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How technological and new societal trends may influence the European sustainable energy transition: analysis of policies, methodologies and impacts

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How technological and new societal trends may influence the European sustainable energy transition: analysis of policies, methodologies and impacts

Hoe technologische en nieuwe maatschappelijke trends de Europese duurzame energietransitie kunnen beïnvloeden: analyse van beleid, methodologieën en effecten

(met een samenvatting in het Nederlands)

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Chapter 1. Introduction

1. Introduction

1.1. The EU's climate neutrality target for 2050

Climate change and environmental degradation present a significant threat to Europe and the whole world. To overcome these challenges, the European Commission has developed the European Union's (EU) new growth strategy called "The European Green Deal" aiming to make Europe the first climate neutral continent in the world by 2050, in line with the objectives of the Paris Agreement (United Nations, 2015). This action plan aims to make the EU's economy sustainable through boosting the efficient use of resources by moving to circular economy, restoring biodiversity and cutting pollution (European Commission, 2019). In 2020, European Commission presented the plan to reduce EU greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, in order to achieve climate neutrality by 2050 (European Commission, 2020a). This new target is based on a comprehensive impact assessment of the social, economic and environmental impacts. Nevertheless, the European Parliament raised the bar even further, proposing a reduction of 60% in 2030, compared to 1990 levels, and insisted that both the EU and all member states individually must become climate-neutral by 2050 and therefore the EU shall achieve "negative emissions" (European Parliament, 2020). In 2021, the European Commission adopted a package of legislative proposals "Fit for 55" as part of the European Green Deal, which aims to strengthen the EU's position as a global climate leader. The package aims to revise and update existing legislation in line with the EU's 2030 climate target and introduce new policy initiatives to encourage the transformative changes in the economy, society and industry to achieve climate neutrality by 2050, and to support it, reduce net emissions by at least 55% (compared to 1990) by 2030 (European Commission, 2021a).

This means that the EU targets for energy efficiency and renewables must also be revised. In March 2023, the EU Council and the European Parliament reached two provisional political agreements: on energy efficiency and renewables. The first, the Energy Efficiency Directive (Council of the European Union, 2023a), aims to reduce final energy consumption at EU level by 11.7% in 2030 (compared to a reference development set up in 2020), which means that member states must collectively ensure this reduction, benefiting from flexibilities in reaching the target. The second, the Renewable Energy Directive (Council of the European Union, 2023b), aims to raise the share of renewable energy in the EU's overall energy consumption to 42.5% by 2030 with an additional 2.5% indicative top up that would allow to achieve 45%. This agreement implies setting up more ambitious sector-specific targets in transport, industry, buildings and district heating and cooling.

The new 2030 climate target shall help European countries recover from the COVID-19 pandemic. In 2020 each member state could receive from the Recovery and Resilience Facility the NextGenerationEU recovery package (750 billion euro) to address the economic and social impact of COVID-19 pandemic, ensuring their transitions to green and digital economy and becoming more resilient and sustainable. The achievement of the EU 2030 climate goal implies the continued progress towards a low-carbon society, in which both ***technological***, but also ***non-technological factors*** influence the success in reaching the national and regional targets for energy and climate. Non-technological factors have a broader frame in so-called *new societal trends (NSTs)*, e.g. social acceptance of clean technologies but also new consumption patterns and others, which impact largely on energy demand in the future.

1.2. Low-carbon energy strategies

Although a number of European countries have developed low-carbon energy strategies and analysed them in the form of scenarios, only a part of them consider projections to 2050 and no country so far developed a complex view on the role of technological, as well as non-technological factors (e.g. social acceptance of technologies, stakeholder participation, lifestyle and consumption patterns), and policies to address both aspects. The countries, which have developed energy transformation scenarios 2050, are notably, next to the EU as a whole: f.e. the Netherlands, Germany, France, Denmark, the UK and Belgium. Nevertheless, in order to achieve the targets 2050, comprehensive and detailed long-term strategies need to be developed and scaled up within European countries, considering both ***technological*** and ***non-technological factors and policies***.

The policy design process should be more transparent and satisfy specific requirements, as well as include the tools to monitor the progress on the way and adapt to possible changes in frame conditions. In the context of the joint global concerns of European member states, the scenarios cannot be isolated and should account for the regional issues and require taking collaborative measures by the countries involved. Therefore, in order to provide effective implementation of energy strategies, it is important to discuss and analyse similarities and differences in approaches among the European countries, which have started to develop a long-term framework, to assess the policy settings in different European scenarios in order to make policies for deep decarbonisation more efficient (European

Commission, 2023). Such a framework may serve as an important step towards a more harmonised approach to the joint achievement of the EU 2050 targets.

In 2019, the European Commission required that all EU countries submit their National Energy Climate Plans (NECPs) for the period up to 2030 taking into account the Commission's recommendations, and then submit progress reports every two years. To better develop and implement the plans, the member states were required to consult citizens, businesses and regional authorities in the process. In 2020, the European Union submitted its long-term strategy to the United Nations Framework Convention on Climate Change (UNFCCC) and required EU countries to develop national long-term strategies (up to 2050) and ensure consistency between long-term strategies and the 10-year NECPs (European Commission, 2020b). Nevertheless, the long-term scenarios and strategies developed so far are lacking in particular a view on ***non-technological factors*** of influence on energy demand, notably by *new societal trends*.

1.3. Technological and new societal trends

Currently, the development of the energy sector is associated with such global challenges as climate change, growth of energy consumption, depletion of natural resources, negative environmental impacts and energy security. These challenges are widely discussed in various reports at the global and regional level (e.g. European Commission, 2019; IEA/OECD, 2022; IPCC, 2023; National Intelligence Council, 2021; UNEP, 2022; United Nation, 2015; WMO, 2023). To reduce negative effects connected with these challenges and to move towards sustainable energy infrastructures, national governments need to be aware of the *technological trends*, which have a significant long-term social and economic impact in different areas. A technological trend can be considered as a continuously growing technology area with a certain pattern, which have existed for a certain period of time, usually about five years, with a good prospect of continuing its development in the future to cover the next 5-10 years or beyond (Ena et al., 2016). In such a rapidly changing complex environment full of opportunities and threats, one of the ways to increase an economy's energy efficiency is by developing green technologies, which can make an appreciable contribution to a sustainable energy transition through the production of renewable energy as well as efficient technologies to satisfy the need for energy services. There are hierarchies between green technologies, notably when it comes to their broader impacts on the environment such as the use of area, of resources and critical materials. For that reason, the European Union defined the "Energy Efficiency First Principle" (EE1) (European Commission, 2021b), which supports a more sustainable approach to the use of limited resources, gives priority to technologies that reduce overall footprints and increases the resilience of the EU's energy system. Energy efficiency is considered as one of the key pillars not only to meet EU's climate objectives but also to reduce dependence on fossil fuels from abroad and increase security of supply and the use of renewable energy, including through the introduction of advanced technologies. Beyond this, the principle also emphasises the importance of reducing energy production, which can help control the level of investment needed for the transition towards renewable energy (European Commission, 2021b).

Technological options to mitigate climate change are, however, only part of the equation. Choices in lifestyles have at least similar impacts on climate footprints. Changes in lifestyle may, at first, be considered as privation from a life we could lead otherwise without the pressure from climate change. However, lifestyles may also consciously integrate limits in our environment and emerge as new societal trends. *New societal trends* can often be linked to general megatrends, which have potentially large increasing or decreasing impacts on energy demand (see for example, Grubler et al., 2018). Such trends include among others: (1) the digitalisation of the economy and of private life; (2) new social and economic models, including the sharing economy and prosumaging[1]; (3) the industrial transformation, including decarbonisation of industrial processes and the circular economy (including a stronger focus on material efficiency); and (4) changes in the quality of life, including health effects, urbanisation and regionalisation. The trend towards digitalisation may act also as a facilitator for all other trends – for example, the diffusion of mobile phone apps facilitates car sharing (Brugger et al., 2019).

1.4. Research gaps and objectives of the thesis

1.4.1. Research gaps

The impact of new societal trends on energy demand in the European countries is gaining attention in the academic literature but still requires further investigation. The related studies have different aims, among which are the following: to reveal societal and technological factors influencing energy demand (f.e. Barbu et al., 2018; Czibere et al., 2020; Kramers et al., 2014; Werner, 2015); to establish impact indicators potentially contributing to energy transition (Kylili et al., 2020) and to measure the influence of specific trends on energy demand (f.e. Fabiani et al., 2021; Mrówczyńska et al., 2020; Woods et al., 2017); to outline the key priorities (Noussan and Tagliapietra, 2020) and possible scenarios for energy transition

[1] By "prosumaging" we understand combination of producing, consuming and managing of energy by households (Brugger et al., 2021).

