Increasing the integration of variable renewable energy in coal-based energy system using power to heat technologies: the case of Kosovo

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ABSTRACT

The goal of this work is to identify the influence which utilization of district heating systems coupled with the power-to-heat technologies based on the flexible operation of coal-based thermal power plants and limited electricity system interconnections can have on the maximum integration of variable renewables. An hourly deterministic tool EnergyPLAN, was used for modelling and simulation of Kosovo energy system. Results revealed that Wind and PV power plant capacities that can be installed in the actual Kosovo energy system, when operating in an isolated mode, are 450 MW and 300 MW respectively. Additional capacities around 800 MW for wind and 385 MW for PV can be further integrated into this isolated energy system with the contribution of power-to-heat technologies coupled with thermal energy storage in district heating with a fixed capacity. Furthermore, it was found that separate integration of wind can contribute to decease total primary energy supply and CO_2 emissions for 3.34 TWh/year and 1.08 Mt compared to the referent scenario. Total primary energy supply and CO_2 emission savings for separate integration of PV power plant compared with the referent scenario were estimated 2.74 TWh/year and 0.5 Mt respectively. Finally, the combined integration of variable renewable energy sources ($1MW_W+1MW_{PV}$) contributed to 3.29 TWh/year total primary energy supply and 1.02 Mt CO_2 emissions savings.

KEYWORDS

Power systems, District heating, Power-to-heat, Renewables, Coal Power Plant, Interconnections

INTRODUCTION

The use of coal for powering entirely Kosovo power sector has put a heavy burden of lignite coal in Thermal Power Plants (TPP) to cover the energy demands for electricity. This conventional resource use is one of the main contributors of CO_2 emission released into the atmosphere by the energy sector in Kosovo. In order to tackle the issue of climate change mitigation and CO_2 emission reduction goals, new renewable technologies should penetrate into Kosovo energy system. A new way of energy generating through integration of new renewable and non-renewable technologies is developed using the EnergyPLAN model to address several possibilities for designing an adaptable energy system in Kosovo [1]. Recent studies have shown considerable progress in renewable energy sources (RES) development by proving that these technologies are becoming more cost-effective and reliable energy supply solutions compared with conventional energy technologies like coal-based TPP. In this regard, solar PV and Wind power plants are being considered as environmentally friendly, inexhaustible and affordable energy production technologies that have found wide applications throughout the world. Electricity production from Wind and PV power plants technologies fluctuates because of the weather depended fluctuations of primary energy sources (wind speed and solar radiation). Storage technologies and smart solutions are needed in the energy system in order to balance the energy supply and demands. Several research approaches are already published with the main aim of increasing the ability of an energy system (flexibility) to integrate variable renewables. Such flexibility of energy systems can be provided in different ways according to country's energy storage potentials and its electricity interconnection capacities with neighbouring countries. For instance, hydro-based energy systems can use water pumped reservoirs (dammed hydro potential), or other systems can use flexible TPP, combined heat and power plants, different energy storage options, grid-connected electric vehicles, hydrogenation, etc. Countries with cold climate can use power-to-heat (P_tH) and thermal energy storage for capturing the excess electricity production and proving enough flexibility through synergetic effect between electricity and heating sector [2].

Traditionally, the conversion of electricity into heat was not a good option (as the energy was produced through the Rankine cycle), but the flexible use of RES electricity for heating purposes combined with heat storage (HS) has recently gained increasing attention as an additional source for providing higher flexibility of energy systems that will be capable to integrate more variable renewables [3]. A comparative analysis between energy conversion technologies like heat pumps (HPs), electric boilers, battery electric vehicles, hydrogen fuel cell vehicles with the main aim to integrate the fluctuating renewable energy sources into energy system is given in [4]. It was proved that large scale HPs are very promising technologies for effective reduction of excess electricity production. In addition to that, the scope of the P_tH technologies will be the turning of electricity into heat with the aim of compression HPs, or electric heater coupled with thermal energy storage.

In some industrialized countries, decarbonization of the heating sector is a precondition for achieving climate policy target. In 2007, 48% of the final energy consumption in EU 27 took the form of heat. That means that the heat was the biggest final energy consumed, which attracted the intention of scientists to put their research efforts into district heating (DH). Different primary energy resources integration into district heating and cooling (DHC) showed that these heating and cooling systems will be part of future energy systems called the fourth generation of DH [5]. DH consists of a central heat source, supply distribution networks, and end users.

Currently, only 13% of the European heat supply is covered by DH systems, which makes the potential for increasing this share significant, especially in urban areas, which are characterized by high heat demand densities [6]. In order to decarbonize the EU's energy systems by 2050, the European Commission proposed 6 different strategies and none of them contained a large scale DH implementation. In contrast, it was shown that good results could be achieved by combining DH and heat savings achieving 15% lower costs when compared to proposed strategies [7]. This was a major reason why the DHC systems were included in the EU strategy for heating and cooling. Lund et al. [6], shows that the future DH systems will have to be able to meet a number of conditions in order to cope with the challenges of modern energy systems. It was concluded that the future DH will have to be able to supply existing, new and refurbished housing units with low supply temperature for space heating and hot water, transfer heat with minimal losses, use low-temperature waste heat, and integrate RES into the system.

Münster et al in [8], concluded that the penetration of DH systems into the Danish energy system at 55% to 57% of heat demand would be economically justified. Penetration of 100% would not be justified, due to the expansion of the system happening, as a rule, only in larger urban areas with a higher density of thermal energy demands. Research [9] analysed different heat supplying options including DH, individual HP and micro combined heat and power plants (CHP's), using Denmark as a case, from the perspective of fuel demand, CO_2 emissions and cost in renewable based energy systems. It was concluded that the optimal heat supply solution is the DH expansion for the whole Denmark somewhere between 63 and 70% while the rest of heat to be covered by individual heat pumps.

Integration of large HPs into DH is a frequently mentioned solution as a flexible demand for electricity and an energy efficient heat producer [10]. The main idea was to make a HP use a low-temperature waste or ambient heat source. The last literature review in renewable energy integration into energy systems showed that P_tH technologies can cost-effectively contribute to fossil fuel substitution, renewables integration and decarbonization [11]. Fischer et al. [12] investigated the application and control approaches of HP systems in smart grids. It was concluded that HPs, when controlled appropriately, can ease the transition towards decentralized energy systems. Chua et al. [13] reviews the recent development of HPs, industrial novel use of HP, methods for enhancing their performance, and their application with various heat sources. There are several P_tH technologies which are available on the market and may contribute to decarbonization of heat supply and integration of variable RES. From the literature review, it is obvious that the central role stands for HPs, to be decentralized or connected to DH grids. Electric boilers are identified as a relevant option too. Moreover, case studies focused on combined analyses of P_tH and other options referred to as power-to-x, for instance, electrolytic hydrogen generation, may shed light on the comparative attractiveness of P_tH. Olsthoorn et al. [14] reviews the modeling and optimization tools that have shown the role of DH and thermal storage in high integration of renewables. Novosel et al. [15] showed the role that DH system coupled with HPs and thermal energy storage can have on large scale integration of RES technologies.

Ancona et al. [16] analysed the effect of thermal substations in smart DH networks with the main aim to show the impacts of bidirectional thermal exchange on supply and return smart DH temperature profiles, respectively the overall production system efficiency. A technical benefit analysis of the connection of thermal end users with ejectors in thermal substations against heat exchangers is given by [17]. It was concluded that significant heat savings can be achieved by applying ejectors in DH instead of heat exchangers. Two alternatives of DH domestic hot water supply (a) DH based on central HPs combined with a heat exchanger, and (b) a combination of DH based on central HPs and a small booster HP using DH water as a low-temperature source for (DHW) production is investigated in [18].

Böttger et al. [19] analyses the potential use of P_tH technologies in German DH grids for the year 2015-2030. It was found that the maximum theoretical potential use of P_tH technologies in Germany is 32 GWel. Moreover, Böttger et al. [20] analyses the overall system cost of German power market coupled with available electric boilers for 2012 and 2025. It was concluded that the cost reduction of electric boilers and a growing share of RES in Germany will lead to a situation where the overall cost saving exceeds the necessary investments costs. Ehrlich et al. [21] assess the future potential of decentralized P_tH (integration of electric boilers in conventional oil and gas boiler systems) as an additional demand-side flexibility option for the German electricity sector. Bach et al. [22] gives a model that represents the system performance of the HP connected in DH distribution and transmission networks. Results have shown better performance was of HP that are connected in DH distribution.

Chen et al. [23] analyses the potential synergies of variable wind power and flexible electrified heating systems (heat pumps and electric thermal storage) for Beijing over the period 2009-2020. It was found that significant wind penetration and CO_2 emission reduction can be obtained when using HPs and electric thermal storage compared with the BAU scenario. Blarke et al. [24] makes a comparative analysis between electric boilers and HPs used for capturing the intermittency of an energy system powered mostly by wind plant and cogeneration. It was found that well-designed HP concepts are more cost-effective than electric boilers, and in future markets where the gas/electricity price ratio is likely to increase, compression HPs in combination with intermediate thermal storages represent a superior potential for improvements in the intermittency-friendliness of distributed cogeneration. Lund et al. [25] estimates significant savings that could be achieved in electricity grid and storage infrastructure when choosing DH rather that electric heating or individual heat pumps.

Hedegaard et al. [26] studies the integration of 50% wind power in the Danish energy system coupled with the individual HPs and thermal energy storage in a form of heat tanks and passive storage. Papaefthymiou el at. [27] presents a methodology for the quantification of the flexibility offered by the thermal storage of building stock equipped with HPs, to power systems with significant penetration of wind power.

