MODELLING SUSTAINABLE DEVELOPMENT SCENARIOS OF CROATIAN POWER SYSTEM

Robert Pašičko * — **Zoran Stanić** ** — **Nenad Debrecin** ***

The main objective of power system sustainable development is to provide the security of electricity supply required to underpin economic growth and increase the quality of living while minimizing adverse environmental impacts. New challenges such as deregulation, liberalization of energy markets, increased competition on energy markets, growing demands on security of supply, price insecurities and demand to cut CO2 emissions, are calling for better understanding of electrical systems modelling. Existing models are not sufficient anymore and planners will need to think differently in order to face these challenges. Such a model, on the basis on performed simulations, should enable planner to distinguish between different options and to analyze sustainability of these options. PLEXOS is an electricity market simulation model, used for modeling electrical system in Croatia since 2005. Within this paper, generation expansion scenarios until 2020 developed for Croatian Energy Strategy and modeled in PLEXOS. Development of sustainable Croatian energy scenario was analyzed in the paper - impacts of CO2 emission price and wind generation. Energy Strategy sets goal for 1200 MW from wind power plants in 2020. In order to fully understand its impacts, intermittent nature of electricity generation from wind power plant was modeled. We conclude that electrical system modelling using everyday growing models has proved to be inevitable for sustainable electrical system planning in complex environment in which power plants operate today.

K e y w o r d s: power system planning, wind power, sustainable development, power system model

1 MODELING POWER SYSTEM AND SUSTAINABILITY

The 1992 Rio de Janeiro Earth Summit ended with industrialized countries signing an agreement, Agenda 21 which defines sustainability as "a way of thinking and acting that would not irresponsibly and irreversibly damage the ability of future generations to satisfy their own needs. Sustainability can be defined in many ways and in relation to different issues such as economic and environmentally sound development, reduction of greenhouse gases, responsible use of natural resources, social equity, *etc.* Some of challenges concerning sustainability relevant for electrical energy system are satisfying minimal production from renewable energy sources, constraints on emissions or minimal energy efficiency goals. Other challenges in energy planning that need to be modelled are price insecurities of investments and energy resources and CO_2 emission price on emission market. First energy system modelling was performed by using economic theories and mathematical models. Todays electrical energy sector is characterized by new challenges such as deregulation, liberalization of energy markets, increased competition on different energy markets with growing demand for security of supply (together with ever growing percentage of imported energy resources) [1 ,2]. Decentralization and liberalization of the national energy sectors appeared in 1990s [3], and systems that were once nationally owned and integrated have been transformed with the idea that market mechanisms will increase efficiency of energy supply. Old centralized least-cost planning approach does not reflect how investment decisions are made in todays electricity markets, where generating companies are competing with each other, both in short-run operations and long-run investments [4]. All challenges mentioned above are calling for consideration of various options (like nuclear, coal, gas or renewable scenarios) in order to optimize energy mix and lead to satisfying development of electrical system [5]. Methodologies commonly used in power system models are [6, 7]:

- Optimization models used for reaching optimal investment or resource allocation strategies [8]. Usually based on mathematical optimization algorithms such as Linear Programming (LP), Dynamic Programming (DP), Quadratic Programming (DP), and Mixed Integer Linear Programming (MILP). Most have economic objective, a set of decision variables and a set of constraints.
- Simulation models are based on logical description of a system, which might get very complex. These models work by performing and analyzing different what-if scenarios.
- Multi-criteria models are analyzing the situation where the available options have to be judged against several criteria (economical, ecological, social . . .) [9].
- Multi-agent systems have two or more software agents that can simulate many market participants with centralized decision making [10], ability to modify, wide

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possibility to implement market strategies, and possibility to influence other market participants by communication.

- Other methodologies which are now days used for energy sector modelling are econometric, macro economic and general equilibrium).

