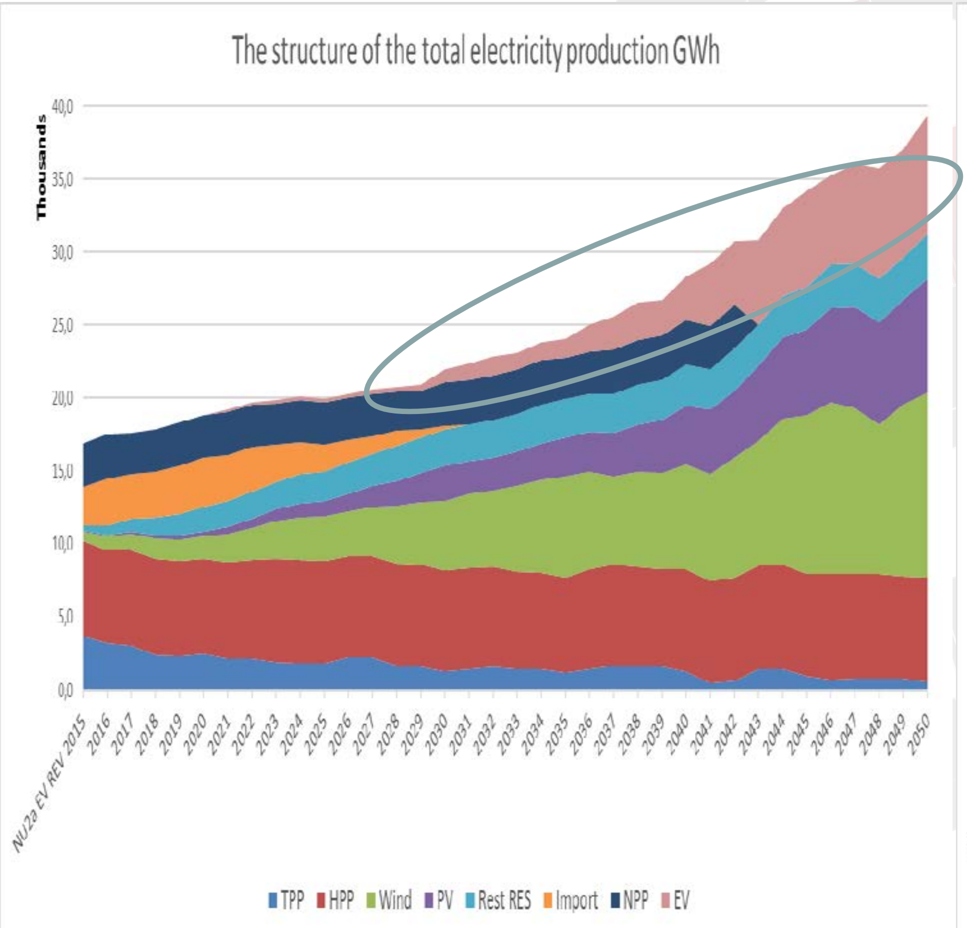


without EVs

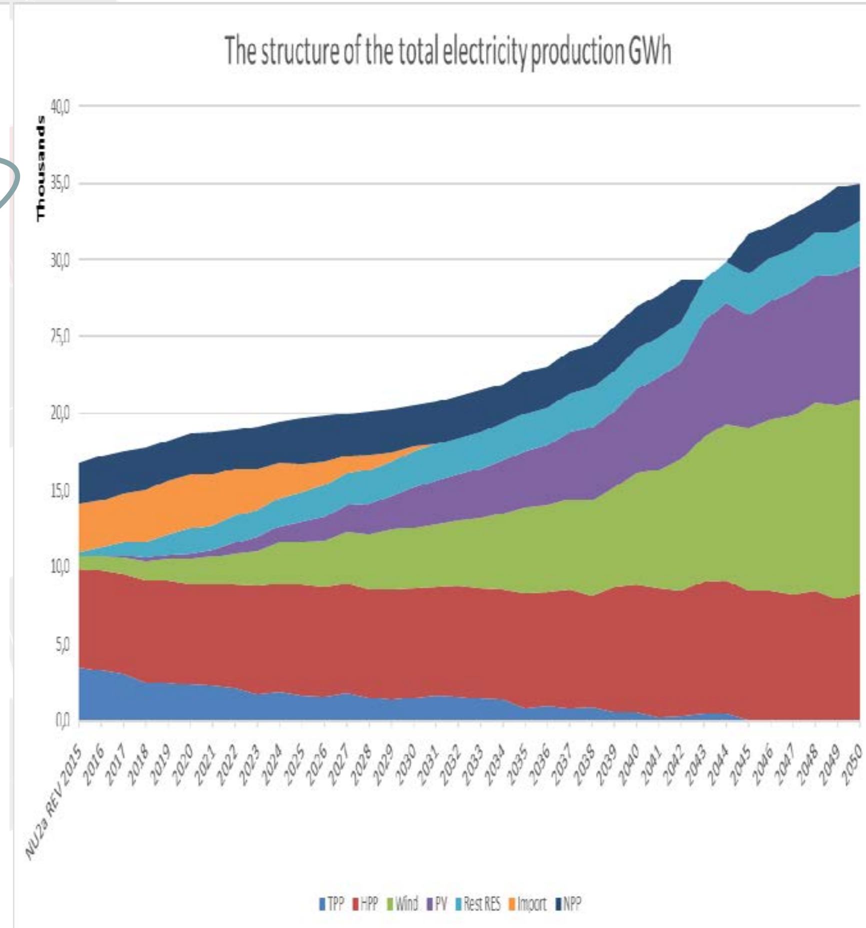


Results with & without EVs modeled electricity production

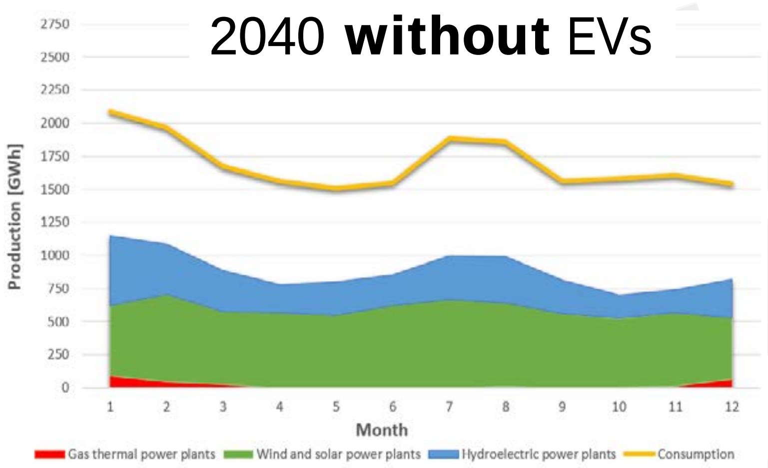
with EV

