International Journal of Sustainable Energy Planning and Management Vol. 46 2025 24–40

International Journal of Sustainable Energy Planning and Management

How sustainable renewable district heating supply and heat saving demand support the transformation of coal energy systems

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ABSTRACT

Smart district heating systems play a major role in the sustainable energy conversation and utilization processes within energy systems by providing a novel and highly efficient way of supplying buildings with heat. This paper aims to advance the practical understanding and transformation of current use of coal cogeneration units by assessing the benefits of integrating higher efficient energy supply technologies in district heating while simultaneously modelling heat demand reduction in buildings. A bottom-up model was developed for capital city of Kosovo "Prishtina" using the referent year 2018 as a base case as the heating demand and district heating potential maps were generated for this year in previous research. Several scenarios for both district heating supply and building heat demand framed by existing and future policies were investigated. Among other the expansion of district heating system, renewable wind integration via large-scale heat pumps with thermal storage, solar thermal heating production with seasonal heat storage, changes in individual heating solutions and heat demand savings in buildings have been modelled and discussed in this article. The EnergyPLAN model was used to assess the share of primary energy supply savings for individual & district heating, electricity produced via wind turbines, while considering the synergies of sector coupling in an energy system with lowering CO_2 emissions. The findings show that developed strategies for decarbonized heating and electricity sector and heat savings in buildings significantly impact the reduction in primary energy supply, renewable electricity production in an energy system with increasing flexibility and CO_2 emission reduction.

Keywords

Energy system analysis;
EnergyPLAN;
District heating;
Variable renewables;
Power-to-heat;
Sector coupling

http://doi.org/10.54337/ijsepm.10004

1. Introduction

District heating (DH) systems supply buildings with heat at a certain temperature depending on the historical time the district heating is developed. In Kosovo, the district heating system was first running in Prishtina through oil boilers. Since 2014 the district heating system was updated and switched to steam coal-based cogeneration units with a temperature supply that can be labeled to second generation of DH. Since then, continued investments have been implemented to maintain the sustainability of heat supply in buildings, however the heating was not utilized and distributed in the best possibly way especially within building distribution systems. Projects like Prishtina Heat save have been implemented recently to properly measure the energy exchange between suppliers and end users. Progress from both sides has been evident, thus additional proper planning for sustainable expansion of existing district heating provides future directions for sustainable energy use in developing countries where things change quickly.

Depending on the water supply temperature, the terminology for different generations of DH systems is created. Lund et al. [1] define the generations of DH systems by showing the differences and similarities

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Received 24.02.2025 | Accepted 04.07.2025 | Published 09.09.2025

List of Nomenclature

CEEP	*Critical excess electricity production*
DH	*District heating*
DHC	*District heating and cooling*
GDH	*Generations of district heating*
HP	*Heat pump*
KOSTT	*Kosovo transmission, system and market operator*
LPG	*Liquid petroleum gas*
NG	*Natural gas*
PV	*Photovoltaic*
RES	*Renewable energy sources*
VRES	*Variable renewable energy sources*

between the generations of district heating (GDH) systems. It concludes that the label established from 1GDH to 4GDH implies a chronological succession, but the label 5GDH does not seem compatible with terms established in other generations of district heating. Evidence from other research and practices, especially around Europe, has shown that DH is a sustainable technology that cost efficiently supports the deployment of low-cost energy production technologies.

Assessment show that low-temperature DH enables an increase in efficiency of coupled energy conversion systems with solar thermal collectors, heat pumps, and combined heat and power plants. A low-temperature level enables heat sources to deliver the heat with lower investments costs as discussed in [2]. As DH in Prishtina is looking for sustainable and low-cost heating options, planning the expansion of low temperature district heating provides additional benefits to local stakeholders. Buildings that are connected to district heating are old, thus significant investments in thermal insulation have been applied recently both in public buildings and apartments.

Switching to sustainable district heating requires changes in water temperature levels and low cost heating supply options as estimated in research [3]. The results show that high sensitivity to low supply costs from lower temperatures was found for geothermal heat, industrial excess heat, and heat pumps, whereas low-cost sensitivity was estimated for combined heat and power plants that use waste biomass. In Prishtina, research on geothermal heat, industrial and biomass is rather limited hence industrial heat pumps in DH seems a more viable solutions considering current local constrains. Apart from sustainable heating supply, progressing towards low temperature DH in Prishtina has other benefits when assessing the energy sector holistically.

For instance, the research evidence in [4] concludes that DH and cooling have an important role to play in future sustainable energy systems – including 100 percent renewable energy systems – but the present generation of district heating and cooling (DHC) technologies will have to be developed further into a new generation in order to play such a role.

The transition from the second generation of DH towards the 4GDH, as it is the case for Prishtina, means that transformed low temperature DH systems will be able to supply heat in a sustainable and efficient manner [5]. In other words, the 4GDH will supply existing and future buildings with low-temperature heat sources, utilize renewable heat like geothermal [6], biomass, solar thermal collectors [7], waste heat from buildings and industry [8], among others. The fourth generation will also be a perfect solution in coupled electricity and heating sectors by integrating low-cost renewable sources, low-temperature heat sources and large-scale heat pumps with thermal energy storage tanks. Looking at thermodynamic perspective, low-temperature DH also enables low energetic and exergetic heat losses, feasible economic integration of waste heat sources such as heat from data centers and supermarkets [9].

EnergyPLAN is a dynamic energy modelling tool capable of analyzing the transformation of integrated sectoral assessments in highly efficient energy systems. In general it is used for analyzing renewable utilization by looking at sector integration of current and future modelling of energy systems [10]. For Prishtina, a model was created in EnergyPLAN to assess different energy transformation measures within the municipality level. Research applying EnergyPLAN includes among others the analysis of DH in energy systems, showing the role of DH for the integration of variable renewable energy sources (VRES). Research in coupled electricity and heating sectors [11] investigates how power-to-heat connected to a DH network provides both heating and enhances the flexibility needed for increasing renewable penetration in the electricity sector. The results showed enhanced power sector flexibility with significant economic benefits thanks to highly efficient heat pumps in DH.

Climatic zones also play a significant role in energy system decision making assessments. As shown in [12] power-to-heat technologies in DHC systems in mild and

Mediterranean climates increase the flexibility of power sector with increasing share of variable renewables such as wind and photovoltaic (PV) . Other studies has also mentioned that integration of VRES in DH is proven and mature solutions for decarbonizing heavy conventional based heating sector. In addition, research [13] and [14] show the significant contribution of large-scale heat pumps in DH to enhance the overall energy system decarbonization.

A recent review on current research in DH systems (including technical, economic, environmental but not limited to energy policy aspects) and building energy transformation measures is provided below. There are already developed various tools for assessing the transformation of exiting district heating systems and how connected buildings can be adapted to those changes. The technical, economic, and environmental benefits for different future DH systems based on scenario modeling and system design optimization for centralized, ultra-low temperature, and bidirectional fifth-generation district heating and cooling (5thGDHC) are presented in [15]. Results suggest that for future building stock the climate reflection with increased cooling demand makes the 5thGDHC system the most economically attractive choice.