Waite at el. [28] evaluates the effects of large scale wind plants with HPs for New York City. It was shown significant increases in wind-generated electricity utilization with the increased use of HPs, allowing for a higher installed capacity of wind power. Hedegaard el at. [29] analysis a share of wind power integration 50-60% in the Danish energy system by the year 2030 considering the influence of individual HPs and various heat storage options. It was shown that HPs, even without flexible operation, can contribute significantly to facilitating larger wind power investments and reducing system costs, fuel consumption, and CO_2 emissions. Further, investments in heat storages can provide only moderate system benefits in these respects. Henning et al. [30] assesses the future energy system of Germany with up to 100% fraction share of renewable energy to cover the electricity and heat demands. The results obtained indicated the minimal cost of the system and its maximum performance. A classification of German and European energy systems regarding the flexibility requirements of electrical systems based on renewables is given in [31].

Current research is based on studying the effects that power-to-heat technologies coupled with thermal energy storage in district heating systems will have on increasing the flexibility of coal-based energy systems with limited interconnection capacities to integrate high fraction of variable renewable energy sources.

METHOD

When increasing the variable RES in power grids, a mismatch will be created between renewable electricity production and electricity demand curves, which may lead to substantial power curtailments needed for securing the grid stability. Therefore, significant power flexibility is needed in the energy systems with high share of variable renewables. This research shows how power-to-heat technologies can increase the share of variable RES in coal-based energy systems with limited interconnection line capacities. A reference model needs to be created for the case study area for the chosen reference year, for which enough data can be found in the existing literature. Contribution of P_tH technologies for providing additional flexibility in a coal-based energy system depends on: capacities of interconnection cables with neighbouring countries, current flexibility potential that energy system offers (in terms of electricity used in heating, cooling, electricity and transport sectors) and minimum operation capacity of TPP among other (their own flexibility). A model of the case study area is created using EnergyPLAN tool. It is a bottom-up specialized modelling tool that is mostly used for assessing large-scale integration of RES, impacts of heating, cooling, electricity and transport sector in energy systems. For instance, EnergyPLAN tool was used for modelling of 100% based RES energy systems in the following countries: Denmark [32], Croatia [33], Ireland [34], Macedonia [35], Portugal [36], and Latvia [37].

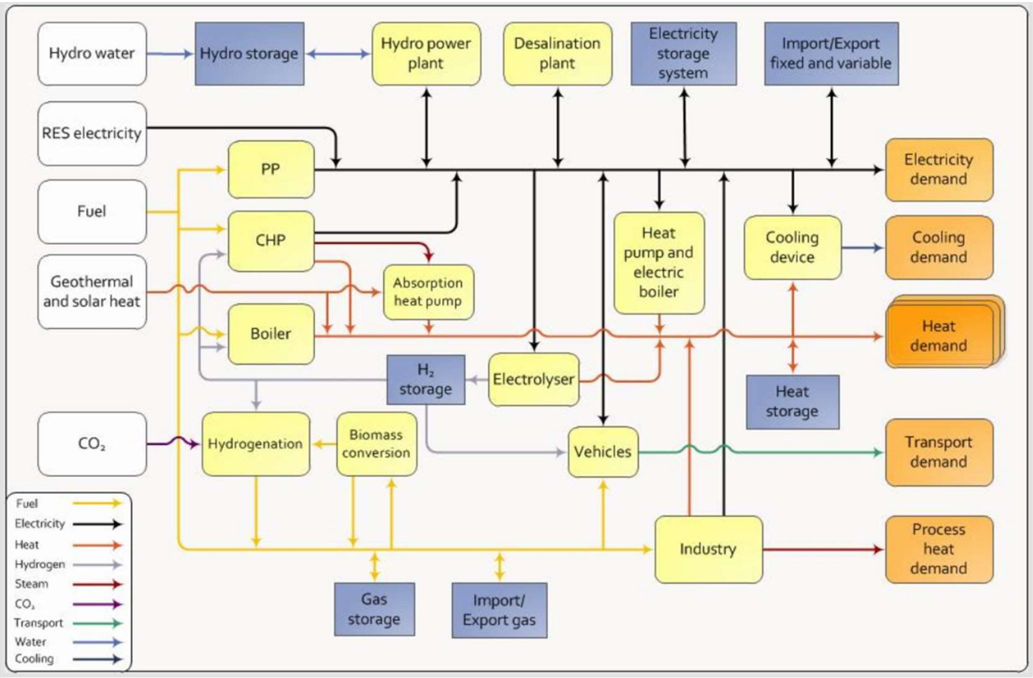

Figure 1 EnergyPLAN model [38]

The model results show the consequences of the technical and market simulation strategies that lead to designing and planning of energy systems with better performances and lower costs. The technical regulation strategy of balancing both heat and electricity demands has been used to create the reference model because is considered more accurate at simulating energy systems with large penetration of variable renewable energy compared to market simulation strategy [38]. Critical excess electricity production (CEEP) is defined as produced electricity that exceeds both the electricity demand and export transmission line capacity out of the power system. It should be avoided in a power system, otherwise such generation would be curtailed to avoid the system collapse. In the model, CEEP regulation options pre-designed in EnergyPLAN were left to zero, because such strategy can be used for defining the largescale integration of variable RES using synergies between the sectors first. A small value of CEEP can be tolerated in the power system since it is not economically viable to build electricity storages for a very short period of time during the year when small values of CEEP appears. In addition to that, the value of CEEP around 5% of total electricity produced by RES is used as a criterion for defining RES integration limit.

EnergyPLAN uses distributions of resources and demand in hourly steps for a one-year period to produce hourly outputs. Hourly distributions of individual and district heating demand was calculated using the total aggregated heat demand and heating degree day method. Using the same approach, the cooling load profile was estimated. Hourly distribution of river hydropower plant was generated using the monthly energy production recorded data in 2015 [39]. The hourly electricity demand profile was taken from Kosovar transmission system operator company (Kostt) [40]. PV and Wind supply power supply were generated using wind speed and solar irradiation data from Meteonorm [41] for high potential areas in Kosovo. General needed inputs in the EnergyPLAN model are the annual energy demand distribution in hourly steps, RES plant capacities, annual import/exports of electricity production, and hence the model outputs are energy balances, total primary fuel consumption, and total energy system costs [38].

Power to Heat Scenario Approach Analysis

For assessing the P_tH technology impact in increasing additional RES power integration in coal-based energy systems, an entirely coal based electricity generation system is selected. Electricity generation in this energy system is based on two lignite coal-fired thermal power plant units, which are considered to be very flexible in terms of their minimum operation capacities. The minimum capacity of thermal power plants was set to 20% of their nominal capacity. Even higher minimums can be achieved with installation of additional devices that keep the thermal power plant under operational working conditions. For the current case study objective, a reference model in EnergyPLAN is created. The research method is implemented by performing scenario analysis:

1. RES integration, interconnections and no P_tH scenario: Because the economical viable DH share is around 50-57% of total country heating demand [8] [42][43], this scenario considers the share of country DH around 50%. It also supposes that the fuel that was consumed in certain technologies (biomass, oil and gas boilers) for providing individual heating solutions has remained the same even after increasing the DH share to 50%, because there is no data that shows geographically what kind of heating sources are used by end-users in urban areas Therefore, no additional P_tH technology (compression heat

pump or electric heater) was added, which means that the flexibility of the power system has remained the same as in the reference scenario. As a consequence, the current energy system was simulated to identify the flexibility which this energy system offers (in terms of the electricity used in heating, cooling, electricity and transport sector), and how much RES power capacities can be added to the current energy system when operating with different interconnection capacities. The results of simulations are presented in Figures 3, 4, 5, but the shares of variable Wind, PV and combined RES ($1MW_W+1MW_{PV}$) power capacities are extracted from those graphs, for CEEP 5% of total electricity production by RES, and are shown in the graphs of Figures 6, 7, and 8 respectively.

2. RES integration, interconnections and P_tH scenario: In this scenario, compared to the previous one, the role of P_tH technologies for increasing additional Wind, PV and combined RES power capacities was identified. The results of the simulation are shown in Figures 3, 4, 5 and the contribution of P_tH for increasing penetration of Wind, PV and combined RES power capacities in the current power system which is operating with different interconnection capacities is shown in Figures 6, 7, and 8 respectively. Sensitivity analysis for different transmission line capacities was carried out in order to determine the influence of P_tH technologies for Wind, PV and combined RES integration in isolated, limited and very well interconnected power systems.

3. Electricity demand, interconnections and P_tH scenario: Because of the contribution of P_tH technologies to add additional RES power capacities, the percentage of total country electricity demand TWh/year that would have been covered because of the utilization potential of P_tH technologies in current power system which is operating with different interconnection mode capacities was shown schematically in the graphs of Figures 9, 10 and 11 respectively. Firstly, the yearly electricity production by increased Wind, PV and combined RES capacities as a result of flexibility offered by interconnections and P_tH technologies is calculated and then is divided by the total country electricity consumption.

4. RES integration, no interconnections and different P_tH capacities: In previous scenarios a fixed (P_tH = HP + HS) capacity was used for estimating Wind, PV and combined RES integration potential. In contrast, this scenario considers different HP and heat storage capacities in DH and identifies different P_tH sizes needed for maximum integration of Wind, PV and RES power plants. All these analyses are being carried out for an isolated energy system, where the contribution of P_tH to integrate variable RES is significant. The result of simulations are shown in figures 12-17.

5. Total Primary Energy Supply and CO_2 emission savings: Maximum utilization capacity estimated for different sizes of P_tH technologies in DH that contributed to RES integration was used for estimation of total primary energy supply (TPES) savings and CO_2 emission reductions compared to referent scenario. TPES (TWh/year) and CO_2 emissions (Mt) savings compared to referent scenario are shown when variable RES technologies are integrated into the power system in a separate and combined manner. The schematic illustration of savings is shown in figures 18 and 19 respectively.

