Valuing the moderation options in Serbia for higher wind penetrations

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ABSTRACT

The flexibility of the national energy system is limited regarding future higher penetrations of wind and therefore it needs moderation options. Different system storage (e.g pump hydro storage power plant) and demand side storage (demand response e.g. electric hot water; plug in electric vehicle) moderation options have different economic weights and availabilities, which are predetermined by their localization. Technically optimized operation for the year 2030 on an hourly basis using the EnergyPLAN tool for the future scenarios of the Serbian energy system has been performed at higher wind penetrations up to 3,000 MW with share of renewable energy sources above 30% on a national basis and up to 7,000 MW on a regional basis. Moderation options have been valued based on investment costs and operation, not including the energy costs, and then sorted according to their marginal costs (1.2 - 24.6 c€/kWh) into a moderation options supply curve. Demand response, as least marginal cost moderator, should be used for the moderation of higher wind penetrations in Serbia.

KEYWORDS

smart energy systems, demand response, system storage, high wind penetration

INTRODUCTION

A national energy system planning for Serbia has been drafted as part of the "Energy Sector Development Strategy of the Republic of Serbia for the period 2025 with projections by 2030" [1] without clear quantification of its alignment to the "European Commission 2030 framework for climate and energy policies" [2] for the year 2030. The proposed energy sources and storage mix has been selected with extraordinary focus on the security of supply, rather than discussing different scenarios enabling to reach the following measurable targets:

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share of renewable energy sources in gross final energy consumption (GFEC), reduction of CO2 emissions and reduction of total primary energy supply (TPES). The proposed penetration limitations for variable renewable energy sources are based only on the existing system moderator option, the pumped hydro storage power plant (PHSPP) in Bajina Basta, but it does not include all moderation options. A study shows that up to 80 % of variable RES can be integrated [3] when all moderation options are included, and even further:

> *"There is no theoretical upper limit for the integration of renewable energies into electricity networks that can be explained by missing control power."* [4]

Since creating possibilities for net export is a strategic goal [1] moderation should also be addressed on a cooperative [5] regional basis, not only on a national basis, while there could be gains of 16-30 billion € in the period 2015-2030 under the EU wide coordinated renewable investment scenario [6] and realization of the projects of common interest. Also, electricity storage representing high investments in combination with low utilization [4, 7] suggest that "all kinds of electricity storage should be avoided if the aim is to put electricity back on the grid".

Sources of system flexibility - ranking of moderation options

Demand response (DR) and system energy storage can serve as alternatives to (or compete with [8]) traditional national energy system moderation options [9], and grid capacity increase [10].

> *"In the real market equilibrium the marginal costs of all options (supply options, grid options and demand options) must be equal and customers must be willing-to-pay for it."* [11]

System storage is usually seen as a less attractive moderation option comparing to the DR [12-14] moderation option since it has associated with CAPEX [15, 16] and round-trip efficiency [8] but it is attractive in comparison to the electric vehicle battery moderation option [17] when valuing their relative economics [18]. Earlier, the investment costs for making the DR possible were assumed to be 200-400 US$/kW and 10-300 US$/kWh [12] but now they are estimated [19] lower to 1.4-250 €/kW for storage capacity cost and at 0.03-20c€/kWh for cycle storage costs. TheDemand response disadvantage of demand response is a short-term flexibility in comparison with thecompassion to PHSPP option [20]. According to [21], there is a flexibility supply curve, analogous to the generation supply curve, in which the EV battery has the highest cost and lowest flexibility followed by system storage that has higher costs and lower flexibility compared to the DR. Modified supply curve [21] can be found in [14]. Another flexibility source prioritization can be found in [22] even including even a curtailment of RES in the indication of possible blackout [23]. Also, DR of electric heaters and electric water heaters has been shown significantly cheaper than system storage [24]. Although moderation options costs are difficult to understand and to access because they depend on the region [14], they could be estimated in the range of 486-2170 €/kWh [25]. A different moderation optionA various m [26] can be sorted into peeking, mid and base, analogous to generation options, based on the valuing methodology, and presented with year duration curves [27]. A value of moderation options to mitigate uncertanity of variable RES forecast errors is 5-30 $/kW [17].

