EXPLORING THE OPPORTUNITIES OF SECTOR COUPLING – THE CONFLICTING INTERESTS OF URBAN AND RURAL ENERGY SYSTEMS

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ABSTRACT

District Heating (DH) with Combined Heat and Power generation is one of the cornerstones of the energy system in Finland. DH largely relies on biomass, that faces tightening EU regulation. An alternative strategy is Sector Coupling (SC), where electricity is used at other sectors including heating. We analyse experts' perceptions towards SC and related policies in urban and rural contexts in a region in Finland using a SWOT analysis on survey and interview data. The tightening regulation on biomass is the main threat in the region's energy system. Main opportunities include use of excess heat and electrification of heating, wind and solar power development, and increasing short term flexibility. We detect conflicting interests dependent on sector and spatial context. Region's energy strategy and policy making should address these remarks to better attain their goals.

INTRODUCTION

Electricity and heat producers were the single most CO_2 emitting sector in the world in 2020. Same applies to Finland, but the sector's CO_2 emissions are in steep decline. In Finland in 2020, a total of 42,1% of all energy consumption came from renewable sources, mainly from wood fuels. Fossil fuels counted for 34,3%, mainly consisting of oil. Nuclear energy share was 18,2%.[1]

District heating (DH) is the largest form of heat energy supply in Finland. The use of solid biofuels in DH has steadily increased during the last decade. Renewable fuels in DH surpassed use of fossil fuels in 2019. The Figure 1 shows that use of coal and natural gas have dropped significantly, while wood fuels have grown to be the largest source of DH. Most importantly for this paper, use of *Other energy sources* is growing. It consists mainly of excess heat extracted with heat exchangers from power plant flue gas, industrial processes and geothermal energy, but also using HPs to extract heat from wastewater, district cooling networks, and data centres. [2]

Electrification of heating is a sound strategy for reducing emissions: The electricity generation from low carbon sources in Finland has grown from 47% in 2010 to 69% in 2020. While nuclear and hydro have kept their share during this period, especially wind power has gained momentum: from 0,3 TWh to 7,9 TWh, overtaking coal (5,2) and natural gas (4,0) in year 2020.[3]

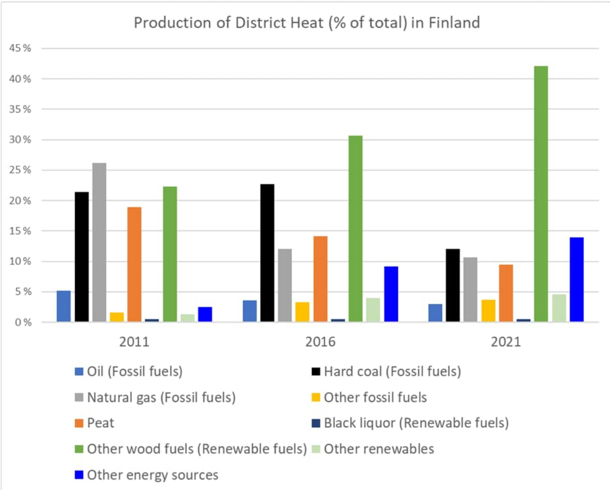

Figure 1 - Production of DH in Finland, share of total production.

While fossil fuels have been replaced with low carbon sources, Combined Heat and Power generation (CHP) in DH has been competed with separate heat production: the share of co-generated heat has dropped from above 70% to below 60% during the last decade.[4] The trend might continue. For example, Pilpola et al. [5] analysed carbon neutrality pathways for Finland and found that abundant wind power with Power-to-heat applications would drive most of the biomass, including CHP, off the market.

The shift brings challenges: Flexible peak power capacity in the electricity sector is leaving the market with CHP. Wind power is weather-dependent, and electricity cannot be easily stored for longer periods of time. Biomass has grown to a very important energy source, which predisposes the energy system to high regulatory and market risks in comparison to a more distributed fuel mix.

Sector Coupling (SC) is an efficient strategy for absorbing the temporary oversupply of electricity to the economy.[6] SC could increase system level efficiency, but the differing regulatory frameworks, market conditions and ownership structures are challenges for co-operation.[7] Electricity Distribution System Operators (DSOs) are regulated as natural monopolies, while District Heating System Operators (DHSOs) operate at the competitive market. In addition to markets, different ownership structures can affect companies' returns [8].