A dynamic modeling approach is developed in [16] to determine the links between different indicators in the planning of 4GDH systems. The results of energy policy modeling show that support schemes in the form of subsidies have a greater impact on key targets compared to tax increases. Research [17] analyses near-optimal solutions that bridge the gap between simulation and optimization approaches of energy systems by evaluating the relevance of these solutions in the context of energy planning using EnergyPLAN. The proposed methodology serves as a tool for policymakers in evaluating energy system scenarios.

Energy conversion in DH production, distribution and end-use can be further enhanced through the introduction of different measures. For instance, Pakare et al. [18] investigate different alternatives for heat loss reduction, including the renovation of existing heat pipes and lowering the heat carrier temperature for DH in Latvia. The results show that national heat losses can be reduced from 12% to 6%. Additionally, the possibility of using low-cost plastic pipes increases the overall economic benefits of heating network renovation. Popovski et al. [19] discuss the compatibility of DH networks with deep retrofits of buildings under various European climate conditions and city topologies. The results show that even in scenarios with a high refurbishment rate, between 23% and 68% of built-up areas, depending on city topography, are suitable for DH supply in 2050.

Joelsson and Gustavsson [20] investigate the house envelope measures and conversion of heating systems for the reduction of primary energy use and CO_2 emissions in the existing Swedish building stock. The result showed that conversion to DH based on biomass, together with house envelope measures, reduces primary energy use by 88% and CO_2 emissions by 96%, while reducing annual social costs by 7%. Ziemele et al. [21] develop a system dynamics model for determining whether energy efficiency policy can accelerate the shift from fossil fuels to renewables in the Latvian DH system. The study concludes that it is possible to reach a 98% renewable energy share in DH if the cost of gas boilers is reduced. Lidberg et al. [22] show the role of different building energy efficiency refurbishment measures in DH systems. The results show a significant difference in primary energy savings for different refurbishment packages. The efficiency of DH for Danish building typologies is presented in [23]. The results show that further energy efficiency improvement of the existing building stock is essential for the realization of the 4th generation of DH technologies in Denmark. Hansen et al. [24] investigate the levelized cost of heating using DH and individual heating solutions. The paper concludes that the annual cost of DH is approximately 18% lower than an individual natural gas boiler and approximately 30% cheaper than an individual biomass boiler and an individual air-to-water heat pump.

Åberg and Henning [25] analyze the potential reduction due to energy efficiency measures in the existing building stock. The energy system optimization model named MODEST was used to investigate the impact of heat demand reduction on heat and electricity production. The electricity to heat ratio for the system increased for heat demand reductions up to 30%. The space heating in buildings is expected to decrease [26], as opposed to domestic hot water, which is likely to increase due to an increase in the standard of living conditions [27].

Prishtina, the capital city of Kosovo, already has a DH system based on a 140MW coal-based cogeneration plant [28]. The system belongs to the second generation of DH systems, where the water supply temperature is 110˚C, while the return temperature is 65˚C [29], [30]. Due to the high temperature, heat losses in the distribution system are around 8% of the total heat demand [31].

Additionally, there were significant losses in end-use building heat consumption, so various measures have been undertaken through energy audits and real consumption measurement device applications to enhance the quality and efficient distribution of heat supply from exiting DH. Local authorities are continuously looking for expansion of district heating dure to high satisfaction of end users being supplied by DH system, hence a proper planning would additionally help decision makers to understand the technical potential of DH in heat supply and overall energy balance coupled with other sectors. There are already plans for expansion of DH from additional coal-cogeneration units, but the potential is even higher when utilizing the renewable heat pumps district heating solutions in Prishtina energy system with reduced heating loads. Studies on buildings audits showed significant potential in buildings renovations and heat savings accounting for up to 68% reduction potential hence, this paper develops a model considering local constraints and exiting geographical studies to shed light on DH system developments. In the local context, this study supports the development of DH infrastructure considering other bottom-up heat demand and district heating potential maps. Furthermore, it informs and prepares decision makers for better managements strategies in DH development and its potential benefits. It is in line with other heat roadmap European studies. This DH system could sustainably switch towards the 4GDH, where the water supply temperature decreases significantly to 50-60˚C, while the return temperature is around 25˚C [32]. This transformation of the DH system should happen from both the supply and demand sides hence this paper develops scenarios for assessing the role of expanded low temperature district heating in the overall energy system and renewable heat pumps integration to lower total primary fuel supply and CO_2 emissions. The 4GDH systems is expected to supply space heating and domestic hot water heating to existing and refurbished buildings [33].

1.1 Aims and scope

There has been extensive research showing the positive impact of DH in renewable energy systems using the modelling tool EnergyPLAN. This paper investigates scenarios that aim to sustainable supply space heating load in an assessed potential expanded DH system from an energy system preceptive. The scenarios reflect the exiting plans of local authorities for supplying current heating load and future expanded DH in Prishtina considering proved and highly efficient heating strategies in coupled heating and electricity sectors. Besides proposed assessed measures in energy supply options the model also considers heat demand reduction as for the introduction of energy efficiency measures in the building envelope. Thus, the contribution of this research focuses on energy system modelling in developing countries with old investment in energy technologies aiming to roadmap the pathway for suitable transformation of coal-based energy production units with renewable coupled expansion of district heating systems and increasing efficient building performances.

As for many countries in Europe, Kosovo decision makers have put significant effort in the implementation of building energy saving measures. The financing scheme includes pp to 50 and 60% of total investment cost in energy efficiency measures in residential and service buildings. Considering these developments in the energy sector a model is created in EnergyPLAN to investigate and assess the impact of expansion strategies in district heating systems, fuel replacement in individual heating solutions as well as heat demand reduction measures in buildings. Dynamic hourly modelling of combined cogeneration and compression heat pumps with diurnal thermal energy storage in the overall energy system of Prishtina municipality is assessed. On the geographical level these scenarios advance energy system efficiency use in coal based energy system infrastructures in developing countries. The choice of technology used in a particular country depends on other local factors including the culture of society. In developed words, changes in energy technology take more time to be utilized properly as they consider holistically the energy transformation, while in developing work these changes are implemented faster without many filters. Due to limited studies on other aspects of heating supply systems like geothermal, waste and other sources and coal phasing out strategies, this study provides a strategy that enhances the performance of exiting district heating systems by introducing industrial heat pump solutions coupled with increasing renewable and coal cogeneration units for grid stabilization requirements.

Apart that as elaborated by many studies this industrial heat pump strategy in district heating is more efficient solutions in terms of overall efficiency and flexibility increase through sector coupling and renewable integration. Local planning in Prishtina include the increasing of coal cogeneration capacity to 280 MW_{th}, installation of solar thermal heating production with 50

MW_{th}, seasonal thermal energy storage 400000m^3 in future expanding DH system. On the distribution side DH also continues rehabilitation of distribution grid and expanding its DH grid to reach higher share. The actual share of DH in Prishtina is 20% of potential heating demand, while the potential for expansion is 4 times higher. Research [28] showed that only 20% of total potential district heat demand is being supplied by exiting 140MW_{th} coal cogeneration DH system, while other research [26], showed that heat saving potential in buildings for Prishtina account up to 70% share.

A similar observation was identified for other buildings in Europe and surrounding countries including Switzerland. Based on our own created and other available data from different sources, a model for the referent year 2018 was created in EnergyPLAN. The referent year 2018 is chosen for further study as heating maps and DH potential assessments where developed based on that dataset created by our own studies. Even in Europe the spatial data provided from Eurostat for buildings is not complete. In the case of Prishtina, we created data manually to improve the quality of spatial distribution and modelling results.