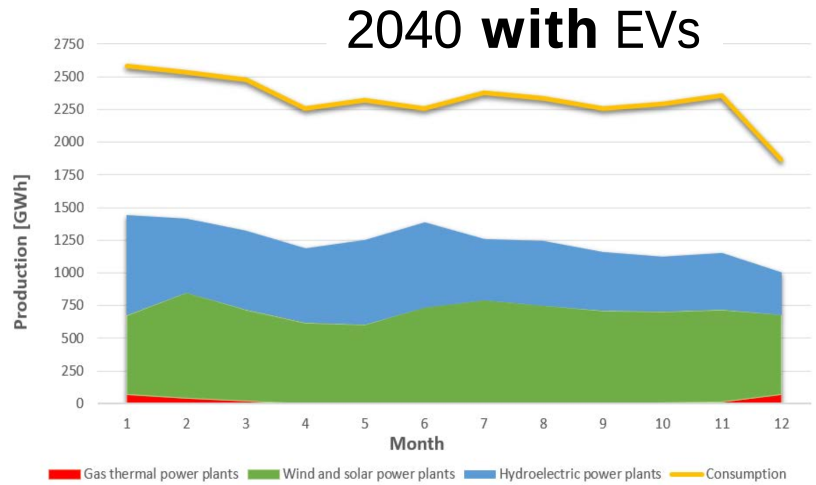


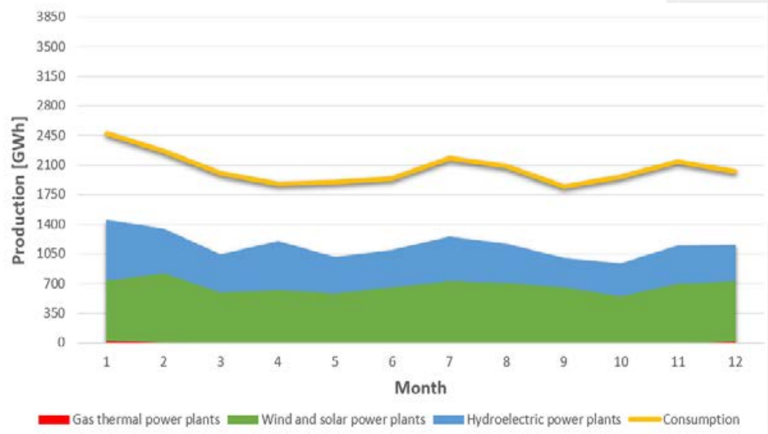
without EV



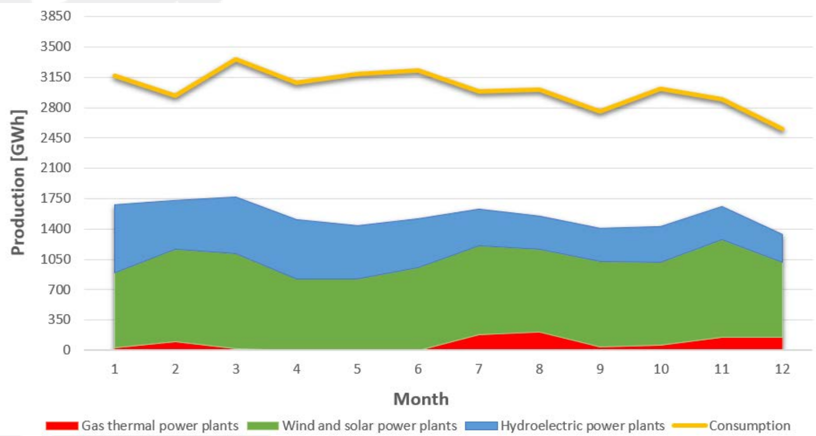
Production from wind and solar, gas thermal (back-up) and hydro power plants