In this paper we ask, what are in DSOs' and DHSOs' own view the opportunities and challenges on the way to carbon neutrality by 2030, with focus on a region in Finland? We deepen the results by analysing for characteristics of urban, suburban, and rural areas.

There are 19 regions in Finland. We focus on Tampere Region (also known as Pirkanmaa), that is the second largest with population of 527 000 inhabitants – an inland region with no shoreline to the sea. The region consists of the City of Tampere (244 000) in the centre, 5 municipalities (20 000 to 35 000) around the city, and additionally 17 smaller towns and municipalities (maximum 17 000 inhabitants). In this paper we consider the City of Tampere as an urban environment, the medium size municipalities as suburban environment, and the smaller municipalities as rural environments. Figure 2 pictures the Southern parts of Finland's land area, with Tampere region coloured in red.

We aim to present relevant insights to regional and municipal decision makers who are currently in the process of updating the energy strategy of Tampere region. Further, we aim to contribute to the discussion of integrating regulatory frameworks of infrastructures.

METHODS

Council of Tampere region has developed an energy strategy for Tampere region during the end of 2022 in co-operation with regional stakeholders including municipalities, energy utilities and other private experts. The strategy refers to a pre-study conducted by an international consultancy, which includes an analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) of the energy system of the region, commissioned in 2021.[10] We aim to complement that work.

Figure 2 - Tampere region [9].

We base our analysis on two data sets. *The urban data set consists of interview transcripts and related survey responses in an urban context*. We collected 20 semi-structured expert interviews alongside a series of workshop related to developing a Positive Energy District in a new urban district in City of Tampere. We sent a survey to workshop participants in March-April 2022.

The regional data set consists of interview transcripts and related survey responses in regional context. We collected the data alongside the regional energy strategy creation during June-August 2022. We conducted 16 semi-structured interviews utilizing the method of empathy-based stories and sent a single questionnaire with questions designed to be comparable with *the urban data set*. In interviews we asked respondents to empathize themselves with a future scenario: "We are living in year 2030. Tampere region is carbon neutral, and the rapid energy system development has weakened the regional economy and security of supply of the energy system". Half of the interviewees were presented with a positive scenario, where the underlined part was altered: "…further strengthened the regional economy and security of supply of the energy system." Finally we asked interviewees to describe what has happened, preferably in the form of a short story.

The respondents typically started with a short description of positive or negative developments, a few presented a short story. After they had finished answering, we asked follow up questions related to their answers. Then we specifically asked if they think the current regulatory framework is sufficient, if SC has a positive or negative impact on region's development targets, and if the need for energy system flexibility will be large or small. Our respondents in regional data set are presented in Table 1 according to their sector and spatial context.

Table 1 – Number of interviews in regional context

	Urban	Suburban	Rural	Total
DSO	1	1	1	3
DHSO	1	2	6	9
Municipal	2	2	-	4
Total	4	5	7	16

SWOT analysis has been applied to strategic energy planning many times before. For example Kiunke et al. [11] applied a SWOT analysis in a Case study on onshore wind energy development at the German North sea region. The SWOT analysis is a useful strategy for identifying internal and external factors affecting energy system development, but it does not prioritize those factors.

We applied SWOT analysis to *the regional data set*. Due to small number of urban respondents, we reflected on the data of *the urban data set*, to validate results for urban context. The respondents included several important stakeholders for energy system development, for example energy technology companies and contractors, construction companies, investors, consultants, and energy system operators. Similar stakeholders have been interviewed in previous studies in Finland. [12], [13]

The survey consists of a multiple-choice question about 1) which targets respondents would pursue, 2) a set of single-choice questions on Likert scale (1 to 5) on which energy technologies they would develop, and 3) of which policy instruments they find favorable.

We took an inductive (bottom up) approach and coded the interview transcripts in *regional data set* with SWOT factors. We used typification to subjectively form groups of codes referring to a same category or subject. We then analysed the SWOT factor groups' incidence against experts' sector (DSO, DHSO, Municipality) and spatial context (urban, suburban, rural). We did similar analysis for survey data on both urban and regional data sets. We discuss both results in parallel in the analysis.

RESULTS

The Table 2 shows the 12 largest SWOT factor groups based on absolute number of mentions. Further on, we use the abbreviations to discuss the groups. Total number of groups after typification was 62. We also highlight some of those less mentioned, yet relevant, in this section.

Biomass is a very important energy source for especially DHSOs in the region, as seen in S1. It's equally related to an important threat T2 and could inflict negative impacts on the region's economy.