Overall, this paper shows, using a scenario approach analysis, how existing and future heat demand in buildings both on individual and DH level can gradually be decarbonized from both demand and supply side measures using different strategies in heating with additional highly efficient heat pump technologies that allow the utilization of benefits of fuel saving, increasing renewable electricity and deeper heating decarbonization.

The paper is structured as follows: Section 2 shows the methodology, the case study and scenario analysis, Section 3 elaborates the results and discussions, and Section 4 elicits the main conclusions, followed by the references in Section 5.

2. Energy system analysis: Referent model and future modeling scenarios

This section is divided in three subsections to show the methodology that is applied in this research. The provided methodology is both a combined method and case study research that can be replicated to other similar energy systems with similar energy balance conditions, climate and technologies. The model does not go into the details of parameters of DH like supply temperatures and similar as that can be simulated with other specialized tools like TRNSYS, but in contrast the model EnergyPLAN applied in this paper through scenario assessments analyzes the overall municipality based energy system considering significant changes in the most energy consumed heating and electricity sectors exploring synergies between them in terms of overall energy system performance.

2.1 EnergyPLAN model and scenario planning

Energy system transformation scenarios were modelled in the EnergyPLAN model to assess the role of an old coal-based energy production system aiming to increase the overall performance with the introduction of various sustainable efficiency measures within the heating and electricity sectors respectively. The measures include the introduction of variable renewable electricity production, energy system flexibility assessment, individual fuel replacement, introduction of individual heat pumps, expansion and switching to district heating, solar thermal heat production in DH, introduction of industrial heat pump system and heat storage units, expansion of co-generation capacities, heating demand reduction in buildings in a coal dominated energy system.

Measures roadmap the transition for increasing the DH system. A significant attention has been paid to the flexibility assessment of sector coupling options with variable renewable electricity production with Critical Excess Electricity Production (CEEP) term. CEEP is defined as a situation in which electricity production exceeds both demand and electricity transmission capacity hence it must be avoided from electricity grid due to other blackout constrains. As EnergyPLAN offers the possibility of investigation of operational technology interaction over one year with hourly temporal resolution the same is considered as well-established tool for similar analysis and hence used in this model. A four step by step approach is used to create the Energy System model in EnergyPLAN.

First, the energy demand for the referent year was defined, second the definition of energy system supply was performed, third the regulation of energy supply system was defined and finally the alternative measures (scenarios) were proposed and assessed. Different technical regulations strategies were utilized to assess the design and modelling of a regional energy system. General inputs in the analysis are energy demands, production capacities and efficiencies, and energy sources. The outputs are annual energy balances, fuel consumption, and CO_2 emissions. The technical regulation strategy meeting both heat and electricity demand was chosen to minimize the export of electricity by replacing CHP heat production with boilers and/or heat pumps.

The EnergyPLAN model is a well-established tool for investigating the role of DH and fluctuating renewable energy integration in the energy system [10]. EnergyPLAN is a bottom-up modeling tool used to assess the large-scale integration of renewable energy sources (RES) and the impacts of heating, cooling, electricity, and transport in energy systems [34]. The coupling among heating, cooling, electricity, and transport sectors contributes to designing energy systems with better performance and lower costs. The schematic diagram of EnergyPLAN is presented in Figure 1. EnergyPLAN uses hourly distributions of resources and demand for one year to produce hourly outputs needed for the analysis of smart energy systems, as well as weekly and seasonal differences in electricity and heat demand among others. It optimizes the operation of a given system as opposed to other models that optimize the investment

The assessed methodology of proposing scenarios is summarized below. Scenarios are free of the case study and can be investigated by other energy systems with similar climate and energy technology use patterns.

Scenario 1 considers the increase of the DH system to 30% of total heat demand, while energy efficiency measures will reduce the heating demand up to 20% of total DH demand. It considers that individual coal and oil boilers will be replaced entirely with electric heaters. The scenario is modelled as an island power system to show large-scale heat pumps' contribution to increasing the share of variable renewables. The scenario considers that heat in DH will be supplied by coal cogeneration-based DH systems and compression heat pumps coupled with thermal energy storage.

Scenario 2 considers even further increase of DH and heat saving in buildings accounting for 40% and 30% of total heat demand. This scenario considers that individual coal and oil boilers will be replaced 50% with individual heat pumps and 50% with electric heaters. The power system is modelled as an island power system. Similarly, the DH will be supplied by a coal-based cogeneration system and large-scale heat pumps coupled with thermal energy storage in DH.

Scenario 3 considers that DH will be increased to 50% of total heat demand while the energy efficiency measures in buildings will reduce the heat demand to 40%. Like scenario two, this scenario considers that

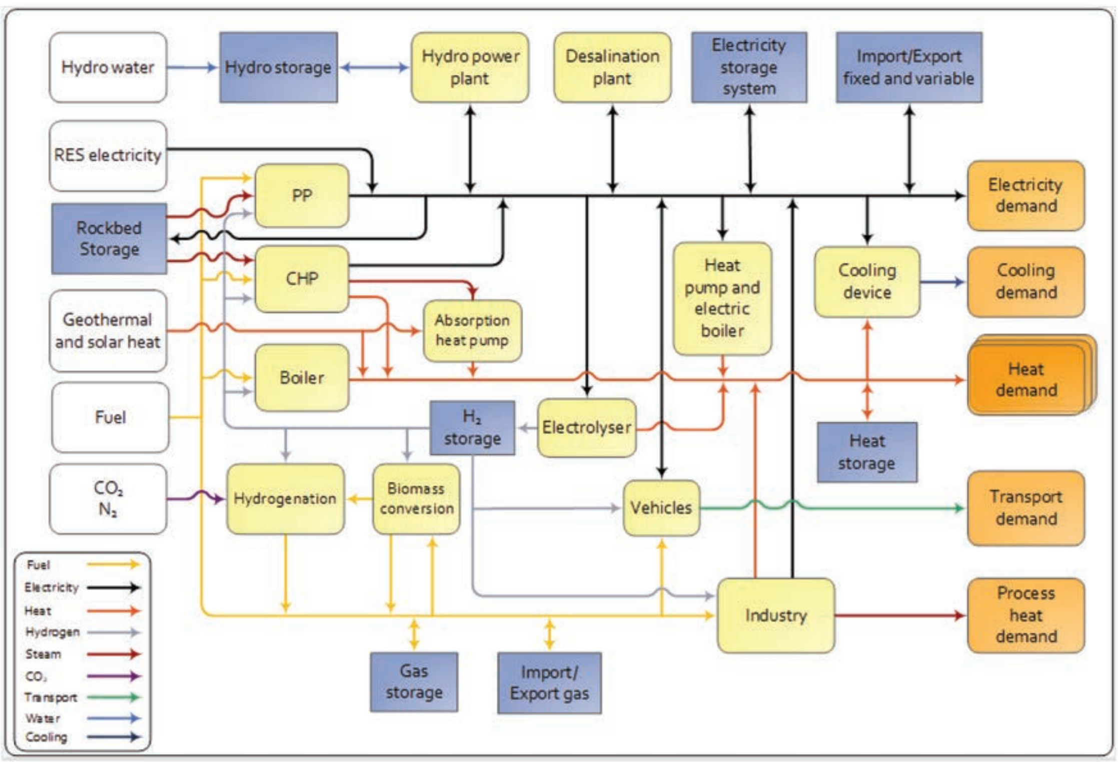

Figure 1: EnergyPLAN model [35].

individual coal and oil boilers will be replaced 50% with individual heat pumps and 50% with electric heaters. A double increase in heat pump capacity compared with the first and second scenarios can be observed. The scenario considers the interconnection capacity for variable power transmission.

