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School of Energy Systems

LUT Scientific and Expertise Publications
Tutkimusraportit – *Research Reports*
120

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Towards Carbon Neutrality – a Delphi Survey Report

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Yliopistonkatu 34
53850 LAPPEENRANTA
ISBN 978-952-335-621-4 (PDF)
ISSN-L 2243-3376
ISSN 2243-3376

Lappeenranta 2020

Summary

A Delphi survey 'Towards Carbon Neutrality' based on two rounds was conducted during 2019. The survey was a continuation of a Delphi survey carried out in 2016. The first round dealt with the question of how to achieve carbon neutrality by 2035, possible barriers inhibiting the achievement, and the importance of certain technologies for achieving carbon neutrality and for the economy and the energy system in Finland. The second round focused on deepening the understanding of the data gathered in the first round.

Some key findings of the survey:

1st round

The respondents saw that carbon neutrality can be achieved in the electricity and thermal energy generation sectors, but as regards the transport, industrial, and building sectors, the carbon neutrality was not considered to be achieved. The need for change was found significant for almost all the industrial sectors. It was also seen that the influence of emissions on pricing should be strong in the electricity and thermal energy generation, as well as in the transport sector.

In addition, it was asked how the respondents saw the potential of different technologies in different contexts. As an example, the following technologies were seen as the most significant ones when considering the export potential:

- Demand response solutions
- Forest biomass (CHP)
- Other biomass (CHP)
- Waste power plants (CHP)
- Geothermal energy
- Power-to-X technologies

The results of the first survey round indicate that some barriers exist in both the business and the social environment influencing the development of energy transition in Finland. However, various non-technological barriers prevail over technological ones in many cases.

As regards Power-to-X technologies, the most potential applications were Power-to-Hydrogen, Power-to-Fuel, and Power-to-Heat technologies. The largest growth potential for different heat generation technologies was seen for heat pumps, geothermal energy, and thermal energy storages.

2nd round

The second round of the survey addressed reasons for and possible solutions to challenges related to why some sectors cannot achieve carbon neutrality, e.g., focusing on the barriers identified in the first round. In addition, there were some technology-specific questions.

For instance, it was asked what kinds of actions can accelerate the transition towards carbon neutrality for different industries. According to the responses, banning the most harmful practices could work in agriculture and mining industry; direct funding for least harmful practices could work in private transport; taxation would help both private and heavy transport; a carbon tariff was only seen useful in agriculture; tightening the emissions trading system was seen potential in petrochemistry, plastic and rubber industry, metal industry, and especially in thermal energy generation; increasing R&D would mainly be effective in mechanical, metal, and textile industries; whereas voluntary actions were not considered effective. As the results indicate, there should be different kinds of solutions for each sector. One kind of solution does not fit all.

As to the technology-specific questions, there were questions related to the preferred capacities of Power-to-Gas and Power-to-Fuel technologies in Finland. For example, many of the respondents answered that Power-to-Gas technologies should produce approximately 10–15% of the gas consumed in Finland in 2045, and power-to-heat technologies should play a major role in the future thermal energy production.

The data received with respect to barriers related to the development of a certain technology should also be considered in the light of data on actions that are needed to achieve carbon neutrality in that specific industry.

Analysis and comparison with the previous survey

In this report, an analysis and a comparison with the previous survey were also conducted. The analysis section covers a few topics related to questions asked in these two rounds, the results of which are analyzed and summarized. For example, the topics include Power-to-X and demand response solutions. In addition, there were some similarities between the surveys conducted in 2016 and in 2019 when comparing the possible changes that have taken place. Some of these similarities are compared and discussed in this report.

Keywords: Carbon neutrality, energy transition, Delphi survey

Contents

1 Introduction

Energy transition is all around us, and it has already affected energy prices and the most cost-effective methods to produce electricity. This transition is driven by the need to achieve carbon neutrality in our society, which is crucial for keeping the global warming at a tolerable level.

The Smart Energy Transition (SET) project studied technical, economic, and social implications of the global energy transition. The main objective of the project was to provide the main actors of the energy sector in Finland with insights into the crucial processes in the global energy transition and their potential impacts on Finland. A further objective was to improve the systematic learning of public administration and companies from the experiments of the energy sector. Moreover, the target was that enterprises would benefit from the research results and events when developing their business. Finally, the project promoted the capability of public administration to lead the economy in the technology transition.

The SET project was funded by the Strategic Council of the Academy of Finland, which investigates the impacts of energy transition on technologies, economy and society. The project was carried out between 2015 and 2020. The project consortium included LUT University, Aalto University, the Finnish Environmental Institute (SYKE), the Consumer Society Research Centre of University of Helsinki, the Science Policy Research Unit SPRU of the University of Sussex, VATT Institute for Economic Research, VTT Technical Research Centre, Motiva, Lappeenranta city and Heureka.

The Delphi survey of 2019 was a continuation of the first Delphi survey organized in 2016, which studied the influence of different forces of change in the future energy system in Finland by 2030 and the potential of different new energy technologies.

The Government of Finland has prepared a roadmap for achieving carbon neutrality by 2035. The objective is to present a proposal for a new Climate Change Act in early 2021. The main topics of the climate work of the Government are a comprehensive reform of energy taxation, carbon neutrality plans for the key industrial sectors, halving the emissions of transport by 2030, carbon-neutral traffic by 2040, and enabling emission-free energy production by removing barriers to these targets (Finnish Government, 2020). Despite the ambitious targets, there are still many questions related to the way of achieving carbon neutrality.

Because of the national targets set for carbon neutrality, the purpose of this Delphi survey was to focus on carbon neutrality and how the energy system should be changed in order to reach these targets. In addition, the barriers that hinder achieving the targets were studied. Following the national targets, the year of 2035 was chosen in this survey as the target for achieving carbon neutrality.

The main research question is as follows:

How can carbon neutrality be reached by 2035?

The main research question was addressed through the following sub-questions:

1. In which areas it is more challenging to reach carbon neutrality, and when it can be reached in these areas if 2035 comes to soon?
2. What are the most significant technologies?
3. What are most significant barriers and how to overcome them?
4. What kinds of organizational innovations can be identified, and what is their impact?

The outline of this report is as follows:

Chapter 1 provides information about the SET project, as well as the objectives of the first Delphi survey in 2016 and the present one. Additionally, the research questions of the study are presented. Chapter 2 introduces the methodology used in the survey and the structure of the survey. Chapters 3 and 4 present the results of the first and second rounds of the survey, respectively. Chapter 5 provides an analysis of the results, and Chapter 6 concludes the results and gives suggestions for future work.

2 Methodology of Conducting the Survey

The Delphi method, being one of the most accurate methods of forecasting, has been chosen to form the pattern of energy development in Finland. A panel of experts responded to two rounds of questionnaires, and the responses were aggregated and shared with the group during the process of the survey.

The survey was conducted in Finland during the autumn 2019, and it included two rounds. Prior to the launching of each round, the respondents received an e-mail invitation to fill in the survey. In both rounds, the respondents were requested to respond to the questions by filling in online forms. Each of the questions had a field for comments. The forms were administrated in two languages: Finnish and English. Subsequently, the comments were translated into English in case they were given in Finnish and incorporated in the report with some minor corrections in wording.

The sample included experts with various backgrounds and occupations, and their professional activities related to the energy sector of Finland. The sample was drawn from the respondents of the previous, 2016, SET Delphi survey combined with new respondents who deal with energy-related issues because of their professional activity. In total, 131 experts were invited to answer to the survey. 49 responses were obtained for the first round and 16 for the second round, which lead to response rates of 37.4% and 12.2%, respectively. However, different questions showed variation in the response rate, which was obviously due to the specifics of the questions. The profiles of the respondents are given in the last section of the presentation of each round.

The structure of the survey is presented in Figure 2.1.

The first round of the survey contained the following five parts:

A) Context and transition factors
B) Technologies
C) Enablers and barriers
D) Organizational innovations
E) Background information

The second round of the survey consisted of the following sections:

F) Significance of different barriers when attempting to achieve carbon neutrality
G) Potentialities of different technologies
H) Background information

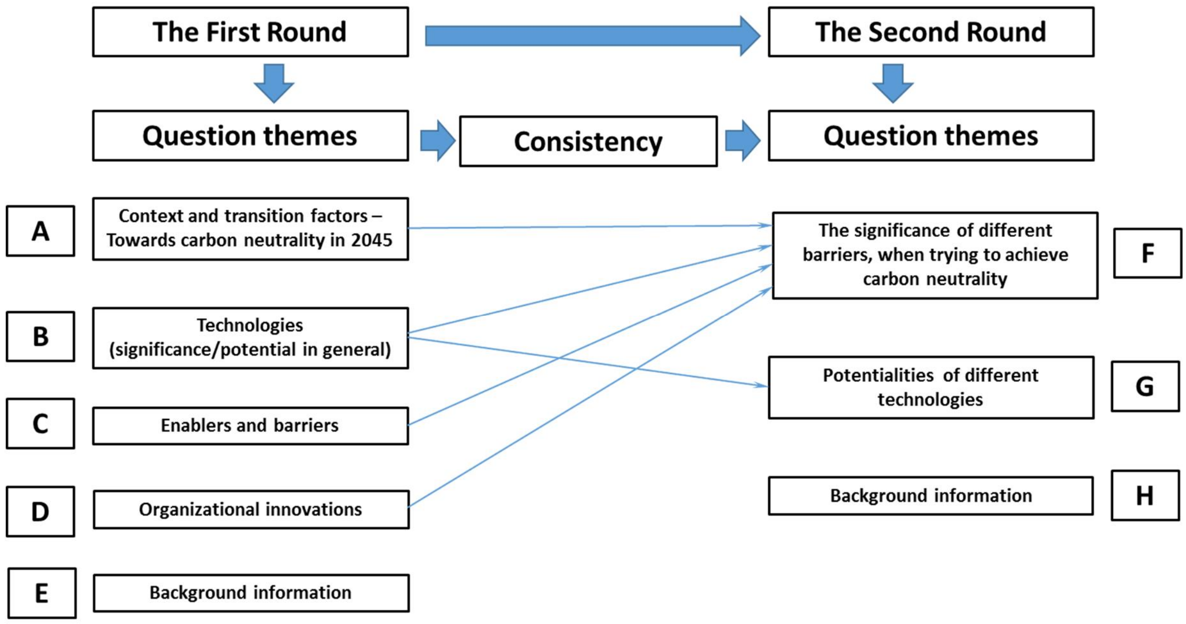

Fig. 2.1. Structure of the survey.

3 Results of the round 1 – Towards Carbon Neutrality 2035

3.1 Context and Transition Factors

The basic definition of carbon neutrality refers to a situation where the net carbon emissions are zero. The broader definition of the term means that the net greenhouse gas emissions are also zero. The situation can be achieved by balancing a measured amount of carbon emissions with an equal vent amount of emissions bound in sinks in a certain amount of time. This survey uses the broader definition of carbon neutrality.

Although the basic definition of carbon neutrality is relatively explicit, there are various approaches to calculate carbon emissions. According to Seppälä (2014), the carbon neutrality can be addressed at multiple levels. These levels are: individual, organizational, regional, and national level. This survey focuses on individual, organizational (company), and national levels. In addition, the calculation can be based on either a production-based model or a consumption-based model. The production-based model covers emissions related to production taking place in a certain area. The consumption-based model includes emissions related to production and consumption (lifetime) emissions minus emissions from products imported into a certain area. The emissions can be compensated for by using carbon sinks either inside or outside the studied area or by using carbon credits. Carbon credits are related to emissions trading programs.

It has been found that the most efficient way towards carbon neutrality is to reduce emissions in the production stages rather than compensating for them. However, Finland is a special case as the country practices intensive forest management, which can provide major carbon sinks, if carried out appropriately.

3.1.1 Transition: Who should take the responsibility for achieving the required changes in each energy-related sector?

Question: Which level (e.g., individual, organizational, or national) should lead the way in making changes to different energy sectors in order to progress towards carbon-neutral society?

Please consider responsibilities as a collective action in carbon-neutral society. Should the change happen based on individual choices/responsibilities, or should the change take place based on choices/responsibilities, e.g., at the national or organizational level? Individual responsibility could mean for instance personal carbon credits or volunteering.

Highlights: The respondents saw that in the industry (services and products), the main actors to take responsibility are companies and organizations. In electricity generation, mainly companies and nations, and in heat generation, companies, municipalities, and nations should take the responsibility. In transport and building, the main responsibility should be taken by the nations. In these two categories, the individuals have a significantly higher responsibility compared with other areas.

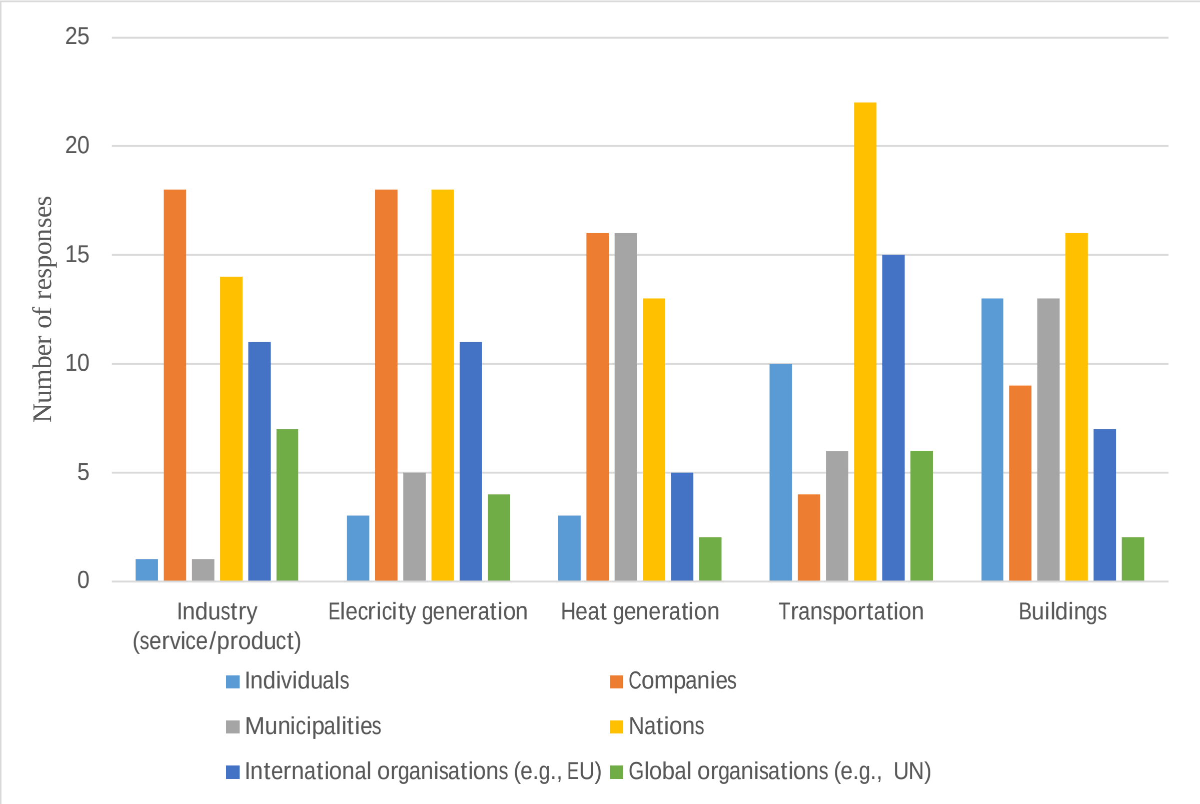

Fig. 3.1.1. Who should take responsibility when heading towards carbon neutrality?

Comments:

- It is most important to set common rules. That is a responsibility of governments. Individuals cannot steer decision-making, and people in general do not have the required knowledge (or that cannot be expected).
- Governments set the framework and thus have the most responsibility. They should steer companies, municipalities, and individuals. The EU legislation has a significant impact on products (e.g., cars, buildings).
- My opinion is that the EU or similar kinds of organizations should regulate and impose sanctions that make it possible to achieve carbon neutrality. This would include foreign business (e.g., the retracting Mercosur contract).
- The question is manifold. The regulations should be set at as high a level as possible. In contrast, the actors making responsible changes should be as local as possible.
- I think that setting strict enough guidelines for emissions reductions should be the responsibility of the national government, and the responsibility for actions and actual implementation should take place at the municipality level. However, I think that we should not rely on international regulations because there are too many other interests and harmful lobbying that lead to watering down the ambition level of international agreements.

3.1.2 Transition: Carbon neutrality in 2035

Question: Can carbon neutrality be achieved in different energy sectors in Finland by 2035?

Please consider production-based carbon neutrality (emissions from production minus compensation). Compensation can be used to achieve carbon neutrality.

Highlights: The respondents saw a possibility to achieve the carbon neutrality by 2035 in electricity production and, to some extent, also in heat production. In buildings and industry, and especially in transport, the respondents did not believe the goal to be achievable.

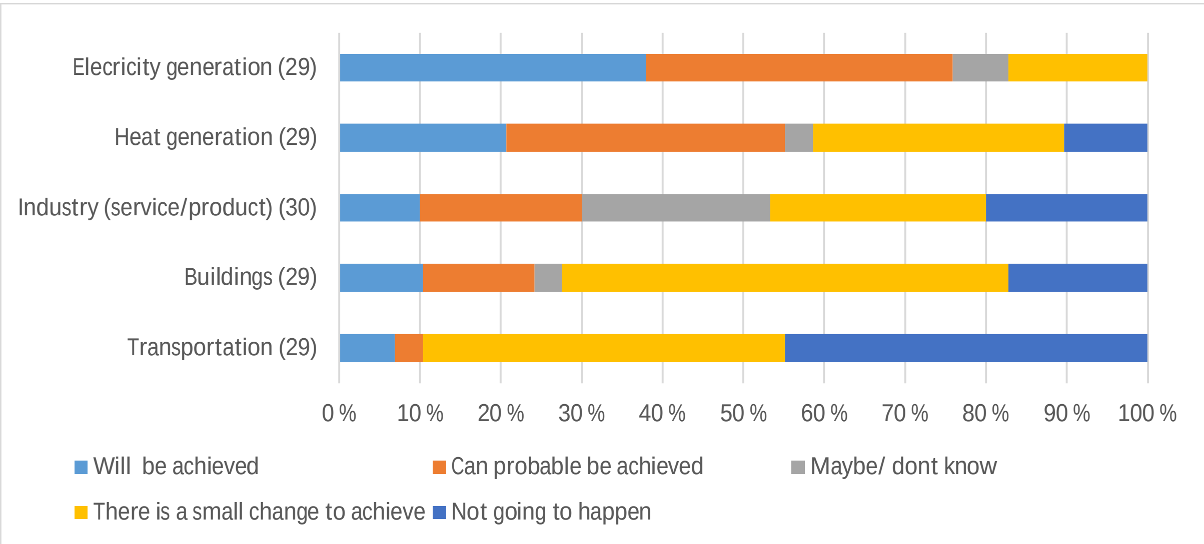

Fig. 3.1.2. Shall we achieve carbon neutrality by 2035? The number of responses is indicated in brackets.

Comments:

- 2035 is only 15 years ahead. I think the answer depends on how strictly we interpret carbon neutrality, and whether it is sector-specific. I think it is possible to reduce emissions from electricity production to close to zero, if we are able to trade internationally and purchase hydropower from Norway/Sweden. And if we consider bio-based electricity as carbon neutral.
- Buildings are for 100 years and we have scores of buildings that cannot be modified. The change in transport is still too costly and cars will be for more than ten years in use. Cement and metals will not happen before 2035.
- A lot of easy things have been done. However, there is still a lot to do. The wind, solar PV, hydro, and nuclear power are the easy solutions for electricity generation. Utilization of waste heat and improving energy efficiency holds a great potential. Still, achieving carbon neutrality in the thermal energy sector is much more challenging than in the case of electricity production. The transport sector is the most challenging. First, I would put the effort into achieving carbon neutrality in the thermal and electricity generation sectors. In transport, I believe that the Power-to-X solutions provide one crucial solution to decrease emissions. Power-to-X solutions should be one of the leading technology development targets.

3.1.3 What has to change by 2035?

Question: By assuming that carbon neutrality is the target for 2035, select the five industrial sectors that have to change their current and future planned practices most. There are several guidelines for how much we have to reduce the CO_2 emissions to achieve carbon neutrality in Finland, but information is still lacking on how to achieve these reductions. Please consider also the already ongoing transition or near future transition in different sectors.

Highlights: The respondents saw that the most significant changes are required in public and heavy transport, agriculture, and petroleum industry. Electricity production and heating the buildings, on the other hand, require changes but not significant ones.

Comments:

- A change in farming has not started at all, nor it is discussed. We have means to produce plastics from sustainable raw materials, but we do nothing. Solutions to heavy duty traffic do not exist yet.
- I would say that everything requires a significant change.
- Industry has to change its operating models radically. This change does not take place without the help of legislation.

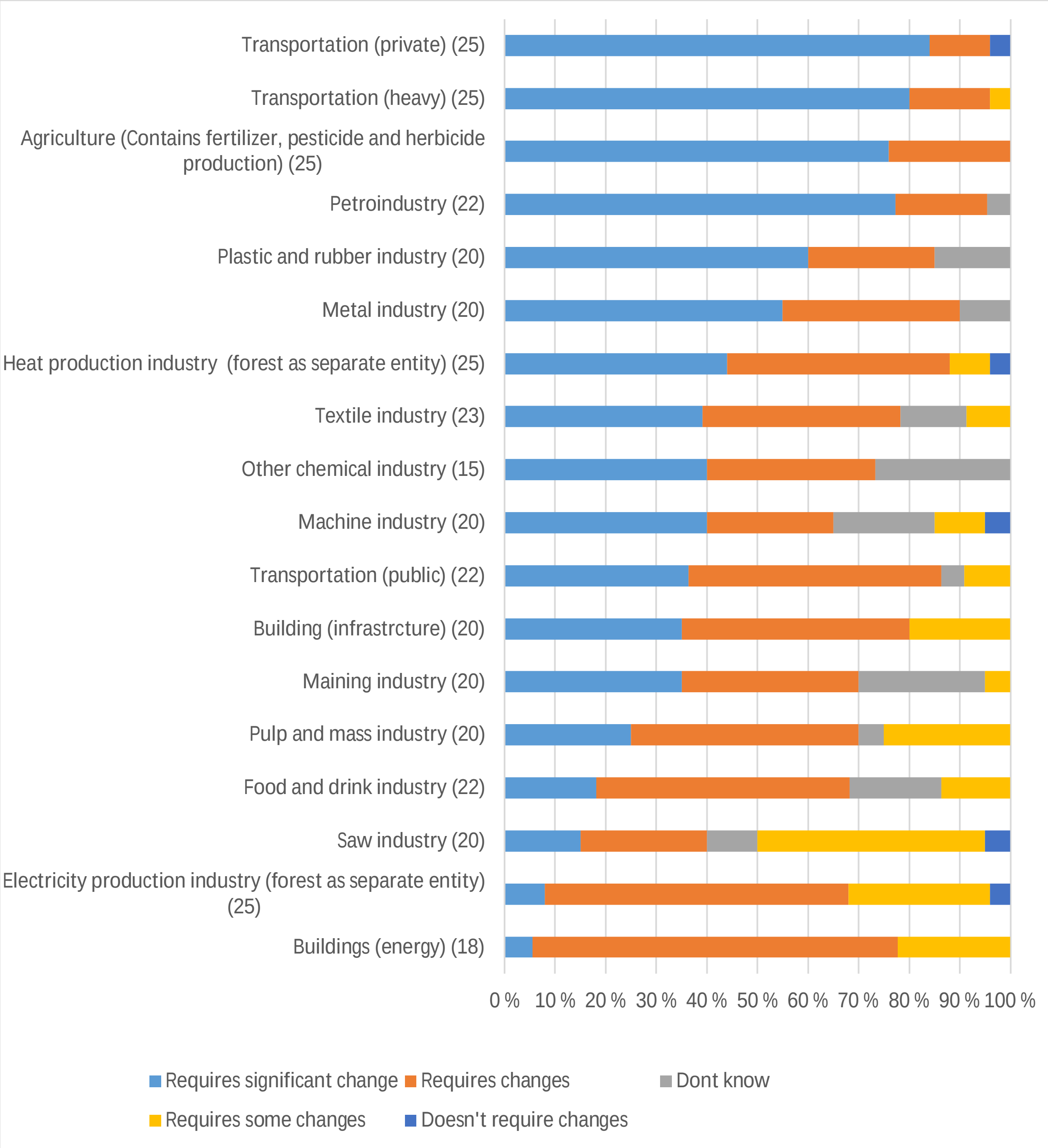

Fig. 3.1.3. Which industrial sectors need to change their current practices if carbon neutrality is a goal? The number of responses is indicated in brackets.

3.1.4 Should carbon emissions affect the price of the product?

Question: What should the cost of CO_2 be in order for the transition to take place in such a way that Finland will be carbon-neutral by 2035?

Economic aspects are among the major factors determining the probability of the transition to take place. One way to progress towards carbon neutrality is to increase the cost of CO_2

intensive emission practices. Should products with high production carbon emissions have a higher cost in comparison with similar products?

Consider the lifetime emissions of a product/services. Please note that the carbon credit system is a sanction-based system and already affects the price of CO_2 in some energy-related sectors.

Highlights: Most of the respondents saw that in order to achieve carbon neutrality, the prices of the products must be increased. In electricity production, industry, and transport, some respondents saw the increase to be over 50%. In buildings, the increase was seen slightly more moderate, most of the respondents considering it to be 30% at the maximum.

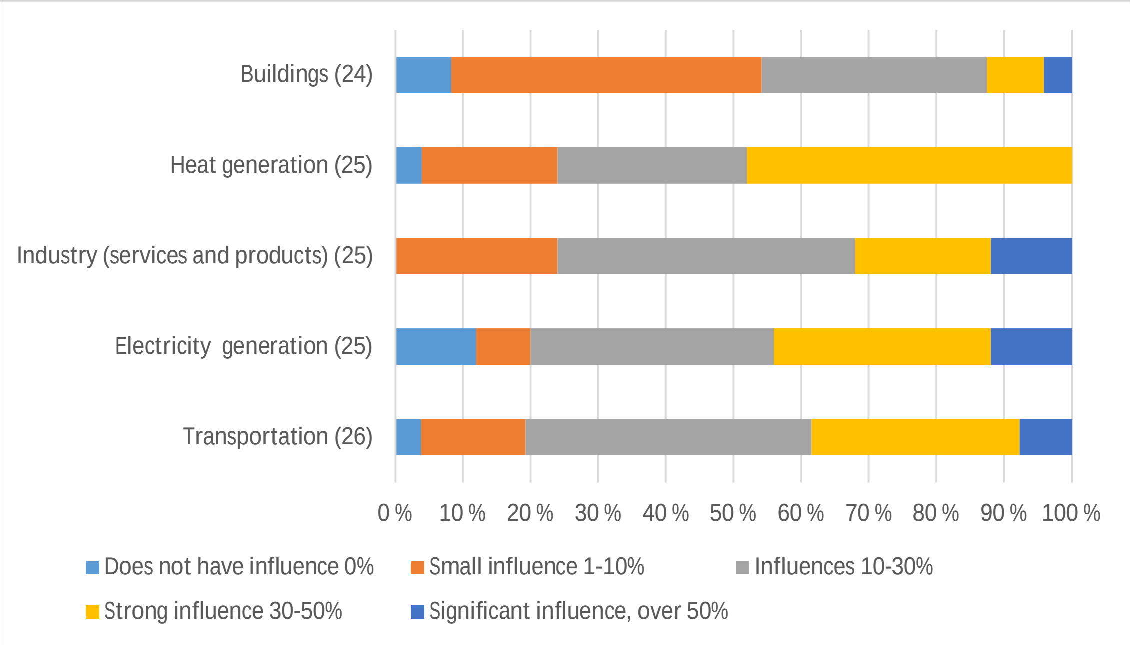

Fig. 3.1.4. Should carbon emissions affect the price of the product? The number of responses is indicated in brackets.