In this paper methodology used to value three moderation options (DR, PHSPP and EV) based on their marginal costs calculated after simulation in EnergyPLAN has been presented to choose least-cost moderation strategy for a national energy system. Besides the economic value of the moderation option that includes the recovered energy, displaced capacity, energy utilization, investment postponement and production costs [28], we focus on its value for the different capacity mix of non-dispatchable energy sources and their maximal utilization. The assumptions and simulation shows that DR is the preferable moderation option for higher wind penetrations into the Serbian energy system, with marginal costs at 1.2 c€/kWh. Firstly, the critical excess electricity production (CEEP) has been presented for the higher wind penetrations moderated under different scenarios, followed by CEEP and moderator duration curves. Finally, the moderation options are compared in national and regional based moderation scenarios.

National energy systems planning to increase penetration of RES in Hungary [29], Romania [30], Macedonia [31], Serbia [12] and Croatia [32] but also in the regional-wide approach [33]. EnergyPLAN has also been used to model DR, PHSPP and electric vehicle (EV) moderation options [34] [35]. A linear programming model illustrating the operation of DR as an energy storage unit has been illustrated in [36].

METHODOLOGY

The modelling of a national energy system has been based on the hourly time step EnergyPLAN simulation model [35] for the year 2030, similar to the procedure for 2020 in [12]. The closed national energy system operation has been performed technically, to minimize emissions, determined with historic availability and variability patterns of supply and demand. Demand projections are based on values for 2030 [1] and reasonable assumptions are made where needed. The operation of moderation options for duration curves was obtained after EnergyPLAN run an output screen for 8784 hourly values of:

- flexible electricity demand
- pump/turbine consumption
- EV and V2G (transport)
- CEEP (Critical excess electricity production),

which are processed in Excel [37]. Electricity exchange costs (import and export) are calculated in EnergyPLAN based upon historical European Energy Exchange data for the border between German and Austrian in 2008 [38], with a resulting average price of 40€/MWh.

An increased penetration of wind that could be reached even in a weaker and medium winds [39] was run as serial EnergyPLAN calculations.

RES share was calculated according to the EnergyPLAN resulting annual fuel consumption in comparison to 2009 as a base year, modelled in [12], and compared with the European Commission 2030 framework for climate and energy policies [2].

Valuing the moderation options, calculation of marginal costs

The valuing of moderation options has been done based on the marginal costs for the moderators. The marginal costs for moderators were calculated based on assumed additional investment costs (CAPEX) and the cost for the yearly operation of moderators. The assumed CAPEX, percentage of operation cost (OPEX) in CAPEX and project lifetime period for the calculation of annualized costs of moderation options are shown in Table 1. OPEX, as a fix part of CAPEX, only present the costs of obtaining the moderation function during the project period e.g. regular maintenance cost, while energy costs are not included like in [40]. The marginal costs (c€/kWh) have been calculated according to the EnergyPLAN simulation as in Equation 1:

$$C_{marginal,i} = C_{annual,i} / (O_{-,i} - O_{+,i}) \quad (1)$$

$$O_{-,i} \geq 0, O_{+,i} \leq 0 \quad (2)$$

where:

$C_{marginal}$ are the marginal costs of i-th moderation option [c€/kWh]

$C_{annual,i}$ are the annualized CAPEX of the i-th moderation option [M€/a]

$O_{-,i}$ is the negative (from a view of the grid) annual operation of i-th moderator e.g. load growth of DR, pump operation of PHSPP or charging of EV obtained after EnergyPLAN simulation [TWh/a].