Scenario 4 considers that DH will increase to 60% of total heat demand while the energy efficiency measures in buildings will decrease the heating demand by 50% compared to the reference case. In comparison to scenario 3, this scenario considers higher power transmission capacities and the application of solar thermal collectors in DH in group 3, besides large-scale heat pumps, to produce heat in the DH system

Scenario 5 considers DH will cover up to 50% of total heat demand. Due to increasing demand for heating in the future it is assumed that the total heat demand will remain the same as in the year 2018. Solar thermal collectors and thermal energy storage will be installed. Coal cogeneration will expand to supply the future expansion of DH. No sector coupling is proposed.

2.2 Case study and data sources

A model based on historical data for the reference year 2018 is modeled in EnergyPLAN. The data used for local modelling are good since they are based on reliable spatial energy data for building and energy supply/demand profiles. In Prishtina, energy consumption is quite high, thus it is assumed that energy demand will remain the same as for the referent year. This assumption was supported with the introduction of energy efficiency support schemes in buildings and heat saving measures on the distribution and consumption side. The model has not specified a particular year forward, but these changes in energy system can by planned/foreseen for the year 2030.

The capital city of Kosovo, Prishtina municipality, is used as a case study to analyze the planned changes in both heating and electricity sector aiming deeper decarbonization of its heating and electricity production/conversion units that are entirely dominated by old coal power plant units. The energy demand/supply data from the main grid are considered in the modeling. The other data include operational capacity of TPP Kosovo A and Kosovo B which is 428MW_{el} and 528MW_{el} respectively. The current net efficiency of the Kosovo A and B Thermal Power Plant units is about 28% and 36% respectively [36].

Kosovo's hourly electricity demand profile was taken from Kosovo transmission, system and market operator (KOSTT) [37], but as there was not data for municipality the hourly distribution profile of electricity consumption for Prishtina is assumed to be the same as the distribution profile of Kosovo. The hourly heating demand was calculated considering the heating degree day method where the 12C is considered as heat switching on threshold. Based on heating degree days, the heating season in Prishtina starts on 15 October and ends on 15 April. Hourly PV and wind power supply distribution profiles were generated using the wind speed and solar irradiation data from Ninja renewables for better potential zones in Kosovo [38].

Based on the data taken from [38] the capacity factors for wind and PV in Prishtina municipality were estimated at 25% and 18%, respectively. The existing DH system is supplied by a cogeneration-based system based on coal with a 140MW_{th} installed and up to date operational capacity. The heat is extracted from the steam turbine of thermal power plant Kosovo B and is exchanged to DH of Prishtina over 5-7 km. Other data that are used to model scenarios are based on published work for spatial and district Prishtina energy system modelling analysis that consider the feasible DH [28] and heat demand and saving potentials [26].

The actual DH consumption for the referent year in 2018 is 0.2547 TWh_{th}/year and it was similar over the years [39]. According to other bottom-up modelling studies, the total estimated demand for individual heating in Prishtina is 1.09 TWh_{th}/year. Table 2 presents the energy demand for different end use energy sectors. The electricity demand 0.6369 TWh_{el}/year was calculated based on specific electricity demand per person and the number of capita of Prishtina municipality. A similar approach was used for estimating the demand data in other sectors using similarities with Kosovo energy system.

Table 2 shows the primary energy supply sources for different energy sectors. As there is no data available on Prishtina level, the assumption that similar share of primary energy supply sources per sector like those one of

Table 1: Energy demand by sectors with respect to Prishtina energy system [26], [29], [31].

Energy demand by sector	(TWh/year)
Electricity	0.6369
Heating	1.3200
Industry	0.2585
Other consumption	0.2116
Transportation	0.5252

Kosovo energy balance reported by Kosovo Agency of Statistics is considered [40]. The electricity production in Prishtina in 2018 was entirely based on coal electricity. The heating sector was based preliminary on electricity and wood sources. Even today 2025, not any changes can be observed in new technology production/conversion investment, besides some changes in individual heat supply measures implemented.

The use of coal for individual heating is abounded by law and recently there is a huge trend of installing highly efficient heat pumps and wood boilers. Wood use is not yet sustainable; hence Kosovo aims to maintain it to the current level of utilization and investigate higher efficient heating solutions. There is no other quantified reported study that shows the impact of the implemented building efficiency measures and individual heat pump against individual boilers. So, this study considers these changes into scenario modelling, hence the data provided in this article sustain and are reliable for further studies.

In 2018, the electricity used for individual heating was entirely based on electric heaters. The total DH supply is 0.255 TWh_{th}/year and the heat distribution losses are only 10% [39]. The other sectoral annual energy demand data are elicited in table 2 and are used for modeling the entire energy system, however no proposed changing measures are considered in these sectors.

2.3 Future Prishtina energy system modeling scenarios

The strategies for future development of Prishtina energy system is investigated through scenario approach modelling and analysis. The model considers all energy system sectors, however the focus of this work is in the utilization of technical and sustainable development strategy of the heating sector coupled with increasing variable renewable electricity without compromising the grid stability and sustainability requirements. There is no other similar study locally that addresses these transformative changes in the energy sector or similar conditioned energy system.

Locally there are plans for duplication of existing coal co-generation capacities from 140MW_{th} to 280MW_{th} and utilize 50MW solar thermal collectors with 400000m^3 seasonal thermal energy storage. However, the potential heat demand is even larger than that, considering the power duration demand curves as shown in [26], and the renewable electrification is going to play a bigger role in deeper decarbonization of the operation of thermal power plants and co-generation units.

Kosovo in her energy strategy for 2021-2031 has set the targets for installing 734 MW wind and 710MW PV, hence the dynamic modelling of increasing VRES capacities with other parts of the energy system further accelerates the use of sustainable practices. Considering these measures, approaching the decarbonization of energy sectors separately is not a smart solution as it may lead to lower efficiencies and higher losses in the overall energy balance.

Overall, the energy system scenario planning include: the replacement of individual heating technologies with high efficient ones, increasing integration of wind in electricity sector, different heating supply options in DH including large-scale heat pumps and heat storage, expansion of coal co-generation units, utilization of solar thermal collectors with seasonal heat storage, and

Table 2: Prishtina energy sector supply data by source [26], [29], [31].

Electricity production (TWh)		**Individual Heating (TWh)**		**District Heating (TWh)**	**Industry (TWh)**	**Transportation (TWh)**	**Other consumption (TWh)**
Fuel	**2018**	**Fuel**	**2018**	**2018**	**2018**	**2018**	**2018**
Coal	0.636	**Coal**	0.168	0.255	0.035	-	0.024
River Hydro	0.016	**Oil**	0.134	-	0.201	-	0.039
Wind	0.000	**Biomass**	0.729	-	0.021	-	0.147
PV	0.000	**Electricity**	0.352	-	-	-	-
		NG	-	-	-	-	-
		Diesel	-	-	-	0.359	-
		Petrol	-	-	-	0.133	-
		LPG	-	-	-	0.031	-

heat saving measures in buildings among others. The increasing technical VRES capacities for wind power in power system are simulated in EnergyPLAN based on the critical excess electricity production (CEEP) term, as already discussed and shown in other research [41-42].

