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Local smart energy systems and cross-system integration

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ABSTRACT

This article focuses on two components of local energy system planning. Firstly, a 100% local renewable energy system is created, based on the interplay between the electricity, heating and transport sectors. Secondly, an analysis of the integration of the proposed local system with the rest of the country is carried out, in order to see how the two systems influence each other. The EnergyPLAN model is used as the modelling tool for creating scenarios, while MultiNode, an add-on tool to EnergyPLAN, is used for the integration analysis. The proposed system is carbon neutral, has a 47% lower primary energy supply and has the same level of total annual costs as the existing system. The integration analysis shows that 14% of the excess electricity production can be utilized in the surrounding system, revealing an opportunity to increase the capacity of renewable technologies. Modelling the hourly integration between local and national system is proved to be more accurate and reliable in comparison to conventional integration studies with EnergyPLAN where only the interconnection capacity is defined. It is also the most efficient way to fully exploit the natural potentials and integrate high shares of renewables in a technically and economically feasible way.

1. Introduction

In order to cope with the damaging consequences of climate change, 196 countries worldwide adopted the first-ever, global climate deal at the 2015 Paris Climate Conference (COP21), accepting to take efforts to keep the increase in global average temperature well below 2 °C above pre-industrial levels [1]. In the European Union (EU), climate and energy goals have been defined within the three major climate strategies: 2020 climate and energy package [2], 2030 climate and energy framework [3] and 2050 low-carbon roadmap [4]. All three strategies are focusing on three key targets: cut in greenhouse gas (GHG) emissions, increase of energy generation from renewable energy sources (RES) and improvement in energy efficiency - resulting in climate change mitigation and increased energy security. In order to achieve these EU and COP21 key targets, countries around the world have started to develop their long-term energy system development plans.

As individual countries have different resources available, as well as different structures of energy markets, they have to develop individual strategies with the objective of achieving the common targets. Every EU country is obligated to provide a national action plan, explaining the implementation of RES and energy efficiency measures in the three main sectors – electricity, heating and cooling, and transportation [5]. Within countries, local authorities, such as cities, counties or municipalities, are developing their own strategies, contributing in achieving national goals. For example, the Covenant of Mayors [6] provides a framework for stakeholders within cities throughout the EU to develop their local action plans in the form of a Sustainable Energy Action Plan (SEAP). However, such plans usually do not pay much attention to the surroundings beyond their systems' boundaries and thus, their contribution to achieving national goals might be less than it seems. If multiple cities within the same nation for instance adopt the same measures, what may work for one city is not necessarily optimal for all. Also, SEAPs are usually focused only on the period up to 2020, therefore do not deal with the comprehensive transition to sustainable energy system or the realization of a carbon neutral society.

Examples from North and West European countries, traditionally leaders in transition processes in various sectors, show that some local authorities have already developed such ambitious strategies. This includes 100% renewable energy plans for the city of Copenhagen [7], Sønderborg [8], Aalborg [9], Ringkøbing-Skjern [10] and Frederikshavn [11] in Denmark, carbon neutrality plan for the city of Malmö in Sweden [12] or climate plans for carbon

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Abbreviations

CEEP	Critical Excess Electricity Production
CHP	Combined Heat and Power
COP21	2015 Paris Climate Conference (Conference of the Parties)
CSP	Concentrated Solar Power
DH	District Heating
EU	European Union
EV	Electric Vehicle
GHG	Greenhouse Gas
HPP	Hydro Power Plant
PES	Primary Energy Supply
PV	Photovoltaics
RE	Renewable Energy
RES	Renewable Energy Sources
SEAP	Sustainable Energy Action Plan
SEE	South East Europe
TPP	Thermal Power Plant
V2G	Vehicle-to-Grid

neutral cities of Flensburg [13] and Frankfurt [14] in Germany. Looking at the East or South East Europe (SEE), not as many examples can be found, which might be due to various reasons – economic development or lack of motivation, expertise and initiative.