Comments:

- Electricity tax could be smaller for clean energy sources, such as wind.
- I vote for a price instrument, although I do not know how it can be reasonably implemented in all the sectors. I assume that costs should be predictable and gradually increasing.
- Traffic has huge taxes to no effect. ETS will affect electricity and heating greatly now that it has reached 30 €. Buildings are too slow to change with tax. Politicians are afraid of changing prices of any industrial product.
- I vote for carrot instead of stick.

3.2 Technologies

In addition to carbon neutrality, a reduction in prices and an improvement in the performance of renewable energy production technologies are among the driving factors in the transition of the energy system.

In 2016, at the time of the first SET Delphi survey process, electricity production with wind was supported with a 83.5€/kWh feed-in tariff, and the installed capacity of solar PV plants was around 20 MW. Now, only after two years, onshore wind is the lowest-cost method to produce electricity. Correspondingly, the installed capacity of solar PV plants is estimated to reach 150 MW by the end of this year.

With this increasing amount of variable renewable energy sources (VRES), fossil-free/neutral energy storage and peak capacity methods are becoming more important in the energy system. In addition to battery storages and pumped hydro, electricity can be stored with different Power-to-X technologies, where electricity is converted into gas, fuels, or chemicals.

As Finland has been the forerunner in the nationwide application of automatic electricity meter reading equipment and we have strong export companies in the energy sector, development of new technologies can provide good opportunities for export markets.

This section addresses the views of the respondents on the most significant energy production and storage methods. Their opinions of different Power-to-X methods are also studied based on the most probable options for this technology.

3.2.1 Most significant technologies—Global carbon neutrality

Question: Rank the most significant low-carbon energy sources and technologies in the context of carbon neutrality. Consider production-based carbon neutrality (emissions from production minus compensation).

Highlights: Wind energy and solar PV was seen significant by almost all the respondents. Hydropower, demand response solutions, heat pumps, and geothermal energy were also considered either significant or having some significance in the context of global carbon neutrality. Wave power and carbon capture solutions were not found to be that significant.

Comments:

- Power-to-X is significant when thinking about fuel production. New technologies related to CCS, CCU, and fuel cells are still developing, but I do not necessarily see that the nuclear power will be economically feasible even in the long run. However, nuclear power will still be relevant in energy systems in 2035.

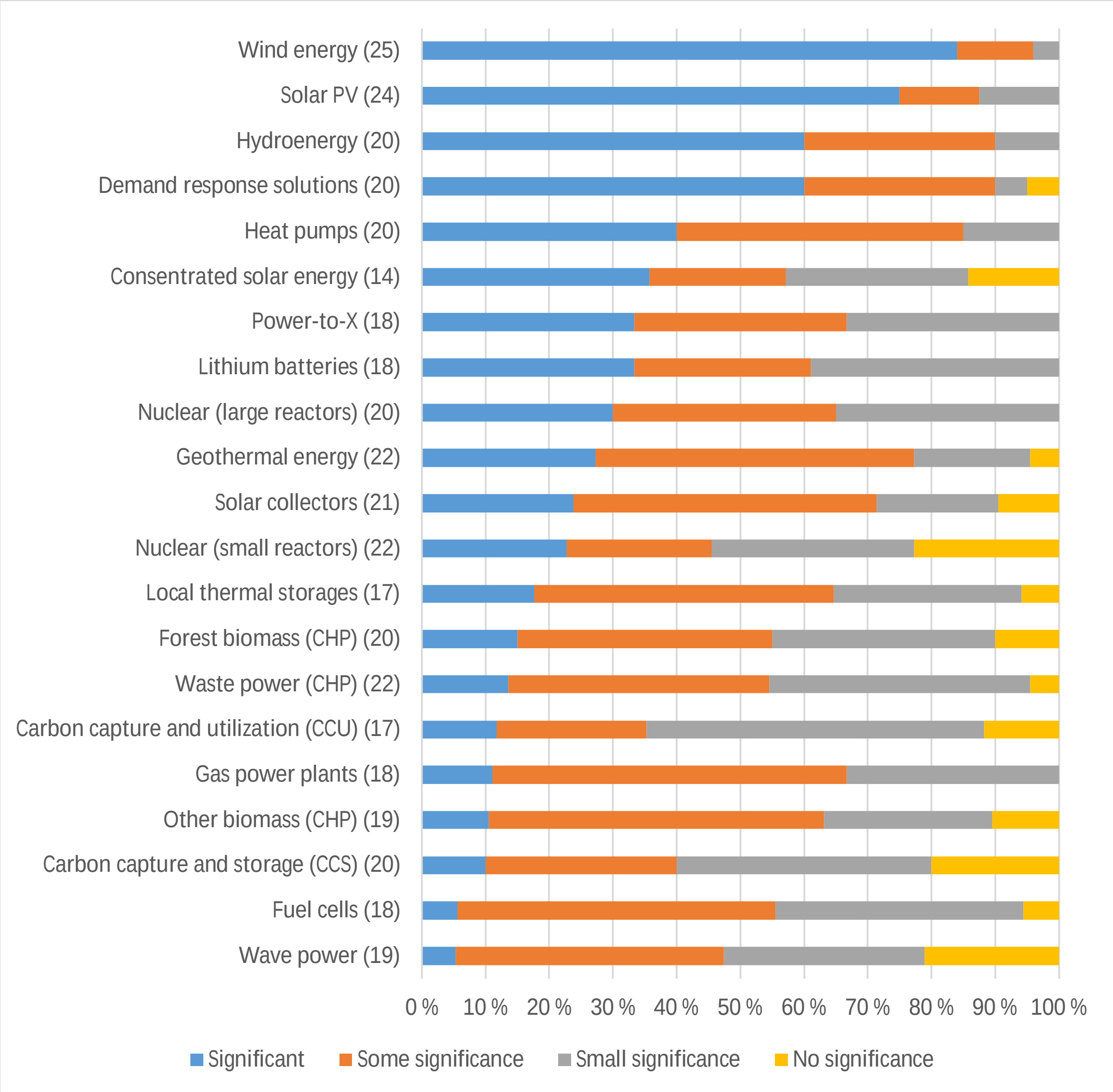

Fig. 3.2.1. Significance of different technologies in the context of global carbon neutrality. The number of responses is indicated in brackets.

3.2.2 Most significant technologies—National economy

Question: Rank the most significant low-carbon energy technologies/sources in the context of national economy in Finland by 2035. Consider, e.g., reliability, jobs, self-sufficiency, and feasibility.

Highlights: Forest biomass, wind energy, demand response solutions, and heat pumps were found to be the most significant technologies in the context of social economy in 2035 in Finland. Concentrated solar energy and fuel cells had only a slight significance. Carbon capture and wave energy were not considered very significant either.

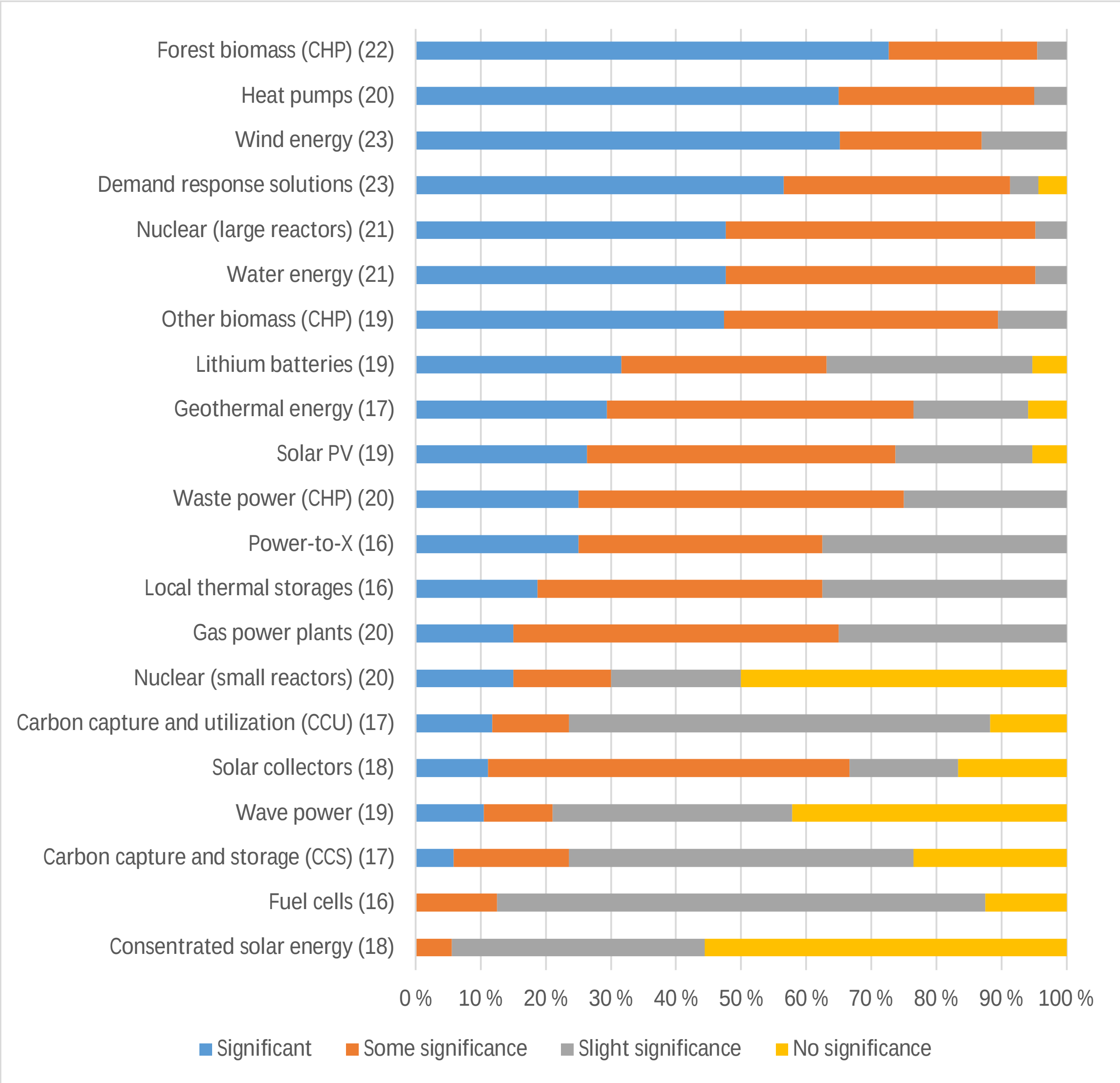

Fig. 3.2.2. Significance of different technologies in the context of social economy in Finland in 2035. The number of responses is indicated in brackets.

Comments:

- Even though forest biomass certainly plays a significant role still in 2035, it is important to consider it from the viewpoint of increasing the carbon capture or otherwise must decrease its use. Hydropower is not so important nationally, even though it is important as part of the Nordic electricity pool. Nuclear power plays a role because of previous investments, but hopefully, there won't be new ones.

5.2.3 Most significant technologies—capacity in Finland

Question: Rank the most significant low-carbon energy technologies/sources in the context of energy production capacity (TWh) in Finland by 2035.

Highlights: In the context of capacity, large nuclear reactors and forest biomass were found to be the most significant, and wind energy, demand response solutions, and heat pumps were also ranked significantly high. On the other hand, concentrated solar energy, fuel cells, and wave energy were not considered significant.

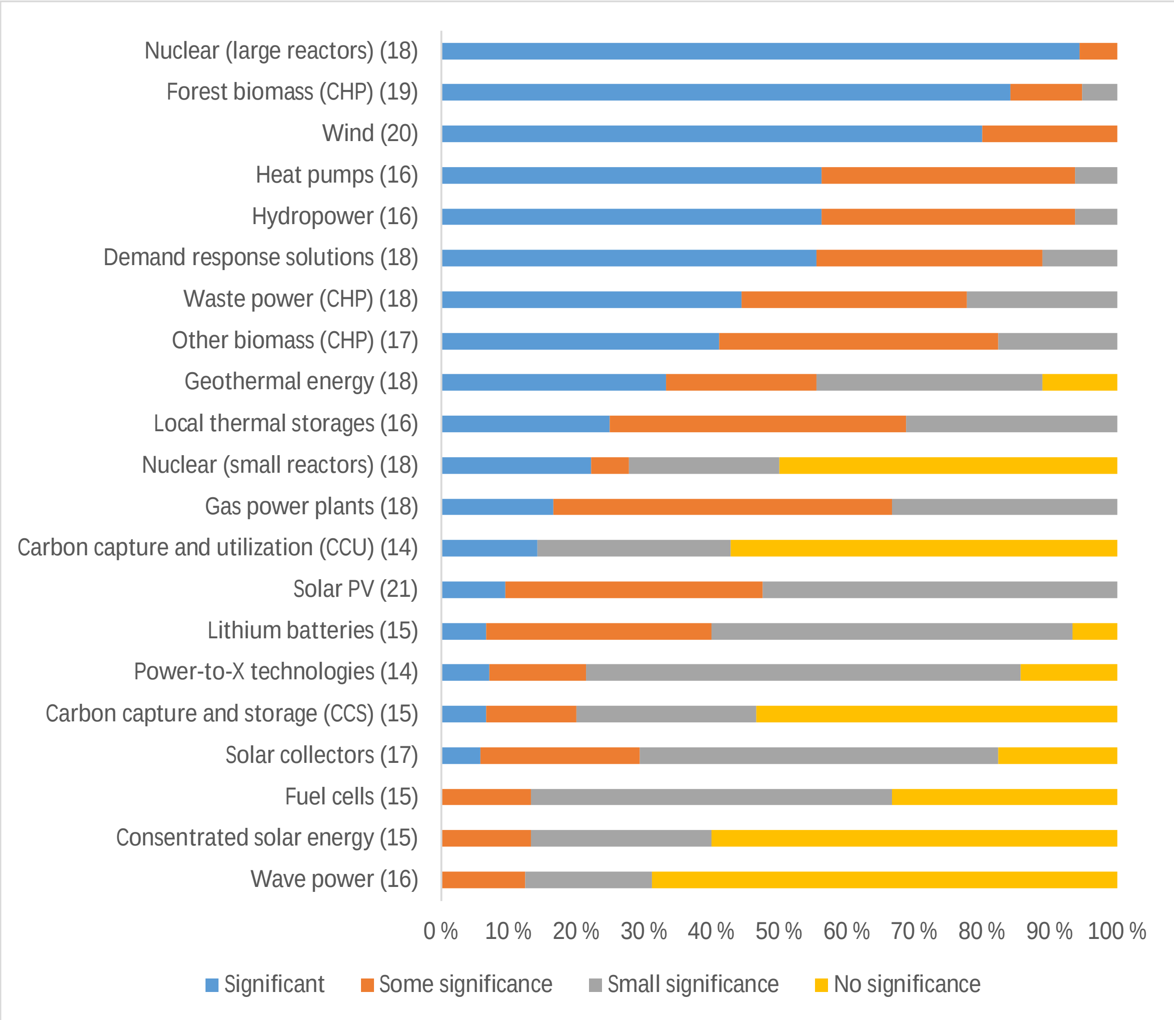

Fig. 3.2.3. Significance of different technologies in the context of capacity in Finland in 2035. The number of responses is indicated in brackets.

Comments:

- Energy production technologies that are dependent on weather conditions reduce the significance of those technologies because of the lack of energy storage options. One solution is to store the energy to hydropower, but in Finland that option is challenging because of the lack of natural water reservoirs with high altitudes. To overcome these challenges, the R&D of converting electricity into fuels for storage should be investigated.

3.2.4 Export potential of technologies for Finnish actors

Question: What is the export potential of the following energy technologies for Finnish companies by 2035?

Highlights: The export potential of demand response solutions was considered the most significant in 2035. Wind energy, Power-to-X technologies, and heat pumps were the next high-ranked ones. The export potential of nuclear reactors, concentrated solar energy, and hydropower was not found to be significant.

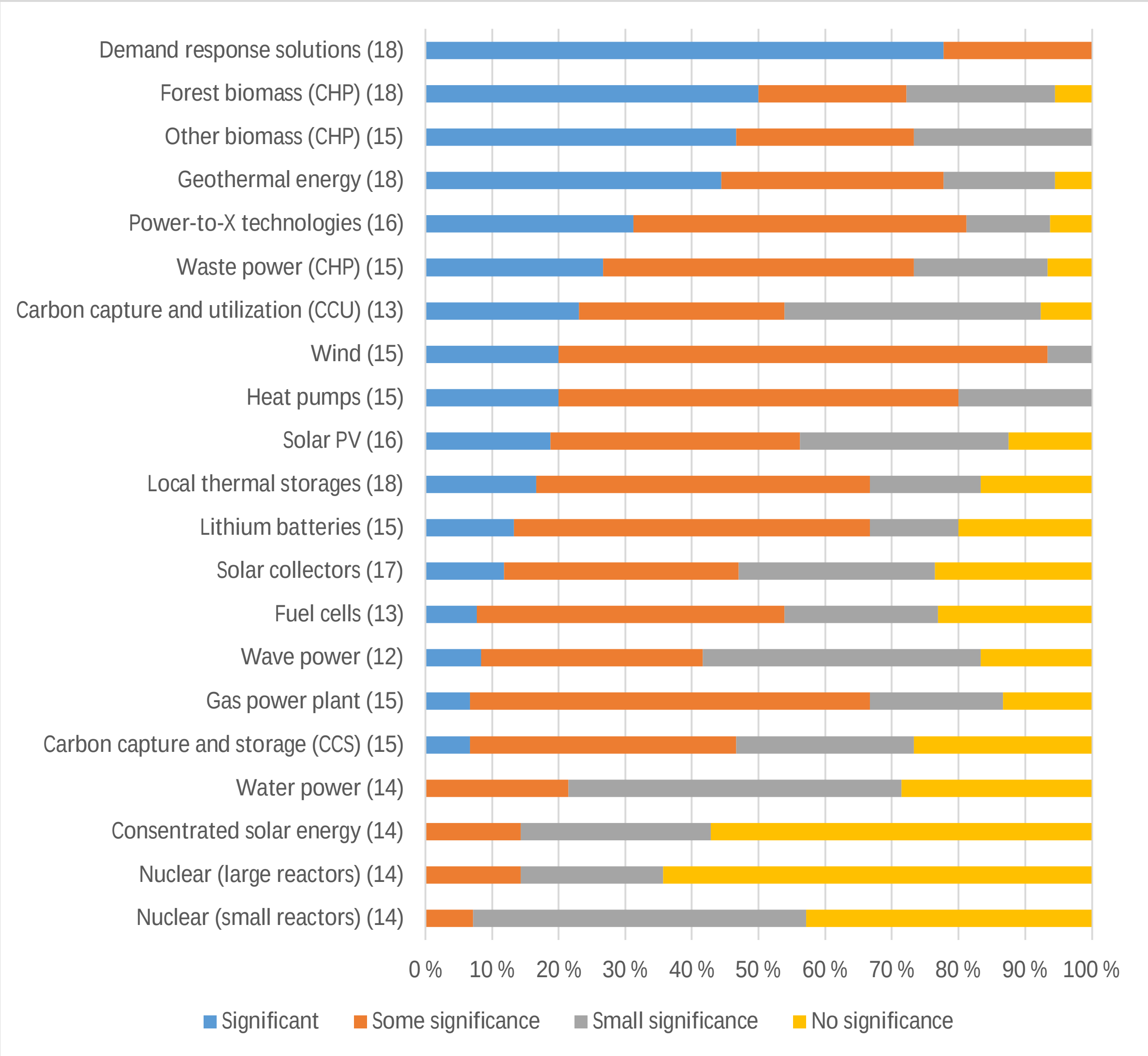

Fig. 3.2.4. Export potential of different technologies in Finland in 2035. The number of responses is indicated in brackets.

Comments:

- Energy services, e.g., for building owners and managers.
- Energy efficiency solutions are significant in different industries, as well as in the construction industry and existing premises.
- Management of energy efficiency in industry.

3.2.5 Potential of Power-to-X technologies in Finland in 2035

Question: In your opinion, what are the most promising Power-to-X approaches at the organizational level in Finland (such as energy companies and industrial plants)?

Power-to-X technologies can be used in many ways, X representing, e.g., gases, chemicals, or materials.

Highlights: All the Power-to-X technologies were mostly found to have potential. All the respondents considered Power-to-Fuels, Power-to-Methanol, and Power-to-Methane to have either significant or some potential.

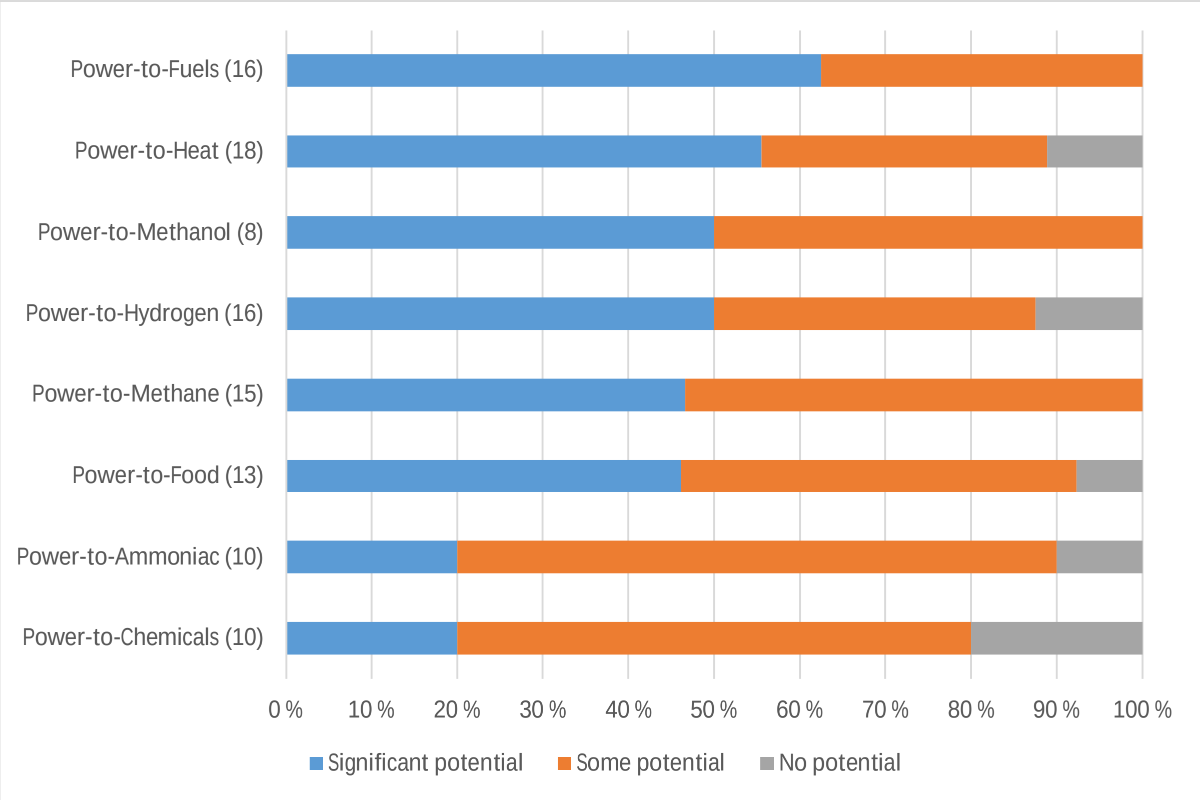

Fig. 5.2.5. Potential of different Power-to-X technologies. The number of responses is indicated in brackets.

Comments:

- Necessary technologies, when thinking about climate aims. For instance, replacing hydrogen production from natural gas with power-to-hydrogen technology might be feasible. Power-to-Heat seems to be an important technology for thermal energy production or to improve thermal storage processes.

3.2.6 Capacity of different thermal energy production technologies in Finland in 2035

Question: Which thermal energy production technologies will increase and decrease in Finland by 2035?

Thermal energy production is vital in areas having cold seasons. However, the production of non-fossil-based thermal energy might be challenging because of the existing energy-related infrastructure and the amount of alternative fuels available. The Finnish Government plans to ban the use of coal for thermal energy production in 2029. In addition, it is possible that the use of peat will also be banned. For these reasons, there is a need for alternative production technologies and storage systems.

Highlights: All the respondents saw that the number of heat pumps in private use either increase or increase significantly in Finland by 2035. Geothermal energy, local thermal storages, and district heating (electricity-to-heat) will also increase. The share of fossil-based technologies was considered to be reduced.