Another assumption is that the minimum operational capacities of thermal power plants were set to zero. This is hard to achieve, hence local decision makers should work out to recover and enhance the flexibility of exiting old TPP's. The technical simulation strategy with the sub strategy balancing both heat and electricity demand is chosen for designing and analysis of Prishtina municipality. This strategy minimizes fuel consumption, while balancing both heat and electricity demand. The municipality has been modelled as an integrated and interconnected energy system with other parts of central power systems.

The DH system is assumed to be increased from its current share that covers 20% of total potential DH demands up to 60% for scenario 4 and 50% for scenario 5 respectively. The DH company TERMOKOS is continuously updating and recovering the distribution of thermal grid and connecting new consumers. Gradually is seems reasonable that in the future 60% of actual heat demand can be covered by DH. Another indicator that supports this assumption is that people are moving to work or even living in cities, hence the findings are in line with other bottom-up models that consider density city space heating and domestic hot water demand maps.

In Kosovo 50% of population lives in cities and the reminder in rural areas, and this trend should remain the same for maintaining the sustainability and balance between different sectors. Due to the application of energy efficiency measures space heating demand in buildings will significantly reduce by 50% in share compared to the reference case. This assumption has seen preliminary benefits when the Kosovo institutions have provided supporting grants for building envelope thermal insulation and window replacement. Previously the efficiency measures have been focused on public buildings, but with the last legislation of support schemes from Kosovo energy efficiency fund, the fund is supporting residential consumers' as well.

The minimum thermal insulation should be at least 12cm and this reduces significantly the space heating demand. The growing interest in investing in these building envelope heat saving measures was significant from the consumer perspective as reported locally. There is no study that considers the role of large-scale heat pumps in future development of Prishtina DH system. The reason why heat pumps in DH are investigated is due to their high efficiency, local constrains and the benefits they offer in terms of energy system flexibility and variable renewable electricity production.

Large-scale heat pumps are considered as one of the least cost solutions for dacarbonization of DH systems and allowing more penetration of renewable electricity due to benefits of sector integration. There is not yet any strategic document locally that supports the utilization of this technology in the DH system. Other geothermal heat production sources are excluded from the research as there is no study that shows the potential for utilization of this technology on a local level. Individual air source compression heat pumps are gaining momentum, and its share is growing rapidly in the market. There is a project announced by TERMOKOS for solar thermal DH and seasonal thermal storage and these input data are considered in further modelling analysis [29].

3. Prishtina energy system modeling results and discussion

The following show the results of case study and scenario approach modeling applied to Prishtina energy system. The first part presents the diagram for identifying the wind power integration potential used to assess the flexibility offered by energy system when applying heat pumps with thermal storage in DH system. This methodology of maintaining CEEP under sustainable threshold is considered in all analyzed scenarios. Once the capacities of acceptable wind integration are defined, the other input data are considered from local studies and other international search as already shown in previous sections.

Additionally, the main findings of scenario modelling are presented and discussed in a logical and systematic way. Finally, a discussion was provided together with the study limitations and future study perspectives.

3.1 Critical Excess Electricity Production

The graph of Figure 2 shows the CEEP diagram used for assessing the wind integration limit in power sector in MW considering the assumptions and input data assigned to Scenario 1. These assumptions and input data include significant increase in DH expansion and building retrofitting share. Only the diagram of CEEP for scenario 1 is presented while the same approach was used for identifying the wind integration limit in other scenarios. Besides these planning changes in infrastructure, the same also includes the replacement of conventional boilers with electric heaters and heat pumps with thermal energy storage referred to as power-to-heat technologies.

Further it is highlighted the increased flexibility benefits compared to referent case (without proposed measures) when applying power-to-heat technologies for wind renewable integration in the Prishtina power sector when considering sector coupling (heating and electricity). CEEP term is used for analyzing the surplus electricity production in TWh/year that is generated in the power grid exceeding both the demand and transmission line capacities. This surplus electricity must be avoided (or utilized properly using other sustainable energy system flexibility solutions) by the power grid; otherwise, the system may collapse.

A small value of CEEP can be tolerated in the power grid thus a 5% share of (CEEP/RES) is considered in the model as an acceptable threshold for identifying the wind power capacities that can be integrated into the Prishtina power grid. Sector integration with power-to-heat technologies both in district and individual heating (heat pumps and electric heaters with thermal storage) with 100% flexible thermal power plants contributed to decreasing CEEP in the power grid, allowing for more penetration of VRES in the power grid.

In addition, Figure 2 elicits the significant contribution of large-scale heat pumps with heat storage in exiting DH system of Prishtina to decrease the CEEP, by increasing the share of wind power in the energy system. The outputs revel that around 100 MW of wind power can be integrated into the current Prishtina energy system with its actual flexibility index. The flexibility index is identified by actual energy system operational capacities to utilize the use of increasing VRES integration. This operational flexible operation is assessed with assumed ability of TPP's to decrease their minimum operational capacities.

Additionally, with the applications of heat pumps in DH with a 20 MW_{el} capacity and 10 GWh_{th} thermal energy storage, the wind share can be increased up to 150 MW. The same methodology was applied for other scenarios and the results of modeling are summarized in table 3.

3.2 Technical and environmental Prishtina energy system analysis

Respective integrated planning changes in both heating and electricity sector are aggregated and presented in Table 3. Generally summarizing the modeling results showcase the increasing space heat demand reduction, wind power integration due to sector coupling, and increasing DH share up to 60% due to application of heat pumps and thermal energy storage in future DH system of Prishtina. Additionally, scenario 5 is developed and assessed based on the exiting plans for the development of Prishtina DH system, while other scenarios tend to highlight and demonstrate the important aspects of DH electrification.

Overall, all scenarios consider an increasing share in DH, space heating demand reduction in buildings, and a substantial increase of wind in the electricity production grid due to flexibility offered by power-to-heat technologies in DH systems. The results of the modeling are summarized in Table 3.

In scenario one, the share of DH is increased by 30% of the total heat demand of the buildings. The individual coal and oil boilers are fully replaced with electric heaters. Electric heaters were considered as the price of electricity was cheap, but recently due to the increase in the electricity price the consumers are switching to individual heat pumps and wood boilers among other options. The CEEP threshold identified that 150 MW of wind could be easily integrated into an isolated power system when considering the contribution of large-scale heat pumps with 20 MW_{el} and thermal energy storage with 10 GWh_{th} in DH considering the electrification rates of individual electric heaters.

In scenario two, the share of DH is further increased to 40% of the total heating demand of the buildings. Because local institutions are providing support for highly efficient heating technologies for individual heating, in the second scenario, coal and oil boilers are abandoned and replaced with 50% individual heat pumps and 50% electric heaters. The cost of electric heaters is very cheap compared with other heating solutions, that's why such model input is considered. Flexibility index achieved in this scenario from both individual and DH allows the increase of wind power up to 125 MW.

