Increasing the integration of solar photovoltaics in energy mix on the road to low emissions energy system – economic and environmental implications

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ABSTRACT

The EU policy aims towards low carbon economy by establishing a goal of reduction of 93-99% in greenhouse gas emissions in energy sector by 2050. This means a complete energy transition from the fossil fuel based systems to mostly renewable and low-carbon based energy systems. In order to integrate variable renewable energy sources, day-ahead and intraday electricity markets influence, demand – response technologies implementation and fossil fuel powered thermal power plants' flexibility considerations need to be analysed. Along with the integration of solar photovoltaics, demand – response technologies (power-to-heat and vehicle-to-grid concepts) needed to balance the system, were deployed. In calculations performed on the case study of Croatia in years 2014 and 2030, a moderate introduction of heat storages in Croatian combined heat and power plants, introduction of electric vehicles and flexible operation of power plants enabled the integration of up to 2000 MW installed capacities of solar photovoltaic plants. The main integration criteria, a cumulative critical excess electricity production from solar and wind power, was kept under 5%. Results of this approach are the reduction in full load hours of economically feasible operation for Croatian power plants up to 2000 and combined heat and power plants to up to 3000.

KEYWORDS

Low-carbon energy system, Solar energy, Demand response, EnergyPLAN, Variable sources integration.

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1. INTRODUCTION

Different rates of integration of variable renewable energy sources (VRE) into the energy system are possible, depending on goals. The price of VRE is getting lower, and has already achieved competitiveness compared to other sources, which is documented in research [1] and reports such as IRENA [2] and [3] and IEA [4] . The solar PV technology is competitive and has reached grid parity on many locations in Europe. Integration of smaller quantities of VRE does not have a significant impact on system's costs.

Up to about 20% of wind energy and 10% of solar energy share per annum, there is an impact on reducing the cost-effectiveness of base power plant construction, which is not necessarily adverse in the context of decarbonisation. Also, occasional curtailment up to a maximum of 5% of critical excess electricity produced (CEEP) can occur, and, in case of poor planning and balancing cost allocation, VRE integration may have an impact on increased cost of balancing. Problems can appear in network building, if network is not adequately designed and in ancillary services, if the market of auxiliary services is inefficient or non-existent. All this is true only if the system is not set in the optimal way. Above this limited share, it is necessary to plan for demand management, in the form of demand response technologies for the conversion of excess electricity to heat, manageable industrial consumption and electro-mobility.

Lund and Kempton [5] compared two energy systems with significant storage technologies and scenario approach discussing electric vehicles (EVs) within "vehicle to grid" concept (V2G). Limitations of aggregated battery model and EV driving cycles were shown, which is usually tackled using pool-based modelling and traffic flow estimates. These issues can be avoided to some extent, as shown by Pukšec et. al. [6], by intelligent long-term forecasting of demand in the transport sector. In another research Connolly et. al. [7] have shown the techno-economic analysis of energy transition of Ireland energy system. The research is comparable to Croatian case in the areas of grid regulation. In the work by Mathiesen et. al. [8], smart energy systems in the electricity sector and management of energy storages were discussed. A solution for long-term design of large energy systems, which can be applied for national level energy system design problem, was suggested by Prebeg et. al. [9] using H2RES. Novel approach was used in Reichenberg et. al. [10] to investigate the demand response in general, for integration of variable sources, such as solar photovoltaics (PV) and wind in the systems with high installed base load units, concluding that it can be facilitated with low curtailment if transmission capacities are available over large geographic area.

For the case of Croatia, Krajačić et. al. [11] demonstrated, using both EnergyPLAN and H2RES models, the role of storage technologies such as pumped storage hydro, heat storage and heat pumps, batteries and electrical vehicles in achieving the VRE share of 78.4% in gross final energy consumption in year 2020 and CO_2 emissions were reduced to 20 Mt, compared to the reference year, 2008. The research was focused on integrating wind power. Using the multi-criteria analysis and Pareto front to determine optimal integration of wind and PV in Croatian energy system, Komušanac et. al. [12] demonstrated that PV will have larger role in Croatian energy transition than expected, with 1650 MW of wind and 1600 MW of solar PV newly installed in 2050. However, demand response developments were not taken into consideration. Integration of wind, with special attention to balancing with dammed hydro power, was demonstrated in [13] by Cerovac et. al.. Benefits of a common low-carbon energy approach for the whole South East Europe was demonstrated in Dominković et. al. [14], taking into account various demand response and storage technologies, such as 100% electrification of light road transport with 85% of transport on smart charging, solar – thermal for space heating with additional storage among other measures aggregated for the Southeast Europe area. With complete transition, this research demonstrated 100% zero carbon South East Europe (SEE) system in the year 2050. Role and flexibility of district heating was investigated in connection to energy efficiency measures in Pavičević et. al. [15] and with waste management and heat markets as factors of synergy in Tomić et. al. [16].

In this paper, the influence of large integration of major VRE sources, solar and wind power, on the feasibility of other technologies and the reduction of greenhouse gas emissions is investigated.