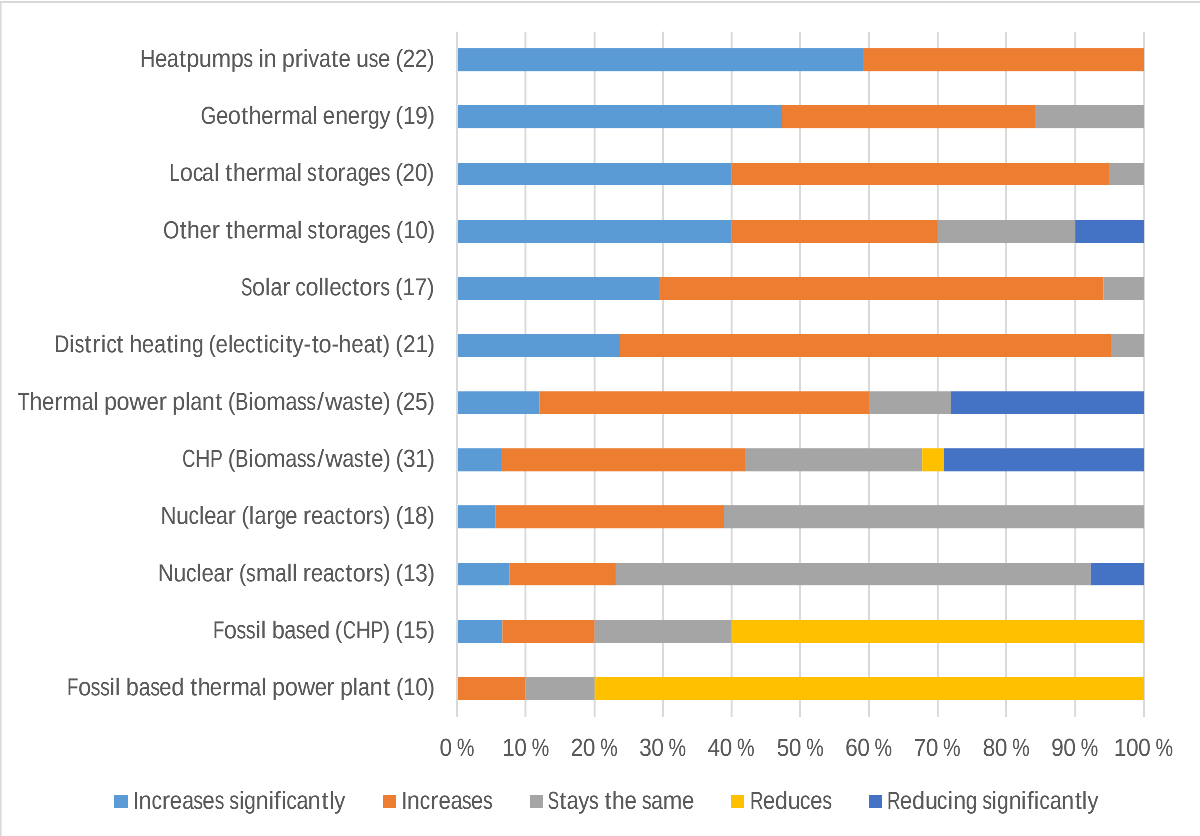

Fig. 3.2.6. Capacity of different thermal energy production technologies in Finland in 2035. The number of responses is indicated in brackets.

Comments:

- The number of heat pumps used by companies is growing fast (HELEN etc.)
- Electric boilers in district heating will also increase as a means to take advantage of the wind power production peaks and cheap electricity prices. Biogas or power-to-gas

turbines will also increase as adjusting power to large- and small-scale heat pumps in the electricity market, during the low-wind power production periods. CHP plants are too slow.

- Decentralized low-temperature heat technologies (solar hear collectors, district cooling, heat pumps) of private consumers will participate more in district heat networks in the future.
- I believe that bio/waste-based thermal energy production will increase in the future, but the primary target is in thermal management and in solar heat. If the geothermal plant functions properly in Espoo, it will most likely have potential.

3.3 Enablers and Barriers

This section addresses enablers and barriers that might have some influence on the energy transition towards carbon neutrality in Finland in the future.

3.3.1 Enablers for and barriers to the energy transition towards carbon neutrality in Finland

Question: Sort out the listed enablers and barriers by the level of significance. Some enabling and hindering factors are found to affect the energy transition towards carbon neutrality in Finland in the next 15 years.

Highlights: The regulatory factors at the EU and national level were regarded by the respondents as the most supportive mechanisms for reaching carbon neutrality in Finland. At the same time, it seems that existing investments in the old technologies tie down the process of transition. This was also mentioned when the respondents answered some other questions.

Comments:

- I see the role of the EU and other sufficiently strong players in promoting carbon neutrality also in Finland. The role of digitalization in achieving carbon neutrality is somewhat alienated as the telecommunications sector has increased energy/material consumption globally. I also see a corresponding “giving effect” in urbanization, which contributes to alienating people from nature and limited resources. Nonetheless, I regard innovation in energy production/transmission as a positive thing.
- Urbanization will make it even more difficult to achieve carbon neutrality because of the associated consumption of goods and services. Construction and land-use changes as a result of migration generate new emissions. In the Finnish conditions, heating of large cities remains one of the most difficult issues to resolve when moving to a fossil fuel-free society. Digitalization is part of the solution and part of the problem. The dramatically increasing data transfer will be an increasingly important energy consumer.
- Urbanization will help to achieve carbon neutrality. Mobility is low and can be based on walking, cycling, and rail-based public transport. Homes in cities are smaller and thus consume less natural resources over their life cycle. Similarly, land use per capita is low. The released area can be utilized to increase biomass production and carbon sinks, for example.

- I deliberately put “national legislation” in both “slow down” and “support” fields (including subsidies vs. taxation). Mostly, of course, it is supportive, but at the national level, lobbying by anti-change actors seems to be increasing. With regard to the labor force, e.g., in comparison with Norway and Sweden, demographic trends are poor.

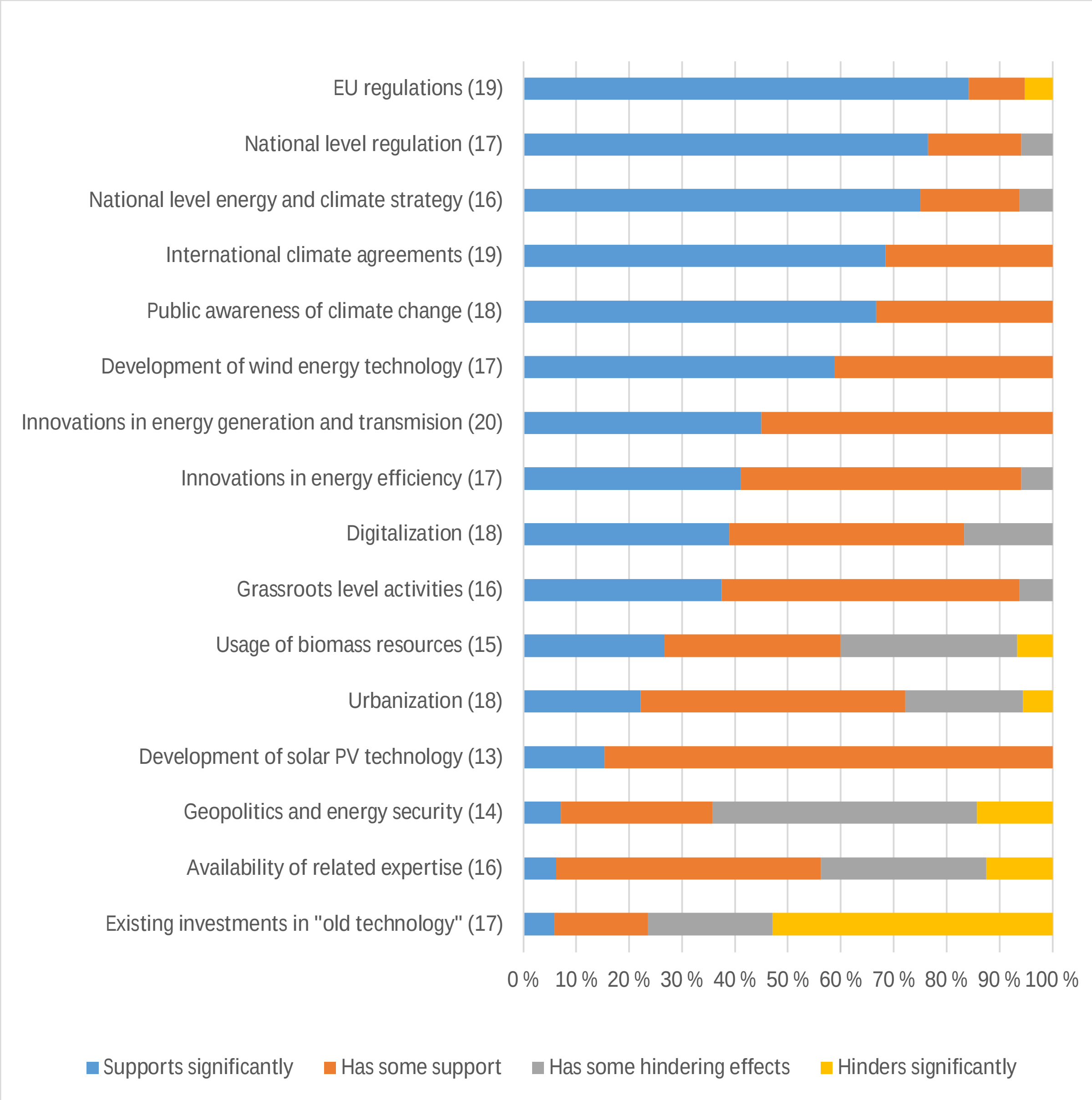

Fig. 3.3.1. Enablers for and barriers to the energy transition towards carbon neutrality in Finland. The number of responses is indicated in brackets.

3.3.2 The most significant barriers inhibiting more intensive use of wind energy in Finland

Question: Sort out these barriers by the level of significance. Some barriers are found to affect the usage of wind power in Finland in the next 15 years.

Highlights: The respondents were very much in consensus on the fact that negative perceptions of society towards building windfarms as well as regulations are the highest barriers. To a much lesser extent, the respondents considered the lack of expertise and the technical limitations like grid limitations to be a high barrier.

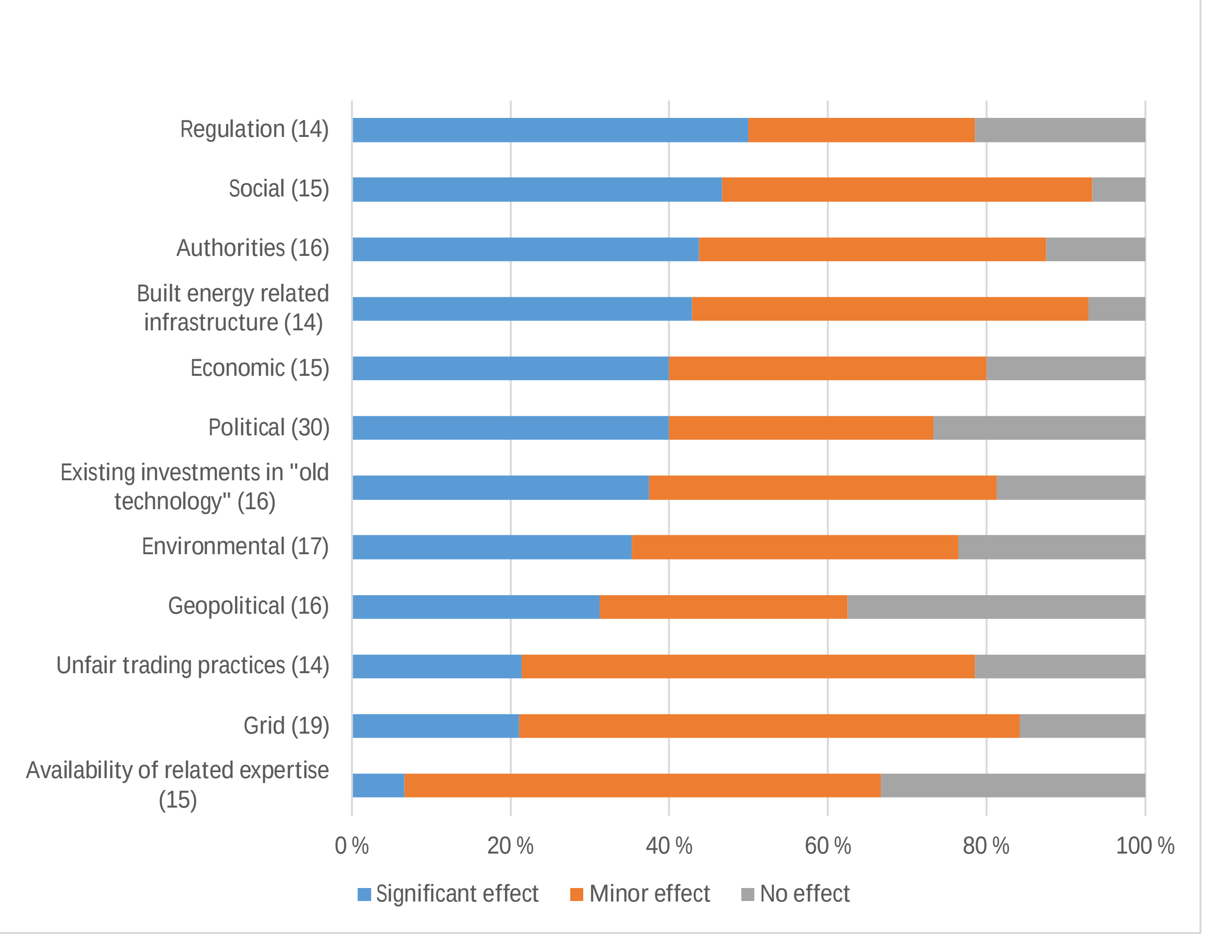

Fig. 3.3.2. The most significant barriers inhibiting more intensive use of wind energy in Finland. The number of responses is indicated in brackets.

Comments:

- Restrictions on Eastern and Southern Finland for national defence reasons (radar systems)
- The defence forces was missing from the list; however, its influence as a wind power blocker is huge
- Defence forces significant. Did the geopolitical influence include this?

3.3.3 The most significant barriers inhibiting more intensive use of solar energy in Finland

Question: Sort out the listed barriers by the level of significance. Some barriers are found to affect the usage of Solar PV power in Finland in the next 15 years.

Highlights: As to the solar PV energy technologies in Finland, the respondents considered that the highest barriers are related to the economic context. These are economic factors and unfair trading practices. The lowest barriers were found in the availability of related expertise and geopolitical factors.

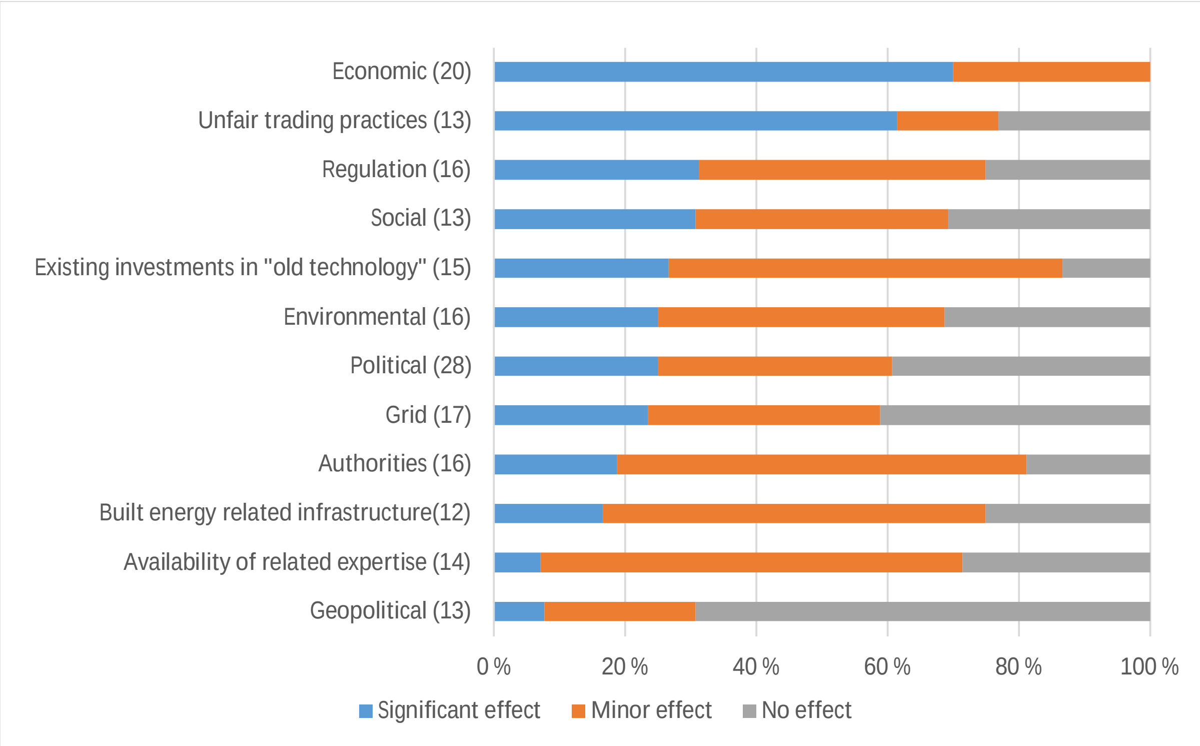

Fig. 3.3.3. The most significant barriers inhibiting more intensive use of solar PV energy in Finland. The number of responses is indicated in brackets.

Comments:

- The payback period of the system should be short enough (for many, ten years is eternity and is realized only by self-compensation)
  In Finland many roofs are/should be repaired first before purchasing a photovoltaic system. I believe that photovoltaic systems are still getting cheaper, and at the same time, the price of electricity (transmission) will rise, which will help in their payback period. Even so, the location and condition of the item must be ok for system installation. In new projects, house/area planning should support the rational use of solar electricity.
- Lack of longer-term, high-capacity storage solutions.
- For example, in housing companies, the use of solar electricity (including taxation, revenue sharing) is still to be determined. The electricity network should be developed

more dynamically. The influence of political factors is uncertain but requires legislative and tax developments.

3.4 Organizational Innovation

Innovation, in general, is an important source of growth and a key determining factor in achieving competitive advantage for many organizations. There are four types of innovations: product, process, marketing, and organizational innovations.

This section only deals with the organizational type of innovation (ORI). This kind of innovation is for instance an implementation of a new organizational method in a company's

1. business practices (e.g., the first introduction of Total Quality Management, supply system elements, practices for codifying knowledge, or establishing databases);
2. workplace organization (e.g., centralization, decentralization of the work of individuals, or re-organization of the organizational structure, integration or diversification of different business activities);
3. external relations (e.g., new ways of building relations with a company's external environment including other companies, public institutions, research organizations, customers, and suppliers in order to enhance the efficiency of production, procurement, distribution, recruitment, and ancillary services).

The introduction of new technologies often presents complex opportunities and challenges for organizations, leading to changes in managerial practices and emergence of new organizational forms. Organizational and technological innovations are thus intertwined.

3.4.1 ORI for development of wind energy technologies in Finland

Question: Arrange the ORI listed below in the order of priority to facilitate (speed up) the development of wind power energy technologies in Finland.

Highlights: The results showed that according to the experts, there are two most important initiatives that should be taken to develop the wind energy in Finland. The first is "Introducing business models involving residents as stakeholders of a local wind farm" that supports the idea of the considerable role of society in promoting wind energy. The second is "Increase of R&D for finding solutions on storage technologies." 82% and 72% of the respondents indicated that these elements are very important while the rest considered them important. It looks like that the least important ORI is "Increase of R&D for finding solutions on long distance energy transmission". Only slightly above 20% of the respondents found this ORI very important.

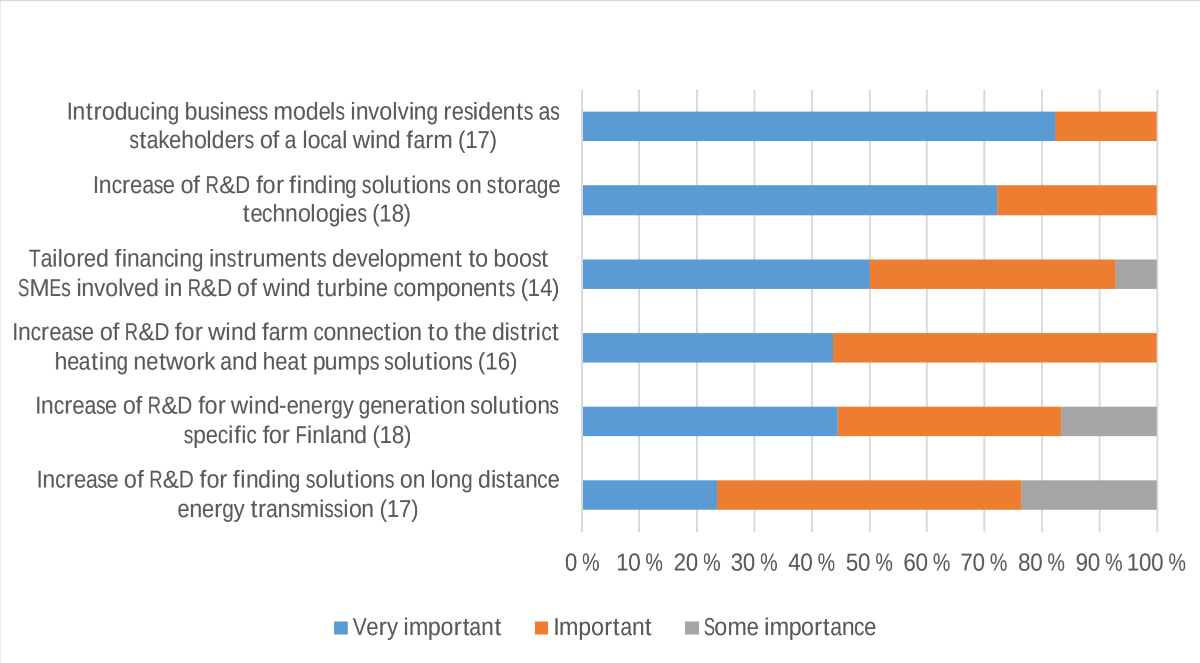

Fig. 3.4.1. Organizational innovation for development of wind energy technologies in Finland. The number of responses is indicated in brackets.

Comments:

- The most significant one has been Power Purchase Agreement.
- In the long run, I believe that the most sustainable development is to support local solutions, whereby socio-economic innovations are important in addition to storage.
- In general, the development of demand-side technology is the key.
- The Government's role in mitigating the financial risk of wind power investments is very important, developing new loan instruments, or continuing the RE auctions where the Government is involved would be very important.

3.4.2 ORI for development solar PV energy technologies in Finland

Question: Arrange the ORI listed below in the order of priority to facilitate (speed up) the development of solar PV energy technologies in Finland.

Highlights: The economic context is also confirmed by the experts when they respond to the question on organizational innovation that boosts the development of solar PV technologies in Finland. The most important innovations that should be taken to develop solar PV technologies in Finland are "Introducing business models of collaboration between house owners related to solar PV energy generation" and "Introducing business models involving prosumers on a large scale in energy generation process". Around 80% of the respondents considered these innovations to be very important.

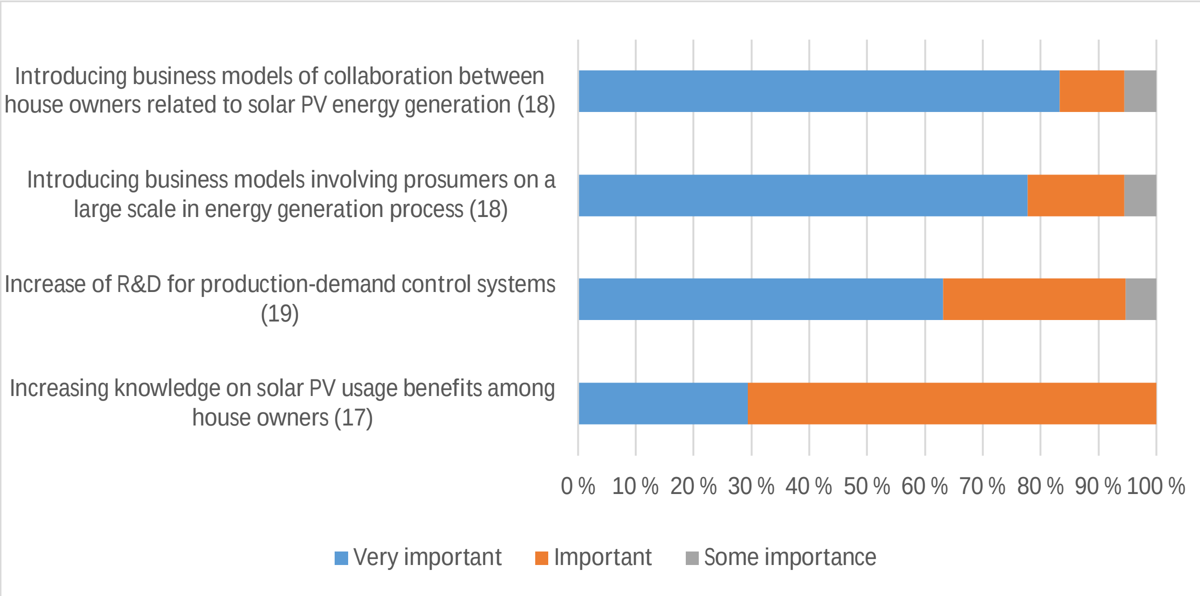

Fig. 3.4.2. Organizational innovation for the development of solar PV energy technologies in Finland. The number of responses is indicated in brackets.

Comments:

- Organizational innovations feed on one another. The development of business models becomes very important, as awareness raising and control systems are already on the road to take their own weight and solutions are known.
- Price is the crucial matter.
- In general, the development of demand-side technology is the key.
- Investment grants for the housing sector would be a very effective method to boost solar PV growth, but grants should target the total energy improvements of buildings. For reducing emissions, hybrid energy solutions including solar PV and energy efficiency improvements in houses are crucial.
- In addition, the removal of commercial barriers that have already been identified, such as the power supply network. Would there be room for improvement in the pricing mechanisms?
- Are service innovations part of organizational innovation? Are new business models understood as service innovations? New services for consumers, such as ready-made solar packages, can continue to play an important role. This survey has a pretty strong “new technology” focus, which ignores innovations that help to spread (perhaps already existing) technology.

3.4.3 ORI for development Power-to-X technologies in Finland

Question: Arrange the ORI listed below in the order of priority to facilitate (speed up) the development of Power-to-X energy technologies in Finland.

Highlights: As to the ORI for development of Power-to-X technologies in Finland, the respondents were very much in consensus on that an increase in R&D for finding new energy conversion and storage solutions is the most important ORI to boost the development of Power-to-X technologies in Finland.