(Bartholdsen et al., 2019; Tagliapierta et al., 2019) and provide a guideline for the European transition to renewable-based power supply systems (Pleßmann and Blechinger, 2017). These studies have applied qualitative methods, such as literature review, scenario development and impact assessment, conducting surveys, interviews and workshops, etc., as well as quantitative methods including statistical analysis, energy modelling, data mining, cluster analysis and others.

The following sections present the research gaps currently existing in the academic literature and in policy circles that require further investigation.

1.4.1.1. The starting point: stocktaking of long-term strategies and scenarios for climate neutrality in the European countries and the need to analyse both technological and non-technological factors and policies

A number of European countries have developed long-term low-carbon energy strategies to combat climate change (f.e. the Netherlands (CPB/PBL, 2015; OECD, 2021), Germany (BMUB, 2016; Fraunhofer, 2021; Öko-Institut/Fraunhofer ISI, 2016), France (Criqui and Hourcade, 2015; RTE, 2021), Denmark (Danish Energy Agency, 2014; Danish Government, 2019), the UK (UK Government, 2020; UKERC, 2013), Belgium (Climat, 2021; FPB, 2015)). Those strategies have been assessed in a large number of energy and greenhouse gas (GHG) scenarios with a major focus on technological factors. Therefore, it is important to compare and evaluate the policy settings of these scenarios in different European countries to understand whether they *consider both technological and non-technological factors and policies*. At the same time, *a more harmonised approach to scenario development* could be helpful, considering in particular methodological improvement to reflect the impacts of non-technological factors and trends. The development of a set of *specific characteristics for scenario assessment* may serve as a starting point for such harmonisation. They may include: modelling framework (diversity), ambitiousness (targets 2050), relations with other (European) countries, stakeholder involvement, technology options, non-technological aspects, economic component, usage of scenarios in policy design, intermediate indicators of targets' achievement and revision of scenarios.

1.4.1.2. Learning from methodologies for monitoring technological trends in green energy (approaches, methods, data sources, software tools)

In low-carbon energy strategies, the achievement of EU 2050 climate goals implies continued progress towards a low-carbon society, in which technological, but also non-technological factors influence the success in reaching national and regional targets for energy and climate (European Commission, 2023). Given that the role of *non-technological factors* in energy transition is still underinvestigated, identifying and analysing of them, taking into account their interrelationships, has become more important. In this regard, the analysis of non-technological trends can profit largely from methodologies used for the analyses of technological ones (f.e. Cuhls, 2020; Kostoff et al., 2008; Saritas and Nugroho, 2012) and develop further from there.

Therefore, presenting an analytical review of international practices for monitoring technological trends, as well as the key theoretical approaches and methods, which have been developed in this field, is necessary. Further, strategies for working with different data sources (f.e. Cozzens et al., 2010; Porter and Cunningham, 2005) for identifying technological trends in the green energy area, is worthwhile investigating *to learn from them for the analysis of non-technological ones*. For this purpose, a comparative analysis of the results of technology monitoring using various data sources (scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations) can provide insights.

The advanced approaches to establish the role of low-carbon technologies for climate neutrality *link systematically trends analysis to scenario analysis* in order to understand how policies may stir the development of those technologies towards a positive contribution to climate neutrality (Brugger et al., 2019). Learning from these approaches developed for monitoring technological trends (e.g. Ena et al., 2016), *a systemic methodology is needed to identify and analyse non-technological trends* for their efficient integration into energy scenarios.

1.4.1.3. (Inter) relationships between technological and non-technological trends and their controversial impact on energy demand

In the transition of energy systems moving from non-renewable fossil-nuclear to renewable sources, to understand a bigger picture, it is important to analyse how technological and non-technological trends can be interrelated, investigating different types of relationships: between technological trends; between non-technological trends; between technological and non-technological trends (Porter and Cunningham, 2005). Approaching from the ***technological side***, green energy technologies, such as solar-, wind- and bioenergy, fuel cells and smart grids, can contribute in a systemic view to solutions of global problems such as climate change, growth of energy demand, depletion of natural resources, negative environmental impacts and energy security but they can also partially contribute to such problems, e.g. leading to depletion of critical material resources or lead to additional land-use (IPCC, 2023). From the ***non-technological side***, *new societal trends*, such as digitalisation, decentral energy supply, the sharing economy, the circular economy and changing consumer awareness, may highly influence future energy demand and, depending on their realisation, may enhance or counteract projected energy efficiency gains (Barbu et al., 2018; Czibere et al., 2020; Noussan and Tagliapietra, 2020). Therefore, there is a need *to investigate the prospective directions of technology development in green energy area* using a combination of qualitative and quantitative methods, as well as to investigate key challenges for green energy technologies and *their relationships with other technological and non-technological areas*. Also, additional research is needed *to analyse the interrelationships between the new societal trends that may influence future energy demand in European countries*. This research aiming to analyse the potential importance and disruptiveness of such trends, as well as to provide a better understanding of their connections, can help designing European energy demand-side policy instruments that may have simultaneous major impacts on the new societal trends, avoiding the development of demand increasing patterns.

1.4.1.4. New societal trends (such as digitalisation, sharing economy, prosumer society, etc.) and their impacts on future energy demand and the realisation of the European long-term energy scenarios

As mentioned earlier, new societal trends (such as prosumaging, circular economy, digitalisation, sharing economy, etc.) can have potentially large decreasing impacts on energy consumption as well as cross-sectoral demand shifts, but may also lead to a substantial increase in energy demand if not accompanied by appropriate policy instruments (Brugger et al., 2019; Barbu et al., 2018; Czibere et al., 2020). Understanding interrelationships between new societal trends and taking into account possible pathways of technological development supporting them, policies can be formulated in a way to stir these trends into the right direction, while if they are not accompanied by appropriate policies with a strong focus on the Energy Efficiency First (EE1) Principle, negative impacts on energy demand are to be expected. It is therefore highly necessary *to develop energy strategies and scenarios for 2050* to assess the controversial impacts of new societal trends on energy consumption and analyse quantitatively how they might interact with energy efficiency (policies). This research is needed to open up the discussion on how new societal trends may shape future energy demand, what can happen if technological advancements and societal trends play in a favourable or unfavourable way, and emphasise the crucial role of policy-making in this process.

The literature review shows that there are important gaps that need to be filled – with respect to ***impacts*** of new societal trends, ***methodologies*** to establish and evaluate them, as well as ***policies*** to direct these trends towards lower energy demand.

Therefore, the main goal of this thesis is to develop and propose an approach to analyse European long-term strategies for climate neutrality with the focus on the role of technological and new societal trends in the energy transition[2].

1.4.2. Research questions

The overarching research question for the thesis can be formulated as follows:

How can technological and new societal trends impact the European long-term sustainable energy transition?

This main research question is divided into sub-questions, which constitute the structure of the thesis:

- **RQ 1:** What insights can be derived on the similarities and differences in policy settings of the European low-carbon energy strategies (taking six north-west European countries as the examples), as well as the potential for their improvement in order to achieve the EU 2050 climate neutrality targets?
- **RQ 2:** What methodological approaches (including qualitative and quantitative methods, data sources and software tools) can be applied to monitor technological trends in the sustainable energy area and what can we learn for the analysis of non-technological trends?
- **RQ 3:** How can information about (inter) relationships between technological and non-technological trends and their controversial impact on future energy demand support the formulation of environmental policies in the European countries?
- **RQ 4:** How would new societal trends (e.g. digitalisation, sharing economy, prosumaging, etc.) influence future energy demand and the realisation of the European long-term energy strategies?

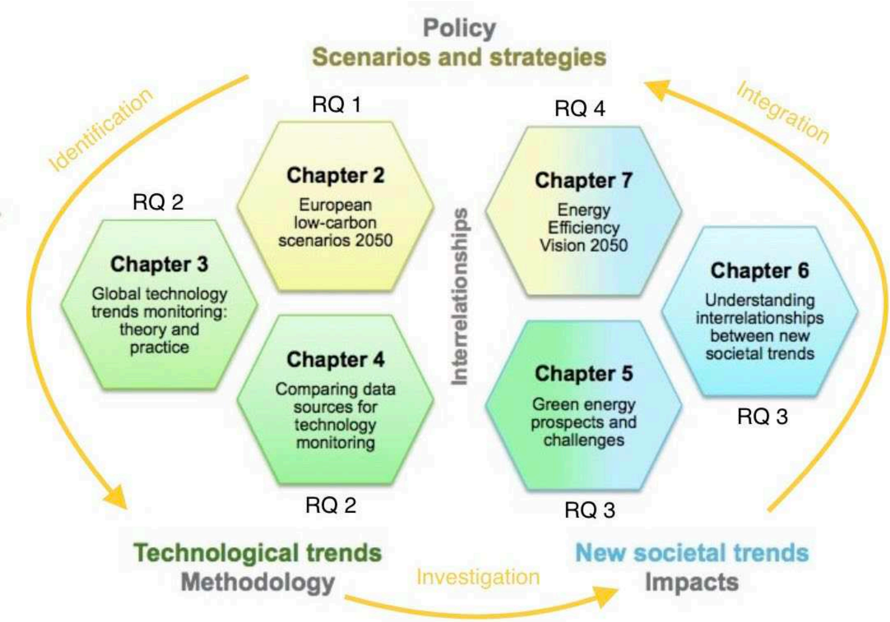
1.4.3. Framework

Figure 1.1 illustrates the focus of the different chapters, showing their connections to trends types (technological and new societal trends), perspectives (policy, methodology, impacts), stages of analysis (identification, investigation, integration) and research questions. To address how technological and new societal trends – in their interaction – may influence the sustainable energy transition, three perspectives are taken in this thesis:

[2] This work aims to contribute to the following areas of academic research: technology foresight and trends monitoring; science, technology and innovation policy; scenario development; energy modelling and energy (efficiency) policy.