Particular analysis of integration of combination of VRE such as solar and wind power, and challenges of their integration in different energy systems was performed in Ueckerdt et. al. [17]. Another recent study by Atia et. al. [18] shows how profitable V2G operation can significantly affect renewable energy sources (RES) sizing, in particular for micro-grids, demonstrating how V2G will take very relevant position in VRE integration. Also, in Weitmeyer et. al. [19], role of storage is discussed in the scenarios with integration of 50% VRE and 80% VRE and beyond, on the pathway towards 100% RES system. The combination of wind and solar PV was used in Weitmeyer's study, too. Further on, recent studies on synergies of energy production and electrified transport sectors in smaller island systems emphasize the role of V2G technology in Dorotić et al. [20], showing the economically optimal mix of solar and wind power, supported by V2G with minimal import and export of electricity. In Dominković et al. [21], it was demonstrated that in some cases, for small islands and integrated planning case, smart charging can reach similar effect as V2G in a simulation with PLEXOS employed as a modelling tool. In most recent study, Groppi et al. [22] it was shown, using EnergyPLAN and HOMER tools, that for islands similar to those from [20] and [21] dump charge and V2G have the opposite effect on electric grid, which is relevant for the present study. Spiegel [23] was investigating how different balancing groups integrate solar and storage units, concluding that power-to-heat technologies offer an option for reduction of balancing issues for such combination of technologies.

Regarding the long-term decision making for development of VRE based energy systems, Vidal-Amaro and Sheinbaum-Pardo in [24] model the energy transition for Mexico, using EnergyPLAN to implement a Minimum total capacity mix method, but without taking into account the synergies between the sectors.

A main criterion for the integration in this research is a cumulative critical excess electricity produced (CEEP) from both solar and wind power plants. In multi-level scenario approach, different demand response technologies are combined to balance the VRE and then, in level 2 scenario simulation, different options for combined heat and power (CHP) facilities are chosen.

2. METHOD

When all the options of cheap, cost-effective demand response are used, then further increase in penetration of VRE is possible only by storing energy at a higher cost. If the goal is to increase the share of renewables as soon as possible, then the dynamics of construction is limited only to the techno-economic criteria at a given moment and to the investment cycle rate. However, this will eventually lead to the rapid build-up of new sources at the beginning, and later stalling of the sector when saturation occurs. Although this has the advantage for the climate policy position, as this reduces emissions at a higher percentage, from the social welfare position it is necessary to ensure a constant value added of the VRE sector. As the value added in VRE is largely comprised of Capital Expenditures (CAPEX), although in wind power maintenance costs are significant (while other operating costs are negligible, OPEX), to ensure a continuous flow of added value, a continuous flow of investments should be provided. Wind power plants and solar power plants have a typical life time of 20 years, which means that, if one wants to achieve high socioeconomic profit, it can be assumed to install an average of 5% of the technically acceptable VRE share for 20 years on average.

Since a strong investment sector has not yet been developed for solar power, it is possible that it would be beneficial to start at a lower yearly installation rate, and to increase the growth rate later. For this reason, a future relevant year needs to be chosen for calculations, and plan for integration of VRE can be backtracked to the base year. For the purpose of establishing the technical potential for new installations of solar PV, calculation can be based on population, aiming for 10 MW of solar PV installed per 1% of population in the cities and corresponding rooftop area needed to accommodate integrated solar PV installation. The rest (if any) installations will then be implemented as ground-based larger solar PV plants.

The possible integration of VRE into the system was examined using the energy planning model EnergyPLAN, which is already known in the scientific literature and used for the research of the energy system development in many countries [25].

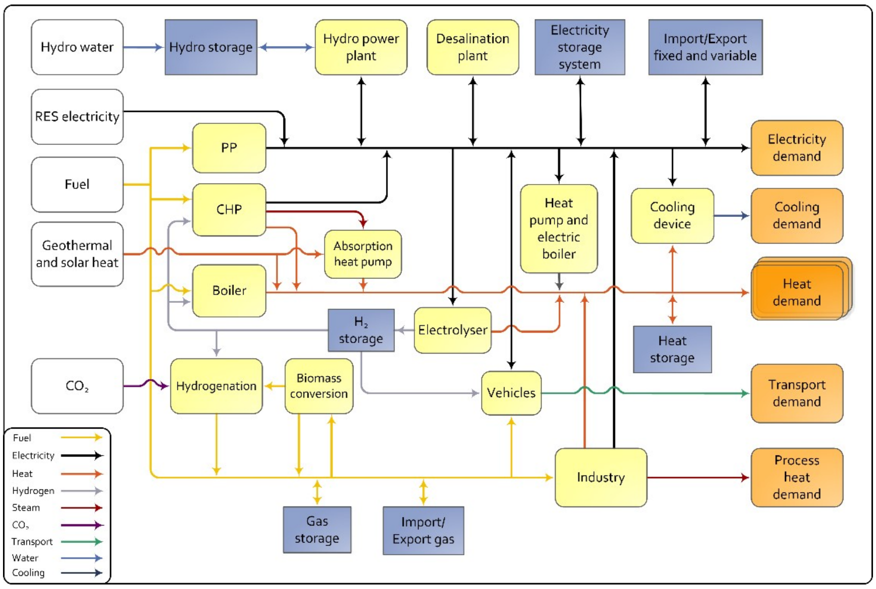


Figure 1 Principal scheme of energy system in EnergyPLAN

First relevant concept, which allows larger integration of energy from VRE, is the flexibility of existing power plants. This is already elaborated in all the research mentioned in the introduction.