$O_{+,i}$ is the positive annual operation of i-th moderator e.g. turbine operation of PHSPP or discharging of EV obtained after EnergyPLAN simulation [TWh/a].This is an analogous method that has been used in the case of moderation on a national basis and that moderators based in Serbia have been using for moderation on a regional basis. There is potential to import wind caused CEEP from the region which lacks storage capacity. The total proposed wind power in the South-East of Europe is 17,474 MW [33]. In order to moderate CEEP on a regional basis, the flexibility of the Serbian energy system has to be fully explored. Based on the decrease of marginal moderation costs on a national and regional basis it is possible to calculate benefits for the joint realization of projects of common interest.

Table 1 Assumed moderation options additional investments.

	CAPEX [M€]	**OPEX [% CAPEX]**	**Period [a]**
DR	300	1	20
PHSPP	560 [1]	2 [25]	50
V2G	4500[1]	1	20 [13] [41]

After the moderation options had been valued according to the marginal costs supply curve of moderation options, the yearly operation was created by sorting moderation options from left to the right, starting with the least marginal cost moderator.

This valuing methodology tends to favor the moderation options that are likely to be operated frequently, in comparison to other methodologies that simply divide CAPEX with its total storage power or energy [28].

Moderation on regional basis does not show the original transmission grid burden from CEEP, because it assumes that the entire wind capacity is used in Serbia. This was possible because CEEP could be seen not only as a grid burden, but also as the amount of residual energy imbalance that exists and what additional moderation options are needed.

The investment costs of existing PHSPP are not taken into account, only the additional investment costs up to 2030 are. The operation of two disconnected reservoirs is not identical to the operation of one equivalent reservoir.

Only buying EV is assumed as an investment cost. Neither the grid extensions nor distribution equipment which CAPEX are assumed negligible [13].

Scenarios for the national energy system in Serbia in 2030

Strategy (S) scenario. For the S scenario, a projection of energy balance for the Republic of Serbia in 2030 with the application of energy efficiency measures according to [1] with GFEC at 128.8 TWh has been used. Generation and moderation capacities are modelled as in the 2020 reference scenario [42] with addition of capacities according to [1] "priority activities" in the period until 2030 and "projections of the construction of the plats for electricity generation using RES". For transport needs, a proportional decrease from 2020 with a reference scenario [42] for all fuels, and the substitution of diesel by biodiesel. Total PHSPP capacity is rated to 1330 MW,

[1] Assumed CAPEX for one EV are 15,000 €.

with a storage capacity of 270 GWh and with round-trip efficiency of 76.5 %. The sum of the thermal power plants' technical minima of 2,490 MW has been valuated as 68.7 % of the installed capacity.

Demand side moderation (S+FLEX) scenario. The S+FLEX scenario has been created based on the S scenario with the addition of flexible demand for one day over a whole year [36]. A yearly demand of 3.17 TWh for hot water in electric storage heaters in 2030 [43] with a max effect of 1,000 MW has been assumed.

EV moderation (S+V2G) scenario. The S+V2G scenario has been based on the S+FLEX scenario with the addition of electric vehicles as a moderation option. Preserving the same annual transport demand of $35x10^9$ km, with a usage of 2 TWh of diesel in transport has been replaced with 0.6 TWh of electricity for smart charged EV, assuming 1.5 km/KWh for diesel and 5 km/KWh for electric car engine. This is equal to around 300,000 electric cars or 17% of the current Serbian passenger car fleet. Proposed power of grid to battery and vice versa connection is 3,000 MW, which is a maximal flexible capacity of V2G option, and with a round-trip efficiency of 81 %. The maximal share of cars during peak demands of 20 % and share of grid connected cars in all parked cars of 70 % has been assumed, with a daily transportation pattern from the average US car usage in 2001. The energy battery storage sum of all EV of 0.9 TWh is assumed.

Moderation on a regional basis (S+SEE) scenario. The S+SEE scenario has been based on the S+V2G scenario with distinction at moderation that has been assumed on a regional basis instead of on a national one. The historical wind pattern has been obtained according to [33]. This wind hourly diagram has been characterized with more dispersion along the year which is are result of "levelling over regions" [5].