2 MICROECONOMIC ANALYSIS OF ELECTRICITY MARKET

Microeconomic theory is a useful tool for understanding how markets work, for characterizing market equilibrium, for characterizing market failures and ways to correct them and for revealing how market outcomes and the behavior of firms and consumers are affected by interventions in the market place. Economic theory can also reveal how the ability to exercise market power can affect electricity price determination. A downside of a theoretical approach in the case of electricity is that it will necessarily involve simplifications in representing both the supply and demand sides of the market. Conceptual models are always a simplification of the real world, but in the case of electricity the simplifications can be even more dramatic. Electricity markets are characterized by long-lived capital and policies such as emissions taxes or renewable portfolio standards will change the shape of the supply curve as generators shift in the dispatch order. With multiple types of generators this type of effect is difficult to characterize within a conceptual model. Also, electricity demand varies greatly between peak and off peak time periods and this type of detail is not easy to capture in a conceptual model. To the extent that these features of electricity markets are important to understanding the relationship between the EU ETS and electricity markets, there may be limits to what can be learned from conceptual modelling. In a fully competitive market, no producer can affect the price, and at the equilibrium between supply and demand the price will be equal to the marginal cost of production for producers and the marginal benefit of consumption to consumers. The short run marginal cost (SRMC) will depend on costs that vary in the short term (e g fuel costs), whereas the long run marginal costs (LRMC) will also include a scarcity rent that reflects the value of fixed resources (e.g. investment costs in a factory). However, wholesale markets for electricity have some specific characteristics that make them particularly prone to imperfections. If a producer can affect prices in order to increase its profits, for example by reducing production or dispatching out of merit order1, the producer has market power. The fact that electricity cannot be stored, limited capacity for production and transmission and low elasticity in demand are all factors that may increase the risk of market power arising. This said, market power is not necessarily exercised even in cases where it would be possible for a producer to do so. Furthermore, many electricity markets are dominated by a relatively small number of large companies. This, in combination with high barriers to entry, co-owned generation capacity and a transparent price could also increase the potential for tacit collusion of firms. However, a transparent price obviously also makes it easier for consumers and external parts to follow the market. Even though the Croatian electricity system is dominated by hydro and nuclear power the carbon price have a substantial impact on electricity prices since the marginal generation is often relatively carbon intensive [11]. In a competitive market this price will apply to all electricity sold in the system, not just the last kWh.

3 MODELING EMISSION TRADING IMPACTS ON ELECTRICAL SYSTEM

Within project "Assessment and Improvement of Methodologies used for GHG Projections [12] in 2008, various EU climate change policies and measures were analyzed (EU-ETS, EU directives: Renewables Directive, Combined Heat and Power (CHP) Directive, Directive on the Improvement of End Use Energy Efficiency, Biofuels Directive). Project goal was to make an overview on the methods used to quantify these policies and measures in EU member states. Project results are showing rather high use of models for modeling impacts of renewable energy sources and (CHP), while modelling is less used for emission trading scheme and even less for flexible Kyoto mechanisms (Joint Implementation and Clean Development mechanism).

4 CROATIAN ELECTRICAL SECTOR TODAY

Croatia is currently importing about 50 % of its energy (80 % of this is oil) [13]. In the period from 2000 to 2006 the annual growth rate of final electricity demand was 4.1 % which was higher than for any other energy form. Energy supplied in 2006 was 18.051 TWh, while net import makes 5.622 TWh — 31.1 % of total energy supplied (2.8 TWh from joint Croatian-Slovenian nuclear power plant is in this number). Almost all electricity generation capacity is in ownership of Croatian Electrical Utility, HEP Group (from 3993 MW installed, 2056 MW is in hydro, 1589 MW in thermal power plants and 348 in Croatian part of nuclear power plant Krsko) [13]. Beside this, there are 210 MW installed in industrial power plants and 23 MW installed in private ownership, namely wind and small hydro. Specificity of Croatian electrical system is large percentage of installed power in hydro — 52 %, which requires reserve capacity during summer period when water level is low. Ever growing electricity consumption is not offset with new generation capacities and electricity import is rapidly rising, and which emphasizes need for new generation capacities.