For second concept, the approach to modelling investment in demand response technology relies on existing plans and trends in the sectors of centralized heat systems and electrification of transport. For centralized heat systems, assumed development implies that the goal of 40% of district heating systems (DHS) is achieved by 2050 (According to EU budgets under the new heating and cooling strategy, the estimate is that DHS can meet 40-70% of heating demand in Europe). DHS use fuel more efficiently than individual boilers. They can also use different sources at one location (in one plant) and can support the integration of renewable sources by using the surplus of the generated energy from the VRE while simultaneously reducing the consumption of fossil fuels. When considering centralized heat systems, cogeneration systems and their improvement of heat energy conservation technologies are considered in the moments when electricity is cheap (for example, VRE energy, which is a critical surplus at a given time). The third major energy-efficient technology concept (electrified transport connected to the grid at times when the vehicles are parked) is used to integrate increased share of renewable energy sources through storage and balancing, reducing CEEP in such way. Electric vehicles can be present in several technological forms: hybrid vehicles, hybrid vehicles with a network connection, electric vehicles with dumb charging, smart electric vehicles and smart electric vehicles with energy discharge to the network (V2G concept). Dumb charging can be a technology that increases electricity demand in the period when it is reduced, but renewable energy sources are abundant (for example: wind at night) and in that sense helps to integrate VRE while reducing the consumption of fossil fuels in transport. However, such a solution is not suitable for a higher share of VRE in the system. Smart charging and discharging (V2G) solutions are in this situation a key technology for integrating high share of VRE, because in a much larger number of hours, when EVs are not in traffic (most of the day), they serve as a fast response battery. The connection to the grid can be achieved by a slow charger at home (3.5 kW per vehicle), which would not have a significant impact on increasing infrastructure costs. Other chargers with higher power and charging speeds will have to be built so that vehicles can be charged and connected to the network, for example in public garages or parking places near the workplace. A key parameter for determining the economic justification of this level of integration of VRE is the critical excess of electricity produced from VRE technologies, which according to considerations from relevant literature can be assumed up to 5% [26]. The price of photovoltaic systems has dropped below 40 c€/watt (2017), in last tenders even below 20 c€/watt of installed power and the trend continues so far, with LCOE between 0.18 €/kWh and 0.22 €/kWh in 2010, falling to between 0.05 €/kWh and 0.08 €/kWh in 2020, according to European Photovoltaic Industry Association. There are already prices from 0.20 €/kWh to 0.06 €/kWh achieved in tenders, so the price is falling faster than expected, since these numbers were projected for 2030. Since the price of the PV panel technology, especially integrated in the roofs of residential buildings, makes a significantly smaller share of the final investment, the cost of laying and designing makes an even bigger share and generates workplaces locally.

Using this concepts, and additional relevant concept of flexibility of power plant (PP) and CHP operation, scenario approach is used to simulate various levels of integration of these demand response technologies, which in turn enable larger integration of additional VRE without crossing the key parameter limit.

Two levels of the scenario approach are:

1. Building scenarios with different use of demand response technologies, according to increasing cost of such technologies. From these scenarios, one which achieves the VRE integration goals with the smallest instalments of demand response technologies is further discussed on second level.
2. For the chosen scenario from previous stage, plans for further instalments of CHP and PP units are discussed in terms of their economic feasibility, expressed through full hours of operation in one year, and their sensitivity to import.

Further considerations after the second level of scenario approach include sensitivity factors and the environmental implications of second level scenarios. The sensitivity factors such as precision of VRE production predictions (factors like geographical distributions and technology advances), greenhouse gas (GHG) emissions originating from imported energy and market prices are to be analysed. To explore the long term strategic choices, following the same method as described above as an introduction to level 1, scenarios for transition to a system based on renewable energy sources can be developed.

3. CASE STUDY AND RESULTS

The reference scenario model of Croatia in 2014 was verified by comparing the known data from [27], [28], and [29] for the Croatian energy system in corresponding year. After aligning the scenario with the results of the recent proposal of Strategy of Low-carbon development of Croatia until 2030, with a view towards 2050 (NUR – low-carbon business as usual scenario) [30] for 2014, the focus of modelling has become the year 2030, for which further elaboration has been made. The Proposal of Strategy of Low-carbon development of Croatia until 2030, with a view towards 2050 discusses three scenarios: business as usual (NUR), gradual transition (NU1) and strong transition (NU2). Scenarios will be mentioned in context of calculations during the further elaboration of results. Data for base year (2014) and business as usual scenario (NUR) and gradual transition is given in Table 1.

Table 1 Installed capacities in base year and in year 2030 according to [30]

NUR	2014	2030 (NUR)
Total installed capacity (MW)	4,469	6,732
Nuclear PP (MW)	348	348
Gas PP (MW)	1,140	1,225
Coal PP (MW)	330	210
Fuel oil PP (MW)	320	0
Hydro PP (MW)	2,095	2,784
Wind PP (MW)	340	1,200
Solar PV PP (MW)	33	120
Biomass and waste PP (MW)	8	135
Biogas and landfill gas PP (MW)	17	80
Geothermal PP (MW)	0	30
Small hydro PP (MW)	33	100

The data from table 1 is chosen from the business-as-usual scenario in order to give the method for approaching the formulation of further scenarios, such as NU1 and NU2, which can later be found in public reports and data. Once such scenarios of development are formulated, the decision regarding the installations in second level of the approach presented in this paper was already made.