- **"Policy"** perspective[3]: aspects related to how new societal trends can be integrated into energy strategies and policies.
- **"Methodology"** perspective: aspects including approaches and methods to identify and analyse technological and new societal trends and their interrelationships.
- **"Impacts"** perspective: aspects associated with how the new societal trends may influence future energy demand.

Figure 1.1. Framework of the thesis



This thesis begins with the ***"Policy"*** perspective[4] including an analysis of low-carbon energy *strategies and scenarios* (marked in yellow), which have been recently developed in the European countries. In order to achieve the EU long-term climate neutrality targets in 2050, these strategies and scenarios need to consider both *technological* (marked in green) and *new societal trends* (marked in blue), which may both influence the success of sustainable energy transition, taking into account their interrelationships.

For more efficient integration of new societal trends into energy scenarios a systemic methodology is needed to identify, analyse and update such trends. This

[3] The "Policy" perspective is less prominently worked out in the thesis, mainly through the strategies and trends interrelationships that it comes in. Therefore, it is important to clarify that we do not look into individual policies, it is rather policy in broader terms of strategies, but not about individual policies how to deal with new societal trends. We dig into individual policies only when we look at the interrelationships between new societal trends (Chapter 6), where understanding them, we are able to formulate policies that take interrelated trends more strongly into account.

[4] In Chapter 2 and Chapter 7 we do not look into individual policies, but rather consider policy in broader terms of strategies.

brings us to the ***"Methodology"*** perspective, which makes use of methodological approaches (including methods, data sources and software tools) that have been developed for the analysis of *technological trends* and which can be transferred to new societal trends, in order to further determine the impacts of those on future energy demand. In the process of energy transition, technological and new societal trends can be closely interrelated, so it is important to investigate the connections between them: between technological trends; between technological and non-technological (new societal) trends; between new societal trends, in order to see a bigger picture of their influence.

New societal trends can potentially reduce energy consumption as well as lead to cross-sectoral demand shifts, but may also lead to a substantial increase in energy demand if unaccompanied by policy instruments. The ***"Impacts"*** perspective helps to assess the disruptiveness and influence of new societal trends on future energy demand using a three-dimensional metric (degree, scale, direction). In addition, a better understanding of the interrelationships between new societal trends, can link this analysis to the ***"Policy"*** perspective[5], which allows to analyse the European energy demand-side policy instruments that may have simultaneous major impacts on the interrelated new societal trends, avoiding the development of demand increasing patterns.

Moving from the analysis of individual policies to a broader ***"Policy"*** perspective, the energy strategies and scenarios for 2050 are developed to evaluate the controversial impacts on energy demand and evaluate quantitatively how they might interact with energy efficiency (policies). This will lead to a better understanding of potential non-linear developments of future energy demand and how energy (efficiency) policies could be designed to take the new societal trends and their interrelationships meaningfully into account in order to enhance their potential positive contribution to climate neutrality.

Therefore, as is seen from Figure 1.1, the analysis can be performed as an iterative process, in which three perspectives are connected through ***three "I" actions (identification, investigation and integration)***. The *"Identification"* stage aims to detect and analyse technological and new societal trends ("Methodology" perspective) that need to be taken into account in energy strategies and scenarios ("Policy" perspective). The *"Investigation"* stage implies the assessment ("Impacts" perspective) of the trends that were previously selected ("Methodology" perspective). The *"Integration"* stage includes incorporation of the trends into energy scenarios and models ("Policy" perspective). Thus, we can

[5] In Chapter 6 we analyse individual policies, rather than consider policy in broader terms of strategies.

“close the loop” (Policy → Methodology → Impacts → Policy) and do several iterations in the analysis of how technological and new societal trends may influence the sustainable energy transition.

1.4.4. Overview of chapters

The investigation of the research questions is reflected in the choice of topics for the related publications each representing one chapter:

Chapter 2. Low-carbon scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets

This chapter proposes an approach to comparing and assessing the policy settings in the European low-carbon energy scenarios. First, it presents the methodology including ten characteristics for scenario assessment: modelling framework (diversity), ambitiousness (targets 2050), relations with other (European) countries, stakeholder involvement, technology options, non-technological aspects, economic component, usage of scenarios in policy design, intermediate indicators of targets’ achievement and revision of scenarios. Further, it uses qualitative and quantitative methods to evaluate energy scenarios developed in six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium). Finally, conclusions are made concerning the possible ways of scenario design improvement.

Chapter 3. Global technology trends monitoring: theoretical frameworks and best practices

This chapter presents an analytical review of international practices for monitoring global technology trends (based on the reports of international organisations, national research centres, universities and research organisations, companies and consultancy agencies), as well as the key theoretical approaches and methods (from scientific publications), which have been developed in this field, in order to transfer the learning for the analysis of non-technological trends. It investigates different definitions and variations on the notion “technology trend”, with an emphasis on the most important effects of trends development, their life cycle stage, the scale of the trends and ways to identify them. The study considers different levels of analysis (global, national, industry and corporate) and various stakeholders (international organisations, government bodies, business, research institutes and other structures) involved in development of long-term forecasts and shaping policy based on their recommendations. It analyses monitoring stages, data sources and methods, as well as automated tools used to increase the evidence base and effectiveness of technology trends monitoring.

Chapter 4. Comparing data sources for identifying technology trends

This chapter considers the strategies for working with different data sources for identifying technology trends, which can be further used for the analysis of non-technological ones. For this purpose, a comparative analysis of technology monitoring results using various data collections (scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations) is conducted. Guidance on how to use them to ensure the greatest output (the maximum number of trends retrieved from a specific information source) is presented. Green energy is taken as an example for comparative analysis and provides improvements in reducing inputs (time) and increasing output (coverage). In addition, the factors that affect data processing results are considered and discussed to more efficiently use quantitative and qualitative procedures for identifying, analysing and updating technology trends.

Chapter 5. Green energy prospects: trends and challenges

Since green energy technologies can contribute to solutions of global problems such as climate change, growth of energy consumption, depletion of natural resources, negative environmental impacts and energy security, in this chapter the prospective directions of technology development in green energy are studied and analysed using a combination of qualitative and quantitative methods. Qualitative research involves participation of experts from the green energy area, while quantitative analysis includes collecting and processing data from different information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, and presentations) with the help of the Vantage Point software. In addition, taking into account the need to analyse the trends interrelationships (between different technological trends and between technological and non-technological trends), key challenges for green energy as well as the relationships between technological trends and other technological and non-technological areas are identified and briefly described on the basis of qualitative and quantitative analysis.

Chapter 6. Understanding interrelationships between new societal trends to inform policy-making for the energy transition

New societal trends (such as prosumaging, circular economy, digitalisation, sharing economy, etc.) are understood as societal developments arising from general megatrends, which can have potentially large decreasing impacts on energy consumption as well as cross-sectoral demand shifts, which may also lead to a substantial increase in energy demand if unaccompanied by policy instruments. In this chapter, we analyse the interrelationships between the different new societal trends that may influence future energy demand in the European countries. Through a literature review and three expert workshops energy relevant new societal trends are selected, clustered and assessed using a three-dimensional metric (impact degree, impact scale, impact direction). Expert survey and network analysis provide a better understanding of the interrelationships between these trends, which is used for the analysis of energy demand-side policy instruments related to their development. This can help to formulate the European energy policies that may have simultaneous major impacts on the new societal trends, avoiding the development of demand increasing patterns.

Chapter 7. Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries?

This chapter opens up the discussion on how new societal trends will shape future energy demand and emphasises the crucial role of policy-making therein. New societal trends are expected to highly influence future energy demand and, depending on their realisation, enhance or counteract projected energy efficiency gains. Therefore, these trends have to be accompanied by policies with a strong focus on reducing energy demand (including Energy Efficiency First Principle). This study analyses quantitatively for all sectors how new societal trends interact with energy efficiency (policies). An extensive consultation with European experts helps to identify new societal trends that are likely to shape future energy demand. Based on these, four energy demand scenarios ("Removing Market Barriers", "New Trends Efficient", "New Trends Inefficient" and "Worst Case") are developed for 2050. Using literature review and expert consultations, the impacts on all sectors are evaluated taking these trends explicitly into account.

