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INTEGRATION OF A ROOFTOP PV SYSTEM INTO A REGIONAL CHP PLANT AND THE IMPACTS ON PRODUCTION PLANNING – A CASE STUDY

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ABSTRACT

This study is part of an investigation on the influences of future energy demand and increased application of renewable resources on production planning of a regional energy system in the central part of Sweden. The study addresses the impacts of power supply from rooftop solar cells, increased application of heat pumps and penetration of electric passenger cars. Optimization results imply that use of heat pumps to replace district heating affects the demand side and reduces the heat production from energy plants. However, the power imports increase by 22%, compared with the reference system. By contrast, 100% penetration of electric vehicles in the transportation system only increases the power imports, without substantial effects on the energy plants performance.

Keywords: renewable resources, regional energy system, production planning, heat pumps.

1. INTRODUCTION

In 2015, around 60% of total power in Sweden was produced from Renewable Energy Sources (RES), such as wind power, hydropower and solar power. Electricity production is largely based on hydropower, accounting for 47% of total production in 2015 [1]. Only 2.2% of total power supply in 2015 was from non-renewable energy sources, which were used in cogeneration plants. Utilization of RES in heat production has also increased in Sweden. According to the data from SCB, District Heating (DH) production using biomass-based resources, such as wood and wastes provides around 60% of the total heat demand in Sweden [2, 3]. The large part of the rest is satisfied by electric heating sources, including Heat Pumps (HPs) and direct-electric heaters. Integrated energy system has become a new approach for sustainable energy development. Increased use of RES in energy systems and their interaction with conventional energy plants add new dimensions and complexity to the energy system [4]. Therefore, optimization of a more complex system is needed to find the effective factors in production planning of the regional energy system. The current study is a part of an investigation, which has been done on the influences of increased application of RES as well as future energy demand and supply on production planning of a regional energy system in the central part of Sweden. The energy system consists of Combined Heat and Power (CHP) plants, heat water boilers, hydropower, and a proposed rooftop Photovoltaic (PV) system.

Several studies have been conducted with the focus on optimization of different integrated systems of energy considering different market conditions. For example, integration of wind power, hydropower and PV system with biomass-based energy plants in Finland [5], CHP integrated with renewable power supply, including also large scale HPs in DH networks in Stockholm [6, 7] and systems including CHP plants, PV and battery storage [8]. The results of these studies indicate the important influence of local and /or changing parameters, such as the electricity price, type of renewable sources and battery lifetime. Review of the conducted studies reveals that the applied objectives in most of the optimization models consider the economic and environmental benefits with few focuses on exploring optimal production planning for an integrated system. Interaction of system with renewable resources with respect to the future trend in energy supply and demand side is less considered in modeling and simulations. There is also a shortfall in evaluation of energy systems at regional scale with respect to the resource availability. The objective of this particular study is to investigate the impacts of adding power supply from a local rooftop PV system on the production planning of existing CHP plants in the county of Södermanland in Sweden. The Mixed Integer Linear Programming (MILP) model under similar scenarios, which is developed in the previous study for the county of Västmanland [9] is used to evaluate the system, considering the regional constraints and conditions. The aim is to compare the results with the previous study and to analyze the importance of optimization at a regional scale.

2. METHODOLOGY

2.1 Case study

The regional energy system in Södermanland consists of around 22 energy plants, four of which are CHP plants and the rest are heat water boilers. Biomass-fuels, including wood chips and wood pellets are predominantly used as input fuels in energy conversion processes; however, a small share of fossil fuels is also used in some of the heating plants. There are 18 hydropower plants in the region with a total power of around 9.5 MW [10], 2 solar cell parks, one with low capacity of 170 kW and the bigger one produces around 1 GWh power per year [11]. There are also nine wind power plants with total installed capacity of 7 MW in Södermanland [12, 13]. Databases from Swedish Energy Agency and Statistics Sweden (SCB) [14] are used to collect the modelling data. The base year in this study is 2015 and all input data are collected for this year.

2.2 Rooftop PV systems

The potential power supply from rooftop PV cells is added to the studied system. Daily solar radiation in Södermanland as well as the available rooftop areas for panel installation are estimated to find the total power production. The floor area of buildings in Södermanland, including multi-family houses, single-family houses and public buildings is mostly between 60 and 120 m^2 [14]; therefore, buildings with floor area greater than 60 m^2 are used for calculations. Using the floor area and geographical data (QGIS), an average roof area is assumed for buildings of different types. The area for single-family houses and public buildings is estimated to be 120 and 100 m^2, respectively. Assuming 6.5 dwellings and a floor area of 80 m^2 per multi-family building with 3 floors, a minimum of 160 m^2 roof area is available for this type of buildings. Thus, solar power production can be estimated using total area, solar radiation per day and the efficiency of the panels, as suggested in [9].