Both scenarios 1 and 2 are modeled as isolated power systems to highlight the contribution of heat electrification in overall energy systems, while scenarios 3 and 4 consider the interconnection capacities of Prishtina network with the remaining grid considering utilized

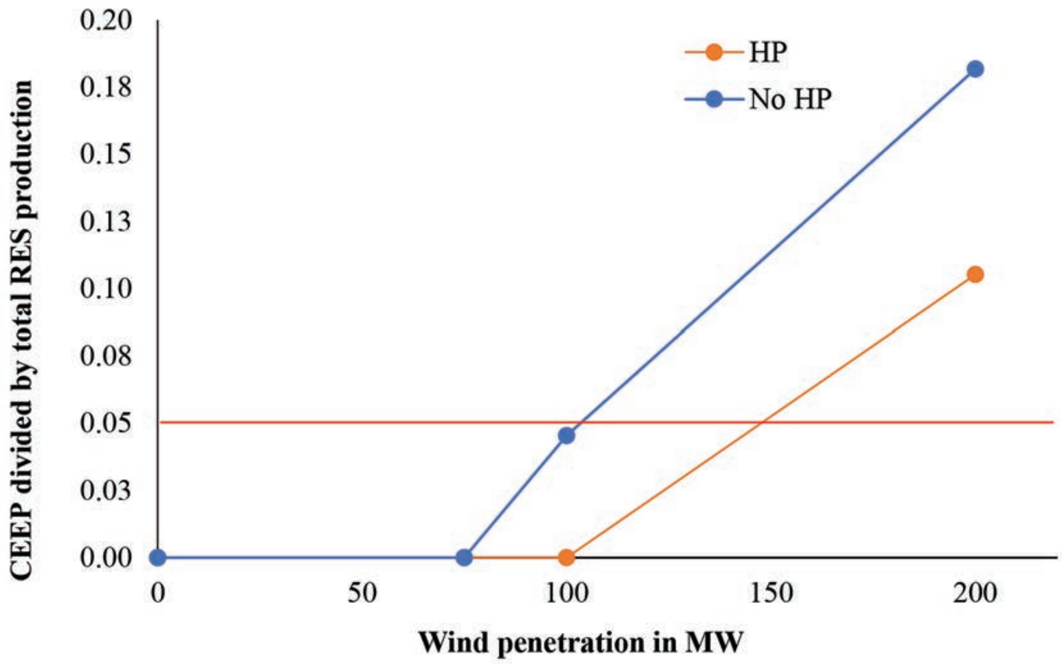

Figure 2: Critical excess electricity production vs wind power penetration in the Prishtina power sector (Scenario 1).

transmission capacities for 50 MW and 100 MW in respective scenarios. These transmission capacities allow for more flexibility in the electricity sector capable of integrating a higher share of wind power in energy system with increasing DH share. Scenario 5 does not consider sector coupling options and models the current pathway that Prishtina DH is already considering in terms of sector decarbonization.

Some additional assumptions about the individual heating were considered. A detailed description of input data used for scenario analysis and assumption is provided in table 4. All scenario analysis presented in table 4 assume that total heating demand will remain the same. In developing countries, the projection of future energy demand and technologies is very difficult as many indicators should be considered; however exiting study provides an assessment of how heating sector may evolve and the role of technologies and demand response contribution in the overall energy system.

Besides the role of heat pumps in increasing the share of renewables, they will also contribute to the decarbonization of the electricity and heating sectors. Figure 3 shows the percentage of VRES in electricity production. The highest share of VRES in electricity production, around 62.3%, can be observed in scenario four, where the penetration of wind power in the power system is 250 MW. In scenario one, the share of VRES for electricity production is 31%, and continues to increase in scenarios 3 and 4 as the wind power in the electricity sector increases.

The CEEP threshold shows that heat pumps in DH can increase the share of wind capacities in coal dominated power systems up to 50 MW or 30% of power system flexibility offered without heat pumps. 10% is the share of electricity produced by VRES as the contribution of the heat pump in DH. This highlights the significant impact of large-scale heat pumps in DH on increasing the share of VRES in electricity production. From the other side in scenario 5 no sector coupling is investigated, and the heating sector is analyzed according to local plans for the development of DH system.

The total planned heat production from solar thermal DH is $43GWh_{th}$/year and considering losses in the existing distribution network for 10%, the final heat supply that reaches consumers (excluding losses in the storage) is 38.3 GWh_{th}/year. The total demand for DH is 0.650 TWh/year. This means that only 5% of total could be covered by solar thermal DH, while the remaining is covered by coal cogeneration units with $280MW_{th}$ operational capacities. This does not help with the renewable electricity production as this modelled DH in scenario 5 does not enhance the flexibility of energy systems to

Table 3: Reference scenario and proposed changes for the Prishtina-energy and heating system.

Reference scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Actual heat demand 1.32TWh$_{th}$/year	Applying energy efficiency measures to reduce 20% the total heating demand of buildings	Applying energy efficiency measures to reduce 30% the total heat demand of buildings	Applying energy efficiency measures to reduce 40% the total heat demand of buildings	Applying energy efficiency measures to reduce 50% the total heating demand of buildings	Due to new buildings the heat demand remains the same as in the referent scenario
	Increase the share of wind penetration in power system up to 150MW	Increase the share of wind penetration in power up to 125MW	Increase the share of wind penetration in power system up to 200MW	Increase the share of wind penetration in power system up to 250MW	Increase the share of solar thermal collectors to produce 40.6GWh$_{th}$ with 10GWh$_{th}$ seasonal heat storage. No changes in the electricity sector are investigated
District heating share 20%	Increase in DH up to 30 of total heat demand	Increase in DH up to 40% of total heat demand of the city	Increase in DH up to 50% of total heat demand of the city	Increase in DH up to 60% of total heat demand of the city	Increase the DH up to 50% of total heat demand of the city
CHP based DH system with an installed capacity 140MW$_{th}$	CHP 140MW$_{th}$, installing large-scale heat pump in DH with 20MW$_{el}$	CHP 140MW$_{th}$, installing large-scale heat pump in DH with 25MW$_{el}$	CHP 140MW$_{th}$, installing large-scale heat pump in DH with 50MW$_{el}$	CHP 140MW$_{th}$, installing large-scale heat pump in DH with 50MW$_{el}$	Increase the CHP capacity to 280MW$_{th}$

integrate more renewables. In addition, even though that are renewable electricity production is excluded the strategies to enhance decarbonization are considered but with lower flexibility integration index as opposed to other scenarios.

Figure 4 shows the share of RES in the primary energy supply. Even in the reference scenario, the share of RES in the primary energy supply is 18.5%, and this is due to the use of biomass for heating in wood stoves. The highest share of RES in the primary energy supply among scenarios can be observed in scenario 4, accounting for 30.2%. There are slight differences in the RES share between scenarios 1, 2, 3, and 4, and this is due to the decrease in space heating demand in buildings and the increase in wind power. As no significant changes were proposed in the heating and electricity sector for scenario 5 the share of RES in primary energy supply is relatively low and even worse than in the referent case due to the planned increase in coal cogeneration units in future DH system.