6. RES investment costs: Maximum utilization capacity estimated for different sizes of P_tH technologies in DH that contributed to RES integration was used for estimation of specific technology investment costs. Technology investment costs were taken from different sources [44],[45],[46]. The cost of electricity and heat production were considered, excluding the cost of district heating extension grids. Proper geographical information system analysis are needed for DH cost grid extension assessment. Technology investment costs are provided in figure 20.

RESULTS AND DISCUSSION

Two scenarios have been developed and compared for demonstrating the role of DH and different sizes of P_tH technologies in variable RES integration, TPES savings and CO_2 emission reduction. Referent scenario was modelled using recorded energy supply and demand data for the year 2015. The second scenario considers that DH is increased to 50% of total heat demand and different capacities of P_tH technologies are applied. Both scenario modelling results are shown below.

Modelling of Reference Scenario

A model for the base year was defined for Kosovo energy system at 2015, with the main aim to show the contribution that P_tH technologies can have as an additional source of the flexibility of coal-based power system for increasing the share of variable renewables. Table 1 shows the recorded data that were used to describe the country energy demands for the reference year. It reviles that the electricity sector consumes more energy than other sectors followed by heating and transport respectively.

Table 1 Energy consumption by sectors with respect to Kosovo energy system [47],[48],[49]

Energy consumption by sector	(TWh/year)
Electricity	5.670
Heating	5.210
Cooling	0.055
Industry	2.233
Other consumption	1.827
Transportation	4.536

In table 2 the supply fuels consumed by each sector are shown. When attention is paid to electricity production, it can be seen that over 97% of total electricity production was based on lignite coal.

Table 2 Kosovo Energy system supply by source [47],[48],[49]

Electricity production (TWh)		Individual Heating (TWh)		District Heating (TWh)	Cooling (TWh)	Industry (TWh)	Transportation (TWh)	Other consumption (TWh)
Fuel	**2015**	**Fuel**	**2015**	**2015**	**2015**	**2015**	**2015**	**2015**
Coal	5.359	**Coal**	0.646	0.265	-	0.302	-	0.214

River Hydro	0.142	**Oil**	0.517	0.277	-	1.744	-	0.343
Wind	0.000	**Biomass**	2.800	-	-	0.186	-	1.269
PV	0.000	**Electricity**	1.930	-	0.055	-	-	-
		NG	-	-	-	-	-	-
		Diesel	-	-	-	-	3.107	-
		Petrol	-	-	-	-	1.157	-
		LPG	-	-	-	-	0.272	-

Table 3 shows the actual operational PP and CHP capacities, while table 4 shows the actual operational RES power production capacities. Kosovo has two power plant units named Kosovo A and Kosovo B and their net, minimum operation capacities, as well as their electrical and thermal efficiencies, is given below. When Wind and PV electricity is available to reliably meet the demands, thermal power plants run with minimum capacity, allowing for more utilization of renewable electricity production.

Table 3 Net, minimum Power Plant Capacities and their efficiencies [47]

Group	Capacity (MW)	Min Capacity (MW)	η_{el}	η_{th}
PP	432	70	0.3	-
CHP	538	70	0.4	0.104

Table 4 RES Plant Capacities [47]

Group	Capacity (MW)
River Hydro	75.5
Wind	1.36
Photovoltaic	0.6

Except for input data provided so far, the software model also requires the energy demand and supply distributions for each technology. The distribution of electricity demand was taken from [47], while distributions for the heating and cooling demands were created using the hourly heating and cooling degree day's method. In addition to distribution data for energy demands, also distribution data is created for supply-side technologies like Wind, PV, River Hydro and DH. Such data was saved and imported to model as txt.files. The capacity factor for wind and PV power plants was 20% and 17% respectively. All this data was integrated into EnergyPLAN model. The data in the model were compared with the recorded data for validating the model. The results of the validation are presented in Table 5.

Table 5 Model Validation with respect to actual data [47].

	Model (TWh)	Actual (TWh)	Difference (%)
PP electricity	2.77	2.74	3
CHP operating Mode	-	-	

PP	1.32	1.35	-3
CHP	1.29	1.32	-3
RES electricity	0.14	0.14	0

Modelling of Power-to-Heat technologies

In the simulated scenario, the DH demand was increased five times corresponding to 50% of total country heat demand in 2015. This utilization potential of total heat demand to be covered by DH was estimated in several research papers [8], [15].

Table 6 Heat supply options in DH with a 50% share of total country heat demand.

Individual Heating (TWh)		**District Heating (TWh)**	
Fuel		**Fuel**	
Coal	0.2761	**Coal+HP+HS**	2.7062
Oil	0.2201	Oil	0.2775
Biomass	1.2007		
Electricity	1.9300		

It was shown that the potential use of P_tH technologies in DH from 30 to 50% of the total DH demand by [19]. In this regard, the compression HPs with 150 MW_{el} capacity coupled with 10 GWh/annually heat storage was integrated into this fictive DH. For installing such HP capacity, a linear decrease of fuel consumed for individual heating solutions compared with the reference scenario is assumed (see Table 6).

Moreover, existing TPP were assumed to be very flexible accounting for a minimum capacity of around 20% of their net operation capacity. Kosovo is well interconnected with neighbouring countries. The total interconnection capacity is 1200 MW, but it is not fully utilized due to political reasons. The electricity imports and exports through the interconnection line capacities with neighbouring countries are given in Figure 2 for the year 2015. Kosovo is a net electricity importer and around 17-25% of total electricity demand is imported especially during the winter, when the use of electricity for space heating is significant accounting for 1/3 of total country heating demand.

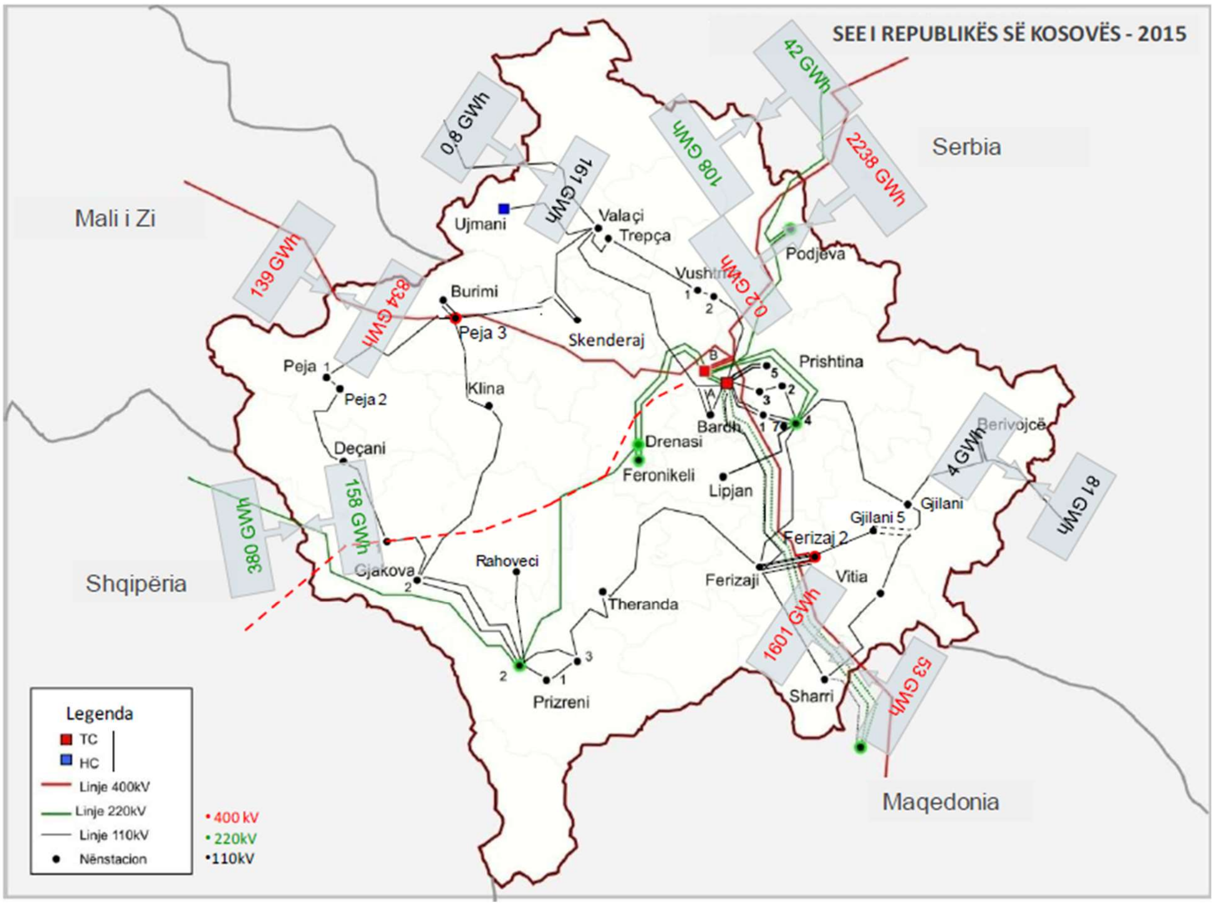

Figure 2 Kosovo power system interconnections [47].

Because of the variability of RES electricity production, is cases uncertainty which pose major challenges in power system reliability. High penetration of variable power may bring negative effect to power distribution grid by causing reverse power flow which leads to unacceptable voltage rise on distribution side. There are some solutions for improving the reliability of power systems using demand response technologies, inverter control technics, and energy storage systems. One of the solutions elaborated in this research for enhancing reliability of Kosovo power grid is the application of thermal energy storage system via the use of PtH technologies in district heating.

Figure 3 presents the critical excess electricity production by wind power plants. CEEP appears in power systems, when the potential electricity production exceeds the electricity demand curves as well as the interconnection line capacities. This is the electricity that must be avoided in the power grids otherwise the electricity system will collapse. In addition to that, the graph shows that P_tH technologies can significantly decrease the CEEP, created by wind power plants, even in a very well interconnected power system.