Table 1. Overview of model use for EU ETS simulation in EU member states [12]

Country	Type of model	EU ETS in theory	Renewables Directive
Austria	Econometric	partial	yes
Belgium	Engineering	yes	yes
Bulgaria	Simulation	no	no
Cyprus	Simulation	partial	partly
Czech R.	Optimization	CO_2 tax	no
Denmark	Econometric	partial	yes
Estonia	Optimization	CO_2 tax	partly
Finland	Optimization	CO_2 tax	yes
France	End-use d d	yes	yes
Germany	Engineering	yes	partly
Greece	Simulation	partial	no
Hungary	Econometric	partial	unclear
UK	Econometric	partial	yes
Ireland	Engineering	no	yes
Italy	Optimization	CO_2 tax	no
Latvia	Optimization	CO_2 tax	yes
Lithuania	Optimization	yes	yes
Netherland	Engineering	yes	yes
Poland	Simulation	partial	no
Portugal	Optimization		yes
Romania	Simulation	partial	unclear
Slovakia	Simulation	partial	no
Slovenia	Engineering	yes	yes
Spain	Engineering	yes	yes
Sweden	Engineering	yes	yes

5 PLEXOS MODEL

For modelling Croatian power system presented in this paper, model PLEXOS was used. PLEXOS is an electricity market simulation model developed by Energy Exemplar (www.energyexemplar.com). PLEXOS has users in 17 countries and it is used by many of the world largest utilities and system operators, including transmission operators, generating companies, regulators, and consultants. The idea behind PLEXOS is to be simulation model that is easily and efficiently maintained, extended, and modified and that can be applied with no customization to every electricity market and modelling project. Model uses Microsoft Access database for data handling, is based on .NET technology and is run on Windows operating system. There are four basic simulation engines in PLEXOS: LT Plan (long-term planning module), PASA (for modelling scheduled maintenance and forced outages), MT Schedule (model medium to long term decisions, “decomposes user-definable constraints to shorter term constraints suitable for detailed modelling in ST Schedule) and ST Schedule (short term modelling, can get to five-minute resolution). Each one of the engines can be used separately, but they can also be used sequentially. In that way, each engine gathers results from the previous engine as an input. After preparation of the input parameters from the Microsoft Access and input textual data, AMMO optimization core is being used for dynamic formulation of the mathematical problem. When problem is formulated, commercial MOSEK software is started for solving large mathematical optimization problems. MOSEK is the default solver, but it is also possible to choose two other solvers, CPLEX or Xpress-MP. After problem is solved, PLEXOS engine prepares data for interpretation in output users interface. The solution simulations are founded in mathematical programming techniques, LP, QP, MIP, and DP. The traditional approach to simulation is to decide the solution method, then build the model to populate the required data. In contrast, Dynamic Formulation (DF) developed by PLEXOS lead author Glenn Drayton in 1996 and implemented in the model [14], allows PLEXOS to decide the solution approach and formulation based on data at runtime. In this approach the data model is a framework for describing the “problem, and the “engine dynamically builds the optimization problem at runtime from the very start. Any model input can be stochastic — commonly used examples are such as demand or hydro production curve, fuel prices etc. There are three options available to model competitive behaviour in PLEXOS perfect competition (taking in account only short run marginal costs), Long Run Marginal Costs (LRMC)/Revenue Recovery (taking in account also fixed costs) and Nash-Cournot competition (for modelling game strategic behaviour on the market).

6 CROATIAN ENERGY DEVELOPMENT STRATEGY

The Energy Development Strategy is the foundation document of the Energy Act that defines the energy policy and future plans for energy development for a ten-year period. The newest Energy Development Strategy of the Republic of Croatia focuses on the period until 2020 to coincide with the period covered by all adopted EU energy strategies, and provides a general forecast until the year 2030, as a “glimpse into the future. First step in adopting Strategy is introducing the Energy Strategy Green Paper of the Republic of Croatia. The final summarized document, the White Paper, will be submitted soon to the Croatian Parliament for discussion and approval. The Green Paper provides final energy demand projections for both a business as usual scenario (BAU) and for a Sustainable Energy Scenario (SES) with applied enhanced energy efficiency measures. The total primary energy supply (TPES) is provided for the SES scenario only. In the SES, final energy consumption increases in the period 2006-2020 by a rate of 2.7 %, and electricity consumption increases by 3.4 %. In the electricity production sector, a high demand for new capacity is projected, due to growing consumption and the age of current substations and power plants. The Croatian Energy Strategy