In Croatia, the youngest EU member, but still subjected to EU requirements, the situation is similar; although 62 towns [6] have developed their SEAP, none of them have a clear vision of how to achieve the long-term future goals regarding renewable energy and energy efficiency. The same goes for the Croatian counties, which are only obligated to develop energy efficiency action plans for the period up to the year 2020. Many counties have exceptional natural potentials to create 100% renewable energy systems and due to a large share of electricity production from hydro power plants (HPPs), some counties already obtain a majority of electricity production from RES. One such county is Varaždin County in the north of Croatia, where around 85% of the electricity demand comes from a large HPP. However, the rest of the electricity production, as well as heating and transport sectors, are still heavily dependent on fossil fuels [15]. Also, if the electricity demand continues to grow, additional production capacity might be needed to meet the demand. Therefore, a clear and comprehensive long-term plan of the energy system development is necessary for Varaždin County to address the issue of climate change mitigation and to contribute to national sustainability goals. Also, integration with the national strategy is needed in order for a plan to be as efficient as possible and to make coordination between the two levels of energy system development, avoid overestimations of potentials and over-dimensioning of the systems and to utilize the maximum level of renewable energy that can technically be utilized. Considering the surrounding when designing a future local energy system based on RES allows the neighbouring area to develop according to the same goals, which is a crucial part of an overall national goal [16].

1.1. Literature review

Reviewing the literature on future sustainable energy systems, first it is important to define the understanding of an energy system, as well as the understanding of different pathways of energy system development. Traditional energy systems usually consist of power plants for electricity production and individual or district heating (DH) boilers for heat production, sometimes in a form of combined heat and power (CHP) plants, together with all the related transmission and distribution infrastructure. The transport sector is typically treated separately and not as an integrated element of the energy system. In such a system, changes affecting one sector do not have any impact on another one, thus there are no synergies or need for coordination between sectors. Recent research shows that merging electricity, heating and transport sector helps to create the most fuel-efficient energy system, implement large amounts of fluctuating energy resources and reduce overall costs of the system [17]. Such an approach in planning a future energy system is called the Smart Energy System and its fundamentals are elaborated in details in Refs. [17,18].

The smart energy system approach has been used in creating scenarios for numerous energy systems on different scales. Among the most extensive researches was one conducted by Connolly et al. [19], who showed that by using the smart energy system approach, it is technically possible to create a 100% renewable energy system of the EU28, consuming a sustainable amount of biomass. Dominković et al. [20] modelled a zero carbon energy system of South East Europe (SEE) and showed that sector integration, combined with numerous renewable energy technologies and energy efficiency, can increase energy security and create a zero carbon system that is cheaper than the existing one. On a country level, Lund & Mathiesen [21] developed one of the first examples of how a whole country can run on renewable energy and domestic resources on a Danish example, while studies in Refs. [22,23] showed that it is possible to create a 100% renewable energy scenario in countries that currently rely mostly on imported fossil fuels, being Ireland and Macedonia respectively. An extensive literature review of smart energy systems was carried out in Ref. [24], where the authors also discussed the exact definition of the concept, as well as the approach in modelling and technology integration.

Applying the smart energy system approach to investigate the performance of different technologies was also in the focus of some researchers. For example, Østergaard [25] compared impacts of different energy storage technologies on the integration of RES in a 100% renewable energy system and concluded that electricity storage gives much better integration of fluctuating RES than heat or biogas storage, however it is associated with significant investment costs. With electricity storage being orders of magnitude more expensive than thermal or fuel storage, cross-sector integration allows for the use of these cheaper storage options [26]. Also, Thellufsen & Lund [27] explored the energy saving strategies in a future smart energy system of Denmark and showed that the combination of heat and electricity savings increases benefits of savings, resulting in synergy effects. District cooling systems were investigated in Ref. [28], where it was shown how the excess heat that is currently being wasted can be utilize to efficiently meet the cooling demand in hot and humid climates.

Focusing on local energy planning, a dominating amount of work comes from the Nordic countries or Germany, as already mentioned earlier. Østergaard et al. [9] showed that the costs of a 100% renewable energy scenario for Aalborg municipality in Denmark are at a comparable level with the reference system, while for the case of the Danish city of Frederikshavn [11], it was shown that a renewable energy system based on locally available resources is technically possible. A study in Ref. [29] investigated technical and economic benefits of interconnecting geographically distributed district heating systems in the context of a future smart energy system and showed that such an approach can lead to reduction in fuel consumption, CO_2 emissions and total system costs. Moreover, participation of municipalities in local energy planning in Sweden was investigated in Ref. [30] and it was shown