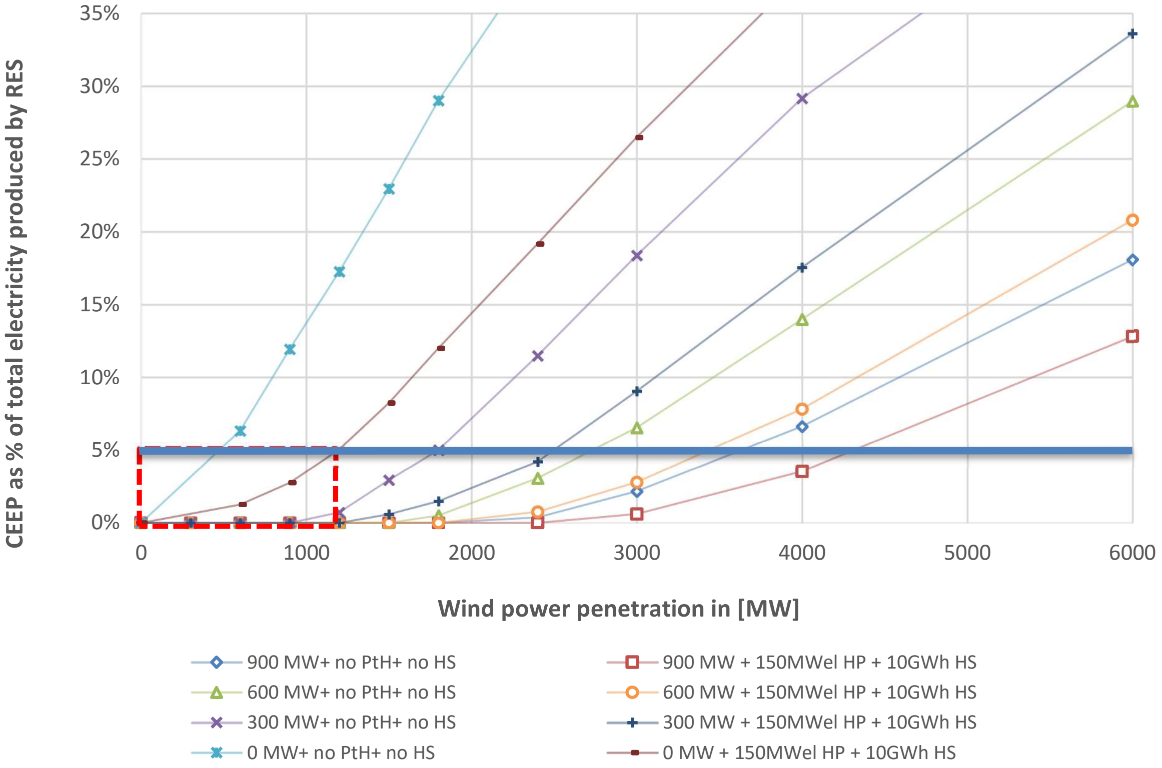

Figure 3 CEEP production by the wind power plants penetration for different interconnection capacities (0 – 900 MW NTC) coupled and uncoupled with P_tH technologies in DH with 50% share of heat demand.

Contribution of P_tH technologies increases with the increasing penetration of wind generators. Higher CEEP reduction because of the P_tH technologies is acquired for an isolated energy system (0 MW interconnection), while less contribution is obtained in a very well interconnected power system (for instance CEEP reduction for interconnection line capacity 900MW).

Similarly, another graph for showing the contribution of P_tH technologies for capturing the excess electricity of solar PV plants is shown in Figure 4. As displayed in this graph the CEEP reduction because of the P_tH technologies coupled with PV is significantly smaller compared to wind power plants. Because of the seasonal operation of DH systems, with the P_tH technologies operating during the heating season (in Kosovo DH operates from 15 October to 15 April) and by this time the contribution of solar irradiation reaching the PV panels on Earth's surface is smaller compared with Wind power plants. If placing all the PV panels in an optimum angle the PV power production curve reaches its maximums during the summer months.

If the country would have had high needs for cooling, the use of P_tH (cool) technologies would have a significant contribution for the reduction of CEEP. Similarly, a higher contribution of P_tH technologies for integrating PV is obtained in an isolated power system, while it is negligible for a very well connected one.

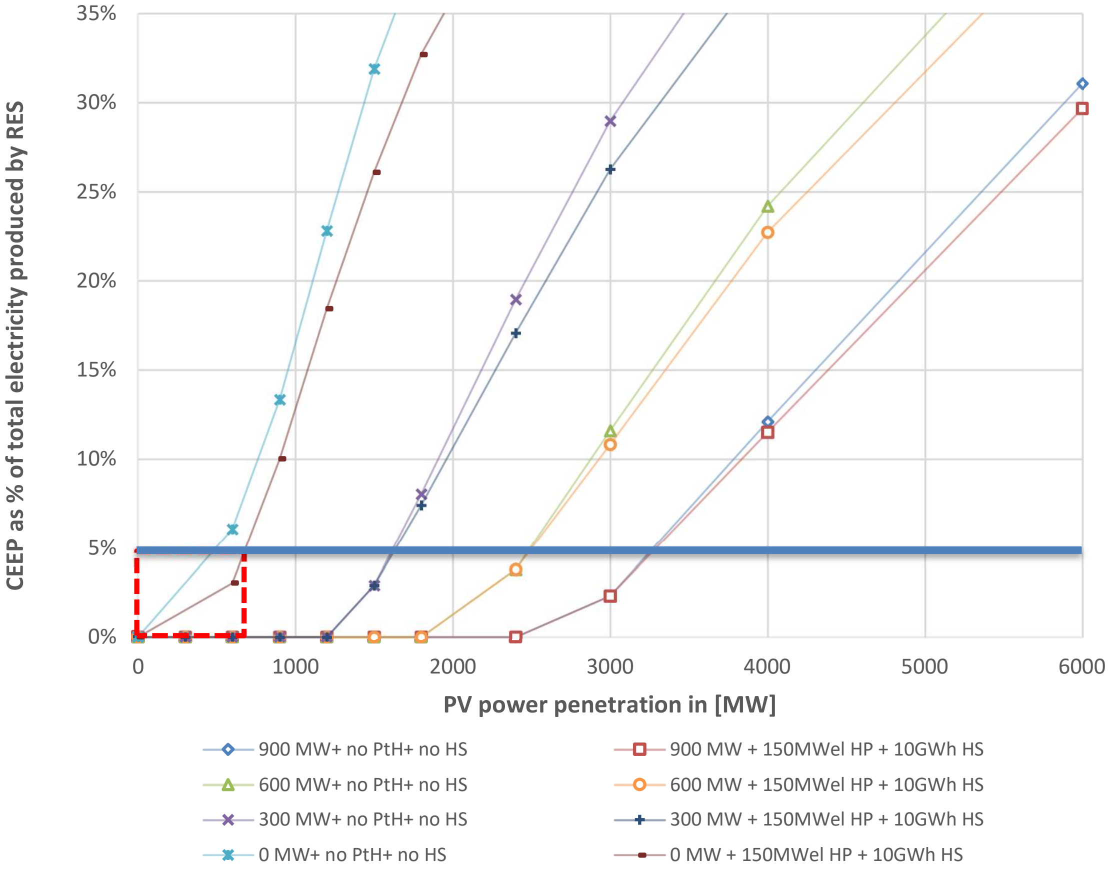

Figure 4 CEEP production by the PV power plants penetration for different interconnection capacities coupled and uncoupled with P_tH technologies in DH with 50% share of heat demand.

On the other hand, the contribution of P_tH technologies for decreasing the CEEP in an optimum power generation mix composed of wind and PV power plants is shown in Figure 5. It demonstrates that a higher share of variable renewable power plant capacities can be integrated into coal-based power systems compared with wind and solar power plants for the same interconnection line capacity compared with separate integration of wind and PV power plants.

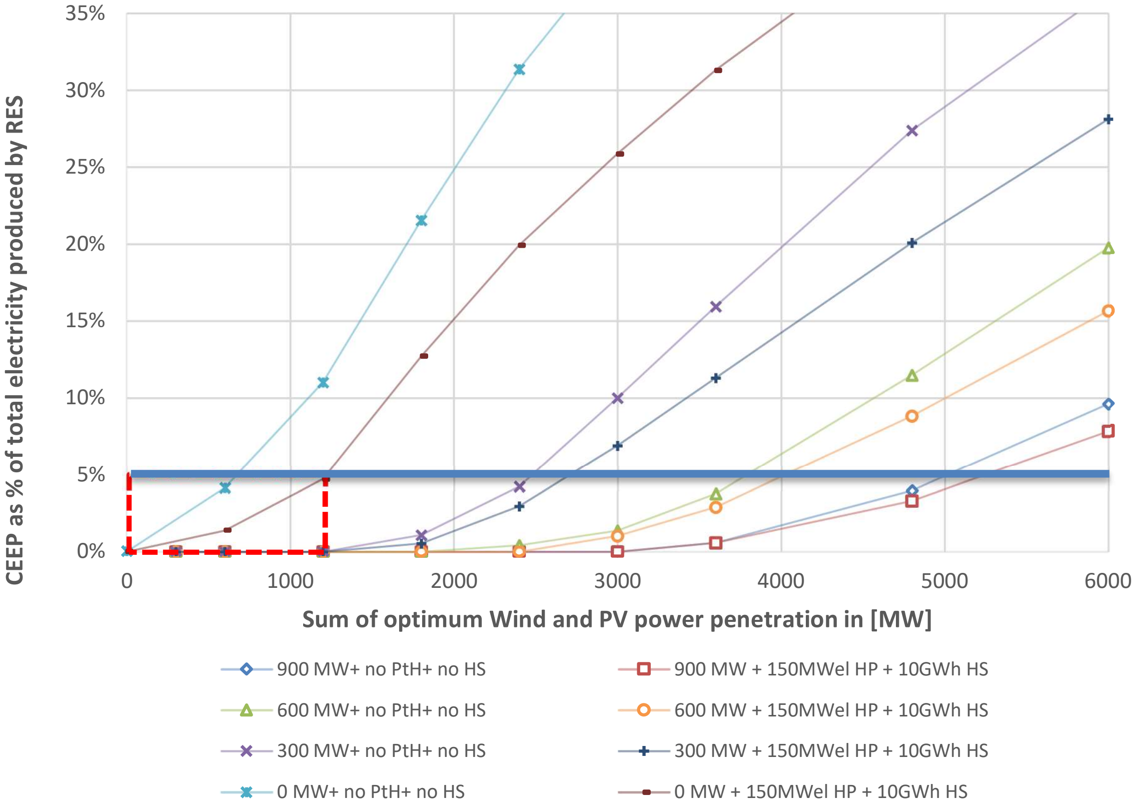

Figure 5 Wind and PV power penetration enabled by P$_t$H and transmission, with the criterion <5% CEEP.