2.3 Optimization model

The regional energy system, which is integrated with rooftop PV cells, is modelled and simulated using MILP method in General Algebraic Modelling System (GAMS). The optimization model, which was developed in the previous study for Västmanland [9], is used in this study. The optimization objective is to minimize the system cost, which consists of fuel production and imports cost, cost of conversion process in plants, products importing cost and exporting benefits. The cost of PV system is also included in the calculation. The real data from heat and power plants in Södermanland and the estimates for power supply from proposed rooftop solar cells are used in the model. The characteristic of different plants in the studied energy system are shown in Table 1.

2.4 *Scenarios and system configuration*

One base scenario and two further scenarios, which were developed for Västmanland in [9], are also used in this study to analyze the influences of future trends in energy demand and supply on the performance and operational strategy of energy plants. The system in the base case (S0) consists of regional heat and power plants integrated with the suggested rooftop PV systems. The idea of increased use of HPs suggested in the ''Increased competition on the heating market'' scenario by Sköldberg and Rydén [3] is used to formulate the first scenario (S1). Therefore, utilization of HPs in some of the DH-based buildings, which can provide up to 30% of the regional heat demand, is added to the base system. The second scenario (S2) addresses the increased penetration of Electric Vehicles (EVs) to 100% in passenger cars in the regional transportation system. The optimization results are compared with the energy system in Västmanland to evaluate the impact of regional constraints, such as available fuels, capacity of energy plants and power grid capacity for electricity import, on production planning of CHP plants. The configuration of the studied system indicating all scenarios is shown in Fig 1.

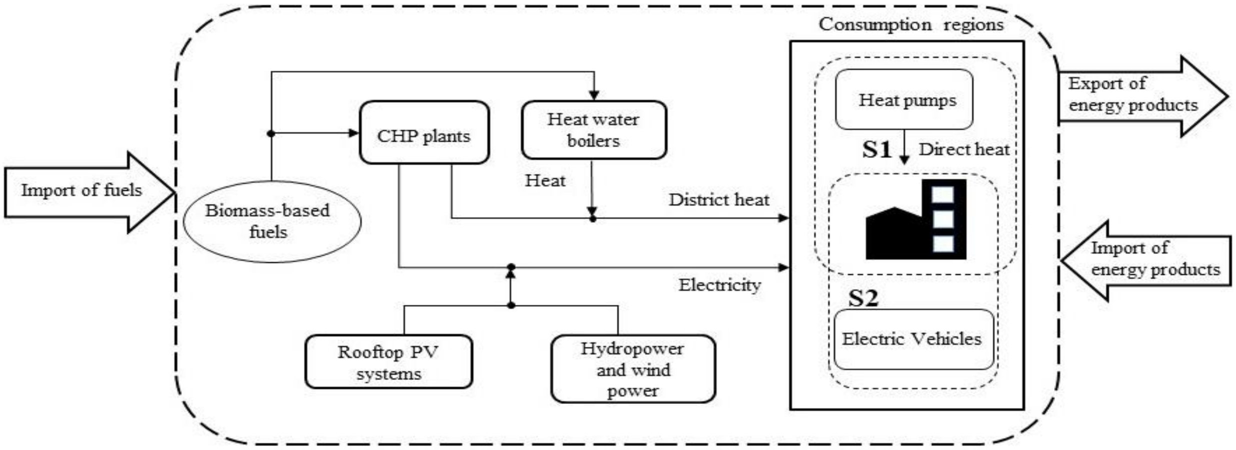

Fig 1 Block diagram view of the studied system.

Table 1 Specification of the studied energy system (real data from local energy companies).

Plant type	Fuel type	Installed capacity (MW)	Plant type	Fuel type	Installed capacity (MW)
Heating Plant	Fossil oil	30	CHP	Wood chips	110
Heating Plant	Fossil oil	65	Heating Plant	Bio-oil	5.5
Heating Plant	Fossil oil	65	Heating Plant	Bio-oil	5.5
Heating Plant	Fossil oil	65	Heating Plant	Fossil oil	5.5
Heating Plant	Wood chips	55	CHP	Recycled wood	36
Heating Plant	Wood chips	4	Heating Plant	Fossil oil	10
Heating Plant	Wood pellet	5.5	CHP	Recycled wood	100
Heating Plant	Wood pellet	5.5	Heating Plant	Recycled wood	25
Heating Plant	Bio-oil	2.3	Heating Plant	Recycled wood	25
Heating Plant	Fossil oil	2.9	CHP	Wood, bio-oil	25
Heating Plant	Fossil oil	10	Heating Plant	Wood, bio-oil	80

3. RESULTS AND DISCUSSION

The results of the optimization align with the results of the previous studies. The power generation from different energy sources in the energy system in 2015 and scenario S0 is shown in Fig 2, including the power demand.

Similar to the findings in [5], increased power supply from PV systems during summer in scenario S0 reduces imports of electricity compared with the real data for the energy system. However, during nights or in winter days, when the solar power generation reduces, the power demand is met by imports and the maximum power import occurs in December. The primary product in CHP plants in Södermanland is heat and electric power is produced as the secondary product. Therefore, increased power generation in scenario S0 would not affect the operation of the CHP plants and it is similar to the optimized energy system in 2015.