In order to realize the possibility of significant increase in plans for 2030, in particular for the case of increasing the planned installations of solar PV power plants, the technical potential of solar energy in Croatia is elaborated in short. Croatia has a significant potential for use of solar energy due to the geographical location and climate. Solar irradiation, presented in Figure 2, indicates the regions in Croatia, which would be suitable for exploitation of solar energy on larger scale. Being predominately in coastal area, such regions would need to focus on implementing solar PV technology. This focus can be twofold: supporting the installations of building-integrated solar PV or securing the locations for ground-based solar PV power plants. Former should come first, since it achieves different socio-economic benefits, such as continuous "green" employment needed for installation of numerous systems and local reduction of consumption ("prosumers" concept).

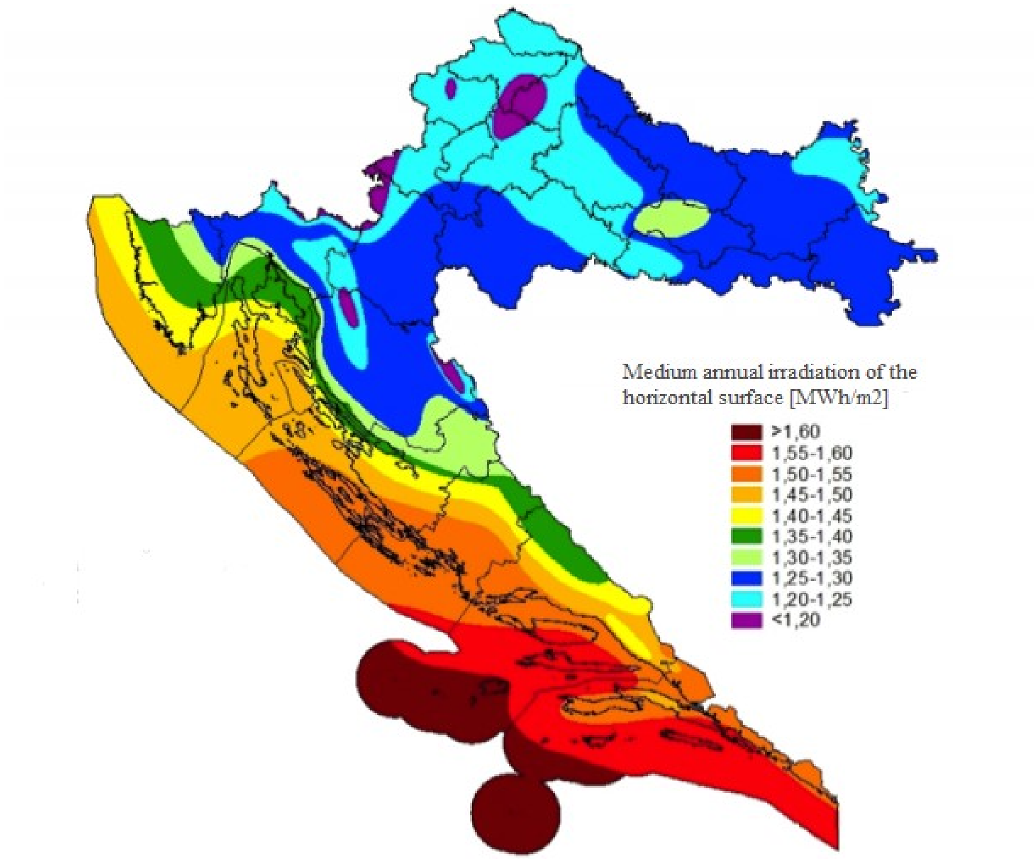


Figure 2 Medium annual irradiation on the horizontal surface in Croatia [31]

In Table 2 Solar irradiation and estimated production for characteristic cities solar irradiation for some characteristic cities in Croatia is given and the specific production from solar PV (on 10 kW) basis estimated by [32].

Table 2 Solar irradiation and estimated production for characteristic cities [32],[33],[34]

Characteristic cities	Irradiation on optimal angle [kWh/m^2]	Specific produced energy per year [kWh/kW]
Hvar	1780	1481
Split	1720	1431
Dubrovnik	1720	1431
Zadar	1660	1381
Pula	1580	1315

Rijeka	1470	1223
Zagreb	1370	1140
Osijek	1370	1140
Sisak	1350	1123
Varaždin	1330	1107

Demonstrated potential can be exploited if there is enough rooftop area in the cities. In Table 3, this area is calculated and compared to population in Croatia. On the basis of calculation, with 6.25 m^2/kW we conclude that at least 1000 MW of solar PV can be installed as building integrated installations, while, in order to reach goal of 2000 MW in 2030, the rest of the installations would be ground-based, aiming for the sub-urban areas of the coastal regions in Croatia.