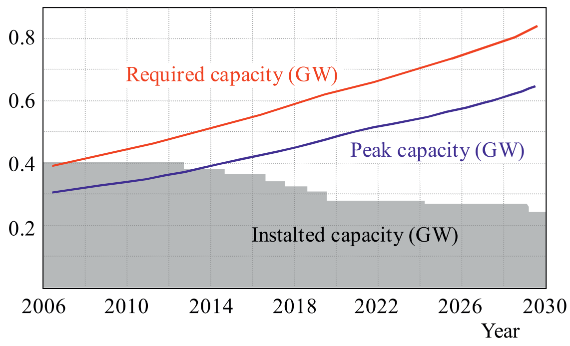

Fig. 1. Decommission of existing power generation facilities and required installation capacities to satisfy the demand

Table 2. Forecasted start up dates of new power generation units by 2020 according to the White Scenario

Facility/Unit/ Part of plant	Nominal power on generator, MW	Foreseeable year for entry into operation
TE-TO Zagreb unit L	100	2009
TPP Sisak unit C	250	2012
TPP GAS 1	400	2013
TPP COAL 1	600	2015
NUCLEAR 1	1000	2020
(CHP) CO-GENERATION	Progressive yearly increasing by 30 MW, additional total 300 MW	2011–2020
HPP other	Progressive yearly increasing by 50 MW, total 300 MW (0.75 TWh new energy from HPP)	2015–2020
Renewable	1545 MW Renewables with production of 4000 GWh in 2020 – 154 MW progressive annual growth	2011–2020
Total GAS	1050	
Total COAL	600	
Total NUCL	1000	
HPP + REN	1845	

set three basic energy objectives, respecting specific situation in Croatia and its national interests: security of energy supply, competitive energy system and sustainable energy sector development.

7 DEVELOPMENT SCENARIOS

Based on the expected electricity consumption and on the forecasted load factor of 0.7, expected peak load in 2020 amounts to 4767 MW. Sufficient available reserves of installed capacity are needed in the power system in order to cover expected peak load. Necessary reserves in the system are determined on the basis of system features and the structure of production units in the system (taking in account large percentage of hydro generation which can provide less than one third of installed power during summer months). The outcome of analysis showed reserve margin of 30 %, so the required capacity in the system amounts to 6200 MW. Scheduled generation capacities in 2020 are described in PLEXOS with technical and economical characteristics: max capacity, scheduled maintenance, heat rate, min stable level, max ramp up/down, equity costs, debt costs, variable and fixed O&M costs, fuel price, start costs *etc.* Transmission capacities were modelled only for 400 kV lines and nodes, with two forecasted 'bypasses' planned until year 2020. In order to exclude hydro meteorological uncertainties on generation planning, all hydro power plants are presented in the model as one power plant block, whose generated output equals P50 (50 % probability of satisfying average level of annual output). Hydro generation was modelled in hourly values, based on hydro generation from previous years. In order to exclude uncertainties from renewable energy sources, due to high share of wind generation which is of intermittent nature, all renewable generation was modelled as coming from one power plant block with fixed output. Electricity consumption is modelled according to hourly values and according to load share on different nodes. Scenarios presented in this chapter dont assume electricity import or export, as one of the simulation goals was to examine self sufficiency of installed capacity and produced electricity. Retirement plan for existing power plants is showing that 1130 MW of installed capacities will be retired until year 2020, and additional 260 MW until 2030. Total installed capacity with demanded peak and required capacity, with a 30 % reserve margin, is shown on Fig. 1.

Several scenarios of development opportunities to construct new power generation facilities were analyzed on the basis of the input data presented. In order to facilitate an easier scenarios handling, they have been labeled according to color: Blue, Green and White.