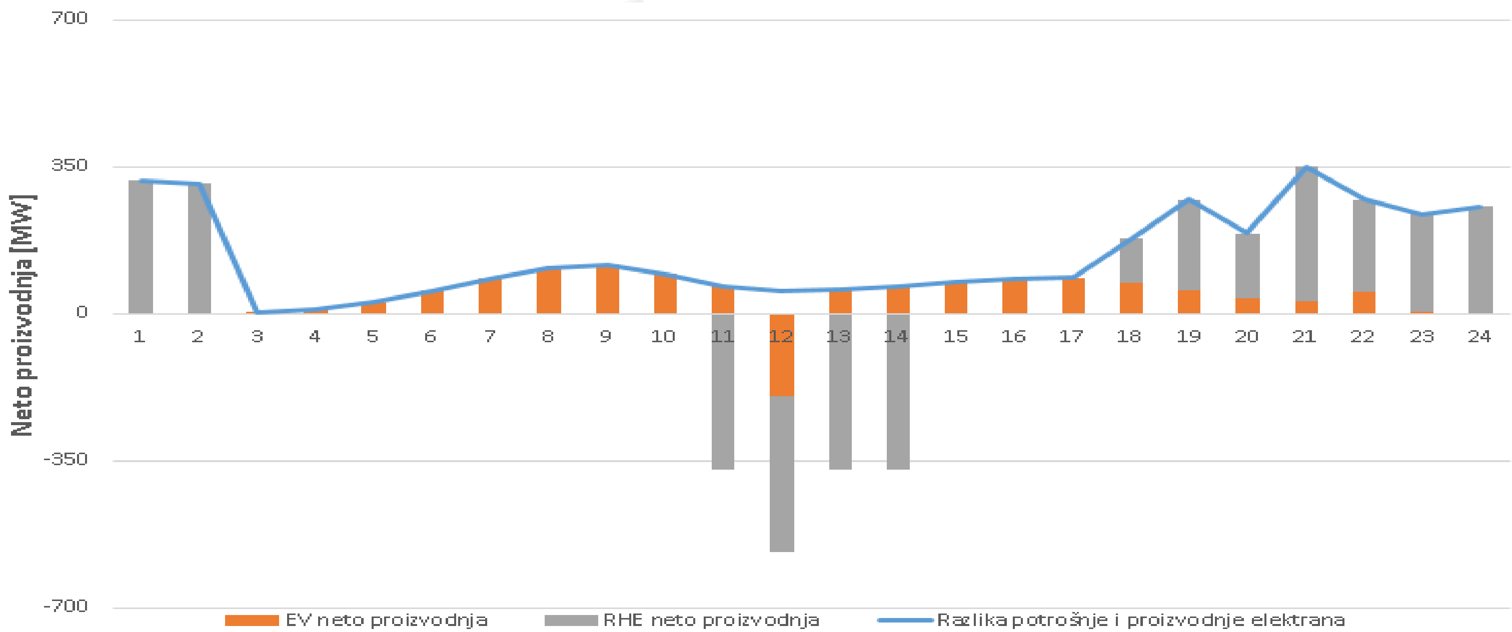


2050 **without** EVs



2050 **with** EVs

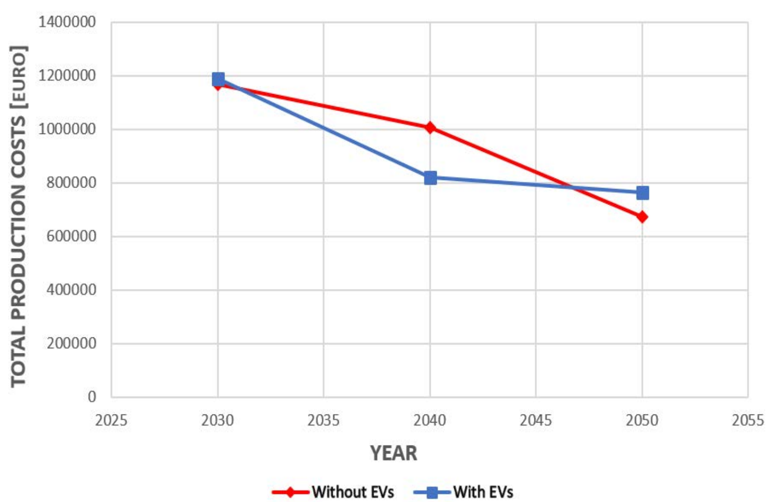
Net production of energy storage in the system for 15.7.2050 for the EV scenario



- In periods 4-11 and 13-23 hours **EV provide power to the grid** to meet the difference in consumption and production, ie lack of production from installed power plants (conventional and OIE).
- It is only the **nocturnal energy that the EV on the grid takes larger than the total energy** that is delivered to the grid, so **net production is negative**.
- The picture also shows the net production of another type of energy storage modeled, reversible **hydroelectric power plants (RHEs).**