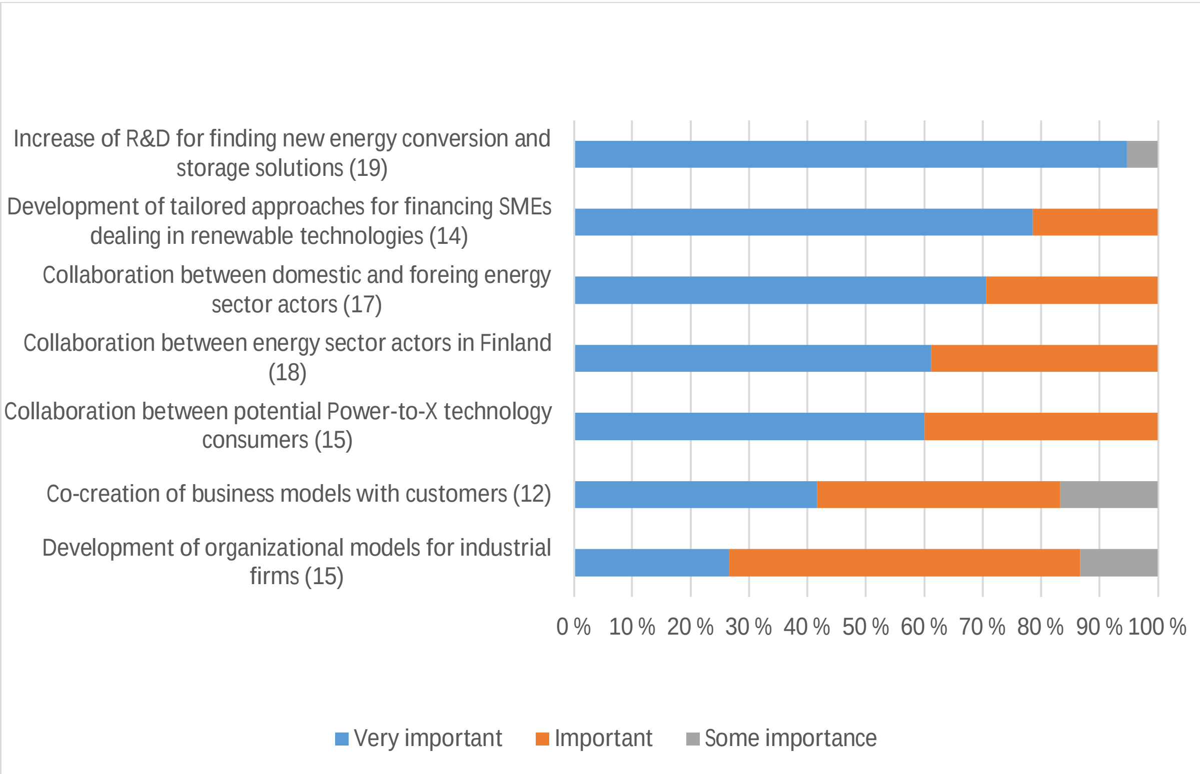

Fig. 3.4.3. Organizational innovation for the development of Power-to-X technologies in Finland. The number of responses is indicated in brackets.

Comments:

- In fact, I see Power-to-X technologies still requiring R&D and pilot projects to lower their cost, so I emphasize the technical options.
- All technology is still in a state of flux where industrial breakthroughs have not yet been made. I assumed that technology would deliver on its promise well before 2035.
- Technology is still too expensive to be incorporated into municipal experiments, for example. There is potential for experimentation, e.g., in connection with biogas plants.
- Thus, in the early stages of technology development, it is difficult to think that any of the above factors would not be important in the future. All are.
- Collaboration with future consumers and also "producers"

3.5 Background Information for the Round 1

The majority of the respondents work as experts in their organizations. One-third is working at the top management. A few also work in the middle management and other positions.

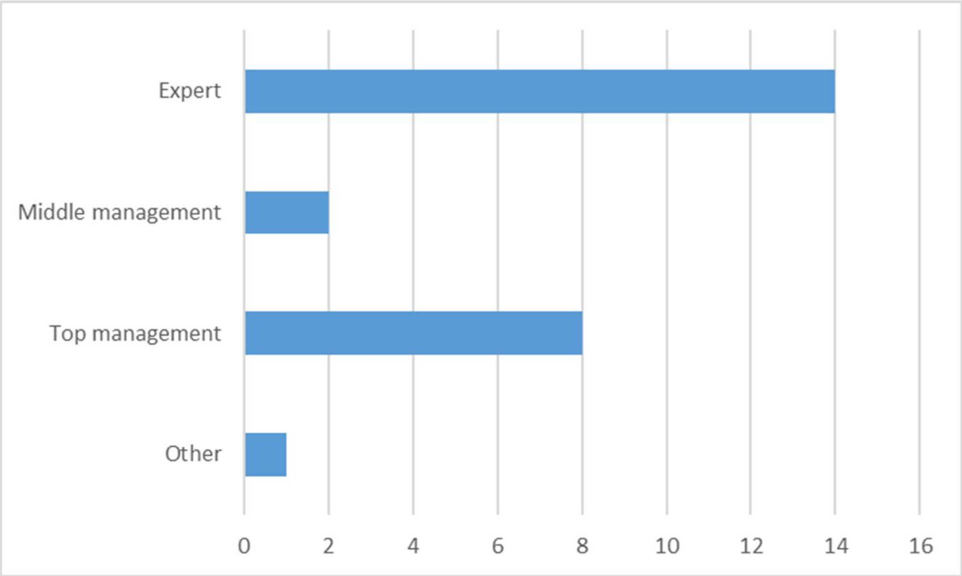

Fig. 3.5.1. Position in the organization of the respondents.

Most of the respondents have a technical or economical education. Less than one-third of the respondents have humanities or other education.

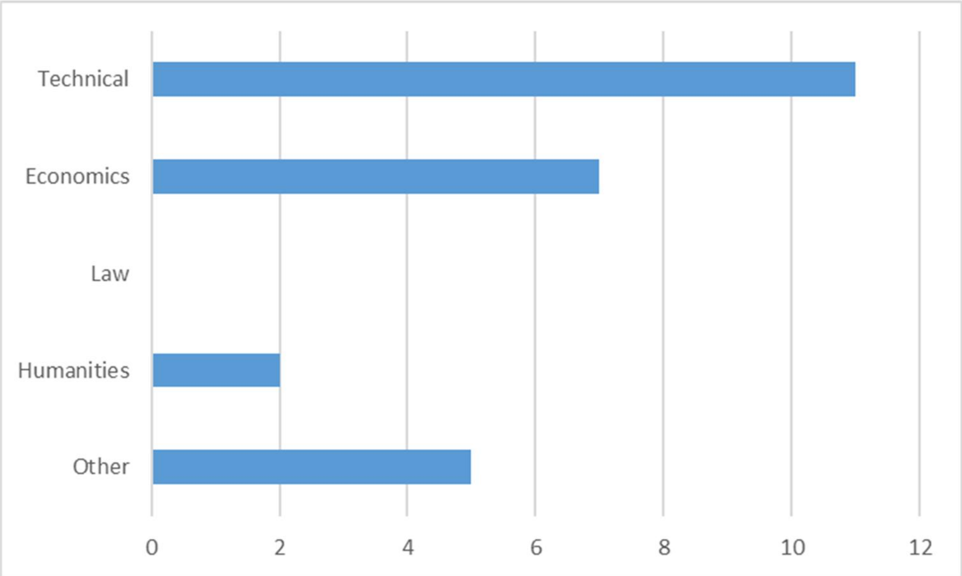

Fig. 3.5.2. Respondents' field of education.

Half of the respondents have a Master's degree (M.Sc.), 42% have a doctorate (PhD), and only 8% have a Bachelor's degree (B.Sc.).

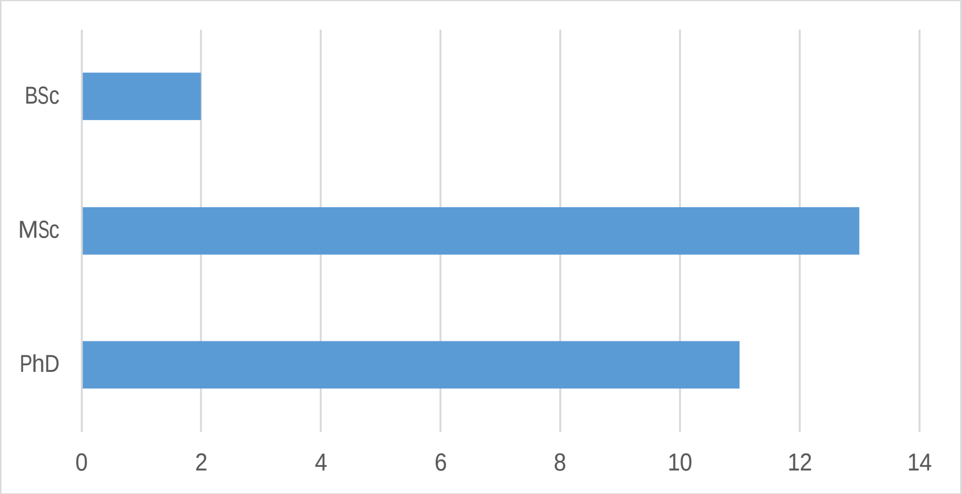

Fig. 3.5.3. Level of education of the respondents.

The majority of the respondents are working in private business organizations or in research and education, 40% in both. 8% are working in governmental organizations or NGOs.

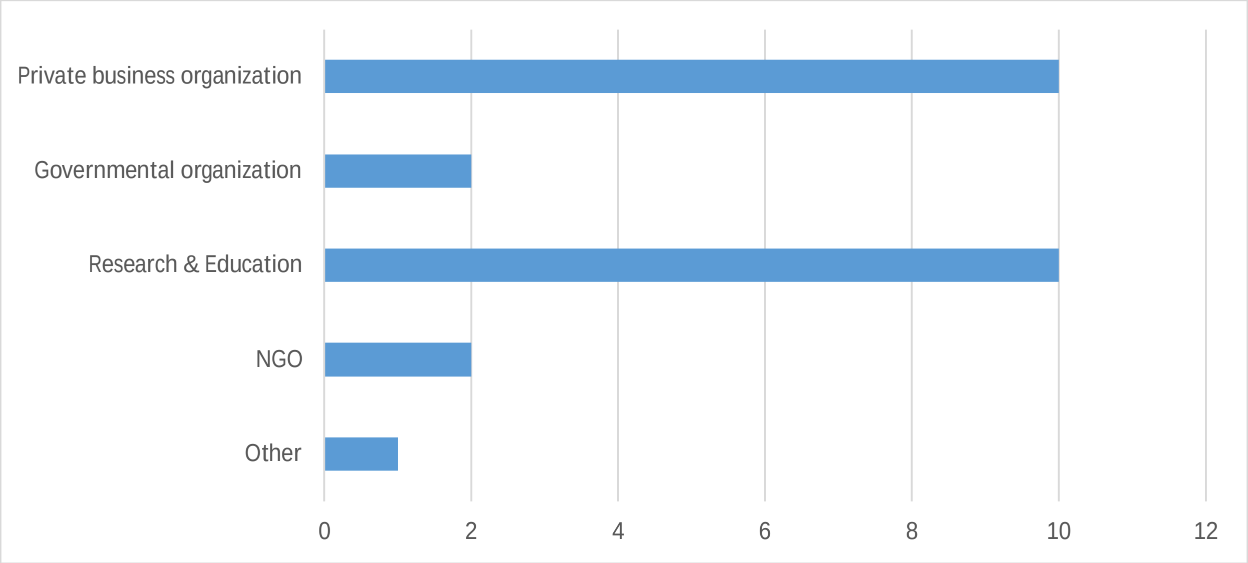

Fig. 3.5.4. Current organization of the respondents.

60% of the respondents are male and 40% female.

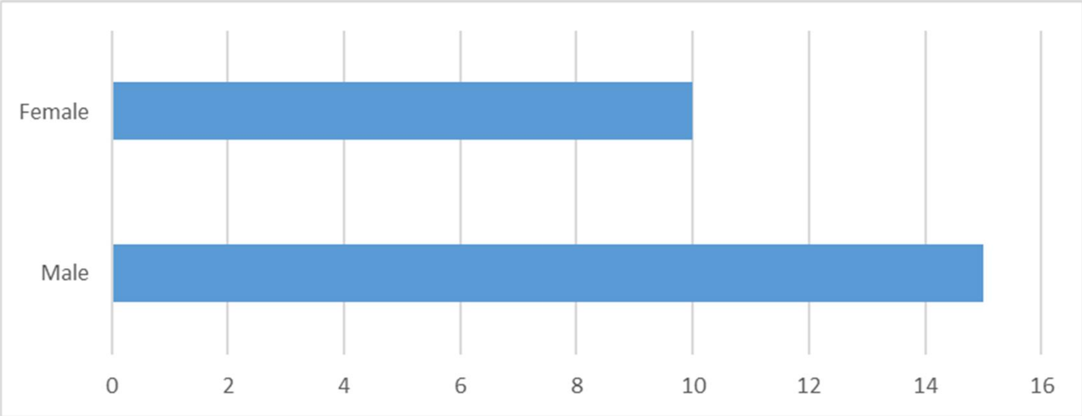

Fig. 3.5.5. Gender of the respondents.

The majority, 44%, of the respondents are 30–45 years old. 32% are over 55 years old and 24% 45–55 years old.

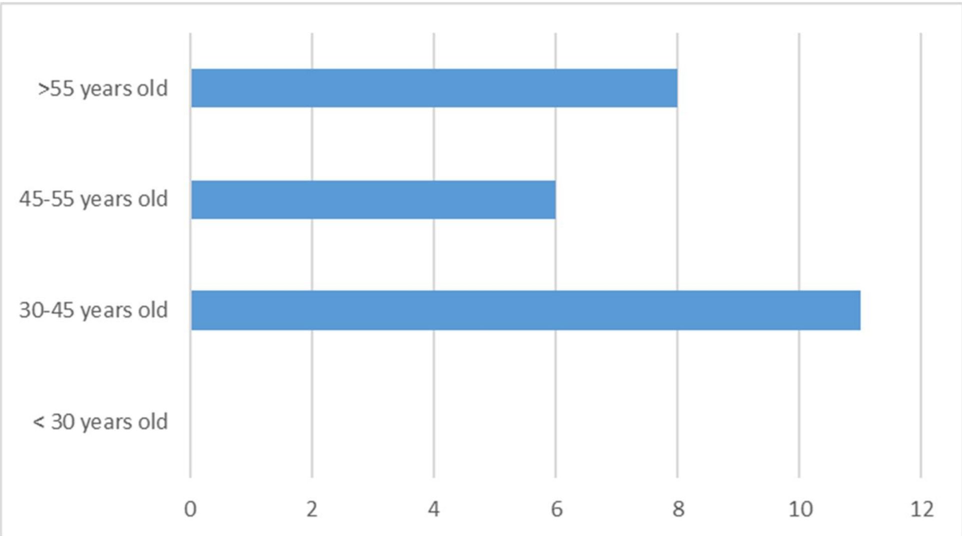

Fig. 3.5.6. Age of the respondents.

Table 3.5.1. presents the expertise of the respondents in different business areas and Table 3.5.2 the expertise in energy-related topics.

Table 3.5.1. Expertise of the respondents in different business areas.

	Large companies	Small- and medium-sized enterprises	Politics	Non-governmental organizations	Academy
Technology expertise	3	4	6	4	3
Business skills	2	6	7	9	4
Policy and public administration skills	4	5	7	4	4

Table 3.5.2. Expertise of the respondents in energy-related topics.

	Expert	Knowledgeable	Novice/not familiar
Solar PV	11	14	0
Solar thermal	3	16	3
Geothermal energy	2	10	10
Wind energy	7	15	2
Wave power	0	9	12
Forest biomass (CHP)	6	10	5
Other biomass (CHP)	2	13	6
Waste power plant	1	16	5
Gas turbines (biogas)	3	10	6
Hydropower	3	15	2
Power-to-X technologies	1	9	9
Heat pumps	3	19	0
Carbon capture and storage	0	6	12
Carbon capture and utilization	1	4	15
Local thermal energy storages	1	13	3
Demand response solutions	9	10	3
Fuel cells	1	5	10
Concentrated solar power	1	5	10
Lithium batteries	1	9	7
Nuclear (large reactors)	2	12	4
Nuclear (small reactors)	1	5	13

4 Results of the Round 2—The Change Required in Different Industrial Sectors to Achieve Carbon Neutrality in Finland by 2035

The second part of the survey focuses on the results of the first round and on the potential and challenges of different technologies in Finland in 2035. Additionally, a few questions from the first Delphi survey in 2016 related to the potential and growth of different technologies in different contexts were repeated in order to see how the opinions have changed.

4.1 Significance of Different Barriers When Attempting to Achieve Carbon Neutrality

The results of the first survey round indicate that some barriers exist in both the business and the social environment influencing the development of the energy transition in Finland. This second survey round focuses more specifically on these barriers.

4.1.1 When is it possible to achieve carbon neutrality?

Question: When do you think the different sectors can achieve carbon neutrality?

The respondents in the first part of the survey saw that building, transport, and industrial sectors are not going to achieve carbon neutrality by 2035. However, electricity and thermal energy generation sectors were seen to have a possibility to achieve the carbon neutrality.

Highlights: In electricity production, 13% of the respondents saw that carbon neutrality can be achieved by 2025, 67% by 2030, and 93% by 2035. In addition, in thermal energy generation, 40% of the respondents saw that carbon neutrality will be achieved by 2030, 60% by 2035, and 87% by 2040. In building, transport, and industry, achieving carbon neutrality will take a longer time.

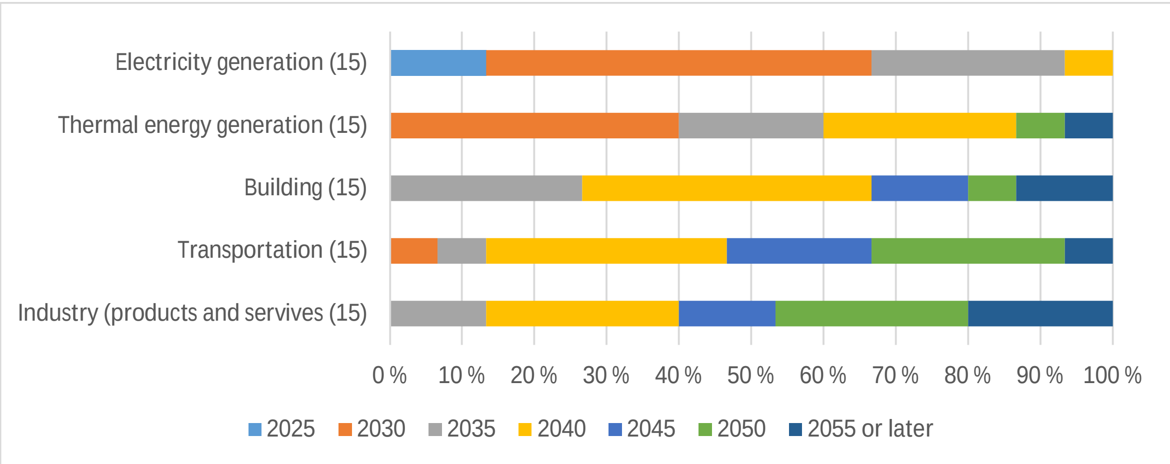

Fig. 4.1.1. When it is possible to achieve carbon neutrality? The number of responses is indicated in brackets.

Comments:

- In cold climate countries, the emissions increase in really cold days should not be counted
- It might be more useful to define two points, i.e., 90% carbon neutrality (i.e., 90% below 2005 values) and 100% carbon neutrality (i.e., 100% below 2005 values). In each of the areas there are some elements that are very hard to convert into carbon-neutral (e.g., steel making and cement, international shipping and aviation, old protected buildings
- Much depends on how the compensation (carbon sequestration) is actually calculated. In Finland, reducing felling and raising forest plantations is probably easier than elsewhere.

4.1.2 Actions required to achieve carbon neutrality

Question: What actions need to be taken to be able to achieve carbon neutrality?

Highlights: The respondents saw that banning the most harmful practices could work in agriculture and mining industry. Direct funding for least harmful practices could work in private transport and, e.g., taxation in both private and heavy transport. A carbon tax could also be useful in private and heavy transport, as well as in textile industry. A carbon tariff was only seen useful in agriculture. Tightening the emission trading system was seen potential in petro-chemistry, plastic and rubber industry, metal industry, and especially in thermal energy generation. Increasing R&D would mainly be effective in mechanical, metal, and textile industries. Voluntary actions were not seen effective. The only potential action could be increasing the voluntary change of consumption habits in private transport.

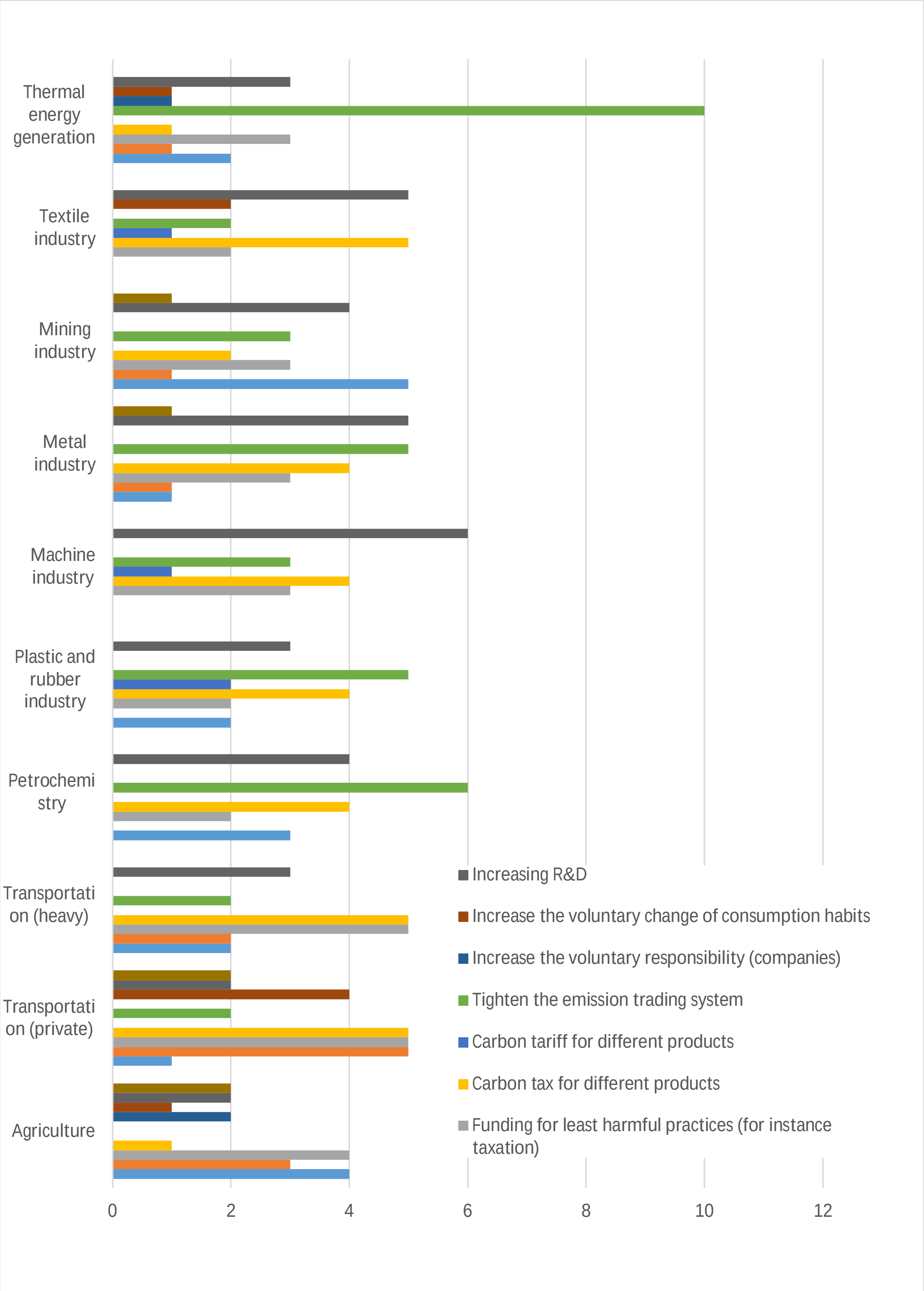

Fig. 4.1.2. Actions required to achieve carbon neutrality

Comments:

- Prohibitions and penalties do not work. An EU-wide carbon tariff will help spread emission reductions but not stop using fossils.
- In agriculture, efforts should be made to increase carbon sequestration.
- Tightening criteria for financiers to determine carbon risk, raising the price of financing the coal-based industry. This would affect the mining industry, thermal energy production, and the metal industry. It is also linked to the ban on coal, which is undermining the sector's prospects in the eyes of financiers. The R&D need in agriculture and the metal industry is primarily related to hydrogen-based processes, development of fertilizers, and metal industries.
- I can't comment on all the different industrial sectors. As concerns agriculture, I think we should simply ban the drainage of peatlands, which as I understand is done in some cases just to get more land on which to spread manure. Additionally, one might offer more technical and even financial support for biogas production from manure. It is not clear to me why farm-scale biogas plants are so expensive. So, people also argue that pyrolysis might be another solution to the treatment of and resource recovery from manure. I also think carbon farming is a promising development, which also requires technical and financial support to mainstream. In the case of private transport, financial instruments are important, but technical support and infrastructure development can also be of importance.
  In heat production, we already have planned to phase out coal, and this is already leading to significant decarbonization. Hopefully, the EU ETS development will take into consideration the coal phase-out that is going on around Europe and might lead to a decline in emission prices.

  Changes in consumption patterns will probably, for their own small part, support developments in agriculture, and perhaps to a larger extent also in district heat (where people are investing in heat pumps and thus putting pressure on local district heat providers).

4.1.3 Barriers to introducing new technologies

Question: What are the barriers for energy companies to adopt new technologies? How significant are they?

Highlights: All the proposed factors excluding the lack of skilled personnel were considered by the respondents to be very significant barriers for introducing new technologies. Two factors, "companies' resistance to change" and "consumers' resistance to change" as a barriers refer to the inertia of thinking.