At all administrative levels security of supply is today seen very important. In conflict with the region's energy system development 1) peak electricity and heat supply capacity is under threat (T1); 2) peak electricity demand is rising (W1); and 3) apartment building owners are supported by investment incentives to switch to HPs, which is especially a threat to DH in urban areas. Latter was referred to by SWOT factor groups *T4: Actors are let to advance their own narrow interests instead of optimizing the larger system; T8: District Heating loses its competitiveness; hence systemic benefits are lost; W10: Sub-optimization takes place instead of system level thinking;* and *W18: Policies support leaving DH for standalone HPs*. Only urban and suburban actors mention the weakness of policies not enough supporting renewable energy and demand response in buildings.

O3 was an opportunity mentioned by all except suburban and urban DHSOs. They also acknowledged the general opportunity of renewable electricity but did not explicitly mention the opportunities it brings to the region. DHSOs were often referring to *S4: DH system is efficient in linking various energy sources;* and that it could harness demand side flexibility with the help of revised tariff structures. This requires investments in ICT technology that is difficult for smaller DHSOs with limited resources.

Table 2 - Most often mentioned SWOT factor groups

SWOT factor group name	Abbr.
Strength: Biomass is local and sustainable and can provide peak power during peak demand	S1
Strength: The RES potential is good and there is intrinsic momentum for deployment	S2
Strength: Energy infrastructures are future proof	S3
Weakness: Electrification has drawbacks when managed poorly	W1
Weakness: Policy is designed for the current system which hinders the transition	W2
Weakness: New low carbon solutions are still expensive or not mature enough	W3
Opportunity: Excess heat and electrification of DH	O1
Opportunity: The need for short term flexibility services is growing	O2
Opportunity: More electricity generation to the region	O3
Threat: Supplying at peak demand becomes harder and more expensive	T1
Threat: Policies related to biomass (and biogas) become stricter	T2
Threat: Inconsistent policy making hinders investments	T3

The W1 was not mentioned by DSOs. Other groups saw challenges: rural actors questioned the long-term security of supply and affordability of energy especially in wintertime if fuels are switched to electricity. Suburban actors wished to have other alternatives alongside electrification such as biogas, again for same reasons. Rural actors saw opportunities in biogas but didn't link it to downsides of electrification. The main threats named by DSOs are the T3, and *T6: Not enough of wind and solar energy will be connected to the grid in the region*. The most often mentioned weakness by DSOs is W7: Regulatory framework of DSOs does not fully support investments. Other respondent groups did not mention this challenge. Main problem for the small DSO is that while prices of components have risen, the prices acknowledged in regulatory framework have been lowered to represent average levels of DSO business in Finland, which benefit companies with larger purchasing power.

Mainly DSOs and municipalities saw the strength S2, while DHSOs, despite spatial context, mostly talked about S1. All respondent groups referred to S3 as well as O2.

Attitudes towards technologies – the surveys

The following analysis is based on responses to question in regional data set *"Which solutions would you develop (progress) in Tampere region during 2023-2030?"* In the urban data set, the question was *"Which solutions would you develop in an urban area such as Hiedanranta, to reach goals Produce more than consume and Carbon negative?"* Figure 3 represents results from regional data.

Despite different contexts, the four key technologies that respondents chose to develop were the same: *Utilization of excess heat*; *Energy storage*; *Demand response*; and *Solar energy*. The next technologies in regional context were *wind power* and *biogas*, equally important as solar.