Table 3 Estimation of available area for integrated solar power in Croatian cities in 2030

City	Percentage in Croatian population	PV [MW]	Surface for panels [m^2]
Zagreb	38.10%	381	2,383,811
Split	8.06%	81	504,274
Rijeka	6.19%	62	387,388
Osijek	4.06%	41	253,777
Zadar	3.45%	34	215,658
Pula	2.77%	28	173,381
Sisak	2.14%	21	133,738
Varaždin	1.87%	19	117,193
Dubrovnik	1.37%	14	85,797
Overall (on sample)	68.01%	680	4,255,018

To use surplus electricity produced in centralized heat systems using electric heaters and hot water tanks, it is calculated with equipping the largest centralized heat system in Croatia with tanks equivalent to that already built in CHP plant TE-TO Zagreb, 750 MWh of thermal tank capacity. By building such a system in the other two largest thermal power plants – CHP plant EL-TO Zagreb and CHP plant TE-TO Osijek, the total tank capacity would reach 2.25 GWh, with the electric heaters' installed power of 250 MW. Adequate heat tanks can be added to all sites that have the need for heat energy and, above all, for flexible cogeneration plants on gas or biomass. With all the other parameters equal to the reference scenario, for the integration of additional 1750 MW from solar PV panels (total 2000 MW in 2030), there should be available over 300 000 electric vehicles with unchanged integration of wind power plants with a total capacity of 1200 MW in 2030. Calculation has been conducted through scenario approach, with varying system flexibility and the level of development of technologies such as the integration of electric vehicles and heat tanks using the surpluses of electricity produced in 2030 (Figure 3).

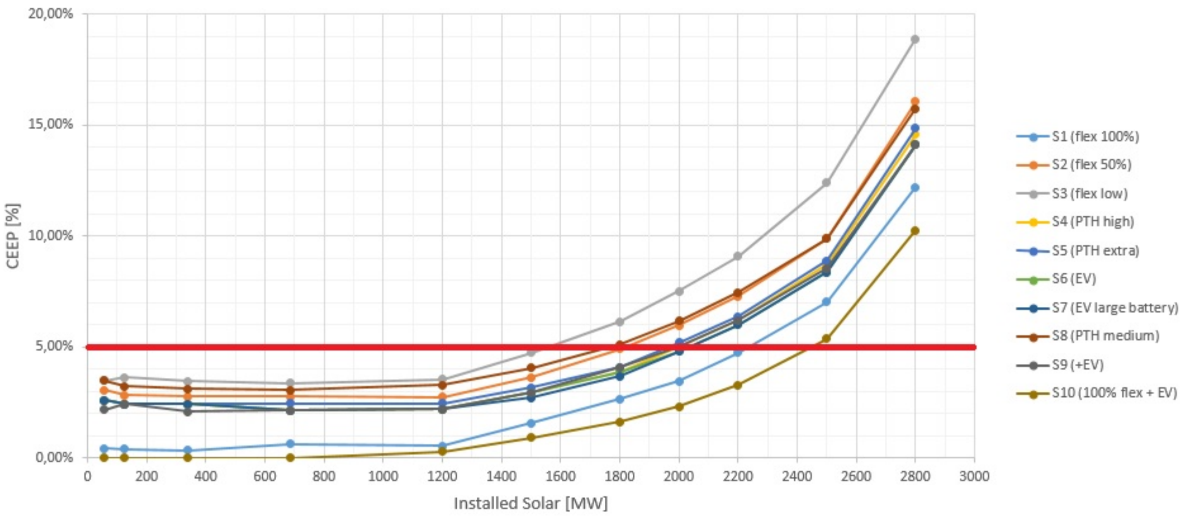


Figure 3 Results of different scenarios compared to the 5% CEEP limit

Input values for all scenarios are given in detail in the Table 4. It is evident that it is possible to integrate, with the input values above, 2000 MW solar PV and 1200 MW wind power without exceeding the techno-economically acceptable critical excess of the electricity produced. Calculating with an annual installment rate of 100 MW, in 2030 the installed solar power would be 1300 MW. For such a level of integration of this technology, the NU2 scenario [30], which envisages 150,000 electric vehicles (with characteristics described above), would still provide an acceptable rate of curtailment below 5% of the energy produced from VRE.

For further analysis, scenario S7 which integrates 2000 MW of solar PV in the year 2030 is chosen. It is illustrated by Figure 4.

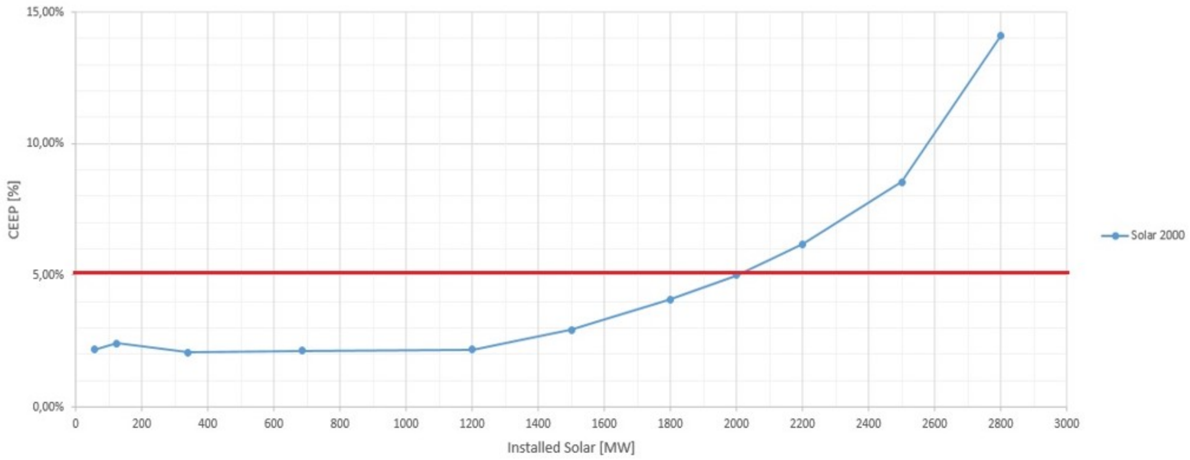


Figure 4 Chosen scenario for fossil fuel technologies feasibility study

Different scenarios for future PP and CHP blocks are given in Table 5.

