How to Establish Local Renewable Energy Scenarios in the Context of National Energy Systems

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HOW TO ESTABLISH LOCAL RENEWABLE ENERGY SCENARIOS IN THE CONTEXT OF NATIONAL ENERGY SYSTEMS

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Abstract

In the transition to 100% renewable energy systems, the local and regional implementation of renewable energy becomes essential. To implement energy systems that fulfil national targets, local investments have to be made creating a need for local energy planning. However, challenges emerge when local energy plans must be related to each other and to national targets. For instance, in terms of the division of resources between the countryside and cities, the amount of biomass to be used, and the placement of wind turbines. If local plans do not include the context of surrounding energy systems and only optimise locally, the consequences might be national sub-optimisation, including excessive biomass use, wind turbines in non-favourable positions, and the misalignment of resources between the open land and the cities. Thus, there is a risk that these necessary local plans can lead to an unnecessary national development. This paper presents methodologies and tools that can assist the design of local energy strategies to include the interaction with national energy systems. The paper applies these methodologies and tools to the case of a local energy strategy in Denmark and shows the results of establishing local energy scenarios in the context of a national system.

Keywords: Energy System Analysis, National Energy Planning, Renewable Energy, Local Energy Planning

1 INTRODUCTION

Several nations and regions are making strategies and plans for transitioning their energy systems to higher levels of renewable energy [1-3]. These are accompanied by various studies from research institutions [4-9]. Most of the plans have a national focus hence they choose the most optimal use of resources without taking into account the actions of local governing bodies. This means that the national plans work under the assumption that the local governing bodies are making decisions that support the national plans. To make the local bodies, such as municipalities, capable of making the right decisions in energy planning they need the right tools. Strategic energy planning has been suggested [10], but both Bale [10] and Sperling [11] points to that it does not necessarily make local governing bodies capable of planning their future energy system in relation to the national system.

Besides this development, cities and local bodies in several countries, for instance Copenhagen, Berlin and Seattle [12-14], have for various reasons started making and publishing their own energy and climate plans either independent or with low focus on the overall state and national goals. On a general level, local plans might help ensure a development towards more renewable energy, but there is a risk they might create a national sub optimisation.

The right local development is key to achieve the national energy strategies most efficiently. Biomass resources have to be allocated correctly between different power plants and transport demands. Wind turbines have to be placed at locations with the greatest wind potential and so on.

Therefore, there is a need for analysing both the consequences of local plans on the national energy plans and a need for developing the right tools for analysing a local plan in relation to the national strategies.

To do this, this paper looks at the development of a methodology that enables the analysis of interaction between local and national energy systems.

2 METHODOLOGY

The study develops a methodology that can analyse the connection between local and national energy planning, and tests it through initialising the development of a tool. The study applies this to the case of Denmark and Copenhagen.

2.1 Primary method

The key problem that this methodology has to address is how to deal with energy systems analysis when analysing and linking part of an energy system with the remainder of the energy system, to calculate the total energy system. An example is how to analyse local energy system in relation to the remaining national energy system in which the local system exists. Currently, tools seem to be able to do either local or national analyses [15], but it is not given that these tools can make the link between the local energy system and the national energy system. What is therefore done in some cases to handle the local-national relationship [16,17] is that certain local aspects are distributed nationally based on for instance per capita share. This concern as an example industry and surplus heat distributed to the local district heating network. Should a city benefit from this surplus energy even though the placement of the industry might be random, or should the city, in a modelling perspective, receive all of this surplus heat or only the share equal to a distribution based on per capita share? The referred studies chooses the latter option, meaning it emphasises the national perspective by reducing the local benefit of such industry. On the other hand, the city does not experience the same emissions from the industry as these are also allocated nationally. By choosing this approach, there is, however, a risk of not including possible local benefits that might be very real when analysing the link between national and local energy systems.