The results for scenario S1 indicate that similar to the combination of CHP plants with large-scale HPs in DH networks studied by Lauka et.al [7], utilization of HPs in DH-based buildings to provide part of the heat demand can also influence the production planning of CHP plants in terms of heat and power production and the fuel use. In this scenario, 30% of the regional heat demand is satisfied by HPs; therefore, district heat demand decreases. This results in less district heat production; hence, the operational time of CHP plants and the fuel use decrease. As an electric-based heating source, increase in HPs application in some of the DH-based buildings would increase the electricity use and power import. According to SVK[1], the maximum amount of electricity imports to the region in 2015 was around 8 GWh per day, considering the grid capacity. Given this value as an upper limit for the power transmission system, the maximum daily import in scenario S1 exceeds the assigned limit. Therefore, the system is not

[1] Direct communication with Swedish TSO (Svenska Kraftnät), 2018-05-15

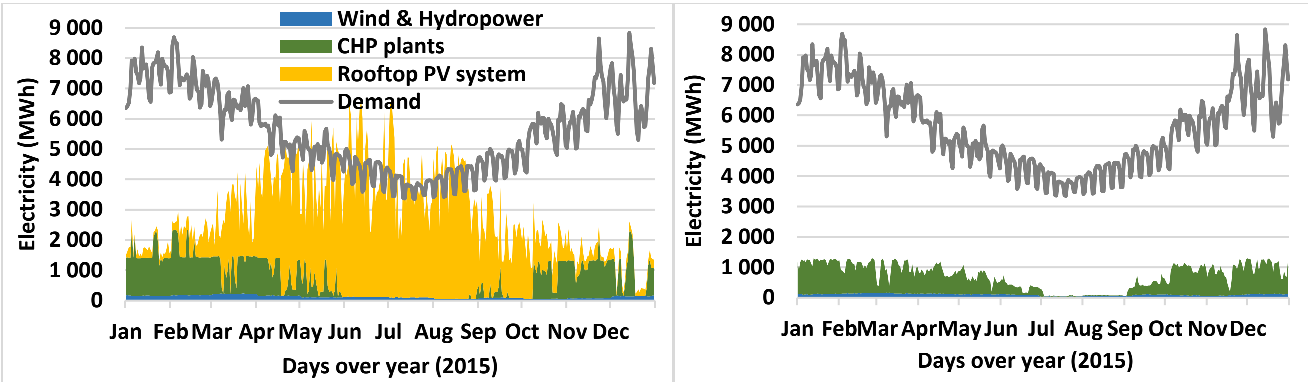

Fig 2 Power production by type of source in the optimized system in scenario S0 (left fig.) and in the real system in Södermanland in 2015 (right fig.).

optimal from power import perspective. Using electricity as the transport fuel in scenario S2 would substantially increase the electricity demand. However, the production planning of the system is not affected and there would be a very small increase in the power supply from the system. Power generation from rooftop PV systems could not meet the increased power demand and it can only cover 33% of the electric power needs in scenario S2. Total power import in this scenario is higher than in scenario S1; however, maximum daily amount is below the grid limit. Table 2 summarizes the main findings and results of each studied case. Utilization of HPs in the buildings will increase the shut-off time of the CHP plants and heat water boilers. Therefore, heat supply from the system will be reduced by 28% and lower amount of fuels will be used in the energy supply compared with other scenarios.

Table 2 Summary of optimization results of different scenarios.

	Base scenario	S1, HPs (30%)	S2, EVs (100%)
Used biomass-based fuels (kton/year)	389	275	391
Power supply-PV system (GWh/year)	798	798	798
Power supply-wind & hydropower (GWh/year)	45	45	45
Power supply-CHP plants (GWh/year)	253	198	260
Power imports (GWh/year)	1 025	1 248	1 282
Max power import (GWh/day)	6.9	8.3	7.7
Power demand (GWh/year)	2 047	2 230	2 343
DH supply (GWh/year)	1 105	774	1 105
DH demand (GWh/year)	1 105	774	1 105
Production cost in energy plants, excl. PV systems($\times 10^6$ SEK/year)	477	458	532

Fuel use in scenario S2 is almost similar to the results in the base case and there is no substantial change in the heat load of CHP plants. However, the power imports increase to meet the augmented power demand in this scenario, which will also increase the system cost. The production planning results of different scenarios indicate that among developed cases, application of HPs can influence the heat load of CHP plants more and DH production from the system decreases. Optimization results for the studied regional system are in alignment with results of the previously studied system in Västmanland. However, the power import in Södermanland is higher. This shows the importance of system optimization at the regional scale. The optimal production scheduling is not dependent on system cost only and other parameters, such as available fuel in the region, power grid capacity and transmission lines to the region and future trends in energy demand and supply need to be considered.

4. CONCLUSIONS

Increased interaction of RES with CHP plants through the proposed rooftop PV system can reduce the power imports. Use of HPs to replace DH demand affects the production planning of CHP plants and DH supply from CHP plants will decrease. Increased penetration of EVs and an increase of HPs use in buildings result in an increase of power demand in the same order of the magnitude for the two cases. The production cost of the system with HPs is also low as the operation of plants decreases.

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