Table 4 Input data for all scenarios

Year 2030	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Minimum CHP [MW]	0	0	150	0	0	0	0	0	0	0
Minimum PP [MW]	0	200	200	200	200	200	200	200	200	0
PTH Storage [GWh]	2.25	2.25	2.25	4.5	10	2.25	2.25	2.25	2.25	10
HP COP	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
HP [MW]	90	90	90	180	180	180	180	100	100	100
EV consumption [TWh]	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.72	0.72
EV battery size [kWh]	15	15	15	15	15	15	20	20	20	20

With the increased share of the installed VRE power, the question is how many working hours remain for the affordable operation of condensing and cogeneration plants and which blocks need to be built in order to meet the electricity demand. Considering the three scenarios, firstly without import (with index 1) , and then with 30% net import-related proportional imports (with index 2), the number of working hours for cogeneration plants and condensing plants on full load ("full load hours", FLH) was calculated.

Table 5 Different options for future CHP blocks

2030		Sisak C	TE-TO Zagreb	EL-TO Zagreb	Osijek 500	CHP total
A	**MW_{el}**	230	320	180	450	1180
	MW_t	50	366	352	160	928
B	**MW_{el}**	230	320	48	200	798
	MW_t	50	366	232	110	758
C	**MW_{el}**	230	320	180	200	930
	MW_t	50	366	352	110	878

The first scenario, A, follows the plans for the introduction of new plants into the system according to NUR, including CCGT Osijek 500, CCGT EL-TO Zagreb and Sisak C in operation. Scenario B is a scenario with minimal construction, without CCCGT EL-TO Zagreb, and with CCGT Osijek in reduced power (200 MWe + 110 MWt). Scenario C is a compromise scenario with CCGT EL-TO Zagreb (this is a new 132 MWe + 120 MWt block) and a reduced block of CCGT Osijek. In all scenarios, Coal PP Plomin 2 runs inflexible (minimum 200 MW), Nuclear PP Krško runs all the time. Full capacity hours are calculated from electricity produced (result of EnergyPLAN simulation – differentiates between PP and CHP) and rated capacity of CHP and PP blocks, which is represented in Table 6.

Table 6 Results of second level scenario approach - FLHs of CHP facilities

	A1	A2	B1	B2	C1	C2
CEEP [TWh]	0.25	0.11	0.25	0.24	0.25	0.12
Import [TWh]		-5.44		-5.44		-5.44
FLHe CHP	2946	1449	2946	2581	2946	1992
FLHe PP	1888	1526	1888	2302	1888	2249

The results indicate that the construction of larger new capacities would be unprofitable in terms of the number of working hours (FLHs - full capacity hours in a year) that such plants can achieve. Scenarios that include the assumption of system operation without import are in fact always the same, because they have to supply the needs, so the construction of smaller capacities cannot be discussed in those scenarios. In order to achieve the full supply of the consumption, it would be necessary to build plants that would work very few hours per year, while the number of operating hours according to NUR is shown. Scenarios with index "2" include imports and show that at minimum construction of new plants, existing condensing and cogeneration plants can remain in operation for a longer number of hours, while the new one would be unprofitable, with a workload less than 2000 hours.

Also, less hours of operation on fossil fuels means less emissions of GHG, which is illustrated in Figure 5.