Usually, during the modelling of energy systems, an amount of 5% for CEEP is used as criteria that underline how much variable renewable power plants can be integrated into the energy system. When looking on how much renewable wind power can be integrated into an isolated coal-based energy system (0 MW interconnection) without P$_t$H technologies (Figure 6), it was found that the wind power that can be installed is 450 MW. An additional capacity of 800 MW of wind power plants might have been integrated into this energy system with the contribution of P$_t$H technologies coupled with thermal energy storage in DH. In case the interconnection capacities increase, the contribution of P$_t$H slightly decreases, but even though in a well-interconnected power system (900 MW) the contribution of P$_t$H is significant for wind power penetration allowing an additional capacity of 622 MW (Figure 6).

Following the same procedure, the PV and RES power penetration was investigated. From the PV penetration perspective Figure 7, the contribution of P$_t$H, is isolated power system (0 MW interconnection) is significant 385 MW, while for very well connected power system (900 MW interconnection) such contribution is not visible, since the export of any excess electricity from solar PV has the priority.

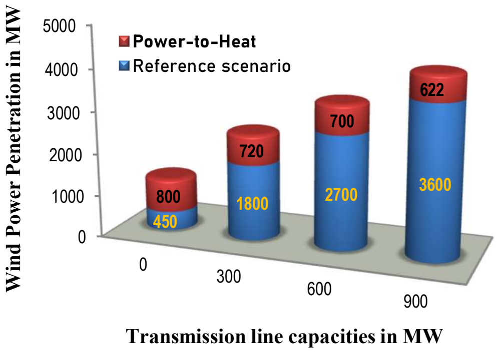

Figure 6 Wind power penetration using P_tH technologies in DH with a 50% share of total heat demand.

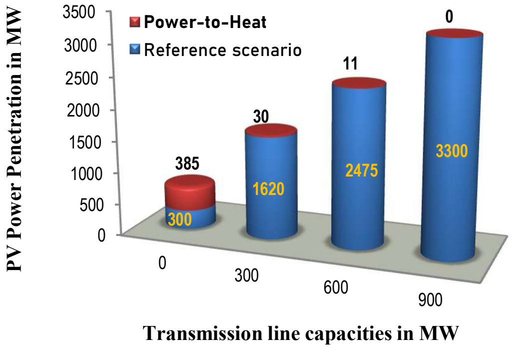

Figure **7** Solar PV power penetration using P_tH technologies in DH with a 50% share of total heat demand.

This is the reason why power to gas, electric vehicles with battery or power-to-x technology would make sense for creating better flexibility of Kosovo power system, especially during the summer. From the other hand, the contribution of interconnection capacities in the current power system is significant (see the blue part of figures 6, 7 and 8).

Figure 8, also underlines the variable power penetration for optimum Wind and PV plants in a power system that is based entirely on coal. It can be shown that when the power system is entirely isolated, the contribution of P_tH increases the variable RES power penetration for 515 MW (257.5 MW Wind and 257.5 MW PV respectively).

Because of the different power plant technologies have different capacity factors, the annual energy produced by such technologies is a better option for showing the contribution of P_tH technologies. In Figure 9, the annual electricity (TWh/year) produced by PV plants, light brawn colour, as a contribution of P_tH technologies divided by total country electricity production is given.

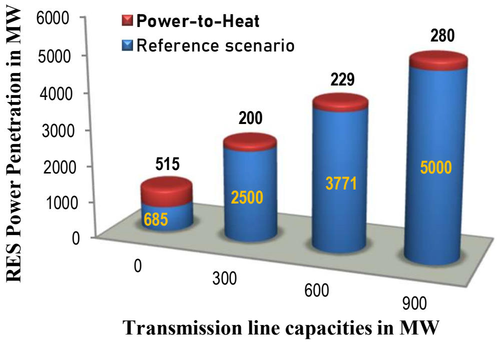

Figure 8 Variable RES power penetration using P_tH technologies in DH with a 50% share of total heat demand.

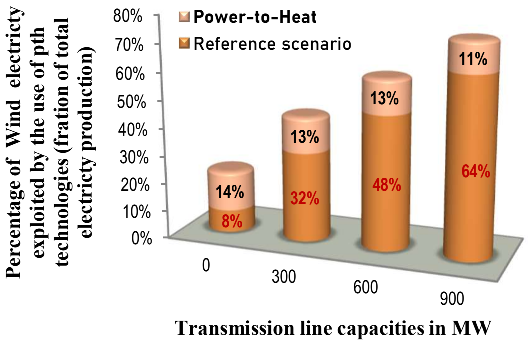

Figure 9 Percentage of wind electricity exploited using P_tH technologies and increased transmission line capacities

An interesting result reveals for the increasing interconnection capacity 300, 600, and 900 MW, the mix of variable renewable power penetration increases to 200, 229 and 280 MW respectively, as a contribution of P_tH technologies, which was not the case when these renewable plants were integrated separately into the power system.

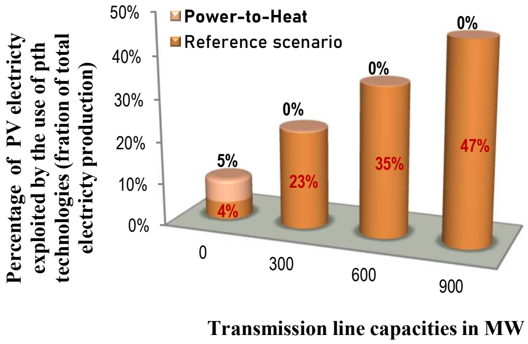

Figure 10 Percentage of PV electricity exploited using P_tH technologies and increased transmission line capacities.

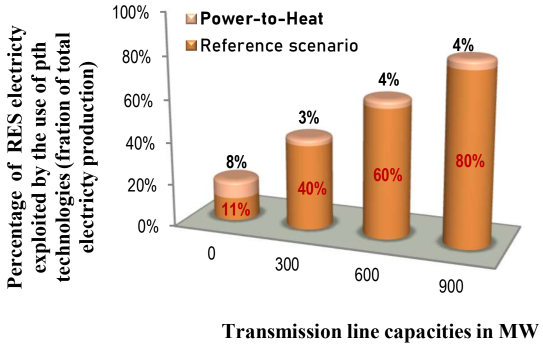

Figure 11 Percentage of variable RES electricity exploited using P_tH technologies and increased transmission line capacities.

It can be shown in Figure 9 that the contribution of P_tH for integrating wind electricity in coal based power system is significant to account for 14%, 13%, 13%, 11% of total country electricity demands for interconnection capacities 0 MW, 300MW, 600 MW, 900 MW respectively. In the same way, the graphs of Figure 10 and 11 were created. It is worth observing that PV penetration increase due to P_tH only becomes favourable if the interconnection capacity is 0 MW, otherwise, no contribution was found (Figure 10). Obviously, better results can be obtained for optimum RES power mix (Figure 11), with the use of P_tH that can allow larger use of potential surplus RES.

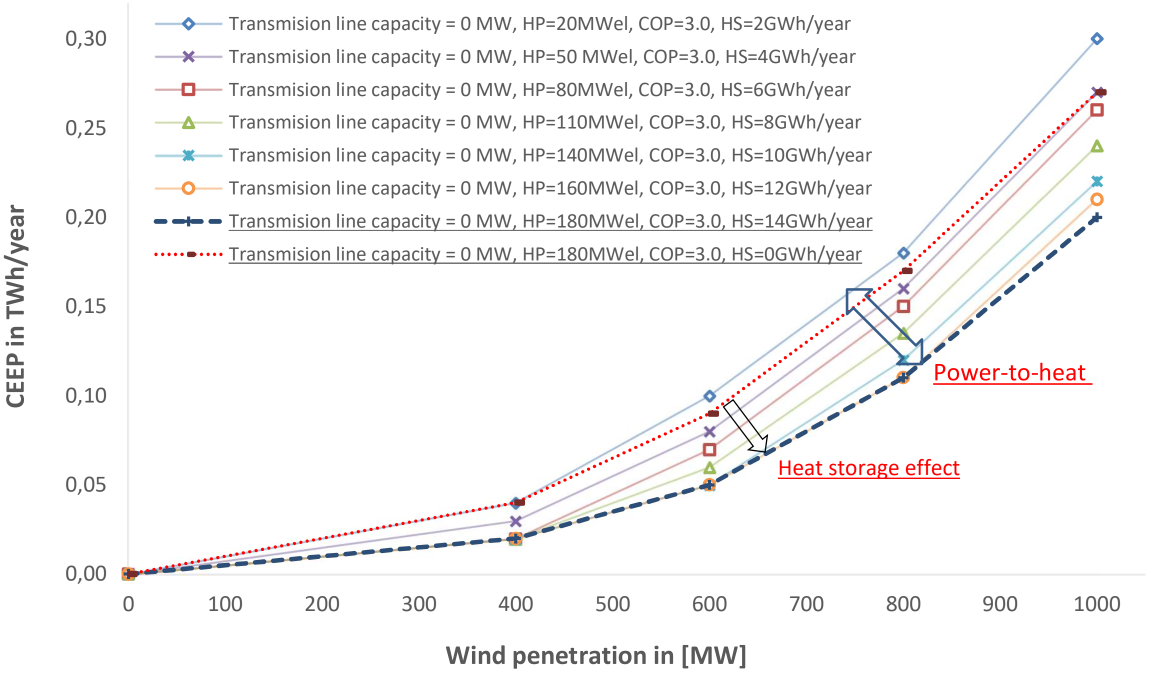

Figure 12 CEEP wind production in TWh/year for different HP and HS capacities in DH with 50% share of total heat demand.