- It is noticed that in moments when the EV can not deliver power to the grid, or at night when the batteries are full, RHE produces a lack of energy to meet the consumption.

Total generation costs

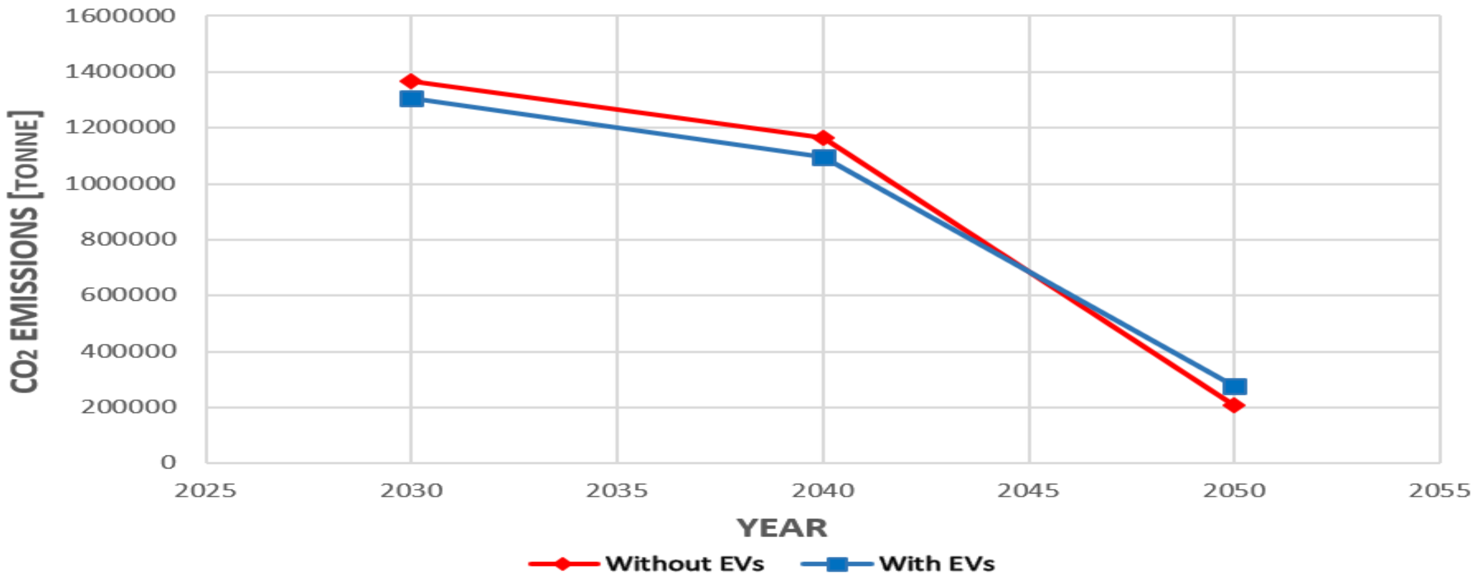
- **Total production costs** are calculated as the **sum** of all production costs, including fuel costs, variable operating and maintenance costs (VO&M), start-up cost, shutdown costs and emission costs.
- By comparing both scenarios, it can be seen that in the case of the **model with EVs the total production costs are lower** during most of the analysed period.
- The **production from RES** in the scenario **with EVs is higher** and the costs of the production of such units are lower than conventional production units, hence the total production costs are somewhat smaller