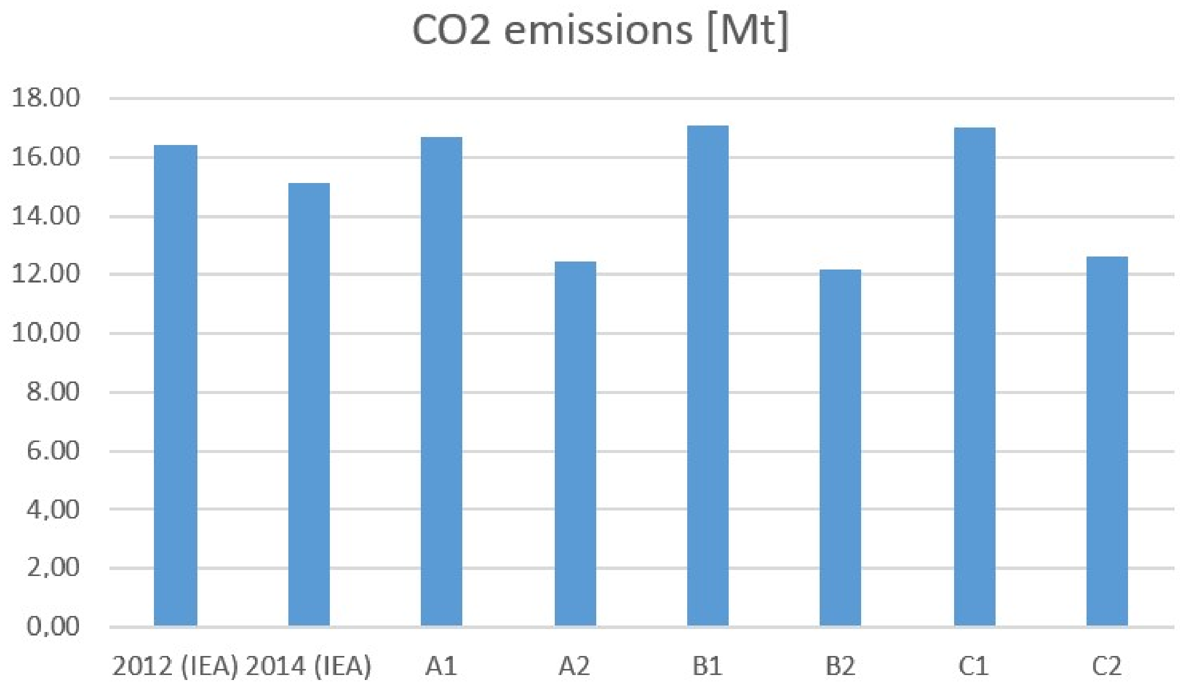


Figure 5 Emissions of GHG for all scenarios

4. DISCUSSION

As it can be concluded from the two steps of the method, applied on the case study, first level's scenario S7 and second level's scenario B2 can be chosen for further discussion regarding the long term planning of the system, in order to better understand the implications of choices resulting from described method. By demonstrating the appropriate synergetic effect of combining increase in VRE installations and storage and demand response technologies, the method aims to prevent the lock-in effect of sub-optimal choices in fossil fuel capacities expansion. In level 2 the influence of harmonious implementation of VRE and demand technologies on potential full load hours of new power plants and cogeneration plants is presented. After the choice in scenario B2 was made about capacities expansion, further models can be created to investigate the path towards an energy system based on renewable energy sources and demand response technologies.

For the presented case study, data for such scenario, which would achieve zero carbon energy system based on locally available VRE is given in table 7 for year 2040 and table 8 for year 2050.

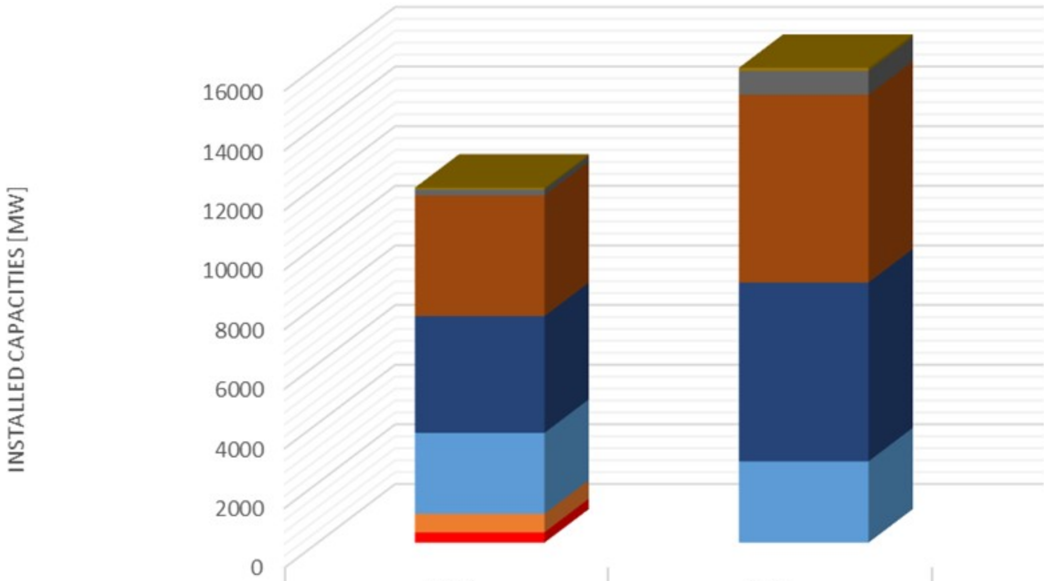
Table 7 Fuel consumption in 2040

Fuel consumption in the transition scenario in year 2040 [TWh]					
Households		Transport		Industry and other	
Coal	0	Jet fuel	0.83	Coal	0
Oil	0	Diesel	2	Oil	0
Natural gas	0.8	Gasoline	0.83	Natural gas	1.15
Biomass	4.11	Natural gas	0.02	Biomass	1.29
Heat	4.33	LPG	2.77		
Electricity	1.44	Electricity	4.82		
Solar heat	3.45	Biofuels	4.77		

Table 8 Fuel consumption in 2050

Fuel consumption in the transition scenario in year 2050 [TWh]					
Households		Transport		Industry and other	
Coal	0	Jet fuel	0	Coal	0
Oil	0	Diesel	0	Oil	0
Natural gas	0	Gasoline	0	Natural gas	2
Biomass	1.2	Natural gas	0.05	Biomass	0.9
Heat	3.09	LPG	0		
Electricity	1.03	Electricity	6		
Solar heat	2.79	Biofuels	5.9		

Installed capacities of production units are given in Figure 6. Additionally, EV batteries capacities are assumed to amount to 60 kWh per vehicle in years 2040 and 2050, while V2G connection amounts to 4400 MW in 2040 and 5400 MW in 2050.