Figure 5 shows the decarbonization potential of electricity and the heating sector. It can be noted that the emission reduction potential between scenarios is significant. The emission decreases are due to the increase in the DH system, an increase in wind in the power system, and a significant decrease in space heating demand because of energy efficiency measures. In the reference scenario, the CO_2 emissions accounted for 1.293 $MtCO_2$/year, while in the first and second scenarios, the CO_2 emissions were decreased to 0.89 and 0.87 $MtCO_2$/year, respectively. Even further emission decrease potential was observed for scenarios 3 and 4, accounting for 0.683 and 0.519 $MtCO_2$/year, respectively.

When comparing the reference scenario with other scenarios, the CO_2 emission decrease potential for scenarios 1, 2, 3, and 4 is 31%, 32.5%, 47.2%, and 59.8%, respectively. Only a slight decrease of 0.135 Mt/year in total CO_2 emissions were observed for scenario 5 compared to the referent case.

3.3 Discussion

This paper focuses on broadening our understanding for additional contribution of decarbonized heating and electricity sectors in a coal dominated energy system. It opens new ways of thinking and approaching the energy sector by firstly focusing on key components of energy systems like base load energy production technology and then progressively contributing with other

Table 4: Future scenario energy demand analysis in the heating sector.

Demand analysis	**Reference**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
District heating TWh/year						
Heat demand	0.250	0.3573	0.4169	0.4467	0.4467	0.6500
Diurnal storage GWh_{th}/year	**0.000**	3.5733	4.1689	4.4667	4.4667	-
Individual heating TWh/year						
Coal boiler	0.120	0.0000	0.0000	0.0000	0.0000	0.0000
Oil boiler	0.110	0.0000	0.0000	0.0000	0.0000	0.0000
Ngas boiler	-	0.0000	0.0000	0.0000	0.0000	0.0000
Biomass boiler	0.510	0.5016	0.3762	0.2687	0.1791	0.3762
Electric heating	0.350	0.3994	0.2402	0.1781	0.1018	0.2410
Heat pumps	0	0	0.059375	0.0424	0.0565	0.0565
	1.340	**1.258**	**1.093**	**0.893**	**0.784**	**1.324**

renewable increase in integrated sectors. The model has considered that coal power plants should be flexible enough to allow for renewable utilization in energy system, however in the case of Prishtina, this is limited and technology recovery with new investment in base load technologies are needed for maintaining the grid flexibility and stability needed to cope with modern decarbonization of energy system.

The paper showcases the role of coupled electricity and heating sector to advance further the integration of wind power hence achieving greater contribution in emission reduction impact and fuel savings. Technically approaching the electricity and heating sector integration highlights the benefits if increasing integration of wind power in Prishtina energy system. Other studies have already shown that power-to-heat technologies for both individual and DH solutions are among the most cost-effective solutions for the decarbonization of the energy system depending on the local constrain conditions.

Research investigated low temperature heating strategies [39] and showed that geothermal heat, industrial excess heat and heat pumps are also sensitive to low costs, which can be an additional open local research that needs more data and other field cooperation. As for the limited data on geothermal, the model was focused on heat pumps analysis, while there is no large industry with excess high heat temperature that can supply Prishtina DH system. Hence, this research focuses on deep electrification of the heating sector but also considers current plans and strategies in the development of the heating sector.

There are already plans for the expansion of DH, coal cogeneration capacities and some solar thermal collectors, but besides that the research highlights the benefits of sector coupling and potential replicability to other municipalities in Kosovo and other similar energy system elsewhere. On the local level there is not any other similar study carried out for Prishtina considering a coupled energy system perspective that considers both changes in the heating and electricity sector, thus this paper is important for local decision makers that develop strategic documents.

This study is the base model for further research on the decabonization of Prishtina energy system expanding to other sectors including transport sector. The model has limitations such as: the same the does not consider future changes in energy demand, or optimize the capacities of technologies, however it assumes that energy demand will remain the same as in the referent year. The strength of scenario modeling assessments include the data input from strategic documents, exiting research on future development DH systems and local policies.

Some bottom-up spatial models are already developed for Prishtina considering both maps for space heating demand and DH potential as shown in references [26] and [28]. Models on the heat production and distribution systems can be also beneficial for future planning and development strategies in Prishtina DH system and beyond. The research also highlights the importance of sector coupling (electricity and heating) compared to the alternative of that do not consider renewable plans (scenario 5).

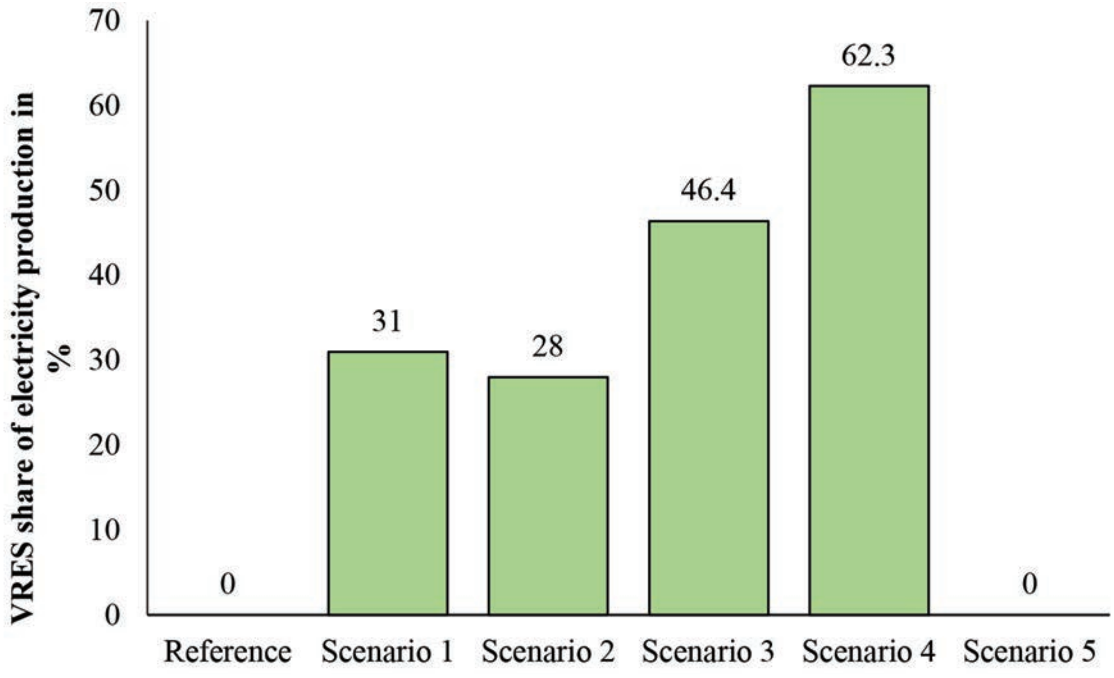

Figure 3: The share of VRES for electricity production in percentage.