RESULTS

The simulation shows increased biomass usage of total 25.87 TWh, but it is still under biomass potential of 39.6 TWh [1]. Total fuel for the heat production has been relocated from district heating to the combined heat and power, with savings of 0.75 TWh.
According to S scenario only the RES in the GFEC goal has been reached (34.2 %) while CO2 and TPES reduction goals have not been. CO2 emissions have decreased by 1.7 % instead of 40%. Total primary energy consumption has increased by 10.2 % although targeted savings are expected to be above 20 %. According to S scenario import and export will reach 1.51 and 0.16 TWh respectfully, with an exchange cost of 198 M€. In the FLEX scenario total exchange costs decrease to 87 M€ and to 108 M€ in V2G because total electricity demand has increased to 46.54 TWh.
RES 2030 goals can be met at higher wind penetrations but it is followed by CEEP increase (Fig. 1).

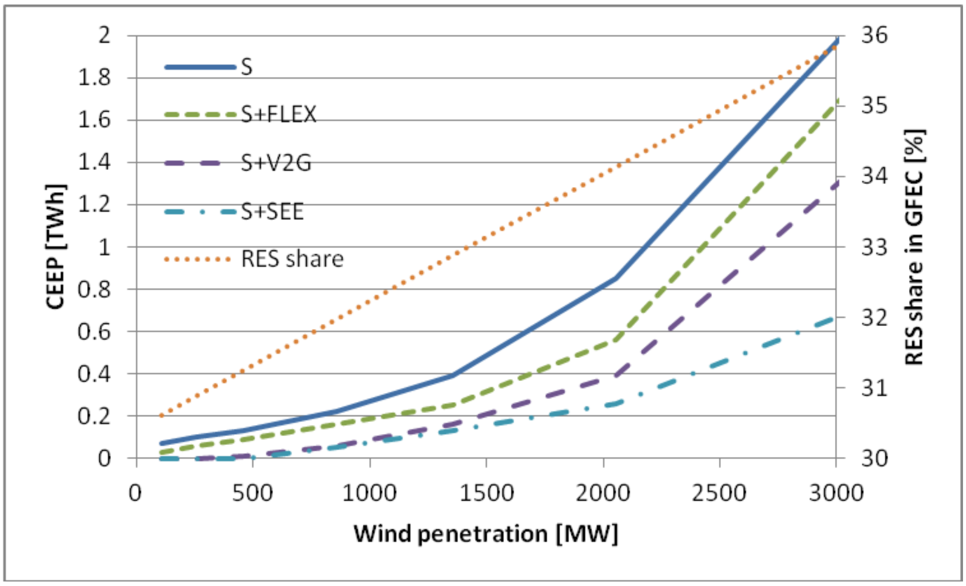

Figure 1. Higher wind penetrations caused CEEP in different moderation options.

Following PHSPP moderation in S scenario, CEEP could be further decreased through two other scenarios: S+FLEX and S+V2G. In the case of wind penetration of 2,000 MW, CEEP could be decreased for 0.29 TWh, 0.46 TWh and 0.59 TWh in the S+FLEX, S+V2G and S+SEE scenarios respectfully. With the same penetration level and moderation options, the regionally dispersed wind in S+SEE scenario is moderated with less residual CEEP than nation localized wind in the S scenario.

With higher wind penetrations, national and regional based moderation options for CEEP reduction have been presented in detail, hourly, with the CEEP duration curves in Fig. 2.