The difference between White scenario and other scenarios is that instead of: 600 MW coal-fired power plants scheduled for 2015 and 1000 MW nuclear power plant scheduled for 2020; they forecast following power plants and scheduled dates (all other details such as generation from renewables, hydro, cogeneration and old power plants remain the same):

– Blue scenario schedules 2 TPPs firing coal, 600 MW in 2015 and 600 MW in 2019, and 400 MW from TPP firing natural gas in 2020. -Green scenario schedules 400 MW TPP firing natural gas in 2015, and one 1000 MW nuclear power plant in 2020.

8 EMISSION TRADING MODELING IN CROATIAN ELECTRICAL SYSTEM

Simulation of emission trading impacts in electricity sector should be able to add additional costs to SRMC

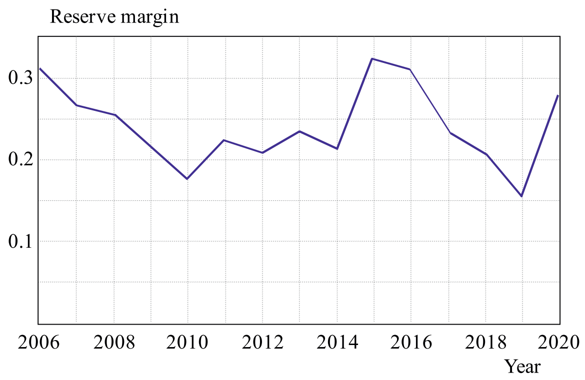

Fig. 2. Reserve margin in White scenario fluctuates between 16 % and 33 % of installed capacity

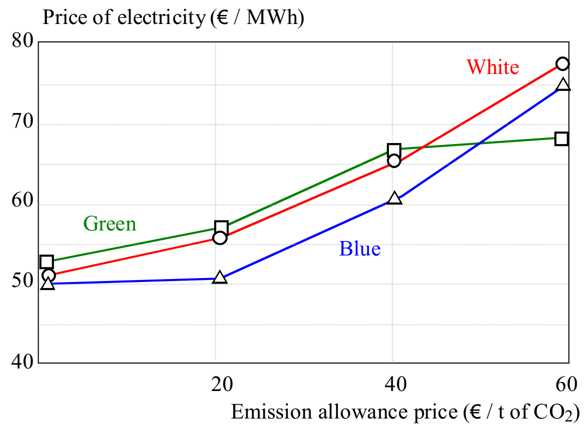

Fig. 3. Impacts of emission allowance price on electricity price in different scenarios in year 2020

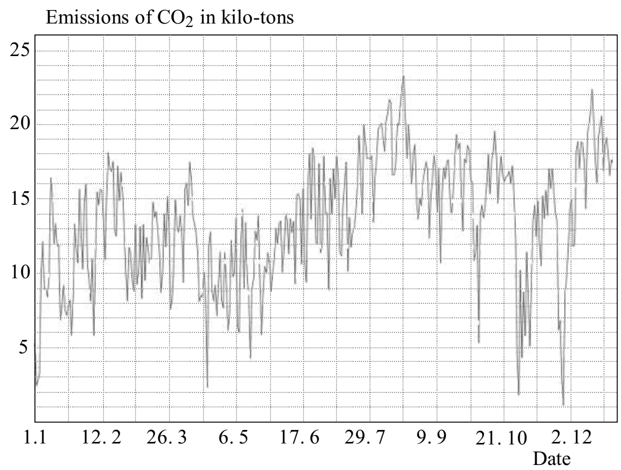

Fig. 4. Daily amounts of CO2 emissions in White scenario in year 2020

from each generator, which PLEXOS was not able to provide. This problem was recognized within research program "Simulator Development for Analysis of Emission Trading Impacts on Electricity Market [15] at Faculty of Electrical Engineering and Computing in Zagreb. The solution proposed was to include shadow emission price which would increase SRMC on the basis of defined emission price and emission production coefficient (tCO_2/MWh for each generator). In communication with model developers, this was added as a new function in PLEXOS model and makes it possible to model emission trading in a more realistic manner. To analyze impacts of emission allowances' price on electricity market in Croatian electrical sector four different scenarios were modelled, with different prices per ton of CO_2 emissions: 0, 20, 40 and 60€/tCO_2. Results have proved dependence of coal intensive scenarios on rise of emission allowance price. This dependence especially shows in the Blue scenario which has the highest share of coal. Because of high share of nuclear and gas produced electricity, the Green scenario is most immune to emission allowance price rise.