Therefore, this study suggest a method where local and national systems are modelled on their geographical premises. By having this approach, the indicators become measuring the individual systems but more important to identify when and where exchanges between two or more energy systems happen. These exchanges can happen across multiple sectors. In terms of Smart Energy Systems [18], the three main areas are gas exchanges, district heating exchanges and electricity exchanges. By identifying when these possible exchanges can happen it becomes possible to include a national context when analysing local systems. If it is possible to exchange the surplus electricity produced at an industrial CHP plant, the city or municipality can deduct the CO_2 emissions from these and instead attribute these emissions to the remaining national system. This approach also allows for analysing cities' local energy and climate plans, as they might include the local benefits. The goal is therefore not to only identify the possible interaction, but also to deal with it in terms of transmitting electricity back and forth or exchanging gas or heat. The measure points for this approach therefore becomes both the

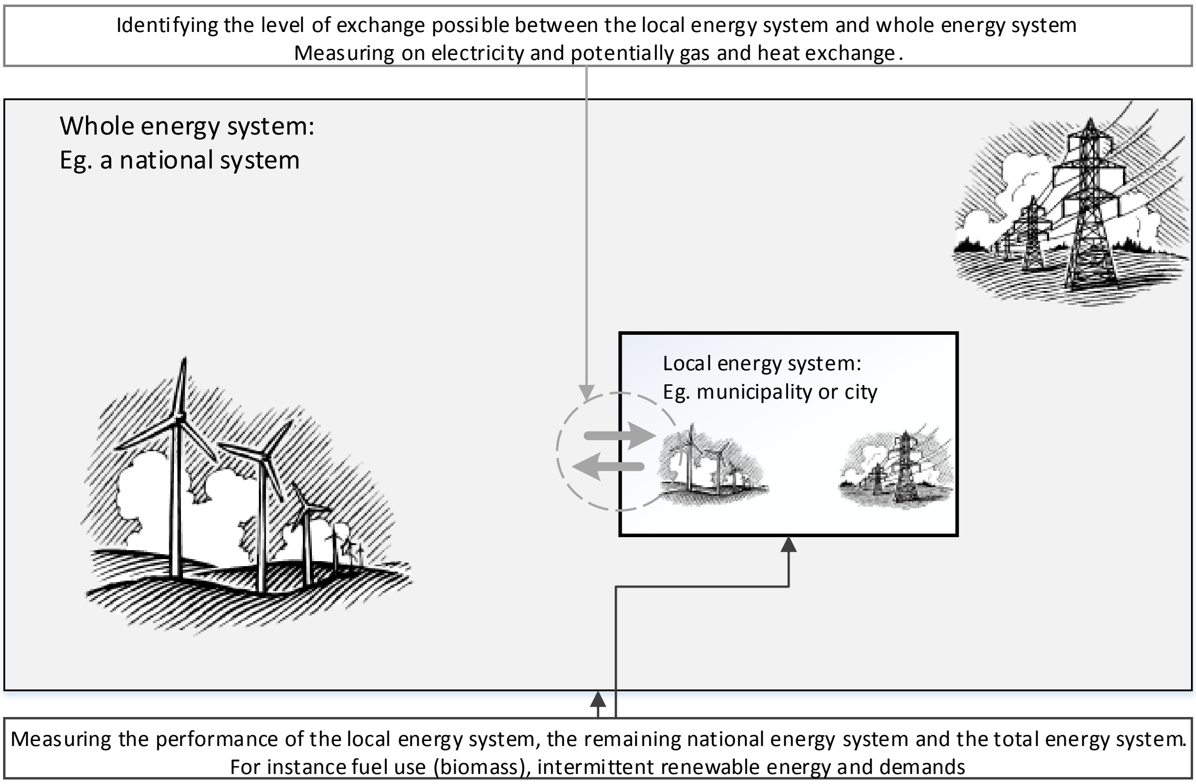

Figure 1. Methodology for analysing local energy systems in relation to national energy systems.

performance of the local system and the remaining national energy systems, and the possibilities for exchanges between the energy systems. The key to this methodology is the possible exchanges between the systems, as the measure points for the two systems could be achieved by running individual simulations for the two systems. Figure 1 illustrate this approach.

2.2 Multiple Execution Tool

To utilise the methodology described in section 2.1, and to perform analysis on a case, this study illustrates the development of a Multiple Execution Tool. The Multiple Execution Tool is modelled as a help tool for EnergyPLAN [19] meaning it operates within the same framework as EnergyPLAN. EnergyPLAN operates deterministic with hourly calculations hence, with the same inputs, the tool generates the same outputs every time.