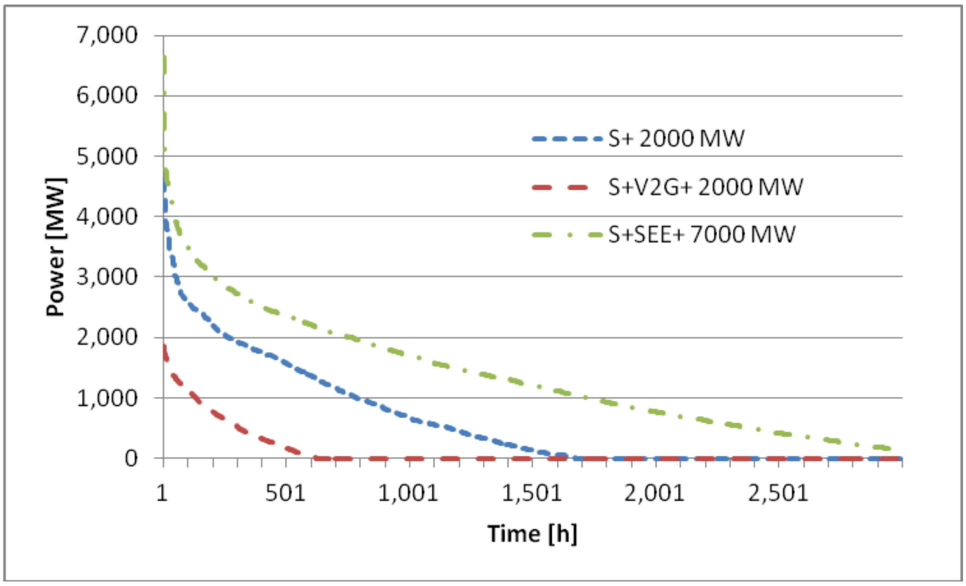

Figure 2. A CEEP duration curves: needed moderation time, energy and power.

We notice that CEEP is decreased with DR and EV moderators, but they do not have the flexibility needed to moderate higher wind penetrations on a regional basis. With a 2,000 MW wind penetration, the CEEP, seen as an energy moderation need, decreases by 0.46 TWh in S+V2G ("S+V2G 2000 MW") in the comparison to the S scenario ("S 2000 MW") resulting in moderation time decrease of 1,054 hours and requiring moderation power of 2,741. Besides significant investment costs, moderators will be operated only for 1,673 hours a year on a national basis with this scenario. Increase in operation comes with the moderation of 7,000 MW on a regional basis. This increased flexibility must come from increased operation of existing moderators (see Fig. 3), since the maximal storage capacity and power of the moderators are predetermined. In this case, residual CEEP still exists.

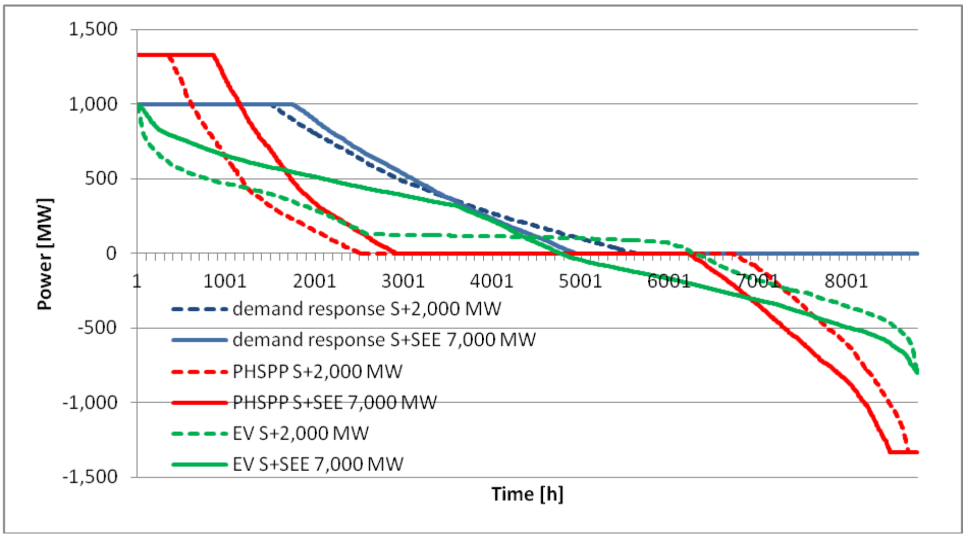

Figure 3. Moderator duration curves: S+V2G+2,000 MW of wind at national and S+SEE 7,000 MW of wind at regional basis moderation.