Apart from RES integration in Kosovo energy system for different interconnection capacities, with a fixed size of P_tH, additional analyses were carried out to emphasize the contribution of different P_tH = HP+HS capacities in CEEP reduction in Figure 12 and wind power integration in Figure 13. Different capacities of compression heat pumps and thermal energy storages in district heating for an isolated energy system were investigated for demonstrating their impact in CEEP reduction from variable RES technologies. Figure 3 has shown that the critical wind penetration zone is between 0 - 1000 MW for an energy system operating in an isolated mode, and that is the reason why this zone is considered for further analysis. Zone area between the top and bottom curves (Figure 12), shows additional flexibility that is created in the energy system because of the utilization of different HP+HS capacities. Curves that are built with smaller HP+HS capacities show higher excess wind power production leading to the smaller ability of power system to integrate wind power plants. The upper limit about 180 MW_{el} capacity for compression HP's was selected to cover around 40% of total heat demand if operating with such capacity and the priority was given to HP against other DH fuel-supplying options. Two dot curves (red and dark blue ones) with same HP capacity 180 MW_{el}, but with and without thermal energy storage options (in figure 12) were investigated to show the contribution of HS in CEEP reduction. It can be noted that HS application with the power-to-heat has a significant contribution to CEEP reduction potential especially in energy systems with high penetration of wind power plants. Diurnal thermal energy storage in DH was considered in all analysed scenarios. However, in market different heat storage technologies are used for storing heat diurnally and seasonally in the form of sensible, latent and chemical storages. Figure 13 shows the CEEP in the percentage of total electricity production by RES. CEEP percentage 5% is considered as criteria for estimating wind power integration in the energy system with different HP+HS capacities. It can be noted that wind power integration can be increased significantly from 400 MW (curve HP=20MWel, COP=3 & HS=2HWh/year) to 680 MW (curve HP=180 MW_{el}, COP=3 & HS=14GWh/year). Larger HP+HS capacities for actual energy system do not have any effect on wind power integration since they do reach the CEEP limit of 5%. This is the case when comparing bottom curves (curve HP=160 MW_{el}, COP=3 & HS=12 GWh/year and curve HP=180 MW_{el}, COP=3 & HS=14 GWh/year), which show that they have exceeding the limits regarding the contribution of P_tH in wind power integration.

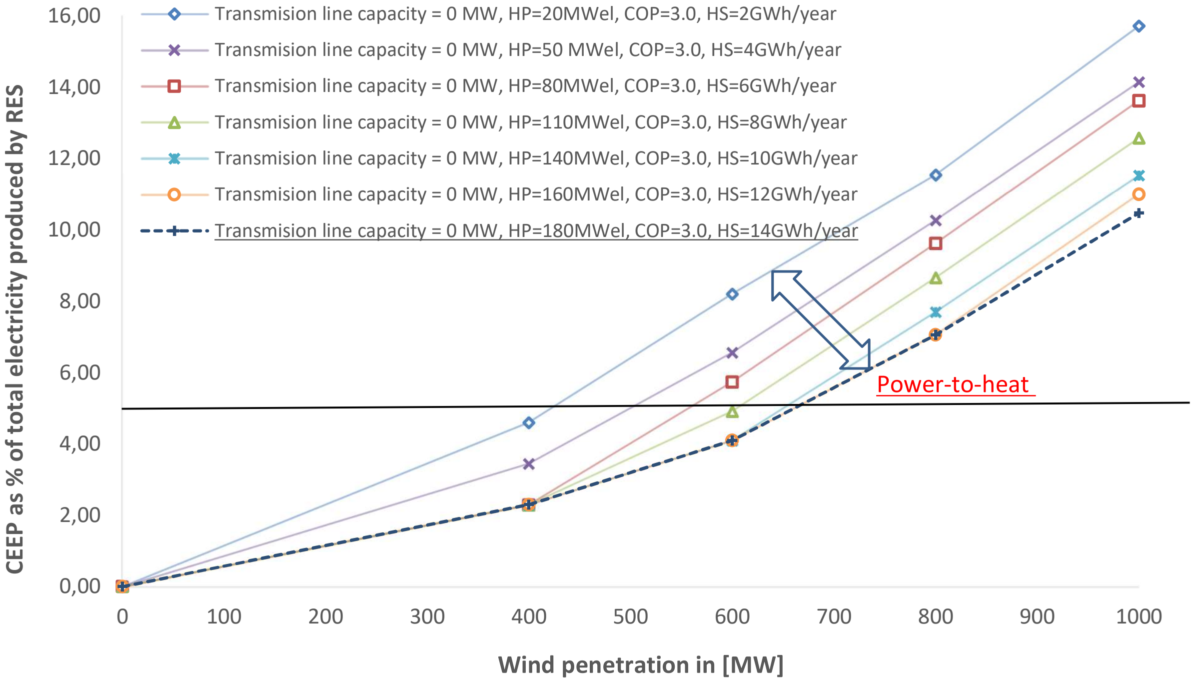

Figure 13 Wind percentages of CEEP for different P_tH and HS capacities in DH with 50% share of total heat demand.

Using a similar procedure, CEEP curves (expressed in TWh/year and CEEP % of total electricity production by RES) for solar PV power integration were constructed in Figures 14 and 15 respectively. Smaller contribution of HP+HS capacities were identified for solar PV integration compared with Wind. The reason for that is that DH has been operating between 15 October to 15 April to cover both space heating and hot water demand, in times, where the availability of solar irradiation is low. The remaining time, district heating has been used to cover just hot water demand and that demand was low compared with space heating demand. It means that there are not needed significant HP+HS capacities because the heat demand by DH is low. This fact is illustrated in figures 14 and 15, where is shown CEEP for different HP+HS capacities for increasing flexibility of the energy system as well as for PV integration. The only curve with HP=20MW_{el}, COP=3, HS=2GWh/year has shown not enough HP+HS capacities available to integration maximum share of PV power plants. All other capacities have shown the same ability to reduce CEEP and utilize maximum integration of PV. It was shown in figure 15, that because of the application of different HP+HS capacities in district heating, the maximum integration of solar PV increase is around 80 MW.

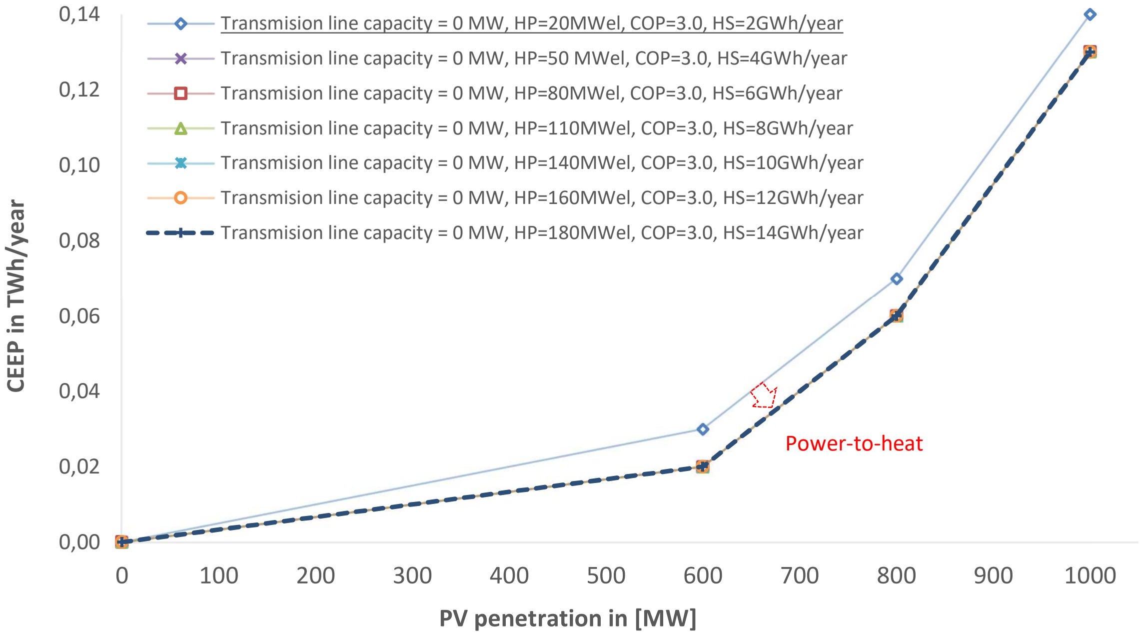

Figure 14 CEEP solar PV production in TWh/year for different HP+HS capacities in DH with 50% share of total heat demand.