Table 1.1 provides an overview of the chapters in this thesis and how they contribute to answering the research questions.

Table 1.1. Overview of chapters

Chapter	Content / Title of paper	Research questions
1	Introduction	1-4
2	Low-carbon scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets	1
3	Global technology trends monitoring: theoretical frameworks and best practices	2
4	Comparing data sources for identifying technology trends	2
5	Green energy prospects: trends and challenges	3
6	Understanding interrelationships between new societal trends to inform policy-making for the European energy transition	3
7	Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries?	4
8	Summary and conclusions	1-4

1.4.6. Data and methods

The research in this thesis is based on using various *data sources*, such as:

- international and national reports and strategic programs (including energy scenarios);
- scientific publications;
- patents;
- media, trend alerts and newsletters;
- foresight projects;
- conferences and workshops;
- dissertations;
- presentations;
- statistical databases and models;
- EU policy documents.

The *qualitative methods* used include:

- literature review;
- expert surveys, workshops, consultations;
- impact assessment of trends;
- review of policy instruments;
- scenario development.

The workshops and surveys are conducted with the experts and stakeholders from energy-related fields and aim to gain insights into individual perspectives of developing areas, such as impacts on future energy demand, which are used for further modelling and scenario development.

The *quantitative methods* used include:

- text mining;
- statistical analysis;
- clustering (factor analysis);
- mapping with radar diagrams;
- network analysis;
- scenario assessment;
- modelling.

Detailed methodological descriptions can be found in the relevant chapters, where the methods are applied to a specific context and research question.

Table 1.2 presents an overview of research questions, trends types, perspectives, as well as data sources and methods used in these chapters.

Table 1.2. Overview of research questions, trends types, perspectives, data sources and methods

		Chapters					
		2	**3**	**4**	**5**	**6**	**7**
Research questions	*RQ 1*	x					
	RQ 2		x	x			
	RQ 3				x	x	
	RQ 4						x
Trends types	*Technological trends*	x	x	x	x		x
	New societal trends	x			x	x	x
Perspectives	*Policy*	x			x	x	x
	Methodology	x	x	x	x	x	x
	Impacts					x	x
Approaches / Analysis	*Data sources*	Scientific publications, international and national (governmental) reports and strategic programs, conferences and workshops	Scientific publications, international reports (including energy scenarios), trend alerts and newsletters	Scientific publications, patents, media, foresight projects, conferences, international projects, dissertations, presentations	Scientific publications, patents, media, foresight projects, conferences, international projects, dissertations, presentations	Scientific publications, international reports, foresight projects, EU policy documents (regulation, economic and financial instruments, soft instruments)	Scientific publications, international reports, foresight projects, statistical databases and models
	Methods	**Qualitative:** literature review, expert questionnaire **Quantitative:** statistical analysis, mapping with radar diagrams	**Qualitative:** literature review	**Qualitative:** literature review, expert workshop and consultations **Quantitative:** text mining, statistical analysis, clustering (factor analysis)	**Qualitative:** literature review, expert workshop and consultations **Quantitative:** text mining, statistical analysis, clustering (factor analysis)	**Qualitative:** literature review, expert workshops, impact assessment of trends (degree, scale, direction), online expert survey, review of policy instruments **Quantitative:** network analysis, statistical analysis	**Qualitative:** literature review, expert and stakeholder workshops, impact assessment of trends, scenario development **Quantitative:** clustering (factor analysis), scenario assessment (energy saving potentials), statistical analysis, modelling

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Chapter 2. Low-carbon scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets[6]

Abstract

This paper proposes an approach to comparing and assessing the policy settings in the European low-carbon energy scenarios. First, it presents the methodology including ten characteristics for scenario assessment: modelling framework (diversity), ambitiousness (targets 2050), relations with other (European) countries, stakeholder involvement, technology options, non-technological aspects, economic component, usage of scenarios in policy design, intermediate indicators of targets' achievement and revision of scenarios. Further, it uses qualitative and quantitative methods to evaluate energy scenarios developed in six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium). Finally, conclusions are made concerning the possible ways of scenario design improvement. The analysis has shown that all selected countries have potential for modifying their energy scenarios, which being implemented may help to achieve the joint European targets 2050. Since these countries are socially and economically interrelated, a more harmonised approach to scenario development is needed to be designed and introduced on the EU level. Ten characteristics proposed in this study may serve as an initial input for such harmonisation. The results can be of interest to economists, business and academic representatives, and especially policy makers involved in the long-term energy scenario development on the international, regional and national level.

1. Introduction

Nowadays, sustainability is regarded as an important landmark for the future development of our planet (UNDP, 2015). Sustainable development can be considered as an approach "that meets the current needs without compromising the ability of future generations to meet their own needs" (UN, 1987). It influences society, economy and environment in every region of the world and raises the challenges that can be addressed only with collective action. Since the energy sector is a major contributor and a driver of the economy in most countries, sustainable development in this area becomes the core international goal. In this

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regard, significant changes are needed on the global, regional and national level in order to set up effective long-term strategies and development policies.

Recent climate and energy debates (particularly, in the framework of the Conference of the Parties (COP21) in Paris (UNEP, 2014) and the activity of the European Energy Union (2018a)) have been indicating a growing sense of urgency about the threats posed by climate change and a great demand for taking collective action to address them on different levels. In 2011, the European Commission developed the Roadmap for moving to a competitive low-carbon economy in 2050 (European Commission, 2011), which reflects the need to find cost-efficient ways of making the European economy more climate friendly and less energy consuming in the long run. According to this Roadmap, by 2050, the European Union (EU) should have cut greenhouse gases (GHG) emissions to at least 80% below 1990 levels. In addition, two milestones were set up to achieve this target: 40% emissions' cuts by 2030 and 60% by 2040. To achieve this, the low-carbon energy transition should be feasible and affordable, which requires the contribution from all sectors (European Commission, 2018). The European Commission (2018) suggested that the 80% reduction target should be reached through domestic measures alone (not relying on international credits). This corresponds to the EU leaders' commitment to cut emissions by 80–95% by 2050, with similar reductions to be taken by developed countries as a group. The achievement of this goal implies the continued progress towards a low-carbon society, in which social acceptance of clean technologies plays an important role (European Commission, 2018). This means that not only technological, but also non-technological factors influence the progress in reaching the national and regional targets in energy area.

Although a number of European countries have developed low-carbon energy scenarios, only a part of them consider projections to 2050. Among these countries are: the Netherlands (CPB/PBL, 2015; ECN/PBL, 2016; SER, 2013), Germany (BMUB, 2016; Öko-Institut/Fraunhofer ISI, 2016; WWF, 2009), France (Criqui and Hourcade, 2015; FMEES, 2015), Denmark (Danish Energy Agency, 2014), the UK (UKERC, 2013), Belgium (FPB, 2015). Nevertheless, in order to achieve the 2050 targets, the long-term thinking can be encouraged and scaled up within European countries. The policy design process should be transparent and satisfy specific requirements, as well as should include the tools to monitor the progress on the way and adapt to possible changes. In the context of the joint global concerns, the scenarios cannot be isolated and should account for the regional issues and require taking collaborative measures by the countries involved. Therefore, in order to provide effective implementation of energy scenarios, it is important to discuss and analyse similarities and differences in approaches among the European countries (European Commission, 2018), which have started to develop a long-term framework and discuss how this framework can be extended to further countries. The absence of the 2050 projections in many EU member states makes the comparison and analysis of their scenarios complicated and often even impossible. Therefore, there is a great demand for a structured framework with a set of characteristics, which allows assessing the policy choice (or "policy settings") within each of them in different European scenarios in order to make the long-term policies for deep decarbonisation more efficient. Such framework may serve as a step towards a more harmonised approach to achieve the EU 2050 targets.

Currently, a number of academic studies have been devoted to long-term EU energy and climate scenarios. For example, Deetman et al. (2013) explore an emission mitigation scenario for Europe up to 2050, Hübler and Löschel (2013) analyse a reference scenario from the EU Decarbonisation Roadmap 2050 (European Union, 2018). Scenarios for the future of renewable energy through 2050 have been reviewed to study the possibilities of transition to a more renewable energy-based European electricity mix (Connolly et al., 2016; Martinot et al., 2007). There has been also research on the role of renewables in low-carbon energy scenarios. The authors analyse the renewable energy sector in the EU member states (Pacesila et al., 2016), assess European renewable energy sources' trajectory towards 2020 (D'Adamo and Rosa, 2016), and discuss efficient strategies for their integration into future energy infrastructures in several European regions (Boie et al., 2014).