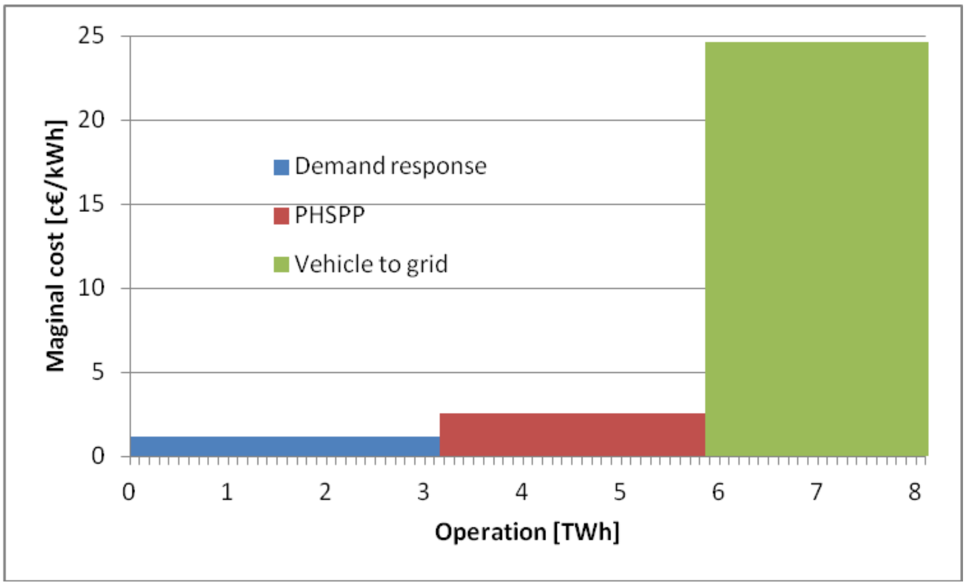

Figure 4. Moderation options supply curve for the S+V2G scenario 2,000 MW wind at national basis.

Table 2 shows that the moderation option investment utilization could be increased in the case of moderation on a regional basis.

Table 2. Valuing of the moderation options on a national and regional basis.

		DR	PHSPP	V2G
S+2,000 MW	Operation [TWh/a]	3.2	2.6	2.3
	Marginal cost [c€/kWh]	1.2	2.6	24.6
S+SEE+7,000 MW	Operation [TWh/a]	3.2	3.8	4.2
	Marginal cost [c€/kWh]	1.2	1.8	13.8

The marginal operation costs for moderators range from 1.2 to 24.6 c€/kWh. The least marginal cost moderator is DR, which is followed by the fairly expensive PHSPP and expensive V2G option. Marginal moderation costs decrease with a regional moderation of 32 % and 43 % for PHSPP and the V2G moderation option respectfully.

By selecting moderation options for of variable renewable generation, priority should be given to the DR within the limits of its operation. When more flexibility is needed, then a PHSPP has to be built, and an EV has to be purchased as the last moderation option because of its high cost. After applying a moderation option, residual CEEP will still exist but it will be lower.

CONCLUSIONS

Demand response is a moderation option offering the lowest marginal costs, followed by the pumped hydro storage power plant and vehicle to grid options.

The operation of moderators could be increased trough region-based moderation and therefore the value of marginal moderation costs could be decreased.

The higher penetrations of wind proposed in the Strategy could be moderated using all available Serbian moderation options. Increased wind penetration at a regional level could not be fully moderated using the presented moderation options, because residual CEEP still exists.

This planning methodology could be used for national energy systems presenting similar demand structures e.g. significant shares of thermostatic electricity loads (electric storage heaters, electric water heaters, electric air conditioners...).

In order to model thermostatic electricity loads EnergyPLAN has to be upgraded, just like electric vehicles.

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NOMENCLATURE

CEEP	Critical Excess Electricity Production
PHSPP	Pumped Hydro Storage Power Plant
EV	Electric Vehicle
RES	Renewable Energy Sources
GFEC	Gross Final Energy Consumption

V2G	Vehicle to grid
CAPEX	Capital expenditures
OPEX	Operating expense
DR	Demand response

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