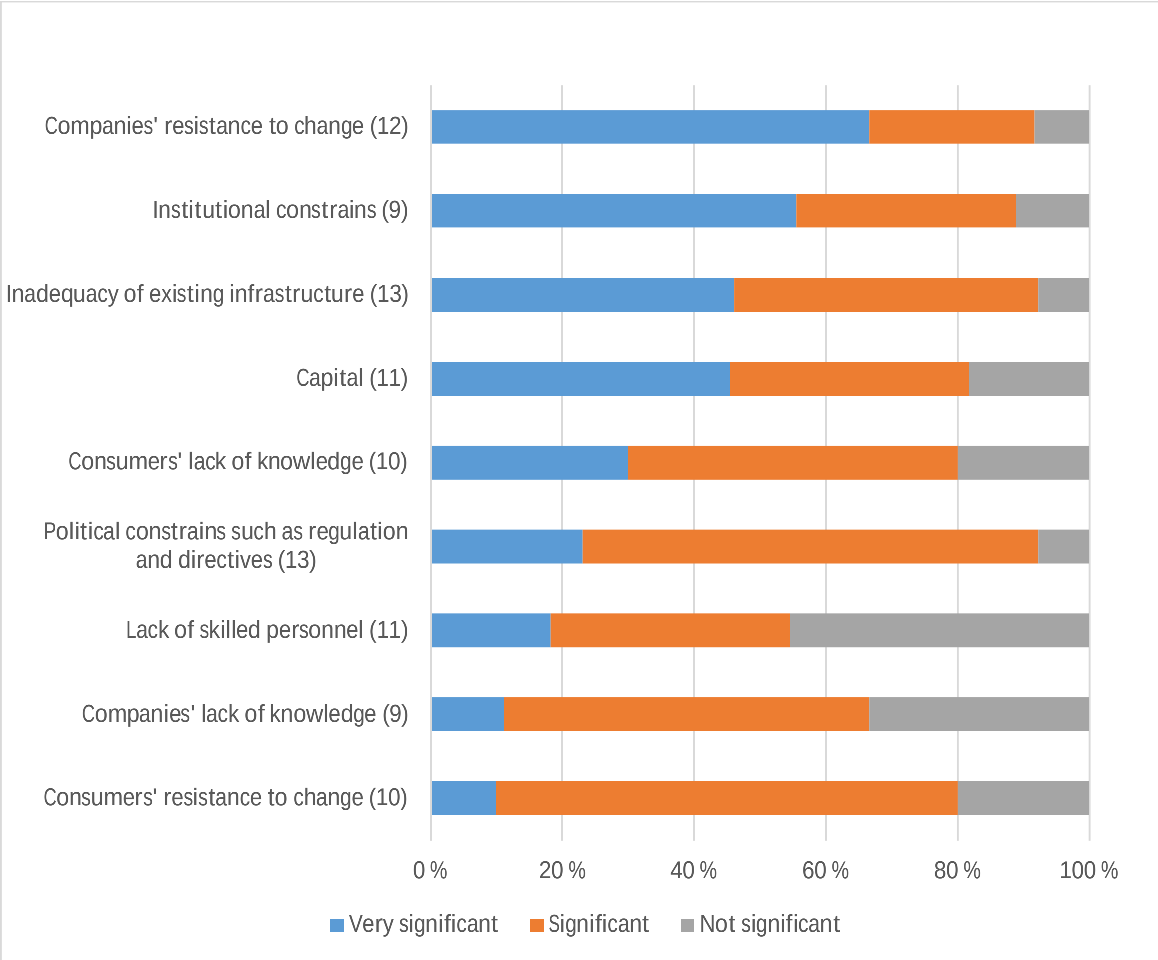

Fig. 4.1.3. Barriers to the introduction of new technologies. The number of responses is indicated in brackets.

Comments:

- A big problem is that no company is eager to change. You can make a change with new companies, but not by changing old ones.
- Often, municipal companies are under strong political guidance. Political guidance can also affect the licensing of new businesses by the municipality within the territory of the energy company. Another challenge is that some of the "old" investments are still economically viable to use, and there is no "rush" for new changes in production methods.
- Companies operate in a ready-made market, and transition to a new one requires investment and involves risks. Short-term policy that changes every four years.
- I think it is very important to maintain political support for the transition (consider our last Parliament elections, and how tight it was). Since the change is very rapid now, we will also probably get bottlenecks in terms of capital and labor. The rapid need to change our infrastructure will also probably require some divestment (we already see this in coal-fired power plants). The transition will require a lot of political skill: people need to feel that they can genuinely benefit from the transition in terms of better jobs and future prospects. This requires a lot of training and grassroots work in municipalities.

4.1.4 Barriers to the electrification of private cars in the transport sector

Question: What are the barriers to changes in electrification of private cars in the transport sector?

There are many considerable barriers to owners' change towards low-carbon technologies in the private car and heavy transport sectors. These originate from policies, technologies, and infrastructure issues. As to new technologies introduced in the building industry, the highest barriers are associated with the lack of information that both the constructors and the consumers have.

Highlights: As to the barriers for the electrification of private cars in the transport sector, the respondents' opinion was that at the present, the cost of infrastructure is too high.

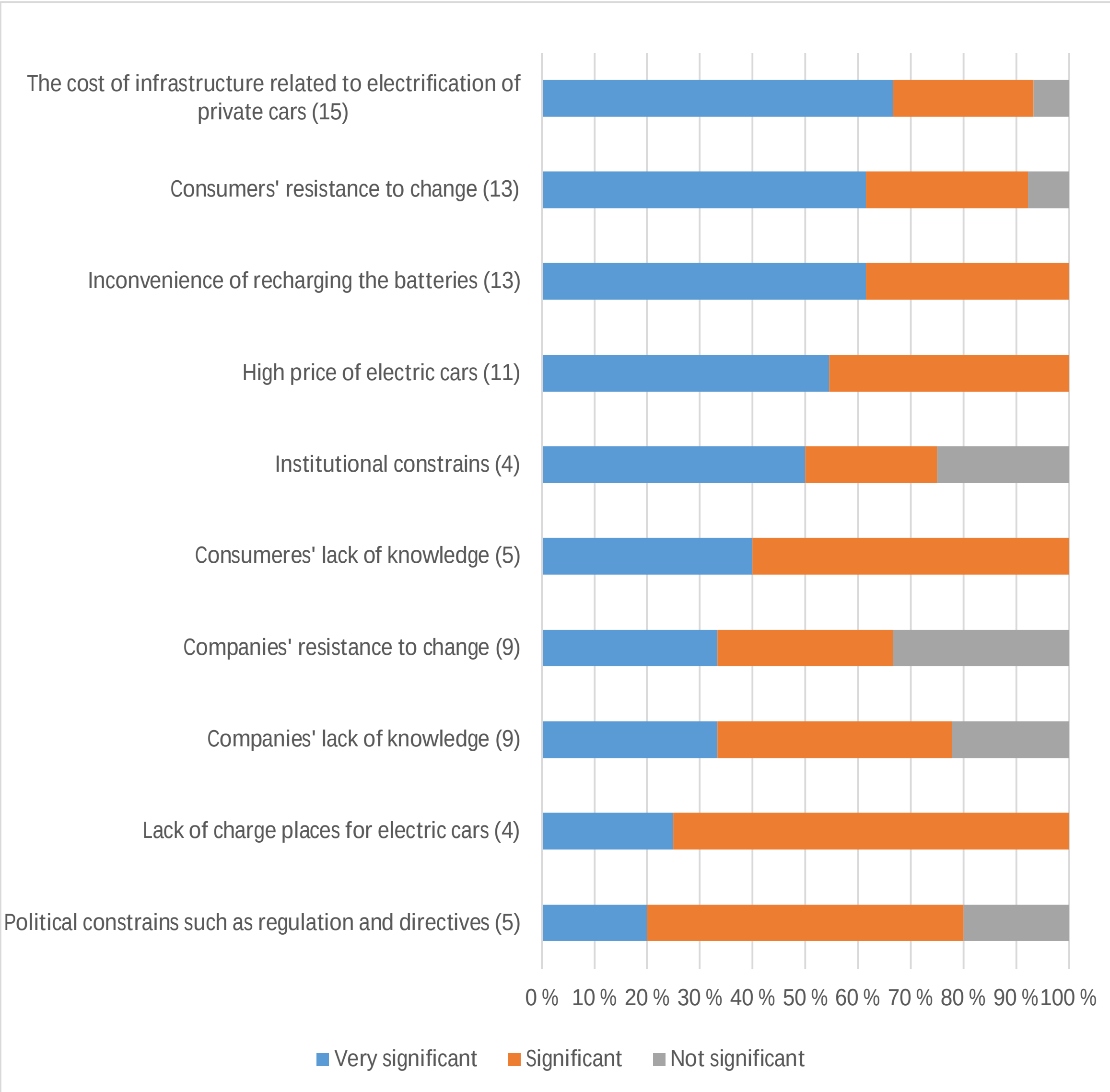

Fig. 4.1.4. Barriers to the electrification of private cars in the transport sector. The number of responses is indicated in brackets.

Comments:

- In many urban centers, the medium voltage network sustainability is a challenge.
- There is not enough knowledge and expertise in housing associations and property managers. Contractors have false knowledge about installation. Wrong skills in design.
- The most important feature of a car is BEING AVAILABLE for unplanned departures. The present cars are still doing well in this regard.
- A stronger backlash against biofuels is also expected. Even after a short period of time, the biofuel option may prove to be the most carbon-neutral solution for electric cars even at a lower price for both the private consumer and society. The heavier traffic is involved, the more likely electricity is to come later.
- There are three problems that hinder the change of traffic towards net zero fossil emissions; the high cost of electric cars and the high cost of electric cars, and, yes, the high cost of electric cars.
- The driving range is constantly growing and improving, and there is no location or charging time for charging points so important in the future.
- Something else has to do with the general uncertainty about the use of a new technology: how to act at all with an electric car, what is its resale value, how long will the batteries last, whether the operating costs are really lower than those of an internal combustion engine, how about motoring taxation, etc.?
- Here, too, the speed of change required is a challenge. I think the problems with charging will be resolved soon. The high cost of infrastructure would not be a problem if there was as much time as it was for the construction of the internal combustion engine infrastructure. It would also be important to take into account the different car users. Particularly vulnerable are the rural people who drive old cars. It is not right to demonstrate the future prospects of the world of electric transport to them. Tailor-made solutions should be found.

4.1.5 Barriers to the change towards low-carbon combustion technologies for private cars in the transport sector

Question: What are the barriers to changes in using low-carbon combustion technologies of private cars in the transport sector?

Highlights: All the respondents chose the option “very significant” for political barriers. This indicates the importance and the great potential of the legislation aspect concerning the matter. Obviously, in the respondents’ opinion, the infrastructure is not ready both in terms of technologies and the monetary aspects accepting mass usage of private cars based on low-carbon technologies.

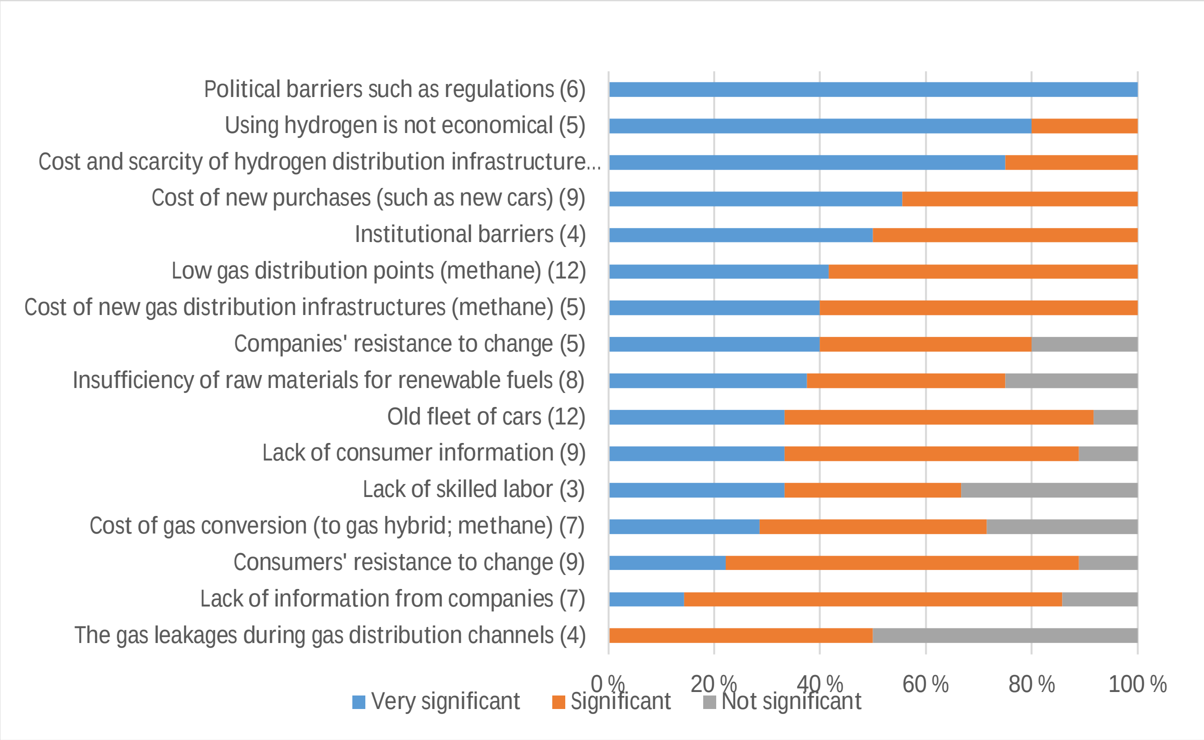

Fig. 4.1.5. Barriers to the change towards low-carbon technologies of private cars in the transport sector. The number of responses is indicated in brackets.

Comments:

- The Finnish car fleet is old. The average car price is € 3,500. Many people cannot afford to buy a car for 35,000. In addition, an old car can be repaired yourself, which means savings.
- The high age of the car fleet can be an incentive and a compelling reason to switch to low-carbon cars, and therefore, not necessarily a barrier at all.
- The average consumer fears that the current old reliable vehicle will be replaced. There will be uncertainty; e.g., start-up problems; maintenance takes a long time and increases effort; downtime; immature technology; poorer performance; fear of losing comfort.
- The high cost of new cars and the fact that, e.g., the tax treatment of a car using biogas does not encourage the car purchase.
- Expenditure on new gas distribution infrastructures (methane), scarcity of gas distribution points (methane), insufficient raw materials for renewable fuels. It’s hard to bundle a gas hybrid and a hydrogen car into one, I personally see the hydrogen car as an electric car, where of course the battery is replaced by hydrogen in the tank. Engineering is also at a completely different point on the evolution curve.

4.1.6 Barriers to the change towards low-carbon technologies in the heavy transport sector

Question: What are the barriers to changes in using low-carbon technologies in heavy transport?

Highlights: As to the heavy transport, the respondents considered the most significant barriers to be the inadequacy of the existing infrastructure as well as the existing regulations. Power-to-hydrogen technologies were also not seen promising by the respondents in the nearest future. In the respondents' opinion regarding this question, the factor "consumers' resistance to change" is not significant at all.

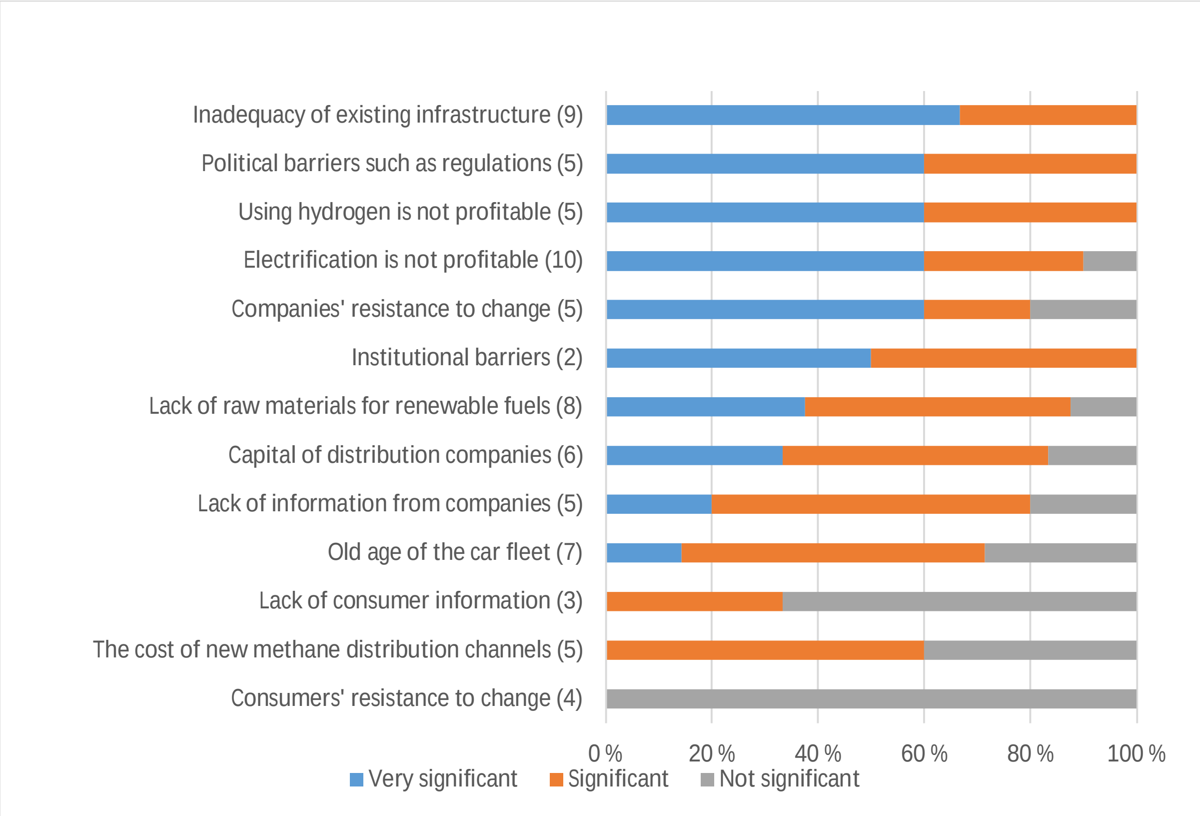

Fig. 4.1.6. Barriers to the change towards low-carbon technologies in the heavy transport sector. The number of responses is indicated in brackets.

Comments:

- Many people think that electrification is not profitable. A wrong belief. We are just doing a thesis work, where, e.g., 3–5 t electric forklifts will certainly become more economical than diesel forklifts. Profitability itself can be an obstacle. If something is not profitable, it prevents change.
- For heavy transport, zero-emission solutions are best competitive in closed logistics entities, e.g., in a factory area or on standard routes in an urban area. The other extreme being probably, e.g., timber transports. Heavy traffic is the job of professionals, so profitability is not everything.
- Heavy transport is highly competitive, so low-carbon alternatives should deliver benefits also in tenders.

- Could the use of gas be profitable in heavy traffic, especially outside urban areas? Is it possible on the regulatory side (e.g., can gas fuel be easily sold - No)?

4.1.7 Barriers to the introduction of new technologies in buildings

Question: What barriers do the energy and construction companies have in adoption of new technological solutions in buildings?

Highlights: Barriers to the introduction of new technologies in the building industry obviously originate from the lack of information. Neither companies related to the construction industry nor consumers were considered by the respondents to experience a lack of information regarding new technologies. According to the respondents, regulations in the building industry are not a serious barrier.

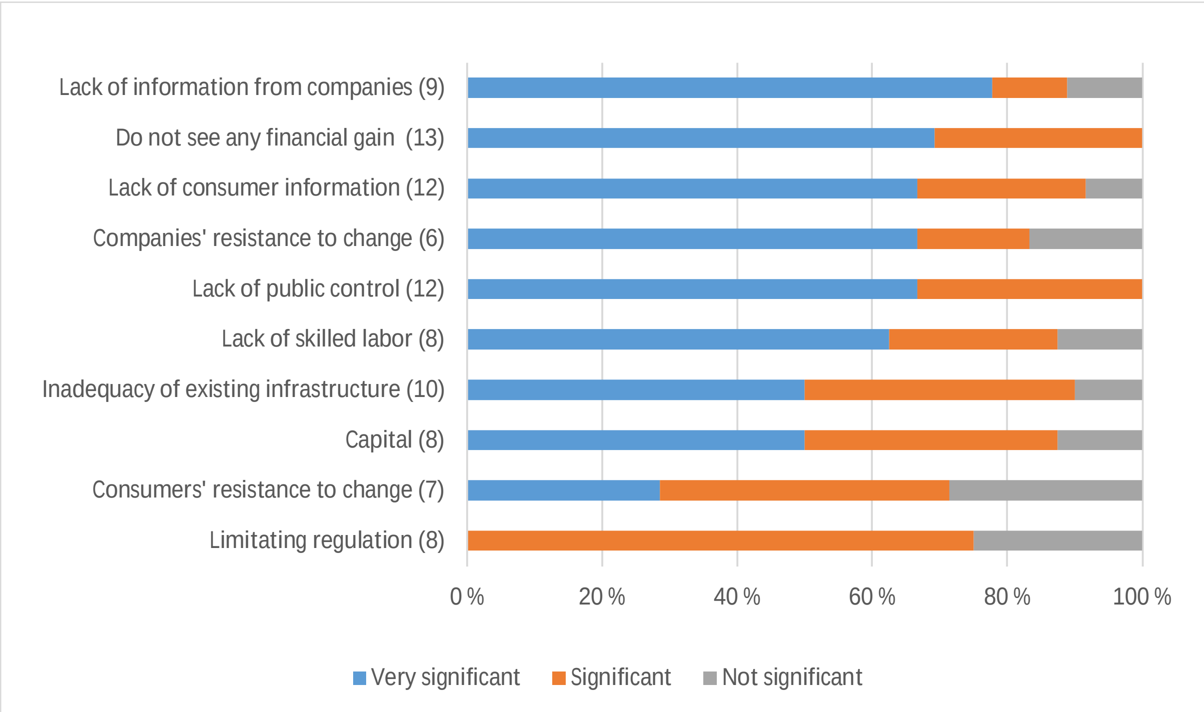

Fig. 4.1.7. Barriers to the introduction of new technologies in buildings. The number of responses is indicated in brackets.

Comments:

- State and municipalities, network companies control too little. On the other hand, when guided, they may not identify the right ways to steer. On the other hand, thinking should change from mere financial thinking to financial sustainability development thinking.
- Property owners often don’t seem to be able to afford to invest in energy technology, and even with investments, the payback period would be reasonably short.
- Much can already be done, but builders oppose the change in rising prices per square meter. On the other hand, consumers do not give enough value and demand for new solutions.

- The lack of public guidance. Financial gain is not seen. Even buildings are considered in the short term, even though they are national assets.
- The lack of public control, which can now be seen as a “major” energy overhaul by the government (e.g., financial support for energy investments in apartment buildings). No clear picture of possible/necessary actions and/or their effects. No centralized counselling either.

4.1.8 Barriers to realization of export potential

Question: What are the most significant barriers to realization of the export potential?

In the previous round, as shown in Section 3.2.4, the respondents listed the most potential technologies for export.

Highlights: The respondents saw that the solutions related to demand response are the most difficult to export. Additionally, it can be seen that several technologies lack R&D activities. However, there are three factors that were not regarded by the respondents as significant barriers for all the sectors. They are unfair trading practices related to other countries (e.g., taxation and salaries), the lack of distribution channels, and the challenge to obtain foreign educated personnel. These factors are not included in the graph.

Comments:

- CHP and waste boilers are a very small market where no large increases are seen. Should the market pick up, then Finnish technology would have a good position.
- Finland is a small market player, and in order to succeed, it needs clusters.
- There is a lot of underdeveloped market and a lack of services in demand response solutions and automation. The issue with biomass solutions is that the market is not ultimately globally growing because the raw material is not endless. Geothermal energy is no longer an issue from the viewpoint of R&D, but the functionality and profitability of the technological solution still has to be demonstrated. Power-to-X still requires R&D. In terms of energy storages, there is a partial lack of techno-economic potential and completion demonstrating a solution.
- I think one important export barrier is that solutions are not tailored to customer needs, and the different needs and operating environments of customers are not understood. The lack of capital or investment is also a considerable barrier.

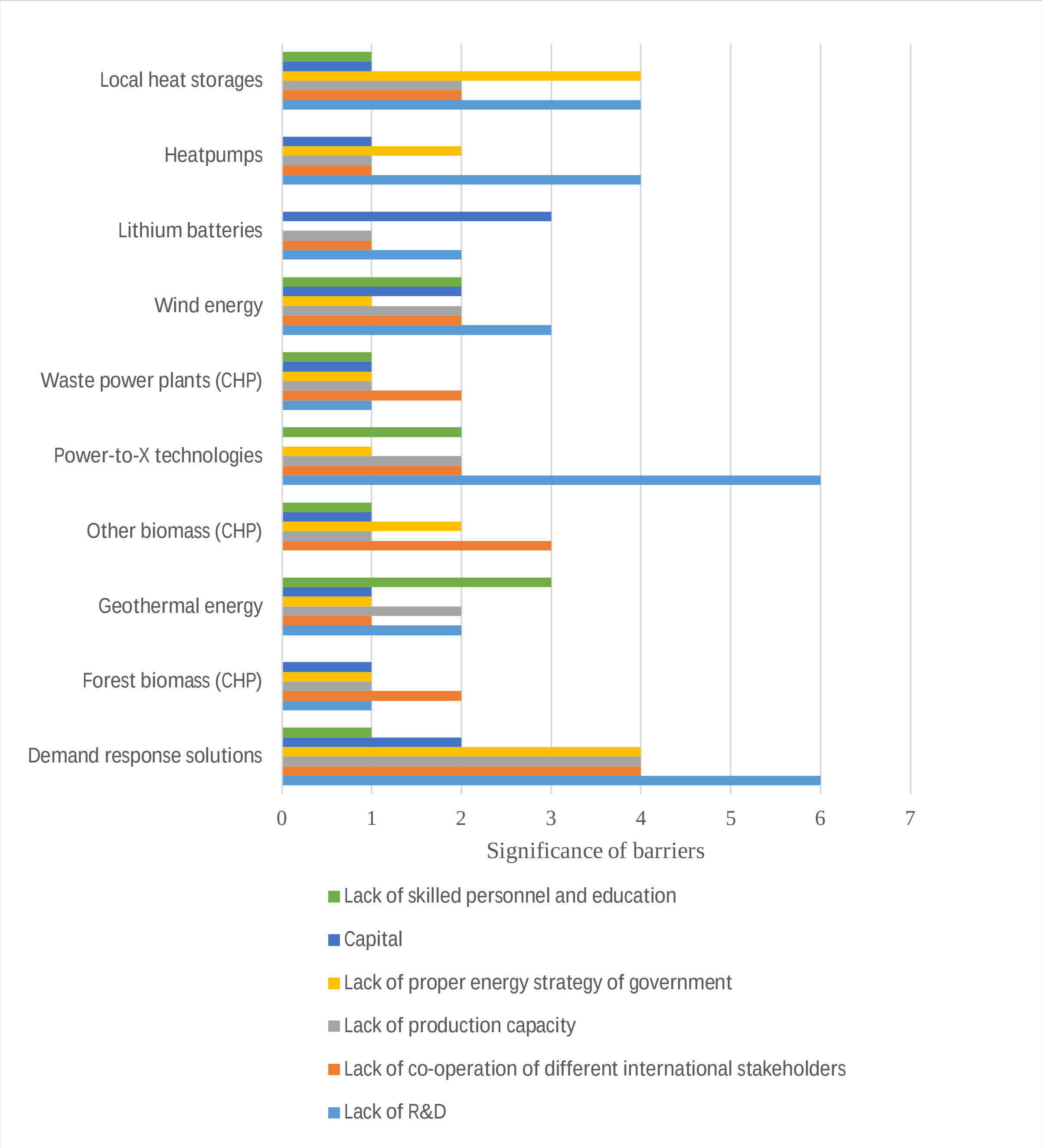

Fig. 4.1.8. Barriers to realization of export potential

4.2 Potential of Different Technologies

In the first survey round, the following technologies were found to be the most significant ones when considering the export potential:

- Demand response solutions
- Forest biomass (CHP)
- Other biomass (CHP)
- Waste power plants (CHP)
- Geothermal energy
- Power-to-X technologies

During the second survey round, the respondents' views were asked about the potential of different technologies in different contexts.