In addition, there have been examples of country-specific studies on energy transition pathways, e.g. in Germany (Boie et al., 2016; Hochmeyer and Bohm, 2015; Nagl et al., 2011; Schmid and Knopf, 2012; Scholz et al., 2014), the Netherlands (Benders et al., 2011), France (Ze Ya, 2016), the UK (Brand et al., 2012). Van Sluisveld et al. (2017) propose a systemic approach to analyse the European low-carbon strategies towards 2050, comparing ex-ante policy evaluation studies and national planning processes. They investigate the differences in country strategies by comparing the long-term planning processes of five EU countries (Denmark, France, Germany, the Netherlands and the UK). The authors discuss (1) the governance of ex-ante policy planning and evaluation processes and the national arrangement for (2) quantitative (model-based) ex-ante policy evaluation and (3) qualitative ex-ante policy evaluation (stakeholder participation).

Thus, different practical studies in relation to low-carbon energy scenarios have been conducted at the national and regional level, and some attempts were made in academic research to compare these approaches. Nevertheless, there is not enough work in the scientific literature analysing on a systemic basis the differences in policy settings of the European low-carbon energy scenarios. Existing studies mainly deal with fragmented aspects and are not comparable. Therefore, the main goal of this paper is to propose such a structured approach, taking six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium) as the examples.

The research objectives of this paper are as follows: in *theory* – to propose a methodological framework for the comparison of low-carbon energy scenarios in north-west European countries, in *practice* – to compare and assess the low-carbon strategies in these countries based on the proposed methodology.

Therefore, the research question is:

How can we compare and evaluate the policy settings of the low-carbon energy scenarios 2050 in European countries, which they have put in place to achieve the EU 2050 targets?

The approach developed in this paper may be of a specific interest for policy makers discussing the priorities in the specific energy sectors and monitoring the success in sustainable development at international, regional and national level. In addition, the results may be used by business representatives to understand the risks, uncertainties and possible disruptions in the energy markets and develop effective corporate strategies. The proposed framework may also invite academic researchers involved in energy-related activities to contribute to a general methodology of scenario design assessment.

Following the introduction, Section 2 will describe the methodological approach used in this study. Then, based on this methodology, the assessment of scenario design in six north-west European countries will be presented in Section 3. Subsequently, the results will be discussed in Section 4. Finally, Section 5 will formulate an answer to the research question and draw conclusions.

2. Methodology

Section 2 presents the methodology of the study in terms of case selection, conceptual framework, stages of analysis, methods and information sources. The conceptual framework including ten characteristics is described in detail to provide the basis for the further assessment of low-carbon energy scenarios in selected countries.

Although European countries have close socio-economic relationships and a joint (general) vision of the EU energy and climate future (in terms of roadmaps), so far not for many countries detailed 2050 projections are available. Six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium) are taken for analysis in this study for the following reasons. First, they developed the long-term low-carbon energy scenarios (2050) that can be found in open access. Second, these countries are from one sub-region (relatively homogenous group of countries), which increases the comparability of results. Third, the energy policy experts from these countries (6 experts), were invited to fill out the questionnaire including the description and assessment of scenarios, and provided additional information, which assures a detailed comparison of the scenarios. Although only six selected countries have been analysed, the approach proposed in this study can be scaled for other European countries.

The methodology of this study includes the stages of ***preparing***, ***analysis*** and ***integration of data*** (radar diagrams). For this, *qualitative* (literature review, expert questionnaire) and *quantitative methods* (statistical analysis, trend monitoring) are used. The following *information sources* form the basis for research: scientific publications, international and national (governmental) reports and strategic programs (e.g. the Netherlands (CPB/PBL, 2015), Germany (Öko-Institut/Fraunhofer ISI, 2016), France (Criqui and Hourcade, 2015), Denmark (Danish Energy Agency, 2014), the UK (UKERC, 2013), Belgium (FPB, 2015)), international statistics (e.g. European Commission (2016); European Environment Agency (2018)), materials of energy conferences and workshops (e.g. PBL, 2016; Koelemeijer, 2016; Eichhammer, 2016; Mattes, 2016; Criqui, 2016; Pedersen, 2016; Watson, 2016; Devogelaer, 2016), questionnaire with the experts from energy area. Based on the literature review (publications, governmental reports and strategic programs, international statistics, etc.) and consultations with national experts, the ***conceptual framework*** of this research proposes ten characteristics for the assessment of policy settings in energy scenarios: *modelling framework (diversity), ambitiousness (targets 2050), relations with other (European) countries, stakeholder involvement, technology options, non-technological aspects, economic component, the usage of scenarios in policy design, intermediate indicators of targets' (2050) achievement and revision of scenarios*.

Table 2.1 presents a short description of these characteristics, possible policy settings within them (with the scale for assessment), as well as their advantages and disadvantages. The score ranges are as follows: 1 (low), 2 (medium) and 3 (high). The scores for all characteristics are summed up and the final score for each country is calculated and presented in radar diagrams (see example in Figure 2.1).

Table 2.1. Conceptual framework

Characteristics	**Description**	**Possible policy settings (with the scale for assessment)**	**Advantages (reasons for scale selection)**	**Disadvantages (possible scale limitations)**
1. Modelling framework (diversity)	The diversity of policy scenarios	1 – One single policy scenario 2 – Two policy scenarios 3 – Multiplicity of policy scenarios (range of pathways)	Aiming on a single trajectory might not be desirable (PBL, 2016, p. 15). A multiplicity of scenarios may provide more flexible approach and opportunity to choose the appropriate way to achieve the targets, taking into account various conditions or pathways.	More resources (time, money, people, etc.) are needed to develop multiple policy scenarios. This may be difficult to organise for the countries with a short history of energy scenario development. Too many scenarios may cause confusion and blur the appropriate pathway towards the ultimate target.
2. Ambitiousness (targets 2050)	Maximum modelled GHG emissions reduction compared to 1990[7]	1 – Low ambitiousness (0-49%) 2 – Medium ambitiousness (50-79%) 3 – High ambitiousness (80-95%)	Ambitious targets are necessary for reaching collective EU 2050 targets.	Overambitious scenarios may have a limited impact on actual policy making (implementation gaps might increase).
3. Relations with other (European) countries	Inclusion of trans-border regional developments (TRD)	1 – Low TRD inclusion (isolated scenarios) 2 – Medium TRD inclusion (integrated scenarios) 3 – High TRD inclusion (fully-fledged integrated scenarios)	Fully-fledged scenarios are necessary especially in the power sector, since the market interdependencies are already strong and expected to increase. Ignoring these interdependencies misses both challenges and opportunities.	In integrated scenarios, dependency of one country on another country is possible (e.g. import dependency caused by importing sun and wind energy from Morocco to Germany).
4. Stakeholder involvement	The degree of stakeholder involvement (particularly, public engagement)	1 – Governmental bodies and municipalities 2 – Governmental bodies and municipalities, business, academic community 3 – Governmental bodies and municipalities, business, academic community, the general public	In case of active stakeholder involvement more informed decisions can be made (scientific advice given, society needs translated, etc.), which in turn may increase social acceptance of technological and non-technological changes ("Our opinion was heard").	Active stakeholder involvement requires more resources (time, money, people, etc.) to coordinate. The responses may include extremely different opinions, which are difficult to be collated. Impossibility to balance all opinions might lead to dissatisfaction of ignored opinions.

[7] The maximum ambitiousness of the most ambitious scenario developed in a specific country.

			Moreover, modelling efforts could also include "opportunity costs" into the scenario, which reflect the costs needed to overcome (public) resistance (PBL, 2016, p. 17).	Lack of knowledge / background / experience by the citizens may lead to superficial understanding of social effects and non-democratic input into decision making (Russel et al., 2010, p. 109). By involving stakeholders into the process of shaping long-term energy and climate visions, this also inherently makes the quantification of its implications more complex (PBL, 2016, p. 15).
5. Technology options	Transparency of technology selection[8]	1 – Low transparency (0-3 technology options out of 6 are justified) 2 – Medium transparency (4 technology options out of 6 are justified) 3 – High transparency (5-6 technology options out of 6 are justified)	Clear technology selection is needed to reach the EU 2050 targets, since the 80-95% reduction can be achieved only under full exploitation of available technologies. Transparent technology selection (justification) is needed to chose the best basic technology for a scenario in a specific country and understand why other technologies are not possible to use.	More resources (time, money, people, etc.) are needed to describe all technological options in detail.
6. Non-technological aspects	Inclusion of non-technological aspects (social acceptance, etc.)	1 – Low inclusion (without social acceptance) 2 – Medium (implicit) inclusion (only social acceptance) 3 – High (explicit) inclusion (social acceptance and other aspects)	Non-technological aspects such as social acceptance should be at least taken into account in scenarios, since technological changes sometimes are not possible without the acceptance of an appropriate infrastructure and stimuli for usage by citizens.	Non-technological aspects are difficult to measure, especially in terms of social acceptance of the novel technologies (f.e. CCS), which are not yet massively used in the market.