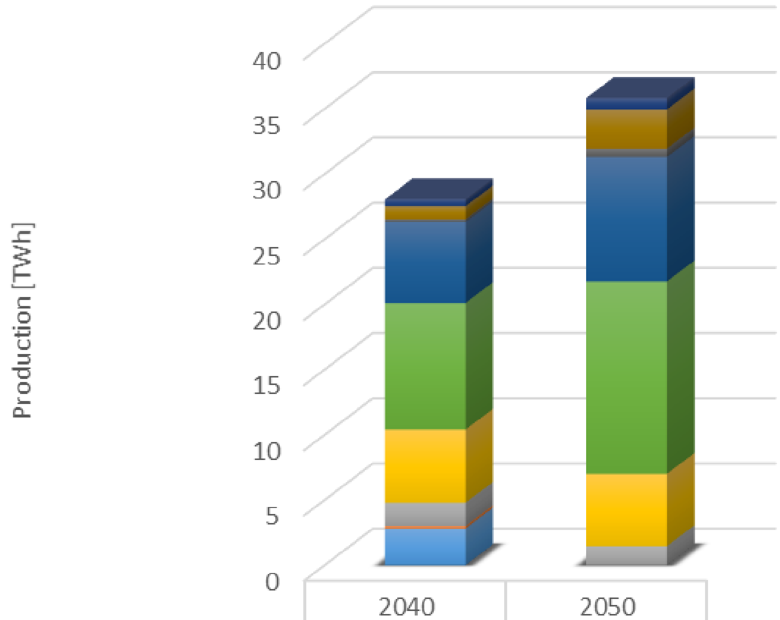


	2040	2050
Geothermal	60	100
Biomass and biogas CHP	200	800
Solar PP	4047	6300
Wind PP	3918	6000
Hydro PP	2713	2726
Coal PP	0	0
Gas PP/CHP	620	0
Nuclear PP	348	0

Figure 6 Installed capacities for energy production in 2040 and 2050

Due to avoiding the lock-in with higher installations of fossil fuels, future scenarios can rely on the homogenous implementation of VRE power plants and demand response technologies. In scenarios in 2040 and 2050, model relies on V2G technology to provide balancing. Calculated on a case of hydrologically poor year, results in terms of energy produced are given in Figure 7.

It is important to notice that discharge from the batteries of electric vehicles becomes a new, flexible "power plant", which returns to the grid more energy then it was produced from nuclear power plant in previous years. Taking this into account, the method proposed by this paper becomes clear and it should be considered as the possible approach to avoid lock-in situations with investments in technologies which will have dubious long-term competitiveness. The method, demonstrated on the case study of Croatia, offers clear guidance on achieving homogenous implementation of VRE and demand response technologies as the most sustainable combination and supports it with long-term scenarios for planning of the energy system development.



	2040	2050
Geothermal	0.53	0.88
EV Batteries	1	3
Biomass and biogas	0.21	0.65
Solar PP	6.21	9.54
Wind PP	9.71	14.76
Hydro PP	5.61	5.54
Cogeneration	1.79	1.46
Condensing (coal and gas)	0.18	0
Nuclear	2.82	0

Figure 7 Production from all technologies in 2040 and 2050

5. CONCLUSION

The price of VRE falls significantly every year, often reaching half of the previous value. Consequently, it can be expected that these technologies will be, in the near future, economically most cost-effective solution on which future low-carbon energy systems should be based. To integrate a larger share of VRE into the energy system, this EES transition needs to be followed by the installation of other technologies that integrate the sectors and achieve synergies. These are energy-efficient consumption technologies that use excess energy produced and VRE for water heating and power-to-heat storage and energy storage in vehicle-to-grid vehicle (V2G) batteries. These technologies are accompanied by efforts to reduce greenhouse gas emissions in other sectors and jointly achieve greater integration of VRE and reduction of polluting emissions. Power to heat technology is related to increasing the share of centralized heat systems, powered by cogeneration plants, to meet the needs for heat energy in households. Main support for integration of VRE, demonstrated by scenarios, is the combination of flexible operation and integration of electricity production and electrified transport system through V2G technology. In scenario S1, 100% flexible operation of PP and CHP, combined with low level of PTH and V2G contribution provided for integration of 2200 MW of solar PV, while in scenario S10, higher level of V2G enabled integration of 2450 MW of solar PV. For scenario S7, which is characterized by larger EV batteries on disposal for V2G, enabling higher consumption of CEEP controlled by smart charging and discharging to shift the loads and balance the VRE, perspective for operation of new PP and CHP facilities was examined. The higher VRE integration will be achieved, more limited number of working hours remains for new CHP installations, with scenario B2 providing the most opportunities for affordable operation of PP and CHP, since this is scenario with lowest installed capacity of new facilities. Implied reduced number of operating hours for fossil fuel powered PP and CHP causes corresponding reduction in GHG emissions. When discussing future scenarios and the energy transition towards an energy system based on VRE and demand response technologies, the approach presented in the paper gives a valuable initial insight for avoiding the lock-in with excess capacities with dubious long-term competitiveness. Further work should address the cost-effectiveness of demand response technologies and further improvements in context of calculating emissions from CHP and PP units and influence of market prices on feasibility of CHP and PP operation.

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