4.2.1 The most significant applications for different technologies

Question: What are the most significant applications/users for the following technologies?

Highlights: The respondents' answers to the question varied markedly. For some technologies there are clear end-users, but for some there can be several options.

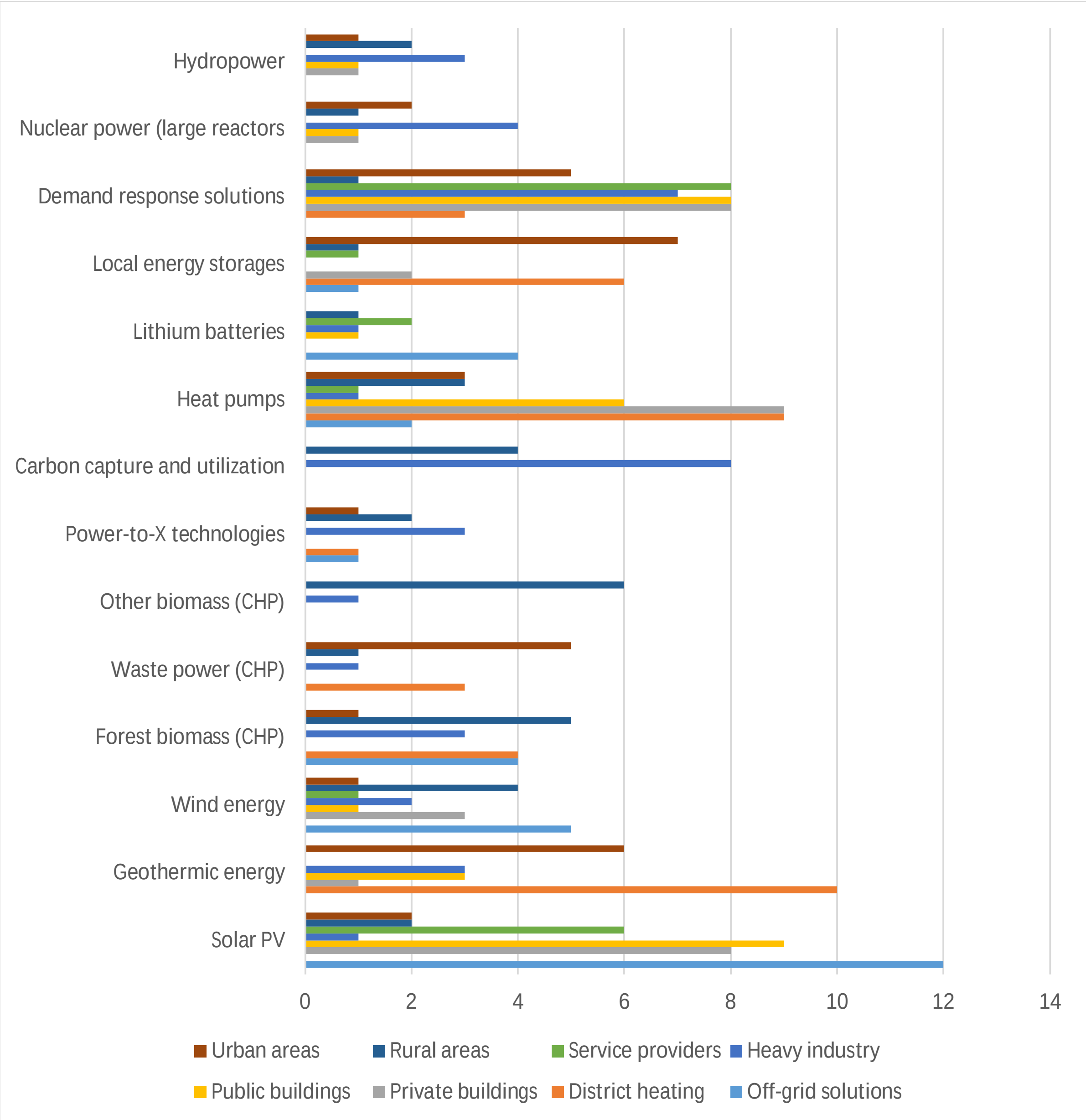

Fig 4.2.1. End-users of different technologies.

4.2.2 The most significant thermal energy generation technologies in 2035

Question: Estimate the capacity of different thermal energy technologies in Finland in 2035.

Consider the capacity as a power unit.

Highlights: Heat pumps, fossil/bio/waste-based CHP, or thermal power plants were seen to have significant capacity in 2035. Geothermal energy, service providers, and solar collectors were not seen to have as much capacity as other technologies.

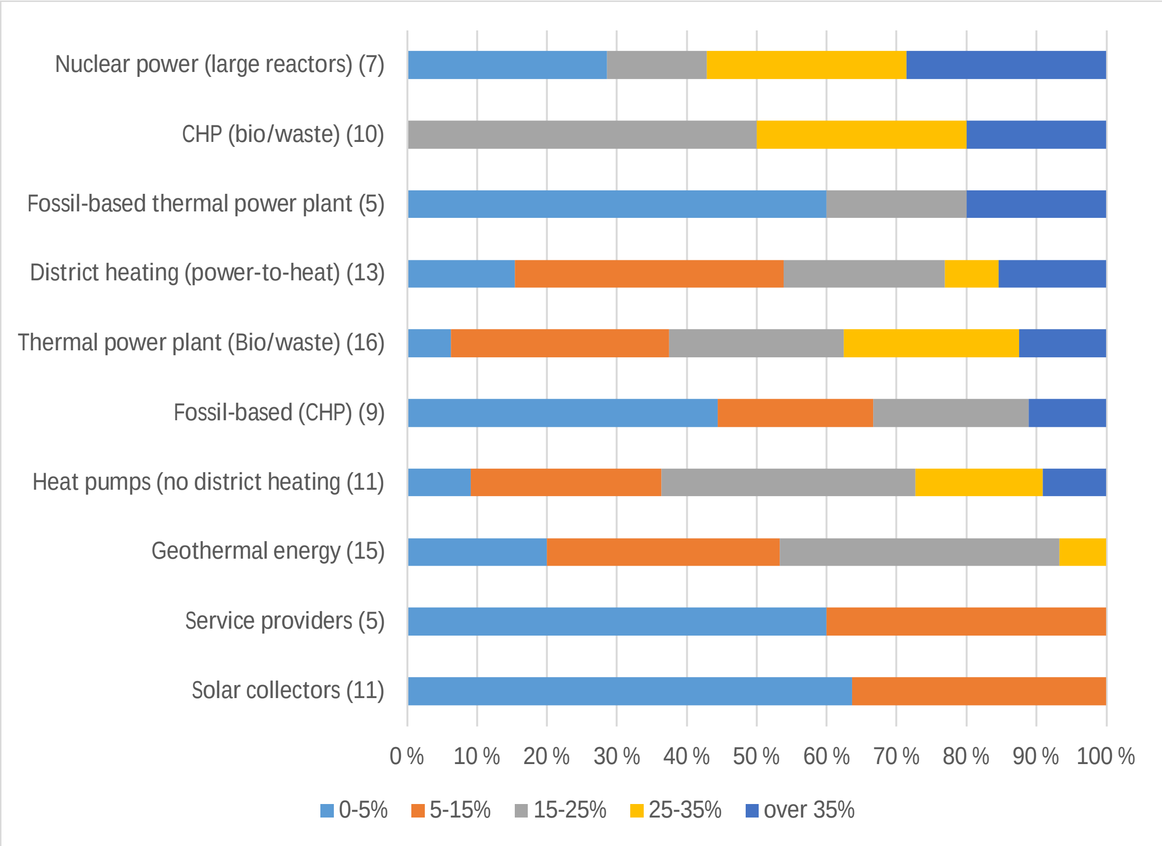

Fig. 4.2.2. Capacity of thermal energy production in 2035 in Finland. The number of responses is indicated in brackets.

Comments:

- It is a challenge to obtain completely carbon-free thermal energy

4.2.3 Peak power and reserve power—National reserve power

Question: What is the importance of the national reserve power in 2035?

Highlights: According to the respondents, there is a significant need for peak power and domestic emergency power.

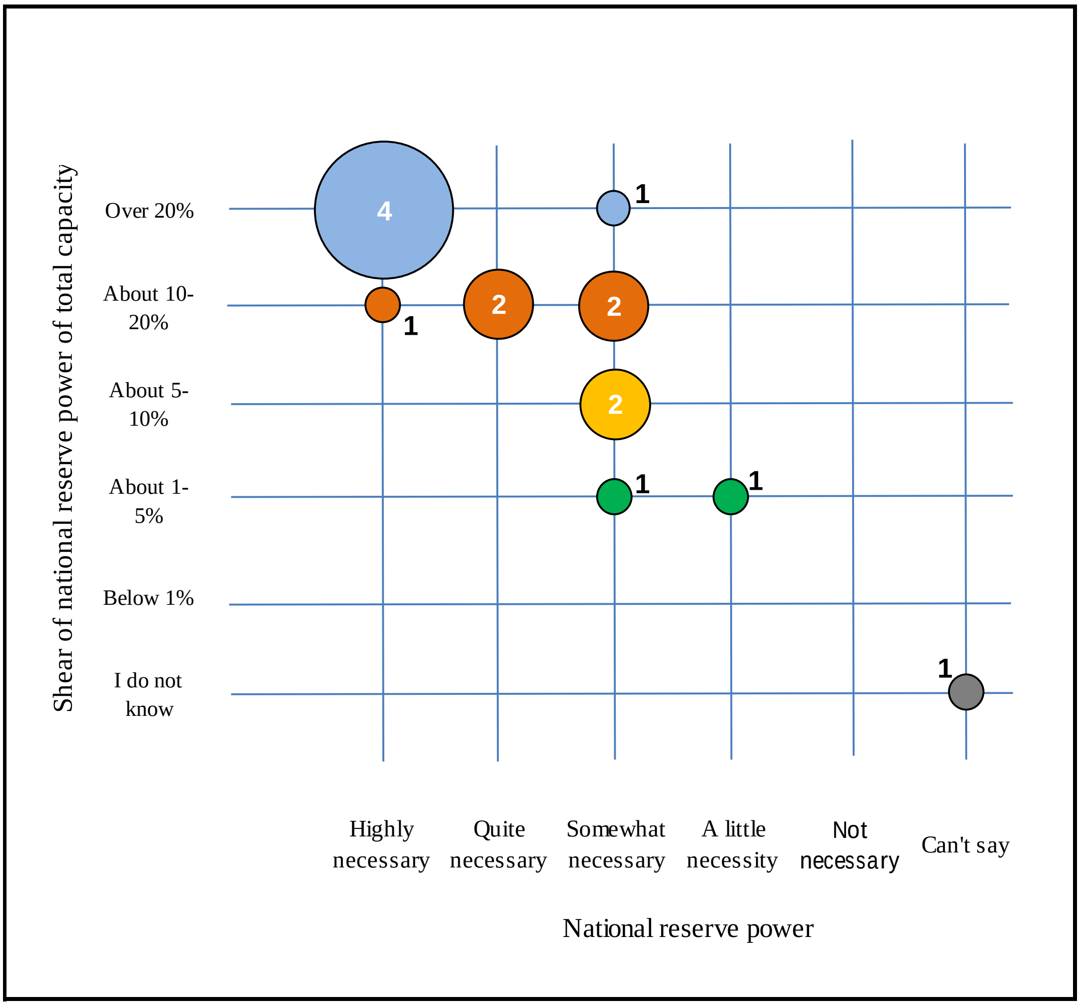

Fig. 4.2.3. Peak power and reserve power—National reserve power. The number of responses is indicated by figures beside and in each circle.

Comments:

- Currently, there are no incentives to build spare and peak capacity.
- The present investments in power plants are mainly focused on and are going to focus on uncontrollable wind power. Increasing wind power decreases the running time of the existing power plants and also the profitability. The removed capacity will be compensated with bio-based fast starting diesels—management of power fluctuation does not help during winter/summer variability. Increase in solar energy decreases the need of management of consumption in summertime. In wintertime, hydro, diesel, large thermal storages, shutdowns of wind power, and management of industry's energy need help to manage the power fluctuation.

4.2.4 What is the importance of strong transmission lines in 2035?

Question: The respondents were asked about the importance of strong transmission lines in 2035.

Highlights: Based on responses, there is a significant need for strong distribution lines.

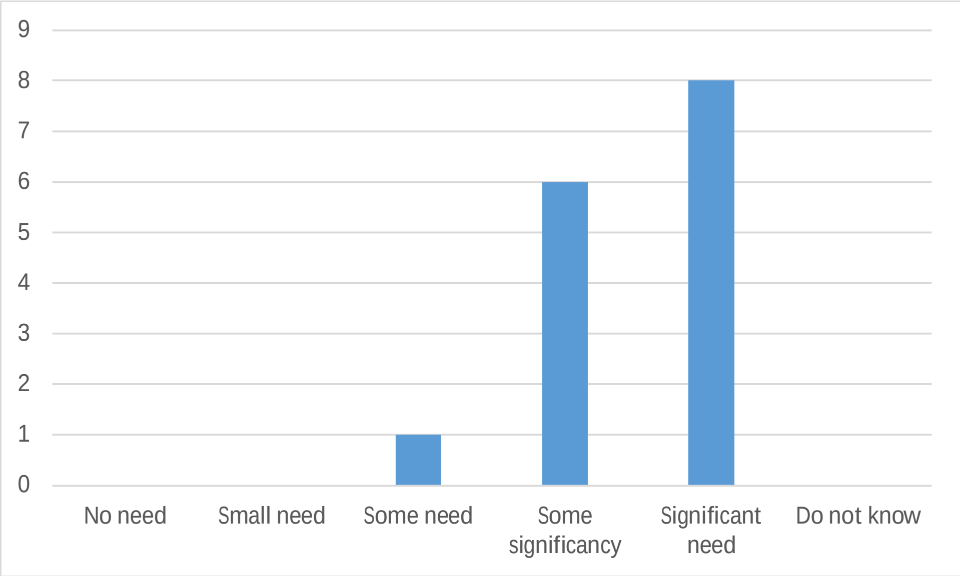

Fig. 4.2.4. Peak power and reserve power—Strong distribution lines

Comments:

- Global distribution lines are increasingly important.
- Capacity is more distributed, thus forecasting loads on the lines is difficult. Therefore, strong distribution lines are needed.

4.2.5 Peak power and reserve power—Energy storages

Question: What will be the need for energy storages in 2035?

Highlights: Having energy storages is somewhat significant.

Comments:

- Large thermal storages needed in cities
- Many distributed thermal storages needed to balance the peak powers
- When the society becomes more and more electrified, we need storages, such as thermal storages. The need is for week-size in capacity

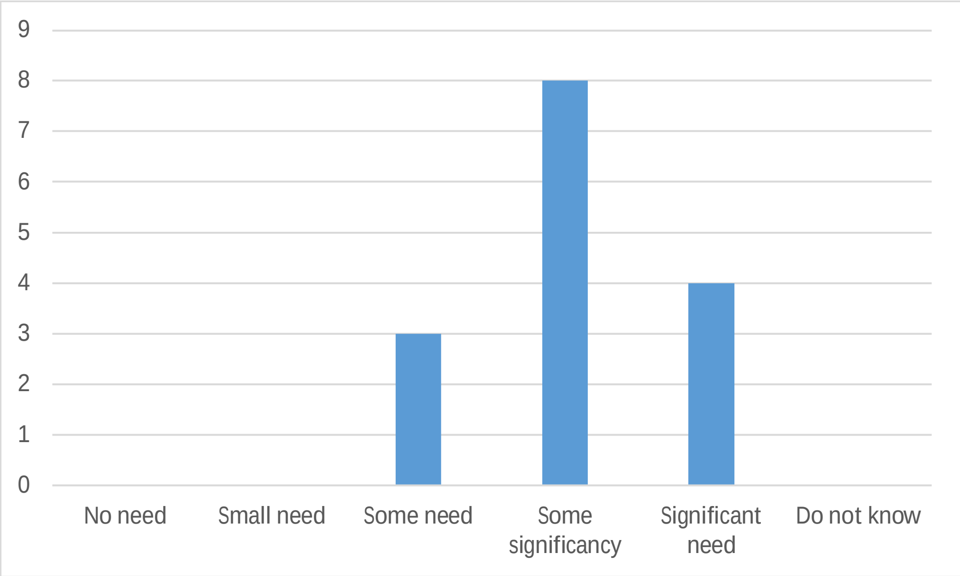

Fig. 4.2.5. Peak power and reserve power—Energy storages

4.2.6 Peak power and reserve power—Market

Question: How will the markets of peak power and reserve power be regulated in 2035?

Highlights: The markets of peak power and reserve power should be balanced between regulation and free markets.

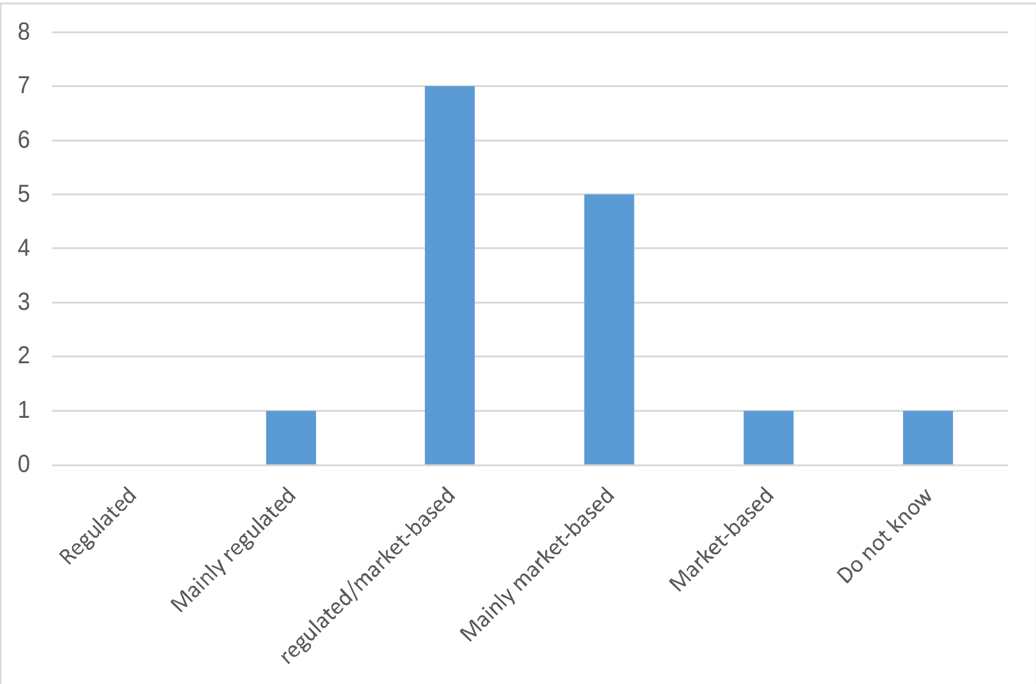

Fig. 4.2.6. Peak power and reserve power—Markets

Comments:

- The starting point is market based, but there is a risk that has to be recognized. For instance, in wintertime, the availability of energy has to be guaranteed.

4.2.7 Peak power and reserve power—Distribution of energy storages

Question: How will the energy storages be distributed in 2035?

Highlights: The energy storages should be distributed rather than centralized, but centralized solutions are also needed.

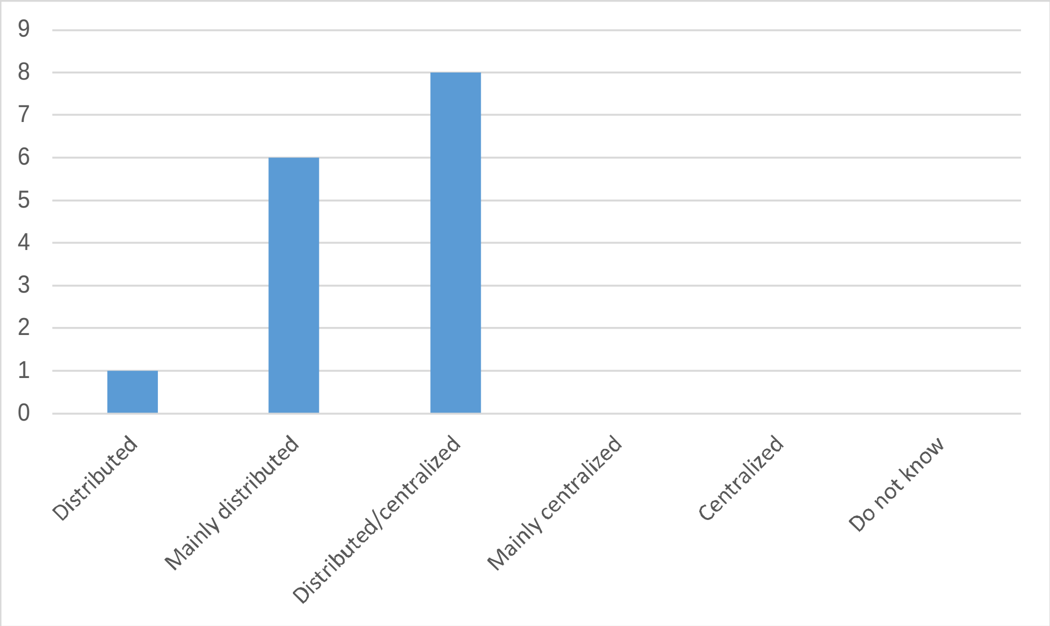

Fig. 4.2.7. Peak power and reserve power—Distribution of energy storages

Comments:

- The storage for electricity should be short term.

4.2.8 Applications of Power-to-Heat technology

Question: Evaluate the Power-to-Heat technologies according to the significance of their applications in 2045.

Highlights: The power-to-heat solutions are of significance for all the end-users except farms.

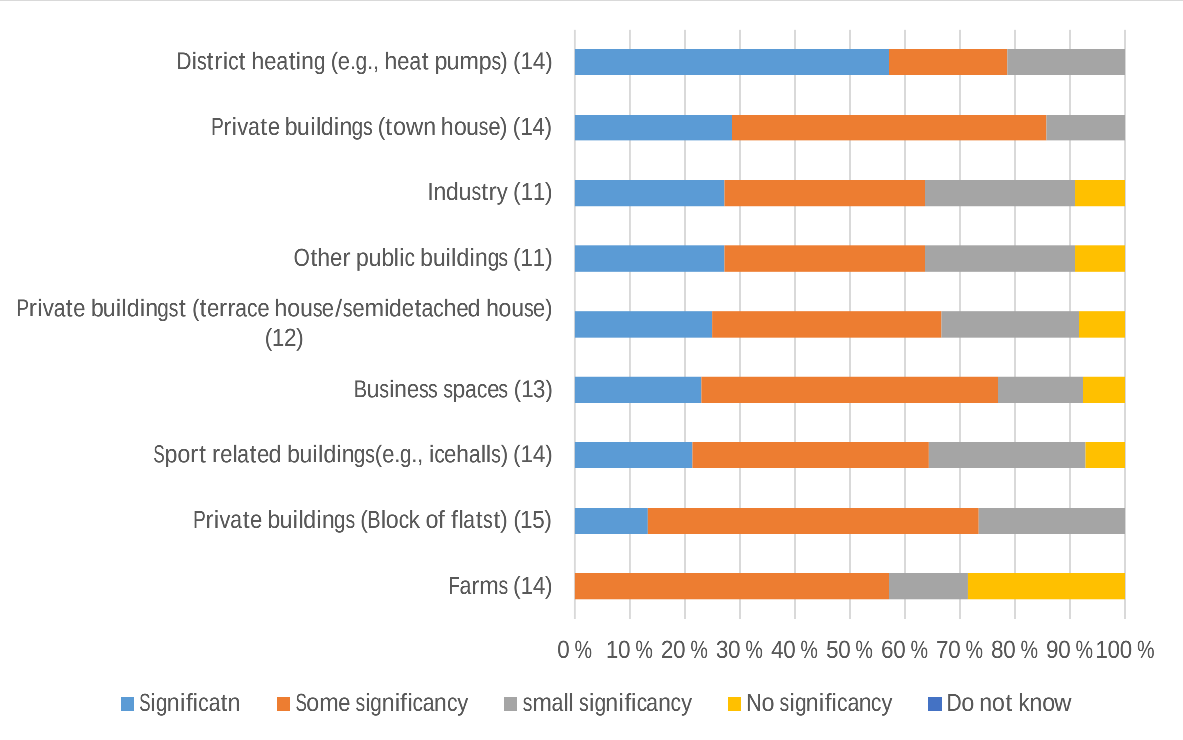

Fig. 4.2.8. End-users of Power-to-Heat solutions. The number of responses is indicated in brackets.

Comments:

- The more flexible you can be, the more significant the end-user will be. For instance, in industry, you schedule the processes and even storage. Commercial premises are somewhat difficult as they are usually efficiently air-conditioned, but in large shopping centres there is already some potential.

4.2.9 Power-to-Gas as an energy solution

Question: What is the role of Power-to-Gas technologies in the Finnish energy system in 2045? Power-to-Gas technology is one of the suggested ways to produce methane, hydrogen, and methanol that can be used, e.g., as an energy storage, in the chemical industry, and transport. In this question, we have chosen the year 2045, because the year 2035 comes too soon taking into account the development stage of the Power-to-Gas technology.

Consider the desired role in the gas market and the probability of its implementation. Further, information about the gas consumption and applications in Finland is provided by the Finnish Gas Association (2019).

Highlights: Power-to-Gas technology should produce 5–15% of the Finnish gas, and this will probably happen in the future.