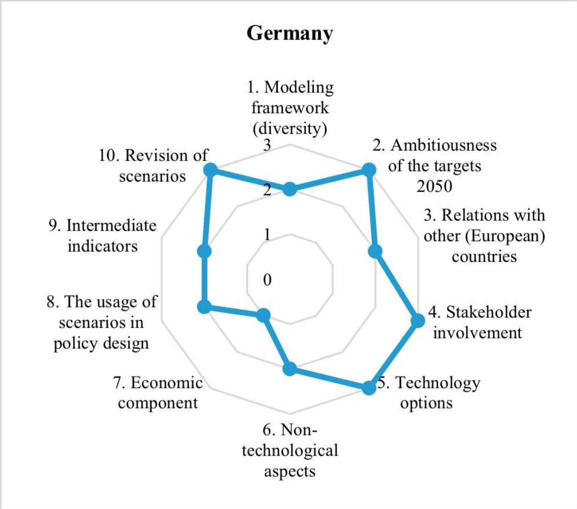
[8] Technology options: see details in Table 2.3.

7. Economic component	Description of economic component (cost-benefit analysis, etc.)	1 – Low description 2 – Medium description (without details) 3 – High description (with details)	Economic analysis is needed to assess what scenario is more feasible, in terms of costs and benefits.	Comparison of the results of economic analysis can be too complicated, since diverse approaches and models are used in different country scenarios. It requires using the harmonised parameters (discount rate, etc.) for analysis.
8. The usage of scenarios in policy design	The degree of scenarios' usage in policy development	1 – Low usage (not at all) 2 – Medium usage (only for strategic thinking) 3 – High usage (for strategic thinking and making tactical decisions)	It is important to use scenarios not only for general strategy development, but also for setting short- and medium-term measures that should be taken in order to achieve both final and intermediate targets.	The effective integration of scenarios into the policy design requires clear understanding of how the scenario targets should be converted into policy indicators and what institutions should be responsible for their implementation.
9. Intermediate indicators of targets' (2050) achievement[9]	Current consistency of scenarios with the EU 2050 targets[10]	1 – Low consistency (0-15% of the EU 80% (2050) achieved) 2 – Medium consistency (16-35% of the EU 80% (2050) achieved) 3 – High consistency (36-100% of the EU 80% (2050) achieved)	Following the average intermediate indicators may be the evidence that a country can effectively contribute to the EU 2050 targets' achievement.	Achievement of intermediate indicators may be difficult, since the countries have different target ambitions, economic potential (population, territory, GDP, etc.) and local context (not easy to compare). All this leads to the variance in their possible speed to achieve the national 2050 and the EU 2050 targets.
10. Revision of scenarios	Frequency of scenario revising	1 – Low frequency (every 4-5 years or more rarely) 2 – Medium frequency (every 3 years) 3 – High frequency (annually)	In order to be able to adapt to the possible changes, it is important to revise the scenarios as frequently as possible.	Regular revising requires additional resources (time, money, people, etc.).

Sources: based on PBL, 2016; Russel et al., 2010; and consultations with the experts.

[9] In terms of total GHG emissions reduction.
[10] A ratio of the targets achieved in 2015 (%) to the EU 80% target (2050).

Figure 2.1. An example of a radar diagram (Germany)



3. Assessment of energy scenarios

Section 3 presents qualitative and quantitative analysis of energy scenario policy settings in six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium) and reveals the similarities and differences between their approaches to achieve the EU 2050 targets for energy and climate protection.

3.1. Modelling framework (diversity)

In this research modelling framework of energy scenarios is analysed in terms of diversity of the pathways developed. The assessment scale for this characteristic assumes that aiming at a single or two scenarios may not well present the diverse nature of trajectories to be considered (see Table 2.1).

In six countries analysed, there are differences in the ***variety and types of scenarios***. As a rule, due to the need to follow the long-term EU targets (80-95% GHG reduction by 2050), the countries deal with several *normative scenarios with additional measures* (the names of policy scenarios developed in each country are presented further in Table 2.3). Such policy measures may be related to: electrification of buildings, transport or industries; improving efficiency in supply sectors (f.e. in energy, telecom, water and waste); diversification of energy prices for local and international energy markets, etc. Most countries (five out of six) start from *a reference scenario* (there is no reference WLO [11] scenario in the Netherlands). At the same time, various approaches are applied for designing *alternative policy scenarios*. This differentiation may be based on predetermined shares or ranges for certain energy carriers, as well as on the main frame parameters: e.g. in France – demand reduction, share of renewables, share of

[11] The name of the scenarios "WLO" stands for "Welvaart en Leefomgeving" in Dutch, which means "Welfare, Prosperity and Quality of the Living Environment" in English.

nuclear (Criqui and Hourcade, 2015); in Denmark – the shares of different "known" technologies: wind, biomass, bio+[12], hydrogen, fossil fuel (Danish Energy Agency, 2014); in the UK – emission reduction, technology development, fossil fuel prices, import dependency (UKERC, 2013).

The scenarios discuss a need to account for uncertainties in the pathways to follow up and so called "wild cards"[13] on the way to achieving the EU 2050 targets. Nevertheless, the challenge of "wild cards" for modelling, mentioned in energy scenarios, is in fact not addressed in the countries investigated. At the same time, diverse ***restrictions and challenges*** are indicated in scenario pathways. One of the major challenges in different scenarios is *availability of natural resources* (e.g. for bioenergy production, as mentioned in the report of Danish Energy Agency (2014)). Some more specific challenges are considered as well. For example, *infrastructure changes* are needed in France: deep retrofitting, electrification, plants' renovation, etc. (Criqui and Hourcade, 2015). Another problem is ensuring *a reliable electricity supply*. In Denmark a wind power-based, fully electrified system assures good fuel supply security but requires a reliable electricity supply, while a bioenergy-based system has to ensure a reliable fuel supply. In Germany *a ban for a specific energy source* (e.g. for nuclear energy) may serve as a significant political barrier. The problems discussed in the UK scenarios are as follows: understanding of *potential winners and losers*, changing *human behaviour and values*, dealing with *inconsistencies with local decision-making* and *testing of policies against a range of futures* (e.g. if the oil, gas and electricity price fall, the government should be prepared) (UKERC, 2013). In Belgian report the importance of *quantitative evaluation in energy decisions* is emphasised, as well as *a complementarity of the scenarios* (they should be supplemented by other analyses to cover all relevant topics) and the role of *coherence and (inter)national communication* (Devogelaer, 2016).

3.2. Ambitiousness (targets 2050)

Achievement of the EU 2050 goal to reduce the GHG emissions to 80% below 1990 levels seems to be possible in case of a significant contribution made by each member state. In accordance with the European Commission's Roadmap (European Commission, 2011), 80% reduction target should be reached through domestic measures alone. Nevertheless, despite these overall requirements that the

[12] Bio+ scenario entails a current fuel-based system, but with coal/oil/natural gas replaced by bio-energy (Pedersen, 2016, p. 12).

[13] "Wild cards" are less likely, but potentially highly important events that could bring about radical negative (e.g. black-outs associated with rare climatic events and high shares of renewables) or positive (e.g. strong cost decrease for electric cars or batteries) consequences (Manchester IIR, 2018).

countries agreed upon in order to achieve the EU 2050 targets, there are observable differences in the modelled GHG emissions reduction compared to 1990 on the national level. Table 2.2 illustrates emissions reduction levels (minimum and maximum) that have been considered in the scenarios under investigation and the countries' reduction ambition compared to the EU 80% goal (2050).

Table 2.2. Emissions reduction levels (2050) in the low-carbon energy scenarios of six north-west European countries

Country	Min emissions reduction level (2050)	Max emissions reduction level (2050)	Ratio = max emissions reduction level (2050) / EU 80% reduction target (2050)
The Netherlands	-45%	-80%	100%
Germany	-80%	-95%	119%
France	-	-75%	94%
Denmark	-80%	-95%	119%
The UK	-34%	-80%	100%
Belgium	-	-65%	81%

Sources: CPB/PBL, 2015; Criqui and Hourcade, 2015; Danish Energy Agency, 2014; FPB, 2015; Öko-Institut/Fraunhofer ISI, 2016; UKERC, 2013.

As is seen from Table 2.2, there is an observable range in reduction ambition within the selected group of countries, which may influence the achievement of the EU 2050 targets (80% reduction). Germany and Denmark determine the maximum EU reduction target of 95% (ratio = 119%). The Netherlands and the UK focus on the lower boundary of the international EU goal (80% GHG emissions reduction, ratio = 100%). At the same time, France and Belgium determine the maximum national targets only at 75% and 65% respectively (ratio = 94% and 81%).