CO_2 emissions

- The **impact of EVs on CO_2 emissions** is one of the key parameters when analysing the application of such energy storage technology.
- By increasing the share of EVs, emissions **from the transport** sector are **shifted to the electricity production sector.**
- The results suggest that in 2050 the additional load caused by EVs results in a small increase in CO_2 emissions since the EV charging was not modelled completely according to off-peak charging; therefore, the EVs charging during peak load hours causes higher production from conventional fast power plants which contributes to CO_2 emission production
- It can also be concluded that although **RES capacity increases each year, the modelled growth around 2050 is not sufficient to cover the demand of the anticipated amount of EVs** so the fast thermal power plants are started during some periods.

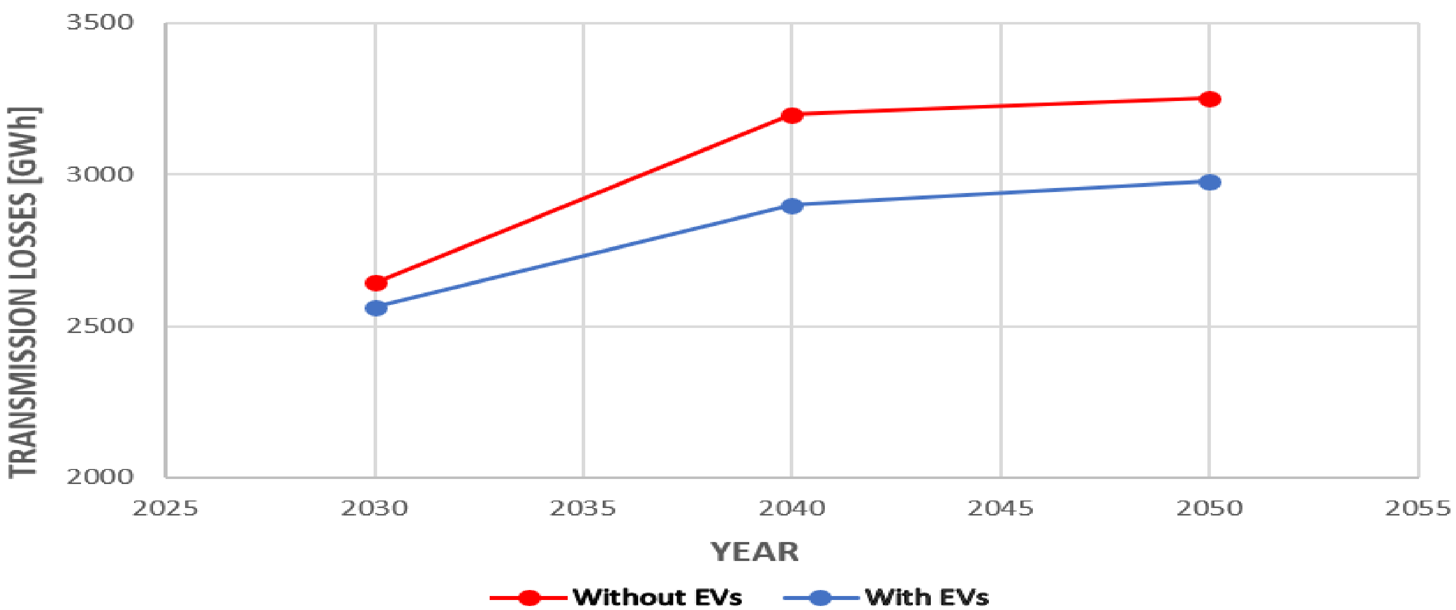
CO_2 emissions



In the case of CO_2 emissions, the higher production from thermal power plants in 2050, caused by the high number of EVs as much as the modelled charging profiles, results in higher total generation cost