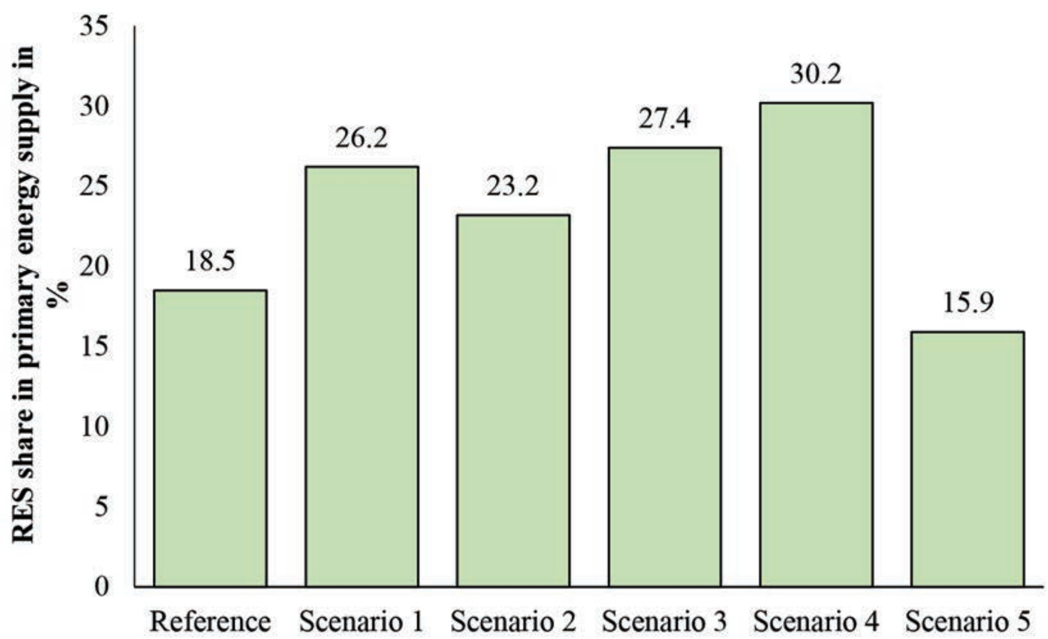

Figure 4: The share of RES in primary energy supply in percentage.

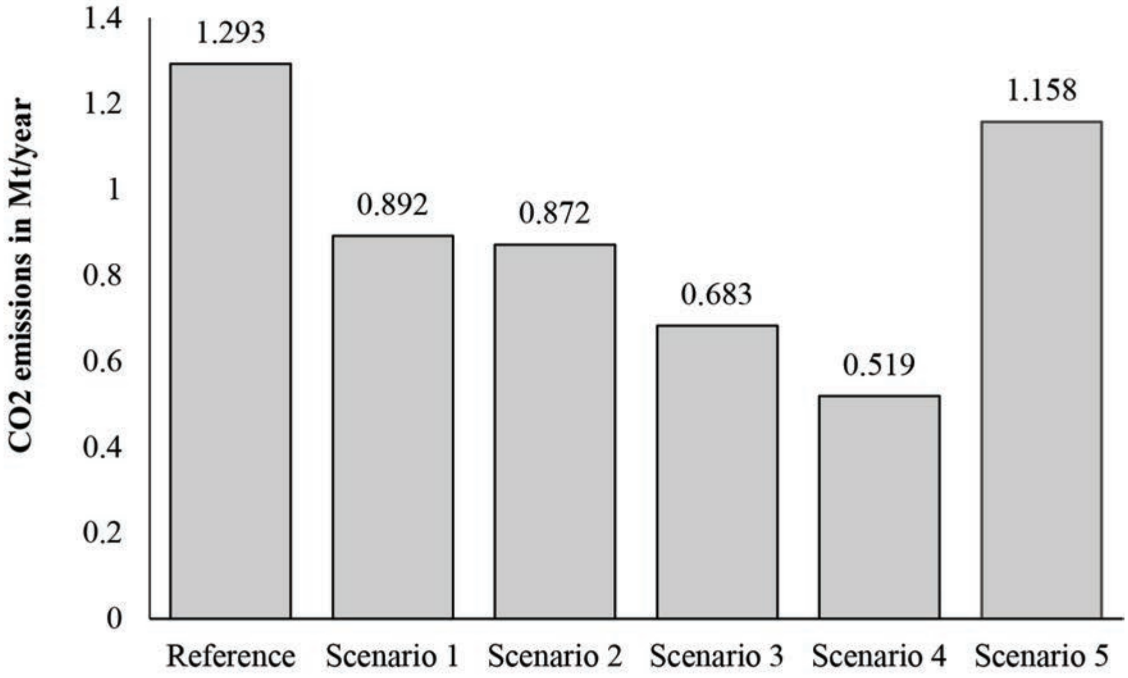

Figure 5: Total CO_2 emissions in Mt/year.

1-4 scenarios consider that heat saving in buildings will play a key role in future development of DH system with heat pumps, while scenario 5 considered that no changes in total heat demand and electricity sector are expected. This is not fully applicable as the electricity sector will evolve, and wind and PV will continue to penetrate in Kosovo energy sector as already planned and initiated in Kosovo energy strategy for 2031. Future work of this work would be the bottom-up models that provide a better understanding of the heating side effects in the heat production, distribution, storage changes like temperatures, heat exchangers, heat emitters among others.

4. Conclusion

This research develops a model to accelerate the transformation of old coal-based energy and district heating systems. An integrated energy system assessment is developed and applied to a regional energy system showcased with data for Prishtina. Greater emphasis has been paid in transformation measures in buildings, coupled heating and electricity sectors while other sectors and components of old coal-based energy systems are considered unchanged. The role of this research was to advance the understanding of sustainable practices in coal-based energy systems by providing a holistic view on current progress in coal depending on energy systems.

The research presents the technical and environmental analysis of an energy system given the focus on the transformative changes towards highly efficient district heating systems by considering the benefits of sector integration. The EnergyPLAN was used for modelling the energy balance and respective proposed changes for existing and future Prishtina energy system. The results of modelling through scenarios show that with respective changes in energy system, the wind power plant capacities that can be integrated into Prishtina power system for scenarios 1, 2, 3, and 4 are 150 MW, 125 MW, 200 MW, and 250 MW, respectively.

No electricity production from wind was identified in scenario 5, as the measures did not consider energy system flexibility increase, but solar thermal collectors in DH would cover only 5% of total future demand. Looking at other technical aspects of renewable share in electricity production for scenarios 1, 2, 3, and 4, the increase accounted for 31%, 28%, 46.4%, and 62.3%, respectively. The high share of RES electricity is only possible when TPP's operate with high share of flexibility, thus for the case study integrated assessment, the recovery of old TPP technology is needed to account for such assumption.

On the environmental impact assessment balance, the total CO_2 emissions for assessed scenarios 1, 2, 3, and 4 accounted for 0.892, 0.872, 0.683, and 0.519 $MtCO_2$/year. In scenario 5 due to only heat change assessed strategies, the total CO_2 emissions where significantly higher accounting for 1.158 $MtCO_2$/year. It sems that renewable electricity with advancement of district heating system is a more sustainable solution for the energy system compared to the case of remaining to the same state of energy system and supplying DH with co-generation and solar thermal. On a percentage values, the total CO_2 emission reduction potential compared to referent case for assessed scenarios 1, 2, 3, 4 and 5 was 31%, 32.5%, 47.2%, 59.8%, and 5% 11.5% respectively.

The best modelling results show that large-scale heat pumps in DH and heat-saving measures in buildings can contribute significantly to wind integration in the electricity sector, up to 62.3% of the total electricity demand, and achieve a 59.8% CO_2 emission reduction compared to the reference case. Future work on this paper might include other holistic approach that takes into account, besides technical analysis, the sustainability assessments to identify the other opportunities for the development of a sustainable energy system in Prishtina.

Funding Declaration

This research did not receive any funding from any source.

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