Such variance in considered emissions reduction levels may be related to inconsistency of the member states' measures, that may be caused by differences in the national context, the level of policy ambitions, technological development in place, the degree of social acceptance, etc. Although there are no explicit requirements for the EU member states to take up an 80% or higher GHG emissions reduction target, it is clear that without national targets aiming at such an ambitious level, the EU as a whole would not reach such ambitious goal. In 2015, the European Commission (2015) provided the requirements for the development of integrated National Energy and Climate Plans (NECP), but it is not clearly stated how these plans should be effectively designed and monitored. Annex IV of the EU Governance Regulation (European Energy Union, 2018b) merely provides the formal requirements how to report on the national long-term strategies up to 2050. The actions of the European countries, which do not have the same ambitions as others, are uncoordinated, which underlines the importance of a more rigid and sophisticated set of requirements that should be accepted and implemented on the European level; otherwise, reaching at least 80% GHG emissions reduction seems unlikely.

3.3. Relations with other (European) countries

Due to the joint efforts needed for transition to a low-carbon future, regional cooperation is influential. That is why the national scenarios should ideally include trans-border issues. The countries under research have close economic and social relationships, which may create stimuli or barriers for their compliance with the EU 2050 targets. However, in fact, national energy scenarios rarely contain information about future socio-economic development in neighbouring countries and in the global markets as well. For instance, under the growing electrification of the key sectors, the importance of import and export of electricity is obvious. Similarly, if biomass availability is crucial for the future low-carbon energy development in Europe, the biomass trade issues with neighbouring countries should be included into the country strategies and the international agenda (PBL, 2016).

The low-carbon energy scenarios may be *isolated* (low inclusion of trans-border regional developments (TRD)), *integrated* (medium TRD inclusion) and *fully-fledged* (high TRD inclusion) (PBL, 2016). Four out of six north-west European countries (the Netherlands, Germany, Denmark, Belgium) have integrated scenarios and two countries (France and the UK) – isolated ones. For example, German energy scenarios take into account the electricity exchange with European countries (in 2050 – up to 10% net imports, essentially renewables) (Öko-Institut/Fraunhofer ISI, 2016). The regional differences in electricity prices and biomass prices are mentioned in the Danish report (Danish Energy Agency, 2014). Nevertheless, there is no clear assessment of the competitive situation for Danish biofuel production compared to imports. In the Belgian projections (FPB, 2015) it is stated that inter-national and inter-regional approaches are needed, but currently they are not being practically used in the scenarios.

Thus, TRD are frequently mentioned but not efficiently explored and addressed in low-carbon energy scenarios of the north-west European countries. However, in order to meet the ambitious EU 2050 targets together, neighbouring countries should develop the models with comparable mutual assumptions about trans-border infrastructure changes and consequences of energy policy on the regional level.

3.4. Stakeholder involvement

The stakeholders of energy scenarios may include not only *governmental bodies*, but also *non-governmental actors* – such as industry associations, business, academic community, non-governmental organisations (NGOs), the general public. Actually, the more ambitious the targets are, the more active discussion they attract. The stakeholders' involvement may reveal who benefits most and who is the loser. Moreover, in the information age, the media can play a significant role in stakeholder involvement and contribute to taking more informed decisions.

The results of the energy scenario development in selected countries are publicly available and can be found in media. While in Denmark and Belgium the non-governmental stakeholders were weakly or not engaged in this process, in the Netherlands, Germany and France they were involved as actively as the governmental ones, and in the UK it is planned to be done in the future. In Germany and France the participants included not only governmental bodies and municipalities, but also environmental NGOs, consumer associations, trade unions, businesses, as well as the general public. German energy scenarios were discussed on the federal and municipal level, as well as with participation of the industry associations and the citizens (Öko-Institut/Fraunhofer ISI, 2016). In France 16 initial scenarios were produced by the civil society (non-profits, NGOs, research centres, etc.) (Criqui and Hourcade, 2015, p. 5). The National Council on Energy Transition included environmental NGOs, consumer associations, trade unions, industry representatives, local authorities, administration actors, as well as the expert committee and the citizen group (Criqui, 2016, p. 2).

The selected countries experience a different level of awareness by the general public of the need for future changes. Being engaged in policy discussions, people may much faster realise the urgency of change, which influences further social acceptance of controversial technologies (PBL, 2016, p. 17). In addition, it is important to take into account possible "opportunity costs" needed to educate people and to overcome possible public resistance (PBL, 2016).

3.5. Technology options

The need for more intensive electrification of industry and other sectors (such as transport, residential and services sectors (heating of buildings), etc.) is a common feature of all country scenarios. That is why in this research the expected contribution of various technologies to the electricity generation is analysed. Table 2.3 contains the available information about such contribution retrieved from scenarios and expert consultations. ***Transparency of technology selection*** is crucial for understanding the role of specific technologies in the scenario settings.

Scenarios may include a diverse (the Netherlands, Germany, France, the UK, Belgium) or a limited set of technologies (Denmark). Technology options may have a local character and be based on *availability of natural resources* (e.g. comparably more wind potential in the Netherlands and Denmark, less biomass potential in Denmark, etc.), *social acceptance* of a technology (nuclear technologies are not considered in Germany, but actively discussed in France) and other factors.

The analysis of the available information from different scenarios (Table 2.3) shows that two countries (the Netherlands, Belgium) have justified 6 out of 6 technology options, two countries (Germany, the UK) – 5 out of 6 technology options and two countries (France and Denmark) – 3 out of 6 technology options. Nevertheless, the role of technologies such as CCS appears as minor in all scenarios discussed, while bioenergy plays more prominent role in them. In 2030 the sum of the biomass proposed in six countries analysed adds up to a range of 45-90 Mtoe, to be compared with 152 Mtoe sustainable biomass estimated for the EU as a whole, which is 15-21% below the projected EU bioenergy use (Transport & Environment, 2016). For example, in the Netherlands both biomass and CCS are necessary to meet 80% emissions reduction in 2050, taking into account their limited availability (Koelemeijer, 2016, p. 18). Total domestic potential of biomass in the Netherlands is predicted at around 200 PJ (primary energy). In WLO scenarios, about 20-30 TWh of electricity production from biomass is expected to be imported (Koelemeijer, 2016, p. 12). In both German scenarios (CS 80, CS 95), a comparison of the biomass use in different sectors and the calculated domestic biomass potentials, which is approximately 1100-1200 PJ, shows that the reductions 2050 can be achieved almost entirely with domestically produced biomass (Öko-Institut/Fraunhofer ISI, 2016, p. 46). In Denmark, the biomass scenario is designed to an annual bioenergy consumption of around 450 PJ, which entails a certain volume of net biomass imports in normal years (around 200 PJ). In the Bio+ scenario coal, oil and natural gas is replaced by bioenergy and fuel consumption is around 700 PJ. The hydrogen scenario is designed to simulate very small bioenergy consumption (under 200 PJ) (Danish Energy Agency, 2014, p. 2).

Table 2.3. Technology options in the scenarios, based on the contribution of a specific technology to the electricity mix[14]

Scenarios	*Renewables*					*Nuclear*	*Hydrogen / Power-to-X*	*CCS*	*Negative emissions (Bioenergy + CCS)*	*Fossil fuels*
	Solar	**Wind**	**Biomass & Waste**	**Hydro (large / small)**	**Geothermal**					
Netherlands 1 (WLO_L)	Low-Medium (10%)	Medium-High (52%)	Low-Medium (6%)	None	None	Low-Medium (4%)	Low-Medium	None	None	Low-Medium (28%)
Netherlands 2 (WLO_H)	Low-Medium (12%)	Medium-High (63%)	Low-Medium (2%)	None	None	Low-Medium (2%)	Low-Medium	Low-Medium (2%)	Low-Medium (10%)	Low-Medium (10%)
Netherlands 3 (WLO_H80c)	Low-Medium (7%)	Medium-High (66%)	Low-Medium (2%)	None	None	Low-Medium (2%)	Low-Medium	Low-Medium (5%)	Low-Medium (11%)	Low-Medium (7%)
Netherlands 4 (WLO_H80d)	Low-Medium (15%)	Medium-High (57%)	Low-Medium (6%)	None	None	Low-Medium (2%)	Low-Medium	Low-Medium (3%)	Low-Medium (8%)	Low-Medium (8%)
Germany 1 (CS 80)	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Low-Medium	None	Low-Medium	Low-Medium	No info	Low-Medium
Germany 2 (CS 95)	Low-Medium	Low-Medium	Low-Medium	Low-Medium	Low-Medium	None	Low-Medium	Low-Medium	No info	Low-Medium
France 1 (EFF)	Medium-High					Low-Medium	Low-Medium	No info	No info	No info
France 2 (DIV)	Low-Medium					Medium-High	Low-Medium	Low-Medium	No info	No info
France 3 (DEC)	Low-Medium					Medium-High	Low-Medium	No info	No info	No info
France 4 (SOB)	Medium-High					None	Low-Medium	No info	No info	No info

[14] The scale is the following: "None" = no contribution at all (0%), "Low-Medium" contribution (1-50%), "Medium-High" contribution (51-100%), "No info" = no information was found in the national report. Additionally, the specific figures (%) are presented where available.