Only Green scenario meets the Kyoto obligations in both 2015 and 2020, while White scenario meets the Kyoto targets in 2020 (Fig. 5).

9 MODELING WIND ELECTRICITY GENERATION IN CROATIAN ELECTRICAL SYSTEM

Energy policies are promoting renewable energy resources especially variable output (only partly controllable) like wind power, solar, small hydro and CHP. The production from wind and photovoltaic units is governed by the availability of the primary energy source. There is therefore often no correlation between the production and the local consumption as can be seen in Figure 7. [16].

Large amounts of variable generation from renewable sources are not fully forecastable and are causing increasing problems in electrical networks (both in local distribution networks and transmission networks including cross-border networks). In some places, we can already observe an increase in the network stresses and needs for upgrades to provide greater capacity and flexibility to integrate the variable generation. It also increases the need for flexible, dispatchable, fast-ramping generation for balancing variations in load, intermittent resources and contingencies such as the loss of transmission or generation assets. Similar problems can be seen at market: national and local balances between supply and demand are more complicated to manage with high levels of variable generation, which can increase total financial electricity costs. There are two tasks for integrating variable renewable generation, both locally and globally: integrating them into the electricity network and into the energy market. Wind power is expected to influence electricity market in two ways [17]:

- Wind power normally has a low marginal cost (zero fuel costs) and therefore enters near the bottom of the supply curve. This shifts the supply curve to the right (see Fig. 7), resulting in a lower power price, depending on the price elasticity of the power demand. In the figure below, the price is reduced from Price A to Price B when wind power decreases during peak demand. In general, the price of power is expected to be lower

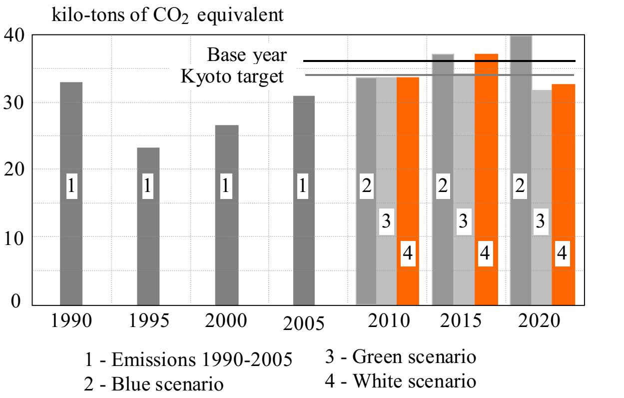

Fig. 5. Influence of different scenarios on Croatian Kyoto targets (electricity sector added to total of other sectors)

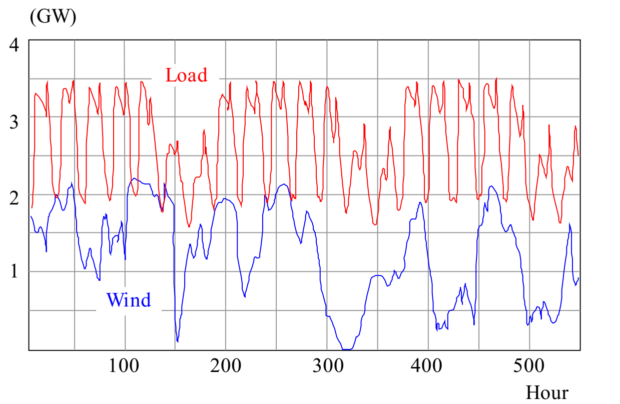

Fig. 6. Wind power production (2400 MW wind power) and load in Western Denmark

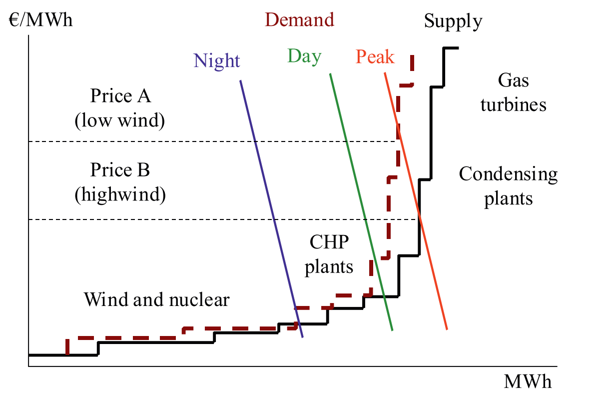

Fig. 7. How wind power influences the power spot price at different times of day

during periods with high wind than in periods with low wind. This is called the 'merit order effect.