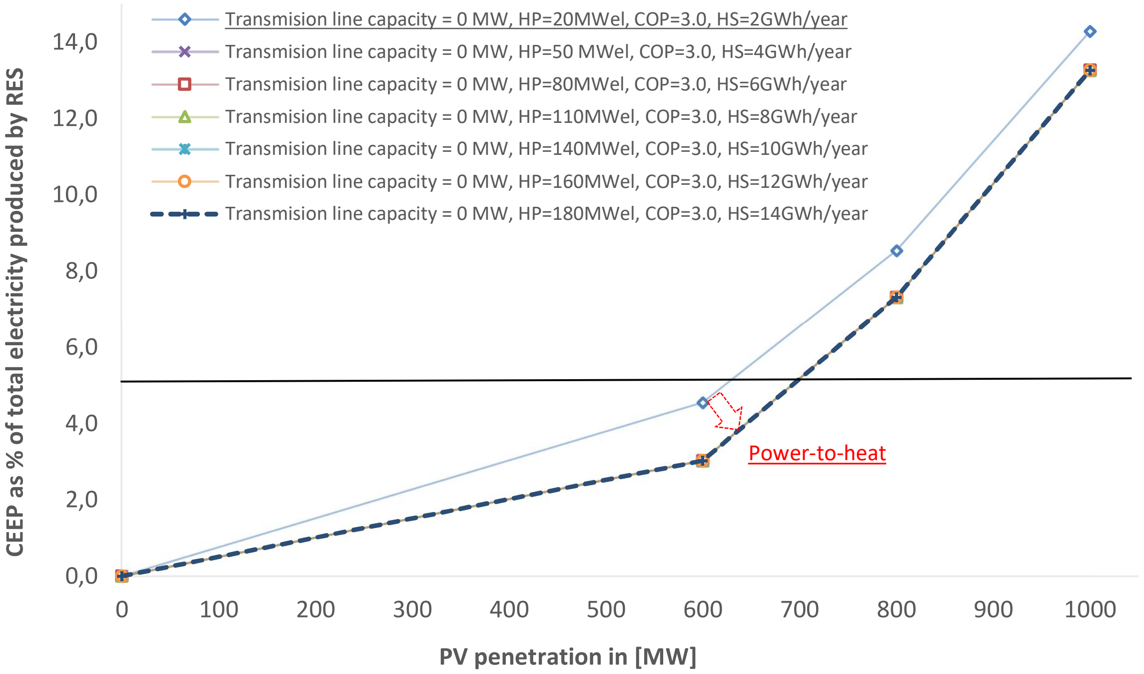

Figure 15 Solar PV percentages of CEEP for different HP+HS capacities in DH with 50% share of total heat demand.

Apart spilt integration of Wind and PV power plants, additional analysis considering both integrations of Wind and PV in energy system happening at the same time were considered. The sum of integration of PV and Wind is called RES integration, counting a power integration 1MW per wind and 1MW per PV respectively. When comparing the contribution of different HP+HS capacities for separate and combined variable RES integration, the larger effect was identified for separate wind integration compared with separate PV and combined RES integration. Figures 16 and 17 presents the CEEP reduction as a function of RES power penetration (sum of wind and PV). It can be seen that CEEP can be reduced significantly for different HP+HS capacities. For illustration, let's take the maximum RES power penetration 2000MW, where the contribution of P_tH and HS to reduce CEEP is 0.73 - 0.61 = 0.12 TWh/year.

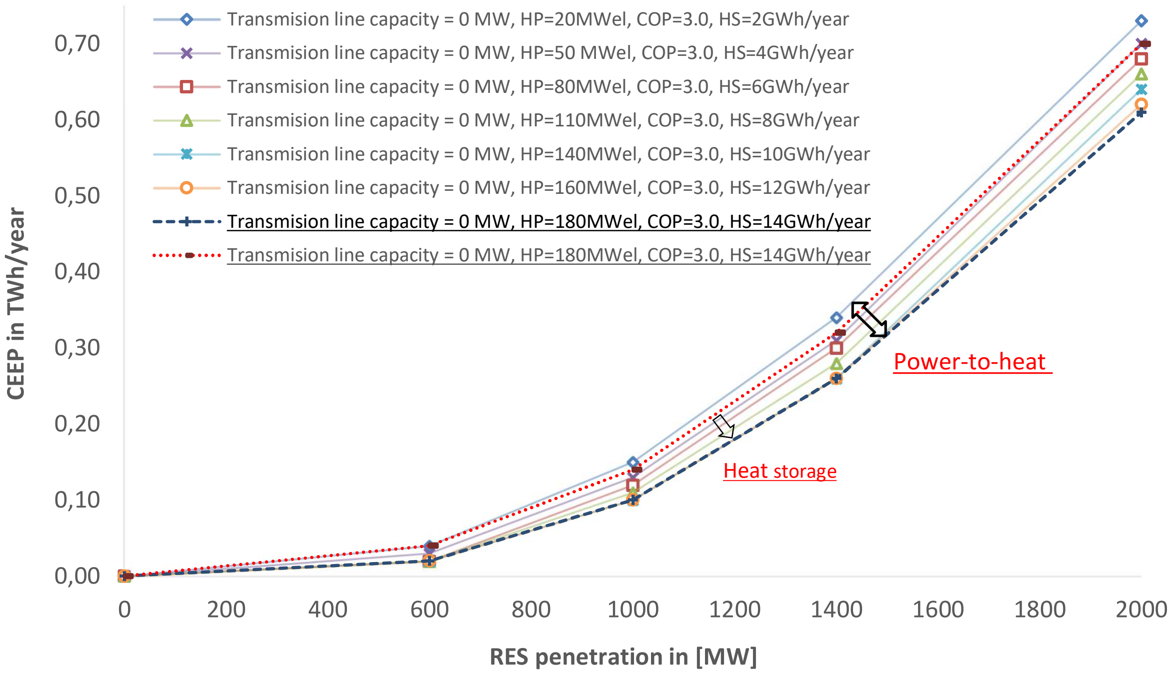

Figure 16 CEEP variable RES production in [TWh/year] for different HP and HS capacities in DH with 50% share of total heat demand.

An increase of RES power (sum of =1 MW_{Wind} +1 MW_{PV}) integration around 800 - 600=200 MW was identified because of the application of different HP+HS capacities in DH. Compared to split wind integration, smaller capacities of P_tH and HS capacities are needed for maximum utilization of variable RES. Figure 16, shows that curve with HP=110 MW_{el}, COP=3 and HS=8 GWh/year is the maximum needed capacity of P_tH contributing in RES integration. Larger capacities mean oversizing of P_tH technologies for variable RES integration.

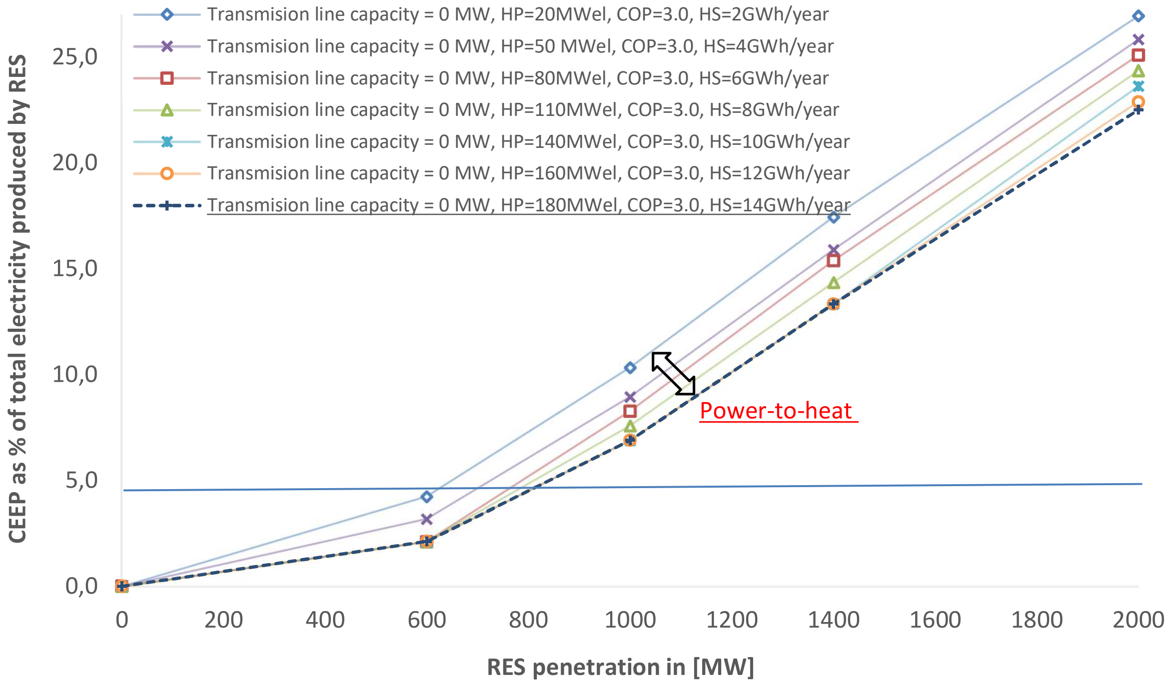

Figure 17 Sum of RES power penetration enabled by different HP and HS capacities in a DH, with the criterion <5% CEEP.