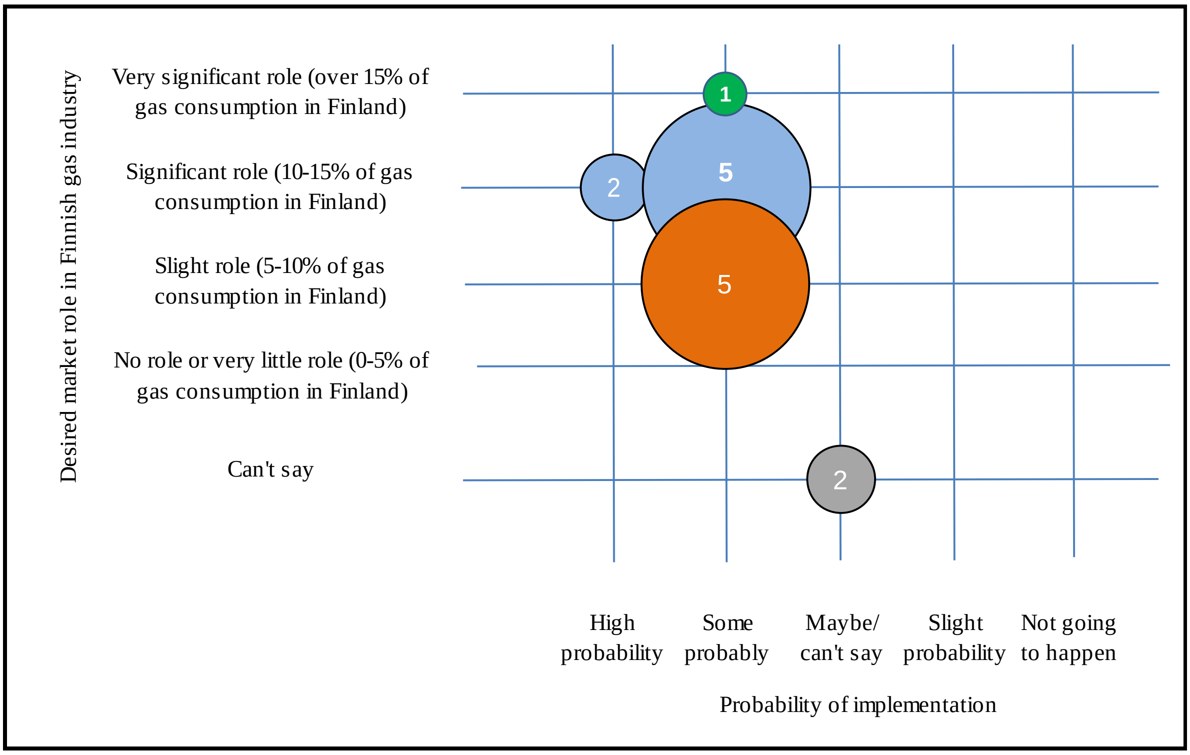

Fig. 4.2.9. Power-to-Gas as an energy solution. The number of responses is indicated by figures in each circle.

Comments:

- This technology is really important, but the utilization of investments is uncertain. Well-balanced synergies should be found between existing facilities and/or companies.
- It is crucial whether gas takes a more important role in Finland or not. Increasing the distribution channels of gas, such as the LNG terminal, and emissions targets of shipping promote the role of gas. If these scenarios make good progress, Power-to-Gas solutions will become more common.

4.2.10 Power-to-Fuel as an energy solution

Question: What is the role of the Power-to-Fuel technology in the Finnish energy system in 2045?

Power-to-Fuel technology is one of the suggested ways to produce liquid fuels, which can be utilized, e.g., as an energy storage, in chemical industry, and transport. In this question, we have chosen the year 2045, because the year 2035 comes too soon taking into account the development stage of the Power-to-Fuel technology. Consider the desired role in the fuel market and the probability of its implementation. Additional information about the fuel consumption in the transport sector can be found in Lipasto (2019).

Highlights: Power-to-Fuel technology should produce 10–15% of the Finnish gas, and this will probably happen in the future.

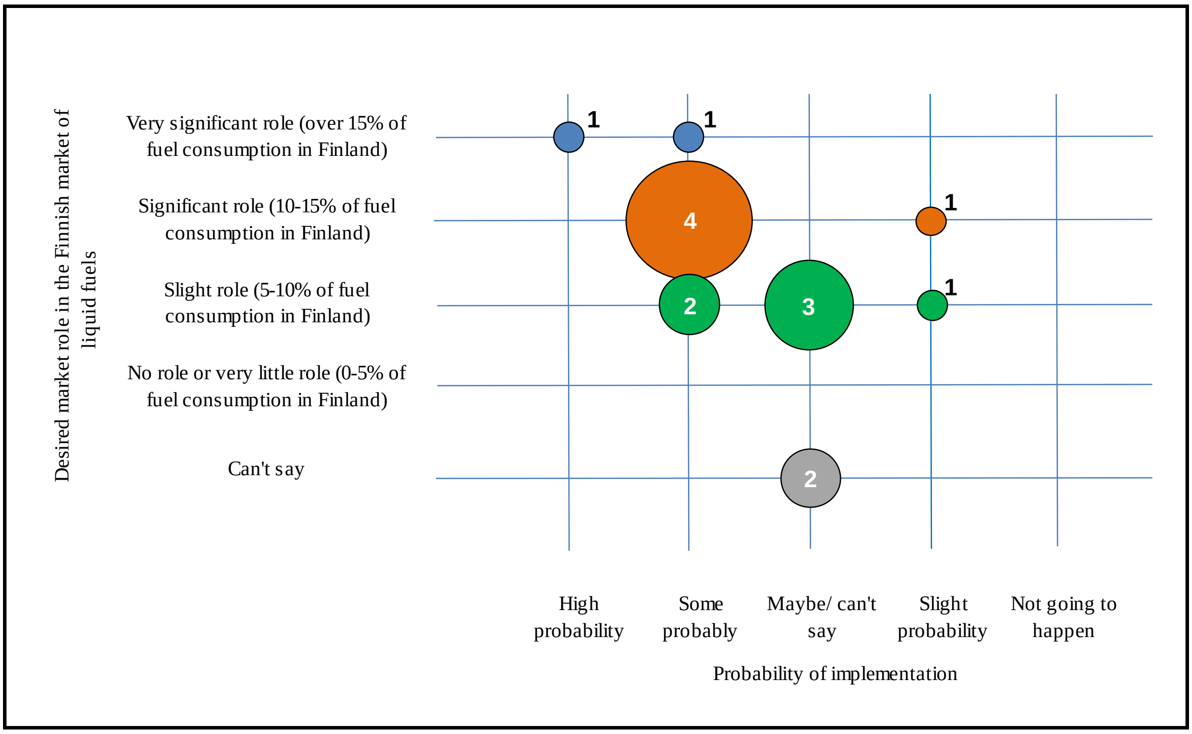

Fig. 4.2.10. Power-to-Fuel as an energy solution. The number of responses is indicated by figures beside or in each circle.

Comments:

- Power-to-Fuel solutions are one solution of interest for combustion engine vehicles when the target is to reduce emissions. I see a low probability for the utilization of this technology, although the utilization is preferred.

4.3 Background Information for the Round 2

The majority of the respondents work as experts in their organizations. One-third is working at the top management, and a fifth in the middle management.

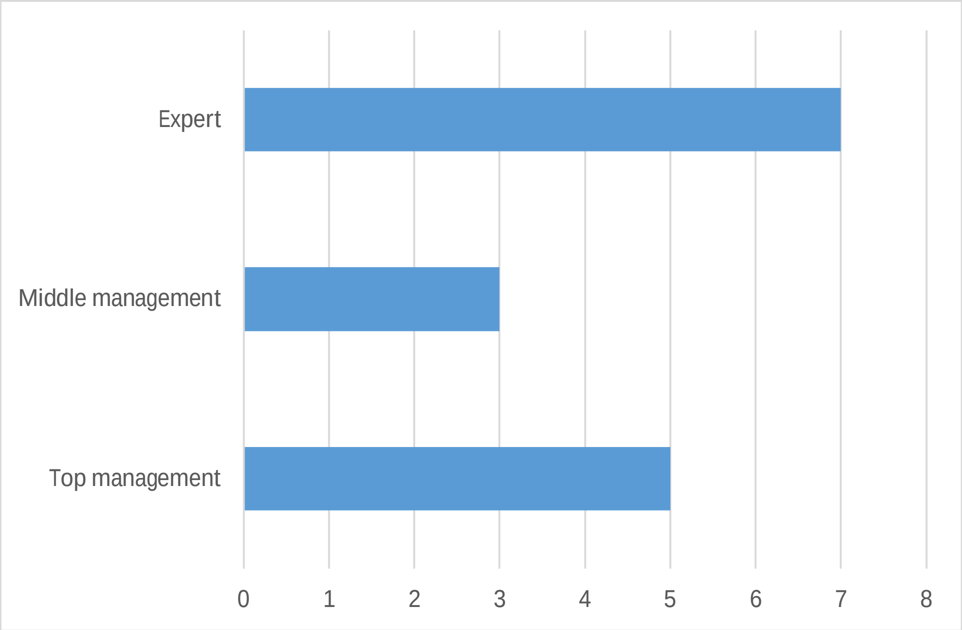

Fig. 4.3.1. Respondents' position in their organization.

Most of the respondents (53%) have technical education; 20% have business education; 7% has humanities and 20% other education.

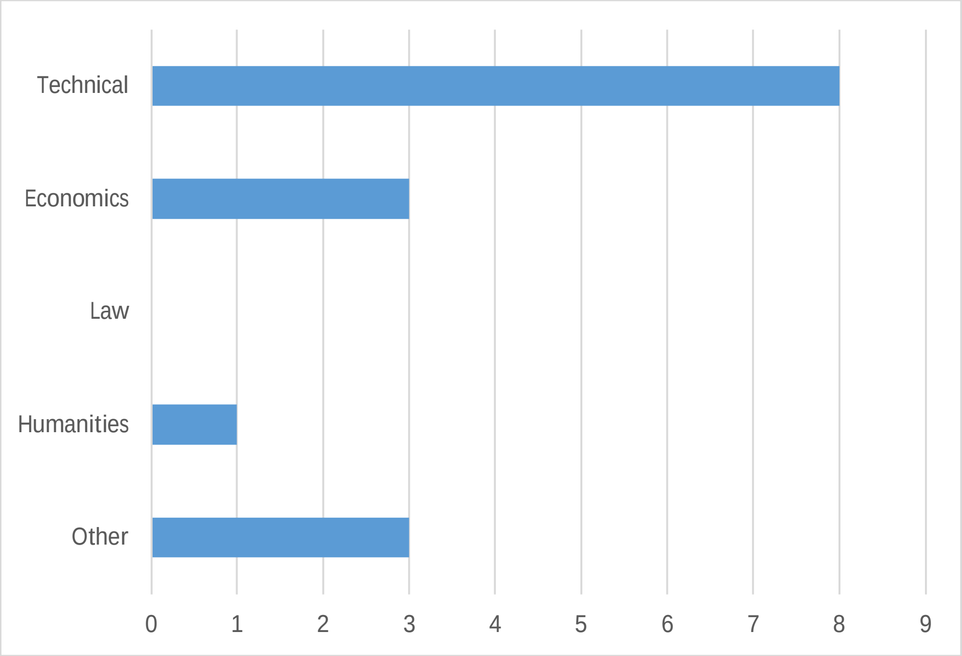

Fig. 4.3.2. Respondents' field of education.

60% of the respondents have doctorate (PhD), 33% have a Master's degree (M.Sc.), and 7% have a Bachelor's degree (B.Sc.).

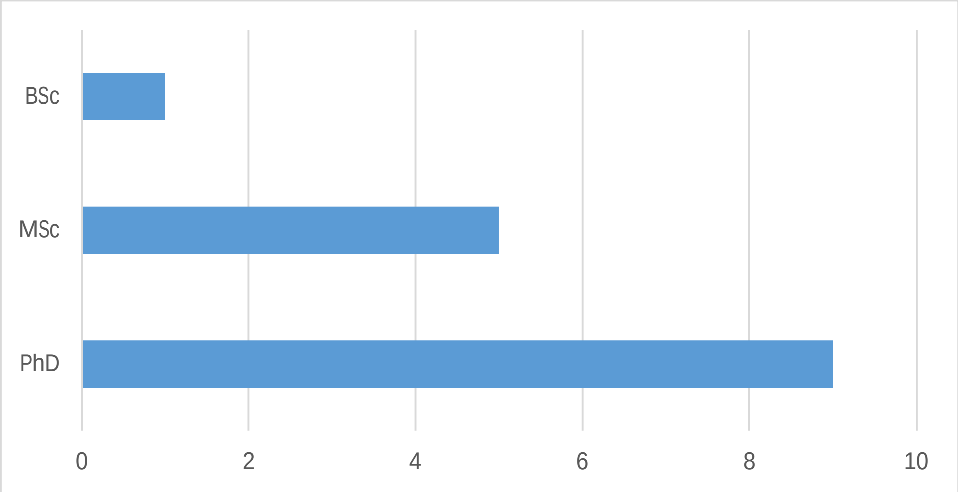

Fig. 4.3.3. Level of education of the respondents.

The majority of the respondents (47%) are working in research and education and 33% in private business organizations. 13% are working in governmental organizations and 7% in other organizations.

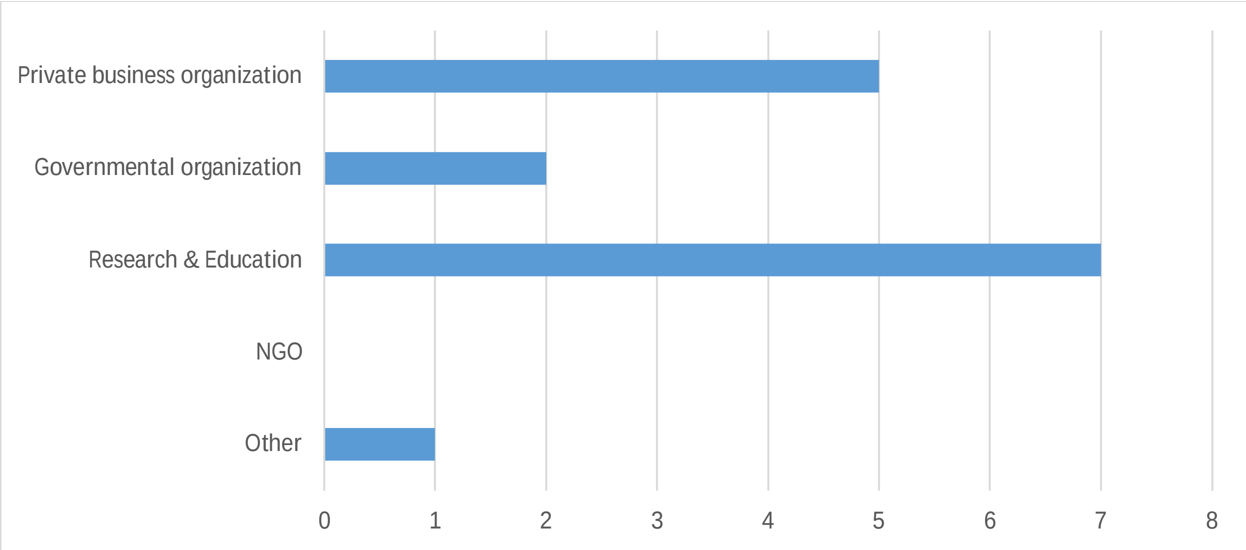

Fig. 4.3.4. Present organization of the respondents.

53% of the respondents are male and 33% female.

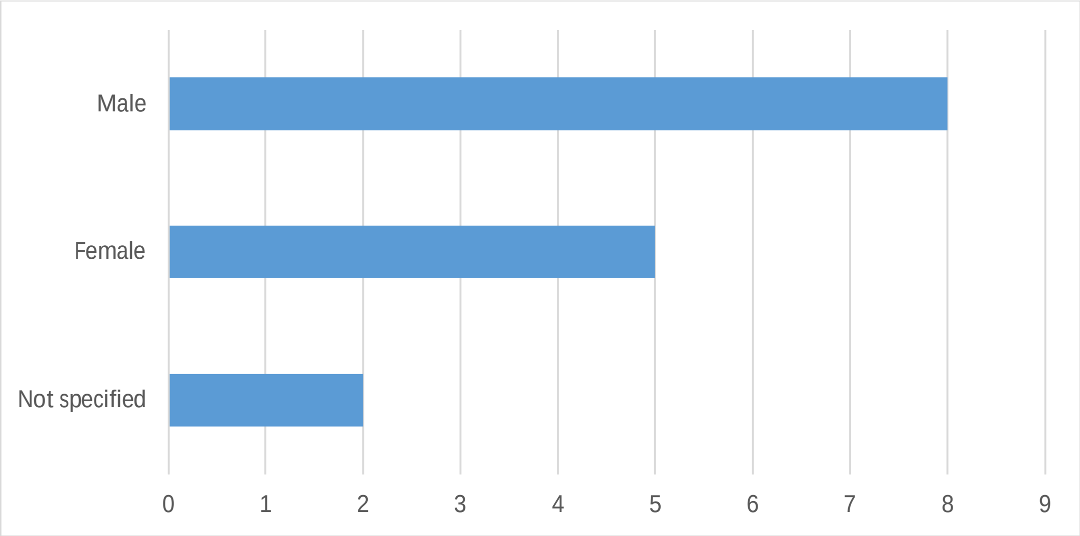

Fig. 4.3.5. Gender of the respondents.

The majority, 40%, of the respondents are 30–45 years old, 33% are over 55 years old, and 27% 45–55 years old.

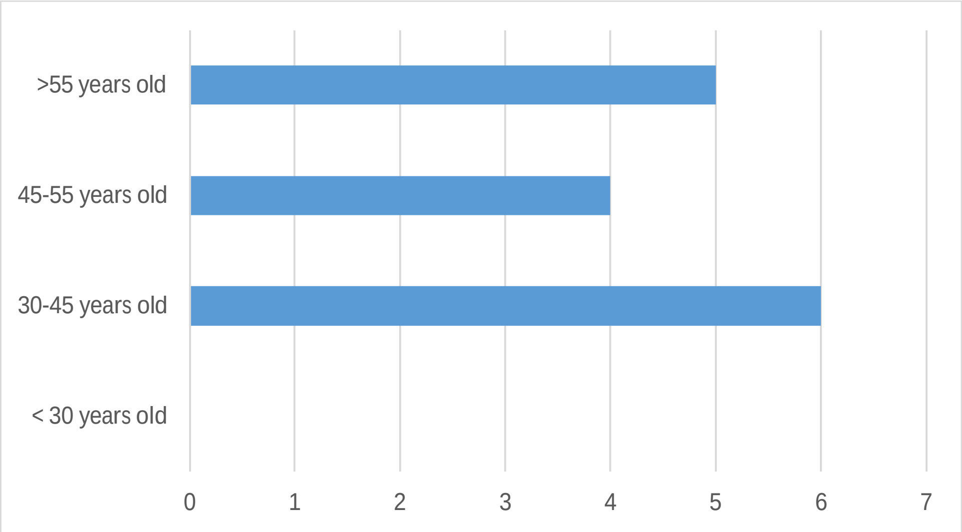

Fig. 4.3.6. Age of the respondents.

Table 4.3.1 presents the expertise of the respondents in different business areas and Table 4.3.2 in energy-related topics.

Table 4.3.1 Expertise of the respondents in different business areas.

	Large companies	Small and medium-sized enterprises	Politics	Non-governmental organizations	Academy
Technology expertise	3	4	3	2	3
Business skills	4	5	2	0	5
Policy and public administration skills	1	3	2	1	4

Table 4.3.2. Expertise of the respondents in energy-related topics.

	Expert	Knowledgeable	Novice/not familiar
Solar PV	6	7	0
Solar thermal	2	9	1
Geothermal energy	0	7	3
Wind energy	5	7	0
Wave power	0	3	7
Forest biomass (CHP)	5	4	3
Other biomass (CHP)	3	5	3
Waste power plant	2	7	1
Gas turbines (biogas)	1	6	2
Hydropower	2	8	1
Power-to-X technologies	2	4	6
Heat pumps	4	8	0
Carbon capture and storage	1	3	9
Carbon capture and utilization	1	1	10
Local thermal energy storages	2	7	3
Demand response solutions	5	7	0
Fuel cells	1	3	6
Concentrated solar power	1	4	6
Lithium batteries	1	5	7
Nuclear (large reactors)	1	6	5
Nuclear (small reactors)	0	3	9

5 Analysis and Comparison of the Results

The main objective of the Delphi survey was to ask experts about technologies, barriers, and organizational innovations related to the transition towards carbon-neutral society. During the two rounds, valuable material was collected from various sub-topics. The Delphi survey conducted in 2019 was partly a continuation of the Delphi survey carried out in 2016, and thus, there are some topics that are related to each other in these two surveys. For these reasons, this chapter provides an analysis and a comparison of some of these topics. Because the surveys were broad, all the topics addressed in the surveys are not covered here.

5.1 Carbon Neutrality and Relevant Technologies in Finland

When asked about the time of achieving carbon neutrality, the respondents saw that carbon neutrality can be achieved by 2035 in the electricity and thermal energy generation sectors, but as regards transport, industry, and building sectors, carbon neutrality was not expected to be achieved. The respondents saw that in electricity production, carbon neutrality can be achieved already by 2025, or by 2030 at the latest. In thermal energy generation, it can be achieved by 2030, or by 2035 at the latest. Achieving carbon neutrality would require changes in all the industrial sectors. However, the most significant changes would be required in private and heavy transport, as well as in agriculture and petroleum industry. It was also seen that the influence of emissions on pricing should be strong in the sectors of electricity and thermal energy generation, as well as in the transport sector. When considering actions required to achieve carbon neutrality, there was no solution fitting all industrial sectors. For instance, according to the respondents, the thermal energy generation sector requires a tighter emissions trading system, but mechanical industry requires increased R&D activities. For these reasons, a tailored solution should be developed for each sector.

In the context of global carbon neutrality, the respondents saw wind energy, solar PV, hydropower, demand response solutions, as well as geothermal energy, as the most significant technologies. The results were quite similar with respect to social economy in Finland. However, in Finland, forest and other biomass energy (CHP) and large nuclear reactors were found significant, whereas solar PV and geothermal were not seen as important. The most significant export potential was expected for demand response solutions, biomass (CHP), and geothermal energy. For future thermal energy production and systems in Finland, nuclear power, CHP (bio/waste), and Power-to-Heat were found to be significant low-carbon technologies. However, fossil-based thermal plants were still regarded as quite relevant. When considering the aspects of peak power and reserve power, the respondents saw a significant need for peak power and domestic emergency power; a significant need for strong transmission lines; a significant need for energy storages, and finally, that the energy storages should be more distributed than they are nowadays.

Furthermore, questions were asked in relation to the potential of different Power-to-X technologies and the growing potential of different heat generation technologies. The respondents saw that all the mentioned Power-to-X technologies had some potential. Power-to-Hydrogen, Power-to-Fuel, and Power-to-Heat technologies were considered the most significant. The largest growth potential for different heat generation technologies was seen for heat pumps, geothermal energy and thermal energy storages, district heating, and solar collectors. However, fossil-based thermal power plants and bio- and waste-based CHP were found to be the most significant thermal energy production technologies.

5.2 Barriers and Organizational Innovations

The energy system in Finland has developed during the 20th century to tackle the challenges of a cold climate, long distances, and increasing needs of the energy-intensive industry. The record-low electricity prices have already challenged the traditional energy sector as investing in conventional power plants has become unprofitable. Thus, in this context, the respondents were asked a few questions to further examine organizational innovations, enablers, and barriers that might have an impact on the renewable energy sector in Finland.

Three questions related to organizational innovation (ORI) were asked in the first round of the survey. The questions focused on ORI that should be introduced for further development of wind, solar, and Power-to-X technologies in Finland. During the first Delphi survey in 2016, the respondents suggested that some drivers for further development of wind and solar PV energy generation must be searched in the non-technological sphere. Thus, the respondents were asked, e.g., to consider what kind of role local communities could play in the development of wind power, or how house owners could be motivated to increase the use of solar PV power. As to the development of wind and solar PV energy, the respondents saw the main drivers of the development to be in non-technological areas. Thus, for wind energy, the respondents thought that an effective way to speed up the development process of wind farms would be to involve local residents as stakeholders in the process of generating electricity by windfarms. The respondents also saw drivers of similar nature in the context of the solar PV energy development. The results obtained show that developing a mechanism for collaboration between house owners in the area of generation and consumption of solar PV energy would provide a powerful tool for further advancement of this technology. While the respondents admitted that for the development of solar PV energy technology there are a few important drivers related to R&D, the key drivers focus on knowledge and business models. This is probably an evidence of the high level of the development of solar PV technology, and that the technology concerns also organizational matters associated with its implementation. As to the Power-to-X technology, the respondents saw the main driver for its further development to be in fostering R&D-related activities.

According to the theory of Technology Adoption (e.g., Rogers, 1995), the speed of adopting new technologies can be described by a bell curve. The adoption rate is low at the beginning of the process and accelerates until about 50% of the users adopt the technology. Then, the rate decelerates. This means that for a certain technology, the speed and barriers to adopting it depend on the phase of the adoption process. However, some common factors deter the adoption process of all technologies. According to the respondents, the factor of “inertia” is common for today’s companies that resist the change. The two more significant barriers that are common for adopting new technologies are the institutional constraints and the inadequacy of the existing infrastructure.

The results show that in order for a new technology to be successfully implemented, the process of its adoption should be considered at various levels; individual, company, institutional, and national level. Thus, the process of progressing towards low-carbon technologies in the private car sector received different barriers that constrain the implementation of the technology at individual and company levels. At the level of individuals, the most significant barriers are associated with the infrastructure. They are related to the demand for a developed infrastructure, convenience to charge batteries, and the high costs of the infrastructure at the present. This is probably partly the reason why consumers are resistant to switch to electric cars. Nevertheless, when considering the adoption of low-carbon technologies to produce cars, according to the respondents, the significant barriers are different. The barriers were seen to be at the institutional level (e.g., they are political and economic barriers). These barriers are very similar for the private car and heavy transport markets. However, for the building industry, the range of significant barriers seems to be different, and the information dissemination process plays a considerable role, whereas in the automotive industry it was not that important. As to the barriers to the realization of the export potential, they are also different for various sectors, which can partly be explained by the different phases of technology development in these sectors. The barriers related to the lack of R&D are common to all the technologies.

The data gathered on barriers to a certain technology development should also be considered in the light of data on actions that are needed to achieve carbon neutrality in that specific industry. These data are, in fact, complementary; e.g., as to the main barrier in the heavy transport sector, the respondents mentioned inadequate infrastructure. At the same time, when considering actions needed to achieve carbon neutrality, the respondents addressed the necessity to terminate investments in out-of-date technologies. Two barriers, namely companies' resistance to change and consumers' resistance to change, indicate inertia of thinking. These can probably be overcome by disseminating relevant information and training/education along with overcoming the companies' lack of knowledge. The question here is, naturally, who would be responsible for change. For further research, the factors related to companies' lack of knowledge and resistance to change should probably be investigated in detail.

5.3 Power-to-X

The first part included questions about how experts see the importance of Power-to-X technologies as a low-carbon technology on a global scale, their influence on the Finnish economy, their capacity in Finland, and what kind of export potential the technology has in Finland. In addition, there were questions about the potential of different Power-to-X technologies in Finland in 2035, and about the most important organizational innovations that could help to realize the potential of Power-to-X technologies.