- There may be congestions in power transmission, especially during periods with high wind power generation. Thus, if the available transmission capacity cannot cope with the required power export, the supply area is separated from the rest of the power market and constitutes its own pricing area. With an excess supply of power in this area, conventional power plants have to reduce their production, since it is generally not economically or environmentally desirable to limit the power production of wind. In most cases, this will lead to a lower power price in this sub-market.

However, the impact of wind power depends on the time of the day. If there is plenty of wind power at midday, during the peak power demand, most of the available generation will be used. This implies that we are at the steep part of the supply curve (see Fig. 7) and, consequently, wind power will have a strong impact, reducing the spot power price significantly (from Price A to Price B in Fig. 7). But if there is plenty of wind-produced electricity during the night, when power demand is low and most power is produced on base load plants, we are at the float part of the supply curve and consequently the impact of wind power on the spot price is low. As an initial exercise, simulation of large amount of wind generation impacts on Croatian electricity sector has been performed by using PLEXOS model. Within previously elaborated 2020 development scenarios — scenario A (that models wind generation linearly), one additional renewable energy scenario — A2 has been analyzed. It includes 1140 MW of wind capacities with average capacity factor of 22 %, on the basis of extrapolated real time hourly data of the first Croatian wind power plant Ravna 1 on island Pag. Some initial results of the correlation between the production and the consumption are shown in Fig. 8 and the influence on electricity market price in Fig. 9 [18].

Results have shown that power market simulator PLEXOS can be used as tool to simulate and quantify how wind power influences the power spot price due to its low marginal cost as shown in Figs. 8 and 9. However, further research is needed in order to improve initial model of Croatian electrical system as well as wind generation input data by including wind power plants that have been recently put in operation.

10 CONCLUSION

Sustainable development in power system has introduced new technologies and new policies to order to provide answers for climate change, security of supply and scarcity of fossil fuels. In order to fully understand impacts of CO_2 emissions and wind production on electrical system, new improved models are needed. One of the solutions is market simulator PLEXOS, used for power system modelling during work on Croatian Energy Strategy in 2008. Dynamic CO_2 price impacts on three different scenarios were modelled for year 2020. Assessment made for emission price ranging from 0–60 €/tCO_2 has shown how electricity prices and total emission amount react responding to emission price. Another task for modelling was focused on uncertainties with large wind generation — as an intermittent source, wind power plants have large influence on power system. Therefore there is a demand for advanced planning models which might help to understand how power system can regulate large wind generation. Further work is focused on development of short term algorithm which would help in planning day-ahead

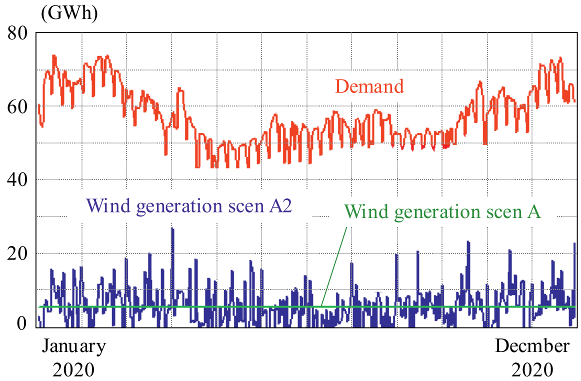

Fig. 8. Initial results of simulation of daily wind power production and consumption in Croatian power system in 2020

Fig. 9. Initial results of simulation of the impact of wind power production on the prices in Croatian power system in 2020

wind production (with information from wind forecast) and on development of long term algorithm which would provide an optimal amount of wind capacities in Croatian power system.

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