Where EnergyPLAN only models one energy system, the Multiple Execution is capable of running EnergyPLAN analysis of up to 28 individual energy systems. The tool simulates the operation of these tools and identifies both the individual outputs of each system as well as an aggregated total of all analysed energy systems. Furthermore, the tool also provides data on exchange possibilities for each system. Currently the tool only simulates each system operating in "island mode". That means the tool is currently not able to utilise the identified exchanges to optimise between the individual systems. Therefore, the user has to study the import/export balances of the separate systems, to identify the possible synergies. The next goal for developing the tool is to enable it to utilise the exchange information to optimise between the systems. However, since the tool has the capability of identifying import and export it still illustrates the use of the identified methodology.

3 ANALAYSIS AND CASE

To analyse the consequences of local renewable energy plans in context with national energy strategies, the study simulates, by applying EnergyPLAN and the Multiple Execution Tool on a case the Copenhagen Climate Plan [13], a local system operating within a national system. The study is a technical analysis that reduces fuel consumption and does not regard costs.

Copenhagen have a target to be CO_2 neutral by 2025 [13]. The plan contains a number of concrete initiatives that makes it possible to model it in EnergyPLAN and run simulations. To define the development of the national Danish system the energy systems from the Coherent Energy and Environmental System Analysis (CEESA) study is used. The CEESA study is in line with the wind energy scenario from the Danish Energy Agency [20]. CEESA defines a number of steps towards 100 % renewable energy in Denmark in 2050. Here, the study utilizes the level Denmark has to reach in 2020 as the context for the Copenhagen 2025 system.

The reason for choosing Copenhagen is the rather concrete political plan for 2025 and that it is a rather big energy system making it suitable to model in EnergyPLAN. The geographic delimitation follows Copenhagen Municipality meaning that only energy demands and energy producing units within this limitation is included in the separate Copenhagen system. This choice is made based on that the Copenhagen Municipality only have power on this jurisdiction. However, the district heating grid in Copenhagen reaches beyond the municipal borders but since the plan primarily touches on activities within the borders this choice is necessary.

Table 1. Key inputs for the analysed energy systems

	CEESA2010	CPH2010	DK-CPH2010	**DK+CPH2010**	**CEESA2020**	CPH2025	DK-CPH2025	**DK+CPH2025**
Electricity demand [TWh]	**35,22**	2,41	32,81	**35,22**	**24,65**	2,05	22,97	**25,02**
District heating demand [TWh]	**35,87**	5,33	30,54	**35,87**	**37,49**	4,26	31,92	**36,18**
CHP3 elec. capacity [MW]	**2500**	443	2057	**2500**	**2500**	442	2000	**2442**
Power plant capacity [MW]	**7522**	610	6921	**7531**	**7450**	610	6912	**7522**
Individual heating demand [TWh]	**22,90**	0,21	22,72	**22,93**	**15,12**	0	15,12	**15,12**
Wind turbine capacity [MW]	**3802**	45,5	3756	**3802**	**6324**	362	6212	**6574**

The analysis of the cases follows the principle of having a reference system to compare with. The reference system in this case is the already defined development described by the CEESA report. The development will only focus on the development from the current Danish energy system (CEESA2010) to the CEESA scenario for 2020 (CEESA2020). The first step of the analysis is to take model a Copenhagen 2010 system (CPH2010) and subtract that from the CEESA2010 system to create a base scenario for Denmark without Copenhagen (DK-CPH2010). Since the goal is to compare two different national systems, the CPH2010 and DK-CPH2010 are added together with the use of the Multiple Execution Tool to generate the DK+CPH2010 scenario. To model the development towards 2025, Copenhagen is modelled based on the Copenhagen Climate Plan. The rest of Denmark follows the same development in CEESA. This means that the DK-CPH2010 develops towards DK-CPH2025 in the same pace as CEESA2010 to CEESA2020. This is done by identifying percentage increases in CEESA2010 to CEESA2020 and using it on DK-CPH2010 to create DK-CPH2025. Again, the CPH2025 is added to DK-CPH2025 and creates the DK+CPH2025 that is the alternative this analysis compares to the reference of CEESA2020. By making this comparison with the use of EnergyPLAN and an add-on tool in the Multiple Execution Tool, the study illustrates how local development has an effect on national energy planning and targets and how the methodology defined helps illustrate this.