Two-thirds of the respondents saw Power-to-X technologies to play a significant role when progressing towards carbon-neutral global society. However, when considering the economy and the capacity of Power-to-X technologies in Finland, their role was not seen to be so significant. The results are in line with the answers to the question of the potential of Power-to-X technologies in Finland in 2035. Several respondents commented that the technology was still immature, and thus, the year 2035 comes too soon for Power-to-X technologies. However, Power-to-X technologies were seen to have a great potential in the long term. There were also exceptions in the answers. Power-to-heat solutions were seen relevant even in 2035. The export potential and capacity of heat pump technology and its significance for the Finnish economy were considered high. All the Power-to-X technologies listed in the survey were expected to have potential or at least some potential. Power-to-Fuel, Power-to-Heat, Power-to-Hydrogen, and Power-to-Methane were found the most potential applications of Power-to-X technologies. As to how to utilize Power-to-X technologies in the future, R&D was seen to play the most significant role. Co-operation with different actors in the markets was also seen to play a key role in the development of Power to-X technologies. However, in general, the number of respondents answering Power-to-X related questions was lower than in the case of other questions. This, together with the background question about the expertise in an energy-related topic, indicates that Power-to-X technologies are not yet as familiar technologies as other technologies.

The lack of R&D was found to be the most significant barrier to realize the export potential of Power-to-X in Finland. The other three significant barriers were seen to be the lack of distribution channels, the lack of co-operation between different international stakeholders, and the lack of a proper energy strategy of the Government. In general, the most significant end-user for Power-to-X technologies was seen to be the heavy industry. For heat pumps, the most significant end-users were buildings and district heating solutions. Heat pumps were seen to have approximately 15–25% thermal energy production capacity in Finland in 2035, which is quite significant. The Power-to-Fuel approach was seen to be a preferable solution to produce fuel, accounting for 10–15% of fuel consumed in Finland in 2045. For Power-to-Gas solutions, the preferable share would be approximately 10–15% of gas consumption in Finland in 2045. For Power-to-Gas solutions to be part of the Finnish energy system, it was commented that there should be high-profile company/companies that would lead the transition towards practical use of Power-to-Gas solutions. Although there were no similar comments on Power-to-Fuel, it can be argued that similar high-profile company/companies should be in the lead in the transition due to similarities of these two technologies.

5.4 Demand Response Solutions

Considering demand response solutions, in general, they were seen to have a great global potential in the transition to carbon-neutral solutions. As to the capacity and the economic aspect of demand response solutions, they were also seen to have a great impact. In all these three categories, these solutions were placed among the top three most important technologies. However, when considering the export potential of the Finnish companies providing demand response solutions, demand response was seen to have the most potential. There was also a question that did not directly ask the potential or the role of demand response solutions yet touched on the topic; in the responses, heat pumps used in district heating systems were seen to have a great potential for demand response, and this kind of technological system can also be considered a demand response solution.

Demand response solutions were found to have many different significant end-users. Only the countryside was not seen to have so much potential. The lack of R&D was seen to be the greatest barrier for demand response solutions. Other significant barriers were the lack of distribution channels, the lack of co-operation between different international stakeholders, and the lack of a proper energy strategy of the Government. It was also commented that a barrier might be the lack of understanding of the needs of the customers. For heat pumps, which can be seen to be part of demand response solutions, the most significant end-users were buildings and district heating solutions. Heat pumps were seen to have approximately 15–25% thermal energy production capacity in Finland in 2035, which is a quite significant proportion.

5.5 Comparison of the Results of the 2016 and 2019 Surveys

In the Delphi surveys of 2016 and 2019, a few similar questions were asked. This section aims to compare the data related to these questions to study whether the respondents had changed their opinions as a result of the rapid development of energy sector technologies. However, because of the time between the two surveys, differences in the panels, and slight differences in the formulation of questions, the results cannot be compared consistently and unambiguously. Nevertheless, the respondents' areas of expertise and positions in their organizations seem to have remained approximately the same over these years.

5.5.1 Peak power and emergency power

A few questions related to peak power and emergency power included in the previous Delphi survey conducted in 2016 were repeated in the Delphi survey of 2019. The target was to compare how the respondents had changed their opinions during these past three years. Although the number of respondents was smaller in the more recent survey than in the survey carried out in 2016, the shares of different areas of expertise remained similar.

- *Question*: What is the importance of strong transmission lines in 2035?

  Comparison: There has been a shift towards a significant need for strong distribution lines over these three years.

- *Question*: Peak power and reserve power—Energy storages

  Comparison: There has been a shift towards a need for energy storages over these three years.

- *Question*: Peak power and reserve power—Market

  Comparison: In 2016, the opinions of respondents were distributed quite evenly from mainly regulated to purely free market. In 2019, the respondents saw that markets of peak and emergency power should be mainly based on free market, yet partly regulated.

- *Question*: Peak power and reserve power—Distribution of energy storages

  Comparison: There has been a shift towards distributed peak and emergence power over these three years.

When thinking about the change in the experts' answers, there are several possible reasons for the change. For example, the increase in renewable energies in the grid has been faster than expected, the markets have failed in making the required changes, or the experts have seen the increasing importance of such technologies. Overall, changes in the answers are clear.

5.5.2 Significance of the selected technologies in Finland

Questions: The survey of 2016 asked how significant a role solar PV, wind energy, heat pumps, forest biomass, digitalization, and demand response solutions play in the energy system of Finland in 2030. The survey of 2019 asked about the most significant technologies in the context of capacity in Finland in 2035. Note that in 2016, the choices were: not significant, only some significance, some significance, significant, and very significant. In the following graphs, significant and very significant options have been aggregated.

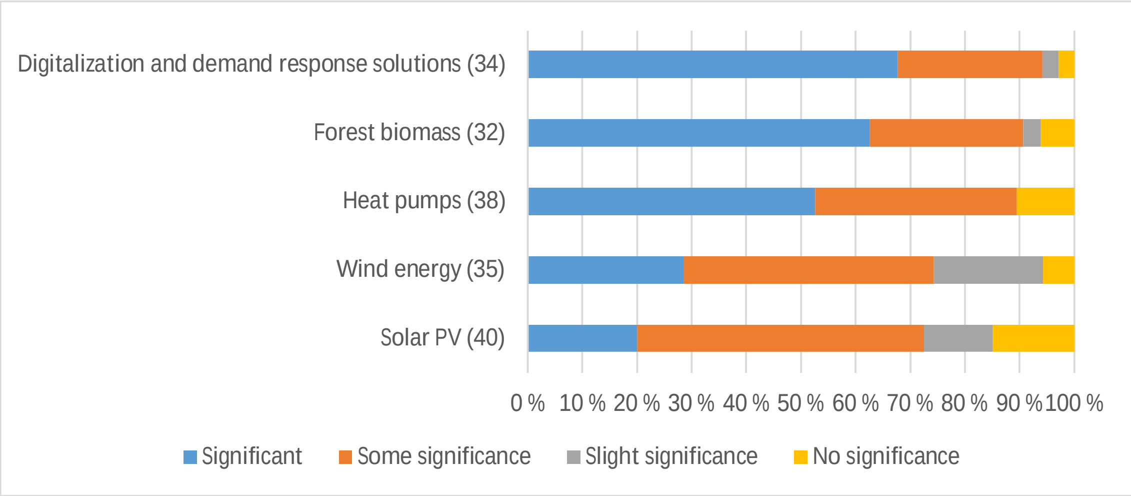

Fig. 5.1. Significance of the selected technologies in Finland, 2016. The number of responses is indicated in brackets.

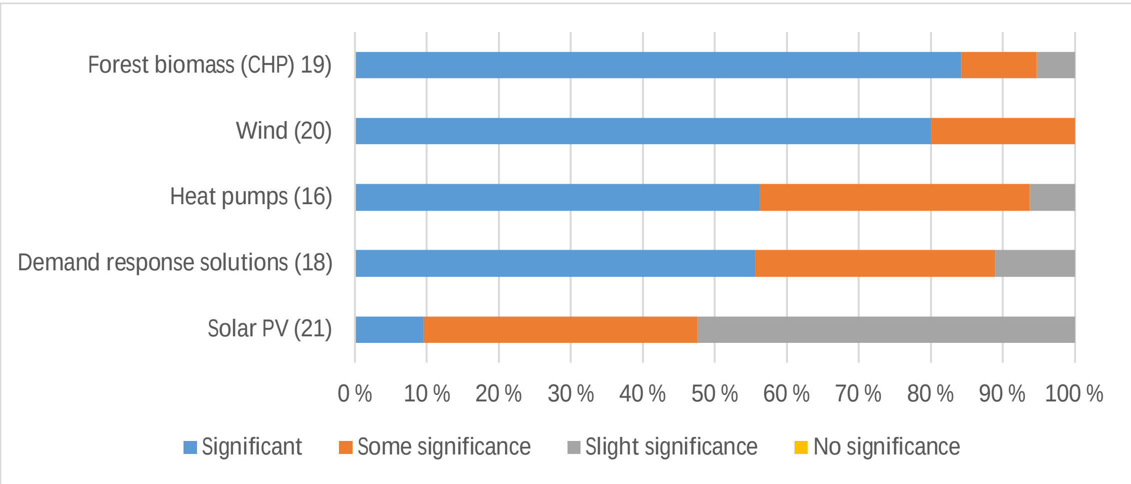

Fig. 5.2. Significance of the selected technologies in Finland, 2019. The number of responses is indicated in brackets.

Comparison:

The results obtained seem to be similar at the qualitative level. In 2016, the question addressed the state of the technology development in 2030, while in 2019 the respondents were asked about the year of 2035. The five-year time extension was obviously not long enough to detect some changes unless there were some disruptive events during that period.

However, some trends could be observed. In respondents' opinion, the significance of forest biomass and wind power has increased from the situation in 2016. The development of heat pumps seems to be quite constant, which indicates that there will be no major development leaps in this technology between 2030 and 2035. In respondents' opinion, the significance of demand response solutions and solar PV capacities seems to remain about the same for 2030 and 2035 in both surveys.

5.5.3 Export potential of the selected technologies

Questions: The survey of 2016 asked about the significance of new energy technologies for the export of Finnish companies in 2030. The survey of 2019 asked about the export potential of different energy technologies for Finnish companies by 2035.

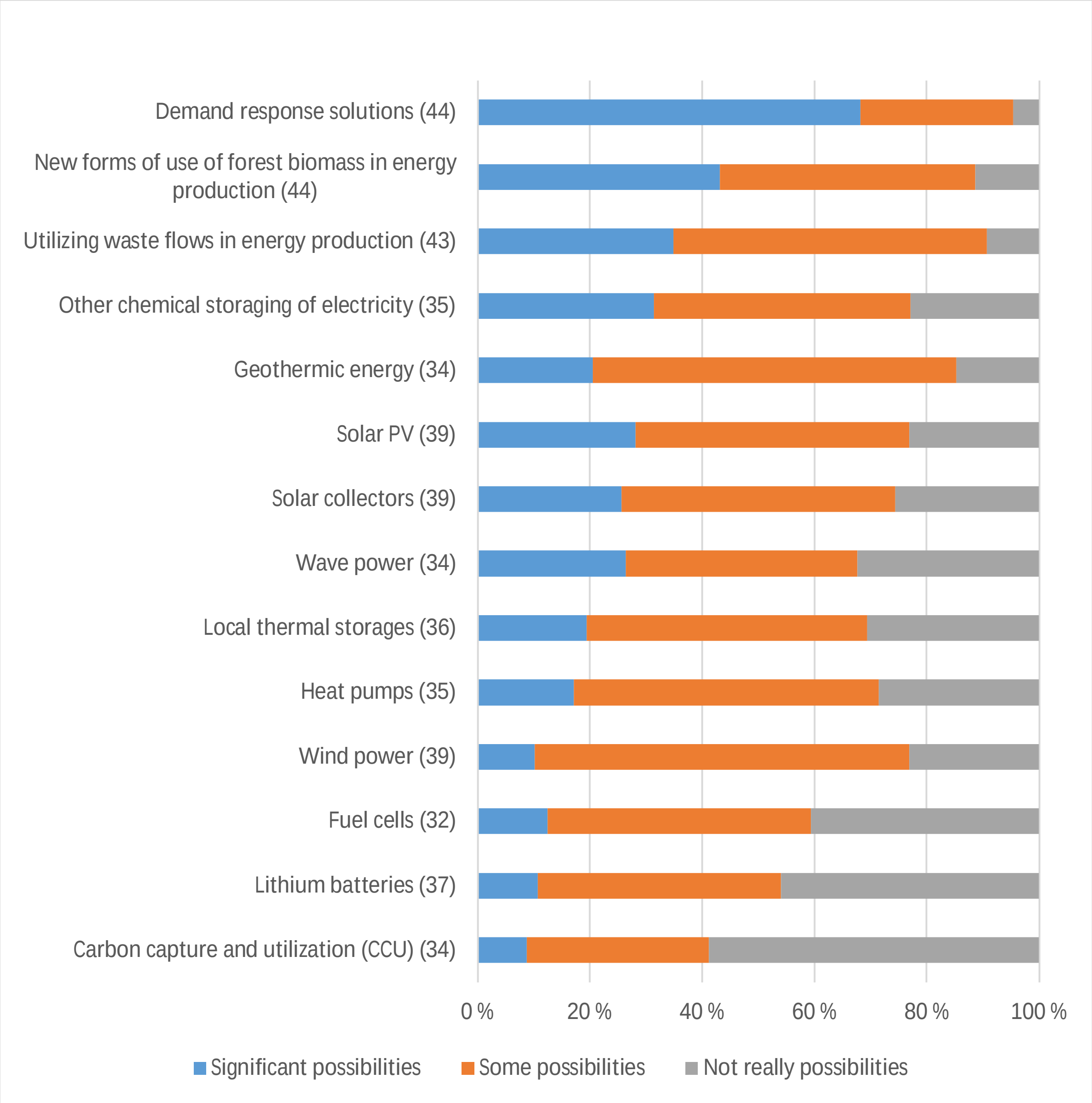

Fig. 5.3. Export potential of the selected technologies, 2016. The number of responses is indicated in brackets.

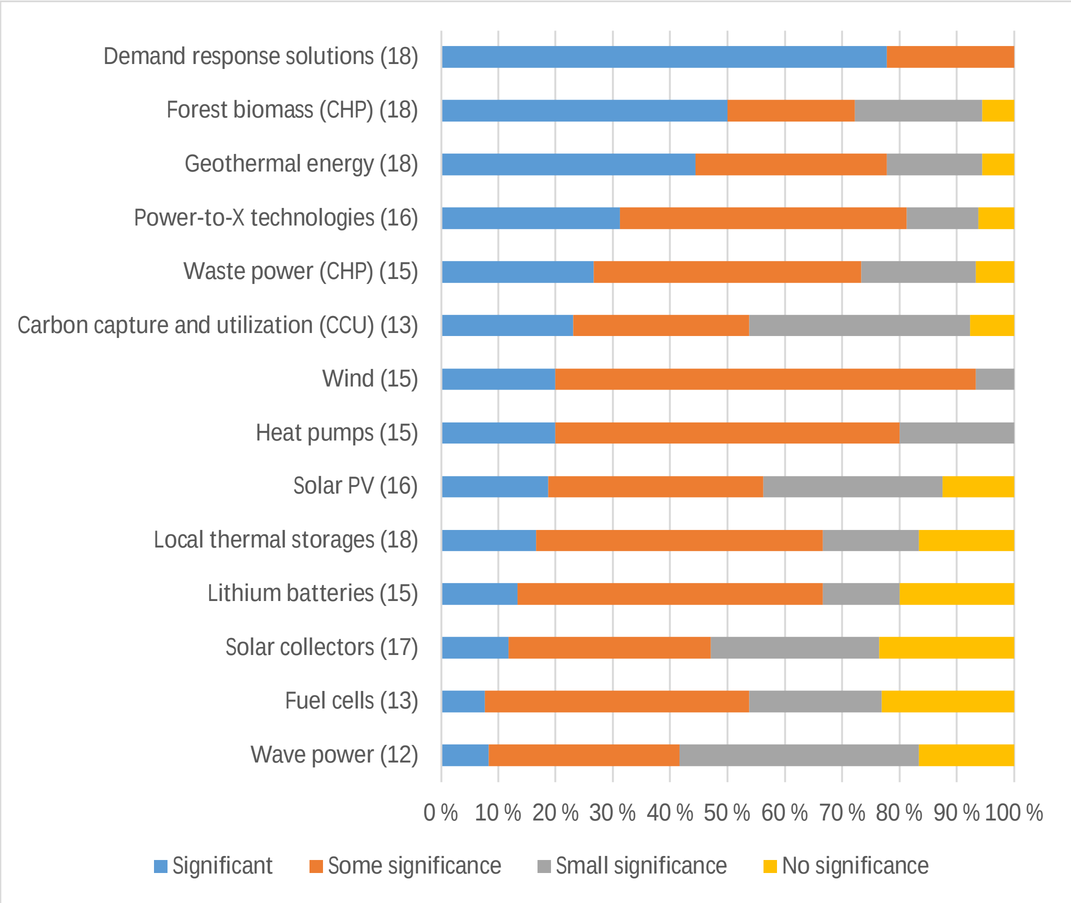

Fig.5.4. Export potential of the selected technologies, 2019. The number of responses is indicated in brackets.

Comparison:

Despite the fact that the questions in the surveys of 2016 and 2019 were somewhat different, the trends of the export potential of the technologies under consideration are found to be quite similar at the qualitative level. The consistency in respondents' replies in 2016 and 2019 provides evidence that very little if anything has happened that might increase the potential of exporting technologies from Finland over the four years between the two rounds of the survey. The trends of the export potential of these technologies were seen to be quite the same. There were some changes for each technology, but the changes were mainly minimal. The largest changes were found in demand response solutions, carbon capture, storage, and geothermal energy. The export potential increased for demand respond solutions and CCS. For the PV technology, the export potential decreased.

5.5.4 Actions needed to progress towards carbon neutrality

Questions: The survey of 2016 asked the respondents to evaluate the desirability of the listed political actions in Finland to promote the development of disruptive technologies.

The survey of 2019 asked the respondents about actions that are needed to achieve carbon neutrality in a certain industry.

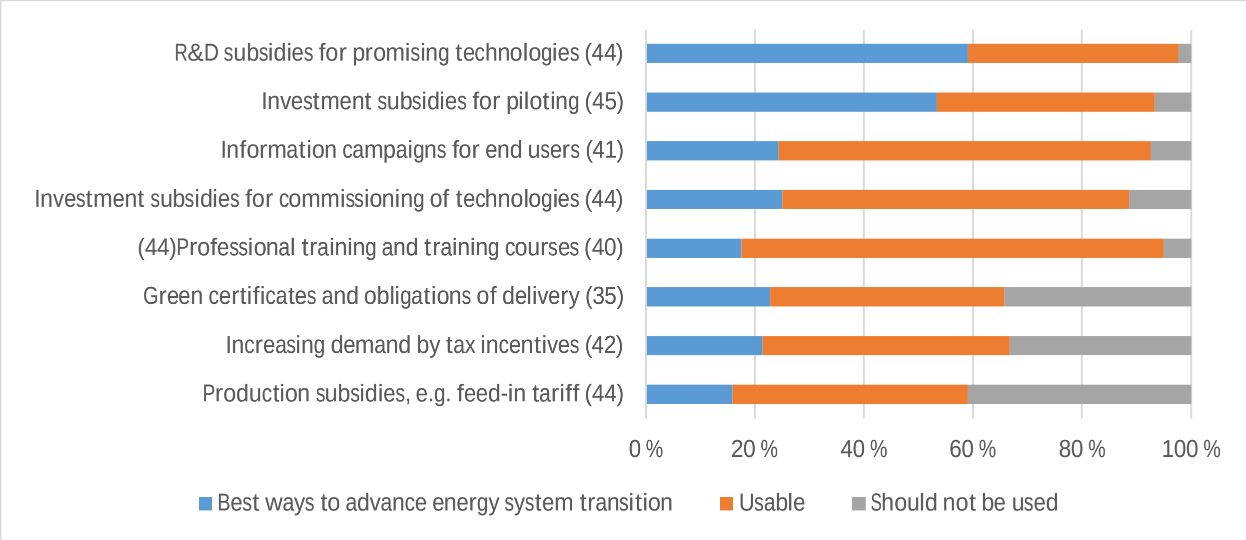

Fig.5.5. Actions needed to progress towards carbon neutrality, 2016. The number of responses is indicated in brackets.

Comparison:

These graphs serve the purpose of complementarity rather than that of comparability. For example, in 2016, the respondents stated that R&D and investment activities are required in various industries related to disruptive technologies. In the 2019 survey, several respondents suggested that there is a need to increase R&D activities in many industries except agriculture and private transport. As to monetary-related activities, in the 2019 survey, the respondents considered tax- and tariff-related regulations important to speed up some industries; also direct funding for agriculture and private and heavy transport was mentioned. The results show that there are no generic solutions for different industrial sectors, but solutions should be tailored for each sector individually.

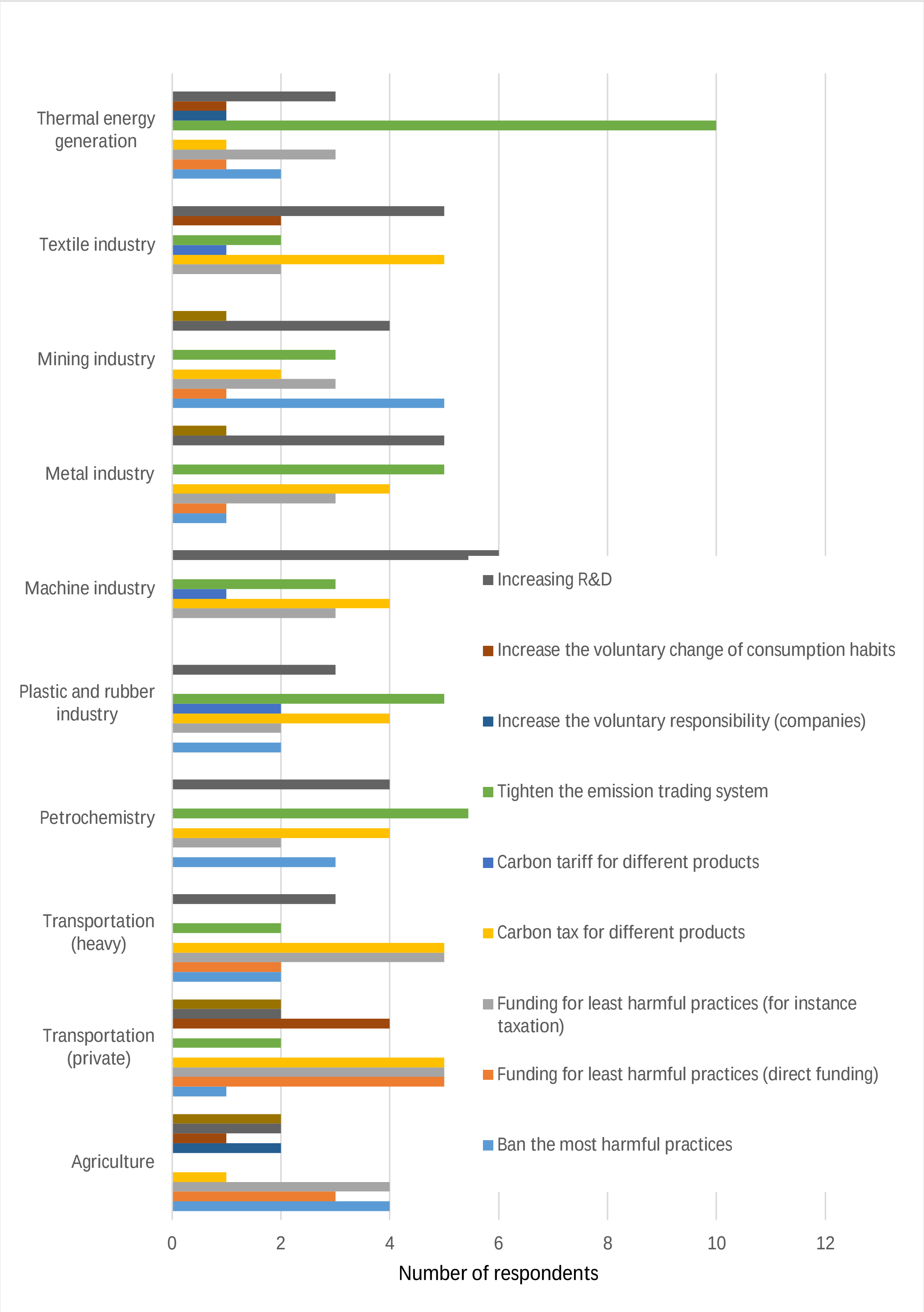

Fig.5.6. Actions needed to progress towards carbon neutrality, 2019.

6 Conclusion

This report reported results of the Delphi survey carried out in 2019 within the framework of the SET project. The survey consisted of two rounds. Along with presenting data as they were obtained from the respondents, the report provided a brief analysis of the results and compared them with some of the outcomes of the first SET project Delphi survey in 2016. In addition to this, the results provide a substantial amount of information for further analysis and interpretation.

One of the specific features of the survey was that the focus was not only on technological aspects of but also on non-technological issues, such as barriers to success in reaching carbon neutrality and organizational innovation that might, in some cases, promote implementation of advanced technologies. The data related to the non-technological questions showed that the technologies, in order to be successfully implemented, should be supported by a complex of managerial, administrative, and social actions.

According to the respondents, there are urgent development needs in various sectors in the near future to achieve carbon neutrality and implement the anticipated technologies. For instance, Power-to-Heat technologies would be widely used in district heating networks, and Power-to-Gas and Power-to-Fuel technologies would cover a major part of our fuel and gas consumption in the future.

The survey has the following limitations:

- First, according to the objective of the SET project, only one country, Finland, was studied. Some issues related to the topic of carbon neutrality should be considered in a global context as technologies developed and implemented in a single country only would not lead to a considerable change, e.g., in emissions or a reduction in the negative impacts on nature.
- Second, because of the Delphi methodology, the results remain at a qualitative level. Despite the fact that the Delphi survey is considered one of the best approaches to make forecasts, very much depends on the quality of the panel and the panelists' understanding of the purpose of the survey. Nevertheless, the project team did their best to invite experts from various related areas to gather a wide spectrum of expertise in the panel.
- Third, the survey was limited by the time a respondent could reasonably invest in answering the questions. This narrowed the number of technologies that could be offered for analysis or evaluation. These technologies were chosen in advance by the research team based on the pre-test results of the survey. In addition, the limited number of technologies could give a biased picture of what happens in reality.
- Fourth, some of the questions were quite general. For example, the questions related to Power-to-X technologies did not address in detail the "X", which can denote quite many substances. Depending on which concrete substance is meant by "X", the answers might differ considerably.
- Fifth, the respondents were offered to analyze only the technologies that are widely known today. This approach does not assume an appearance of a black swan in respondents' answers.

The SET project does not plan any other survey to deepen the data elaborated in this survey. Nevertheless, although the survey answered many questions, it could be proposed that the problems related to some “hot” and promising topics like carbon neutrality of the transport industry or Power-to-X technologies should be investigated further; this would help to plan the transition towards carbon-neutral society.

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ISBN 978-952-335-621-4 (PDF)

ISSN-L 2243-3376

ISSN 2243-3376

Lappeenranta 2020