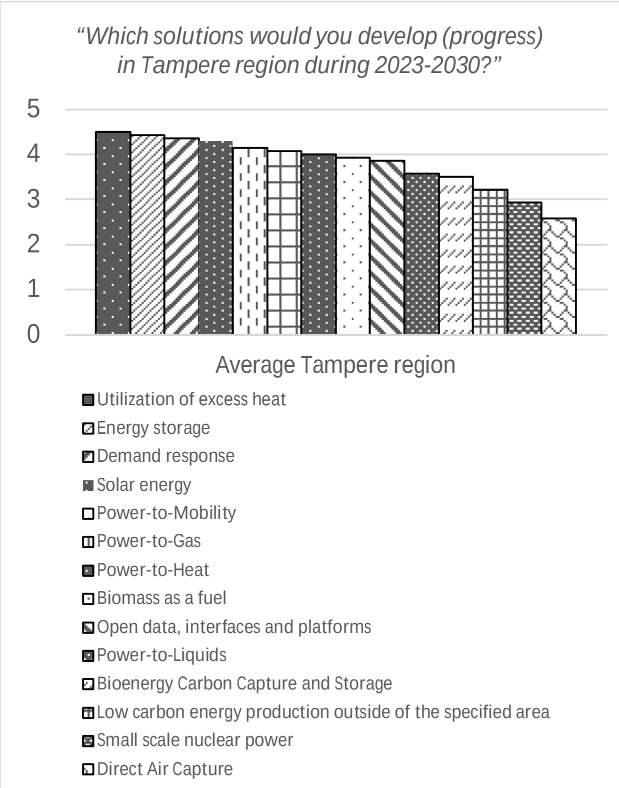

Figure 3 - Attitudes towards technologies in the region

Power-to-Gas is not seen as prominent in the urban context. This was also explicitly stated by several interviewees: in their view there is not enough space in densely populated urban district for Power-to-gas solutions.

Power-to-Heat applications were more favored in urban and suburban contexts. The DHSOs that operate a rural DH network in the region *and are privately owned* gave higher scores for "Large scale heat pumps" in comparison to rural DHSOs that are *municipally owned*. The sample was small. In interviews, these smaller DHSOs explained that large HPs are not needed for their systems, since they mostly use biomass from local sources and do not have difficulties in acquiring their fuels from local sources. In general, DHSOs were much less excited to develop HPs in apartment buildings, than Municipal respondents.

Open data receives most positive attitudes in the urban data set from researchers, municipalities, technology companies (that include ICT companies) and investors. Lowest scores in general come from DSOs, DHSOs and construction, although some experts in these groups highlighted the importance of data and ICT solutions in the interviews. DHSOs see that they are best suited for optimization of the system and hence they should possess the data.

DISCUSSION

Heating sector is the largest emitter of CO_2 in Finland, although the trend is in steep decline, especially due to large investments in biomass boilers and electrification by large DHSO. Energy strategy for Tampere region is aiming to strengthen the regional economy and to ensure security of supply. To contribute to the regional strategy process we asked, what are in DSOs' and DHSOs' own view the opportunities and challenges on the way to carbon neutrality by 2030?

According to our results, biomass is very important topic for the energy system in Finland. This has been distinguished also by e.g., Reda et al, together with the problem of perceived immaturity of low carbon technologies.[13] Its risk adds to the threat of peak power supply in the future. One possible and well acknowledged strategy to disperse these risks would be to continue the electrification of the society and use excess heat to replace some of the biomass use. Peak demand could be reduced by smart management of demand side loads like lowering temperatures in homes.

Electrification relies on growth of wind and solar power. In practice electricity generation that is built in the region generates more tax income to the region and is therefore better for regional economy. This development could be supported with regional planning and action coordinated by municipalities.

DSOs in general are very supportive of electrification since they benefit from it. Previous research shows that DSOs' profits in Finland were in general very high for monopoly business in 2015-2019 [14]. There has been active discussion on the present level of DSOs' profits. The National Regulatory Agency has made temporary changes to the regulatory framework to cut down profits[15], which might have gone too far from DSOs' perspective. Any changes affecting next regulatory period starting in year 2024 are still undecided.

DHSOs are frustrated because in their view its unfair that policy supports building level HPs, and thereby supports leaving DH - a system they consider efficient on system scale. Then again, DHSOs operate on free markets and are also allowed to offer HPs to customers. Developing novel tariff structures would make DH more competitive [16] which is also the strategy of some respondents in our data.

Excess heat is not available in rural communities and urban actors would like to see more industrial investments, that tend to locate themselves outside the central city. Hence, excess heat opportunity might be best grasped in suburban context.

Smaller DHSOs reported the lack of resources for digitalization. Data and data platforms are a prerequisite for Demand Response applications and further optimization of DH. Sharing resources, knowledge and even starting common region-wide information technology related projects might benefit especially smaller DHSOs and DSOs and help reduce the risk of smaller communities leaving behind in the transition.

In future research we'll use Analytic Hierarchy Process to prioritize between SWOT factor groups. Policy integration method could be applied to determine potential policy interventions that will foster co-operation between electricity and heat sectors. International comparison would create information relevant to EU policy.

CONCLUSIONS

The practical impact of our research findings is in influencing the regional energy strategy process and policy making in Tampere region. The results and discussion will help decision makers to see the opportunities and challenges as stated by domain experts in urban, suburban, and rural contexts.

Acknowledgments

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