3.1 Copenhagen and CEESA energy systems

Table 1 show the main inputs for CEESA2010, CPH2010, DK-CPH2010, CEESA2020, CPH2025 and DK-CPH2025. For the analysis, the CPH systems are added together with the DK-CPH systems. Table 1 marks in bold the systems that the analysis compares. One key note to make here is that CEESA estimates that the total utilized biomass should not exceed 50-66 TWh a year, and in none of the scenarios for CEESA does it exceed 60 TWh of solid biomass [5].

3.2 Results

By running the simulations, the study identifies the performance of the system based on comparing the difference in a number of parameters between CEESA2020 and the DK+CPH2025. These parameters are fuel use, wind production and capacity and CO_2 emissions.

Fuel Consumption

Figure 2 shows the development in primary fuel consumption (excluding intermittent renewable sources such as wind and solar). From the figure, in both cases the overall fuel consumption drop. However, whereas the distribution of the four fuels are similar in CEESA2010 and DK+CPH2010, it differs more in the 2025 scenarios. The DK+CPH2025 uses 9.79 TWh of coal whereas the CEESA2020 uses 50 % as much. The two systems uses almost the same amount of natural gas and DK+CPH2025 uses 2.5 TWh more oil and 6.8 TWh more biomass than in CEESA 2020. The reason for this is primarily that the Copenhagen Climate Plan emphasises the use of biomass in combined heat and power plants. Therefore, all of Copenhagen's power plants and district heating plants run on biomass in 2025, whereas CEESA expects that coal, oil and natural gas is still in use

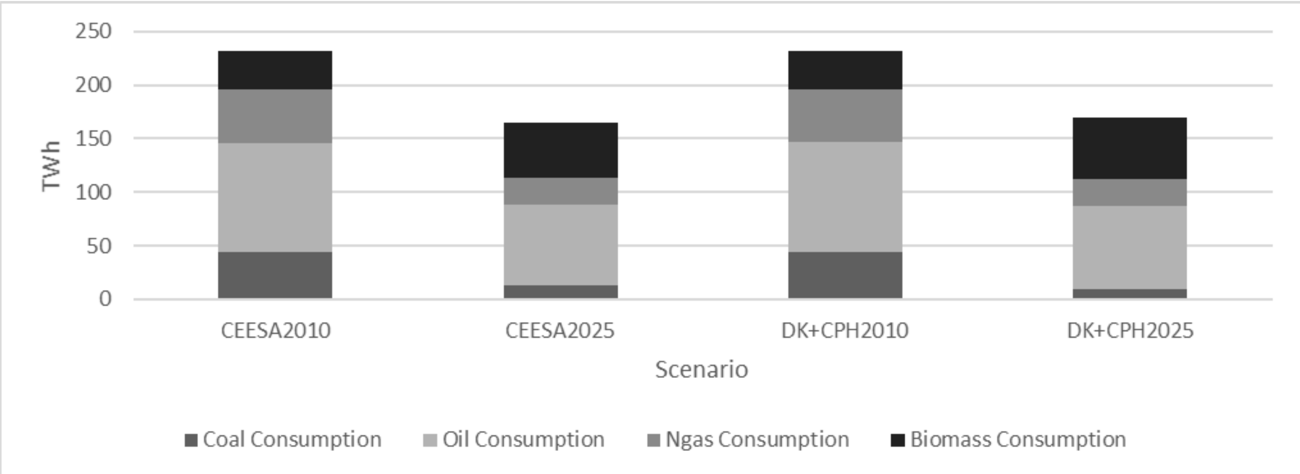

Figure 2. Development in primary fuel use in the CEESA and DK+CPH scenarios

in the electricity sector in 2025. Figure 3 shows that in total, the Copenhagen scenario when compared with the CEESA scenario results in a higher primary fuel use in 2025. The key difference is that most of the coal used for combined heat and power plants in Copenhagen are supplied by biomass instead. When comparing the use of biomass, to the limit set in CEESA it become apparent that the system in which Copenhagen develops based on its own strategy is closer to the desired limit of biomass use.