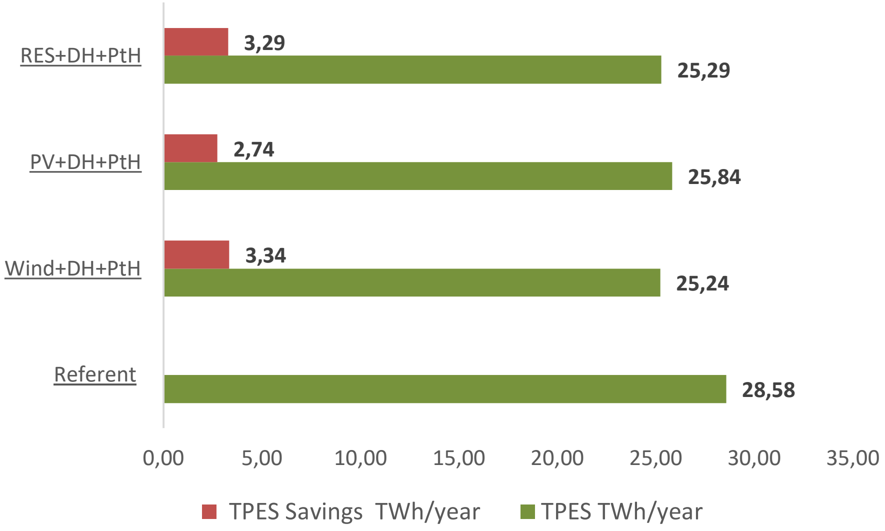

Figure 18 Total primary energy supply and its savings

Besides the contribution of DH and P_tH to increase the share of variable RES power plants in power systems, they can additionally contribute to increasing TPES savings and CO_2 emission reductions. Results shown in figures 17 and 18 are acquired, for an energy system operating in an isolated mode. In the referent scenario, TPES were estimated at 28.58 TWh/year. Considering an extension of DH up to 50% of total heat demand, and maximum estimated capacity of P_tH (HP=180MWel, COP=3, HS=16GWh/year) that can contribute to RES integration, TPES savings for split and combined integration of RES were estimated as well. In addition to that when considering just wind penetration in an isolated power system (around 661MW see fig. 13 with a significant share of DH+HP+HS), it was found that 3.34 TWh/year of TPES could be saved. This means that wind penetration can contribute to decease TPES for 12% compared with its penetration in the referent scenario. Similarly, the contribution of PV power plants to decrease TPES was estimated accounting for a decrease of around 10% compared to referent scenario. A higher contribution of DH and P_tH in TPES saving was estimated for the combined integration of variables RES (3.29 TWh/year) compared with split integration of PV power plants (2.74 TWh/year). However, this was not the case, when comparing combined RES and Wind integration, for which the last one showed the highest TPES saving potential.

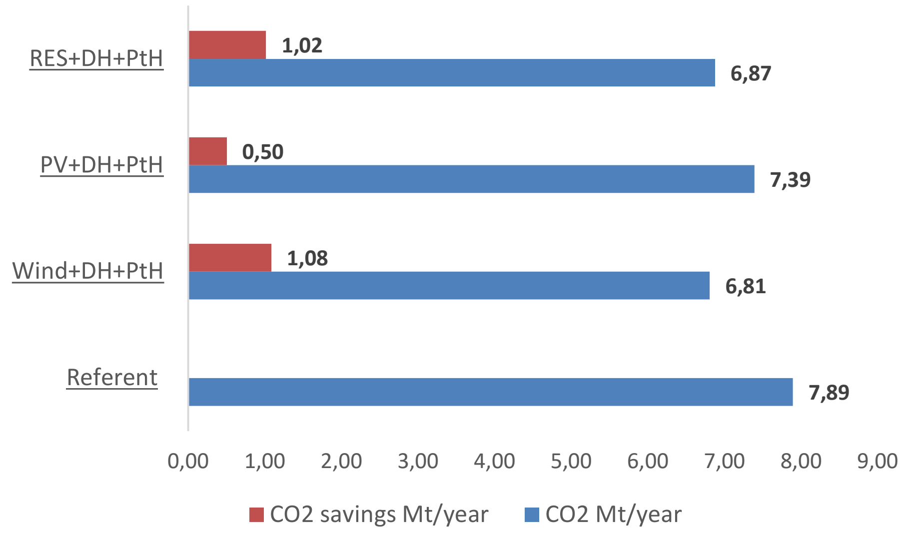

Figure 19 Total annual CO_2 emissions

Figure 19 presents total annual CO_2 emissions and its savings because of the split and combined variable RES integration and the increase DH+P_tH capacities compared to referent scenario. DH supplying 50% of total heat demand with the capacity of P_tH (HP=180 MW_{el}, COP=3, HS=16 GWh/year) was considered for estimation of CO_2 emission and its savings. It was estimated that split wind integration has a greater impact in CO_2 emission reduction accounting for 1.08 Mt/year, compared to PV with 0.5 Mt/year and combined RES integration 1.02 Mt/year respectively. From the other hand, total annual CO_2 emissions released by energy system estimated in the referent model accounted for 7.89 Mt/year. It means that wind, PV and combined RES penetration can contribute to annual emission savings compared with emissions estimated in referent scenario for 14%, 6% and 13%, respectively.

Total technology investment cost for variable renewable integration in a coal-based energy system because of the use of P_tH in district heating is shown in figure 20. The investment costs for DH heat production, large scale HP's and thermal energy storage remains the same for separate and combined integration of variable renewables. The reason is that technology capacities have remained the same in three different cases. In contrast, the investment costs for PV, Wind and combined RES (PV+Wind) technology integration changes because of the different investment costs and power integration capacity. The investment cost for PV, Wind and combined RES integration accounted for 761, 853 and 933 Mil€ respectively.

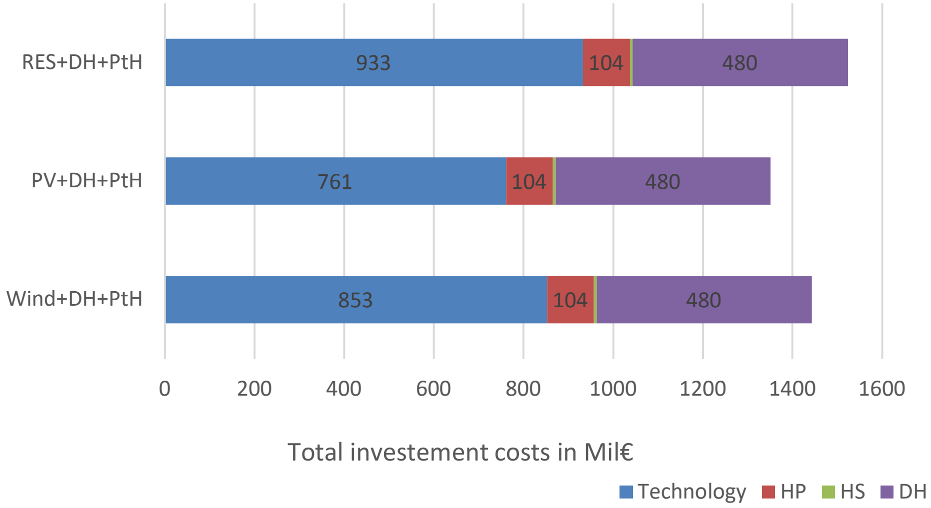

Figure 20. Total technology investment costs

CONCLUSION

The results of this research demonstrate a significant positive contribution to the implementation of P_tH technologies on the increased potential for renewable penetration into coal-based power systems with limited transmission line capacities. From the analysis of results, it has been shown that a significant increase of the coal-based power system's flexibility can be provided by P_tH technologies. A higher share of variable renewables will, of course, have a positive effect on the reduction of CO_2 emissions and fuel consumption. The integration of HPs into DH could increase the potential for increasing the RES significantly, especially in isolated energy systems.

It was found that the wind and PV power plant capacities that can be installed in the actual Kosovo energy system, when operating in an isolated mode, are 450 MW and 300 MW respectively. Additional power plant capacities around 800 MW for wind and 385 MW for PV can be further integrated into an isolated energy system with the contribution of P_tH technologies coupled with thermal energy storage in DH. It was shown that such additional wind and PV capacities will cover 14% and 5% of the total annual electricity demand. Apart from this, 515 MW was estimated variable RES (sum of Wind+PV) integration because of the application of P_tH in DH covering for 8 % of total annual electricity demand. Apart from such analysis, different P_tH capacities were assessed to estimate their impact CEEP reduction and variable RES integration in an isolated energy system. It was found that maximum integration capacities for wind, PV and RES happens at different HP+HS capacities. For instance, for maximum integration of wind power plant, the following capacities are needed HP=180 MW_{el}, COP=3 & HS=14 GWh/year. In contrast, very small capacities of HP+HS (HP=40 MW_{el}, COP=3 & HS=4 GWh/year) is needed for maximum utilization of PV power plants. Compared to split wind integration, smaller capacities of HP+HS are needed for maximum utilization of variable RES. With other words, HP+HS capacity needed account for HP=110 MW_{el}, COP=3 and HS=8 GWh/year.

Besides the contribution of DH and P_tH to increase the share of variable RES power plants in power systems, they can additionally contribute to increasing TPES and CO_2 emission savings. DH supplying 50% of total heat demand with the capacity of P_tH (HP=180 MW_{el}, COP=3, HS=16 GWh/year) was considered for estimation of TPES saving and CO_2 emission reduction. It was found that split integration of wind can contribute to decease TPES and CO_2 emissions for 12% and 14% compared to the referent scenario. TPES and CO_2 emission savings for split integration PV power plant compared with the referent scenario were estimated 10% and 6% respectively. Finally, the combined integration of RES can contribute to 12% TPES and 13% CO_2 emissions savings.

It has been demonstrated that even in a very well interconnected power system P_tH will provide enough system flexibility to integrate a high share of wind penetration. The contribution of P_tH technologies for PV penetration in current power system based on coal is not that significant because the power production from PV happens during the summer months when the heating season ends. Because of the limited countries energy system flexibility potential, this research opens the way for further examinations on P_tH coupled with power-to-x (gas, liquid, electric vehicle batteries, or electrification of transport sector) technologies that will be able to provide enough power system flexibility to capture the excess production from RES, especially during the summer months.

Acknowledgments

The dissemination of this work in 14th SDEWES conference was supported by the Kosovo Ministry of Education, Science and Technology through a small mobility grant.

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