Transmission losses

- The impact of the modelled EVs on the **total annual transmission losses is positive**.
- Due to the possibility of energy storage at locations closer to actual consumption, power flows are reduced and transmission losses in the power network are lower



Additional flexibility

- EVs in 2050. will consume around 4,5 TWh
- It is estimated that additional EV electricity consumption for V2G will be also around 4,5 TWh in 2050.
- That is significant additional flexibility added to system
- With chargers larger than 3,5 kW (highly possible) this flexibility will be even larger
- Network issues?
  - Just in terms of costs

Advantages and disadvantages of connecting EVs to power system

- **Advantages**:
  - **Increase** in production from variable RES – a higher increase in production from wind power plants.
  - **Decreased** need to build additional conventional power plants to cover peak loads (the need for additional capacities of conventional power over the years decreases with an increase in the number of EVs).
  - **Reduced** total production costs due to larger production from RES.
  - **Decrease** of annual transmission losses.
- **Disadvantages**:
  - A relatively **large number of EVs is needed** in order to ensure sufficient capacity of energy storage.
  - When EVs are **charging in periods of peak load**, the conventional power plants with quick response must generate so that the additional load caused by high number of EVs is covered.
  - Compared to the scenario without EVs, there is a slight increase in CO_2 emissions due to the modelled charging profiles.

CONCLUSIONS

- Wind and PV power plants cover the **largest share in newly-installed** capacities around the world.
- They cause **instability of the power** system since wind is volatile and unpredictable, especially in the long-run.
- This causes an **increase of the costs of maintaining the system in balance** and, sometimes, can lead to instability and even system breakdown.
- Different options are being discussed, and one of the most possible and prominent **option is the integration of EVs into the grid**.
- The results based on the analysis made for both scenarios without and with EVs in the power system show that **additional storage in form of EVs allows increased production from RES** and **decreased need** for building additional conventional **fossil fuelled thermal power plants** to cover peak loads.
- The total **generation costs are lower**, while the transmission losses are decreased.

CONCLUSIONS

- Relatively **large number of EVs is needed** to ensure sufficient energy storage and, if the EVs are charging in periods of peak load, the conventional power plants with quick response must generate so that the additional load caused by high number of EVs is covered
- An adequate development of the power network for the integration of renewable energy sources:
  - **the development of decentralized and centralized storage of electricity,**
  - **the expansion of advanced networks and smart grids and**
  - **the stronger integration with the transport sector and thermal systems**.
- It would certainly be beneficial to analyse scenarios with and without electric vehicles, but to also **include the costs of the building the needed infrastructure**, especially the **charging stations**.

General conclusion

- **Renewables represent a clear energy** and they don't produce GHG emissions, but they have **intermittent nature** (wind and solar), their geographical distribution is typically uneven and the variability of renewables **requires more operational flexibility to compensate fluctuations.**
- This problem **limits their participation in the energy market.**
- Our present lifestyle has a big impact on the future.

General conclusion

- **Large penetration** of **fluctuating renewable** sources into the power system **requires a substantial increase in the capacity of various energy storages**.
- One of the **most prominent options today** is the **penetration of electric vehicles**, whose **use reduces air pollution**, while **connecting them to the smart grids** creates the **possibility to increase the flexibility** of the power system, since **vehicle batteries could be used as storage but also as a source of electricity**.
- **Electric vehicles** (EVs) provide the **possibility of storing electricity**, which opens up **new opportunities for the integration of OIE into the grid**.

General conclusion

- **DIGITALIZATION** IS **AN INTEGRAL PART OF THE ENERGY TRANSITION**

- **Digital technologies** will make the energy system more connected, intelligent, efficient, reliable and sustainable.

- The effect will be noticeable in the supply of energy but will **especially drive efficiency in energy end-use**.

General conclusion

- **Need to change** paradigm that **SUPPLY FOLOWS DEMAND**
- TO:
- **DEMAND SHOULD FOLOW SUPPLY**

Thank you for your attention!