Placement of wind turbines

CEESA and Copenhagen Climate Plan expects various types of intermittent renewable energy but the biggest contributor is wind energy.

CEESA suggests an expansion of installed capacity of wind turbines, increasing from 3800 MW in 2010 to 6325 MW in 2025. In CPH2010, the amount of installed wind capacity is 45 MW. Copenhagen Climate Plan however expects a quite large expansion of wind turbines that exceeds the rate that CEESA suggests. Therefore, the total capacity of wind turbines installed in DK+CPH2025 is 6575 MW or 250 MW more than in the CEESA scenario.

By analysing the energy output from these turbines it is possible to see the consequence of installing a higher amount of wind turbines in a possible worse location than on the western coast of Denmark which has the highest wind resources. The CEESA2020 scenario produces 17.63 TWh of wind energy whereas the DK+CPH2025 scenario produces 18.02 TWh. In total, this means that the DK+CPH2025 produces 2 % more energy from wind turbines than CEESA2020. However, DK+CHP2025 have installed 4 % more capacity than CEESA. The reason for this discrepancy between installed capacity and production can possibly be due to the location in the eastern part of Denmark with lower wind resources, but it can also be due to the higher the capacity of intermittent resource become the harder it becomes to utilize the produced energy. The regulation strategy used for EnergyPLAN in this analysis does not take this into account, meaning the primary reason for the lower production per MW installed capacity is due to a not optimal location of the turbines.

CO_2 emissions

As Copenhagen has a target of being CO_2 neutral, it is relevant to see how the two systems compare in terms of CO_2 emissions. When correcting for export, the CEESA2020 system emits 30.7 Mt CO_2 per year, where the DK+CPH2025 emits 29.6 Mt CO_2. This lower emission should be due to the higher use of biomass in DK+CPH2025. What is important to mention is that the modelled CPH2025 system is not CO_2 neutral as it emits 0.7 Mt CO_2 where all comes from oil used in the transport sector. This could, potentially, be recalculated under the assumption that the exported electricity from CPH2025 all is produced on biomass or wind, meaning that it reduces coal and natural gas use in other places. An export of 1 TWh electricity would make the system “CO_2 neutral”, however it will increase the total use of biomass in DK+CPH2025 to 60.05 TWh.

4 CONCLUSION

This study have had the goal of developing a tool and method for assessing how a local energy plan affects the national energy system. To illustrate the use of the tool it has been applied to the case of the Copenhagen Climate Plan and the development of the Danish energy system suggested by CEESA.

The methodology puts an emphasis on both measuring the performance of the individual systems that are connected, and the possible exchange between the systems. The Multiple Execution Tool perform these operations, but it operates in “island mode” meaning the tool itself cannot utilise the identified exchanges to optimise between the systems. The case of developing renewable energy in Copenhagen Municipality alongside a desired national development highlights both aspect of the methodology. Measuring fuel use and wind production in both the Copenhagen system and the remaining Danish system and adding them together illustrate the importance of identifying the performance of each individual system. The CO_2 emissions show how knowledge on possible import and export can be utilised to identify how a CO_2 balance can differ in the local system. What is important to note, when utilising the export/import information is that it changes the balance when measuring locally and nationally. This also indicate why it is important to enable the Multiple Execution Tool to handle the import/export information to optimise between the systems.

Looking at the results from the case, they show that local planning without taking into account the national context and goal can lead to sub-optimisation. In the case of Copenhagen, the plan might lead to an increased use of biomass and if the goal of CO_2 neutrality utilises exported biomass produced electricity, the biomass use for whole of Denmark exceeds 60 TWh that, from a CEESA point of view, approaches the critical point for yearly biomass use. Furthermore, the placement of wind turbines in Copenhagen also generates less electricity than if they would have been placed on the west coast of Denmark.

The study does not evaluate other cases, but since the remaining Danish development is seen as a development that deploys renewable energy technology efficiently, it is assumed that another case with optimal wind resources would indicate the same wind production as CEESA. Therefore, the conclusions is that the methodology applied for this study indicate an approach that allows for modelling the local situation to its fullest while still accounting for the national context. It is also shown that exchange becomes key in how the systems operate, illustrated through the CO_2 balances effect on the fuel consumption.

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