Dennmark 1 (Wind scenario)	Low-Medium	Medium-High	Low-Medium	No info	No info	None	Low-Medium	No info	No info	None
Denmark 2 (Biomass scenario)	Low-Medium	No info	Medium-High	No info	No info	None	None	No info	No info	None
Denmark 3 (Bio+[15] scenario)	Low-Medium	No info	Medium-High	No info	No info	None	None	No info	No info	None
Denmark 4 (Hydrogen scenario)	No info	Medium-High	Low-Medium	No info	No info	None	Medium-High	No info	No info	None
Denmark 5 (Fossil-fuel scenario)	No info	No info	No info	No info	No info	None	None	No info	No info	Low-Medium
UK – UKERC 1 (Affordable)	Low-Medium	Low-Medium	Low-Medium	Low-Medium	No info	Low-Medium	Low-Medium	Low-Medium	No info	Low-Medium
UK – UKERC 2 (Late catch-up)	Low-Medium	Medium-High	Low-Medium	Low-Medium	No info	Low-Medium	Low-Medium	Low-Medium	No info	Low-Medium
UK – UKERC 3 (Maintain)	Low-Medium	Low-Medium	Low-Medium	Low-Medium	No info	Medium-High	Low-Medium	Low-Medium	No info	Low-Medium
UK – UKERC 4 (Maintain (tech failure + no CCS))	Low-Medium	Medium-High	Low-Medium	Low-Medium	No info	Low-Medium	Low-Medium	None	No info	Low-Medium
Belgium 1 (GHG40)	Low-Medium (10%)	Low-Medium	Low-Medium (8%)	Low-Medium	Low-Medium (1%)	None	Low-Medium	Low-Medium (19%)	None	Low-Medium (47%)
Belgium 2 (GHG40EE)	Low-Medium (9%)	Low-Medium (37%)	Low-Medium (10%)	Low-Medium	Low-Medium (1%)	None	Low-Medium	None	None	Low-Medium (42%)
Belgium 3 (GHG40EERES30)	Low-Medium (8%)	Low-Medium (44%)	Low-Medium (12%)	Low-Medium	Low-Medium (1%)	None	Low-Medium	None	None	Low-Medium (35%)

Sources: CPB/PBL, 2015; Criqui and Hourcade, 2015; Danish Energy Agency, 2014; FPB, 2014; Öko-Institut/Fraunhofer ISI, 2016; Watson, 2016.

[15] Bio+ scenario entails a current fuel-based system, but with coal / oil / natural gas replaced by bio-energy (Pedersen, 2016, p. 12).

Significance of the ***infrastructure changes*** is emphasised in the majority of energy scenarios under investigation. Most countries accept a need for massive electrification in different sectors. For instance, in Denmark, transformation of the car fleet is needed (Danish Energy Agency, 2014). In the UK scenarios it is stated that the smarter electricity systems may have a profound impact on energy consumption and reduce costs (Watson, 2016). However, not all countries clearly identify the infrastructure changes required to achieve the EU 2050 targets, which may also depend on the local context (different level of electrification, technology development, etc.).

3.6. Non-technological aspects

In addition to reliance on prevailing technologies, non-technological aspects have been discussed in the energy scenarios under research. Nevertheless, as a rule, non-technological changes needed for achieving the EU 2050 targets, are not implicitly defined in them.

The following ***non-technological aspects*** have been mentioned in energy scenarios:

- *social acceptance* (Germany, France, the UK, Belgium);
- *carbon pricing* (France);
- *taxes, subsidies, tradable permits or certificates* (Belgium);
- *lifestyle/consumption patterns* (France);
- *urban planning policies* (France);
- *appropriate institutions to be developed* (France).

In countries under research the structural changes require strong support from the general public. For example, in Germany social acceptance can be called "the currency of the transformation to 95% (Eichhammer, 2016, p. 3)". In France non-technological aspects are described in different policy scenarios. "Efficiency" scenario states that significant changes in consumption patterns are needed, with substantial energy savings in housing and changing mobility behaviour. In "Diversity" scenario the barriers to energy demand reduction are discussed (low acceptability and lower carbon tax with lower price elasticity) and more decarbonised supply technologies (CCS, decarbonised electricity, biofuels for transport and heat, heat networks at local level, etc.) have been promoted (Criqui and Hourcade, 2015, p. 37-38).

Considering institutional changes as a non-technological aspect as well, in France the appropriate institutions should be developed in order "to maximize the learning and allow for stakeholders' participation in the dynamic management of the different goals, targets and instruments (Criqui, 2016, p. 20)".

3.7. Economic component

A half of scenarios do not include a detailed analysis of the economic side of their implementation (the Netherlands, Germany, France). For example, the German report contains selective information about possible economic effects of the scenarios (Öko-Institut/Fraunhofer ISI, 2016, p. 47-49), but it is not clear what costs are needed in different sectors to implement the changes. In France only the assessment of economic impacts of each pathway is done, within the computable general-equilibrium (CGE) model Imaclim-R (Criqui and Hourcade, 2015, p. 3).

At the same time, in Denmark, the UK and Belgium the economic component of the energy scenarios includes a detailed cost-benefit analysis. For example, in Belgian scenarios the calculations are based on the PRIMES model (FPB, 2015). The policy scenarios determine the additional costs compared to the reference scenario – they are calculated to be around 2.5-3% as share of GDP (FPB, 2015, p. 6). The Danish low-carbon scenarios require additional costs of 5-23% relative to a fossil system (Pedersen, 2016, p. 22). In accordance with the calculations for this country, around half of the costs of a fossil fuel independent energy supply in 2050 refer to the transport sector. They may include investments, operating costs, fuel costs, energy savings, costs of propulsion systems for all types of transport, costs for energy producing facilities, etc. (Danish Energy Agency, 2014, p. 3-4).

Generally, the cost calculations in the energy scenarios have been made with a high degree of uncertainty, because of the possible rapid changes in future fuel prices, electricity prices and technology costs, including costs of energy savings. In addition, dependency of the pathways on the costs (dynamic development of the costs) is weakly or not at all considered in the energy scenarios under research.

3.8. The usage of scenarios in policy design

The important issue on the way to improving scenario efficiency is understanding of how they are embedded into a broader national development strategy and to what extent policy will be shaped based on the scenario work. Unfortunately, the current role of scenarios in the general policy process is still limited in all countries under investigation, which means that the connection between the scenarios and policy making in these countries is still quite weak. In most cases, scenarios have been used for developing a long-term strategy, however no government has adopted a single strategy as leading for the policy design (PBL, 2016, p.16) and more concrete short-term measures (tactical decisions) are not linked in detail to the strategy development process. Currently, the low-carbon energy scenarios are used only for strategic thinking in the Netherlands, Germany, Denmark, the UK and Belgium. Some tactical measures based on the scenarios are derived from the strategies in the Netherlands (CPB/PBL, 2015) and Germany (Öko-Institut/Fraunhofer ISI, 2016), but they cover the horizon 2020-2030, not 2050. In France, Energy Transition for Green Growth Act (FMEES, 2015) includes some policies based on the information from energy scenarios 2050: e.g. operational targets (number of thermal retrofit, biodigester or loading docks, etc.) (Criqui, 2016).

3.9. Intermediate indicators of targets' 2050 achievement

The analysis of European statistical data (European Commission, 2016) has shown, that all selected countries made progress in reducing total GHG emissions by 2015. Nevertheless, most of them have achieved less than 30% reduction of GHG emissions by this year.

Table 2.4 illustrates the EU target 2050, the targets achieved in six countries by 2015 (%), as well as the ratio of the targets achieved in 2015 (%) to the EU 80% target 2050.

Table 2.4. The percentage of achievement of the EU 80% target 2050 by 2015 in six countries

Country	Projected progress of countries towards 2030 climate targets (gap to 2030 Effort Sharing target with existing measures, in percentage points) in 2017	The EU target 2050, %	Target achieved in 2015, %	Ratio: Target achieved (2015) / The EU 80% target (2050)
The Netherlands	-5.2%	-80%	-7%	9%
Germany	-15.8%	-80%	-25%	31%
France	-9.0%	-80%	-14%	18%
Denmark	-15.0%	-80%	-30%	38%
The UK	-6.6%	-80%	-29%	36%
Belgium	-21.1%	-80%	-15%	19%

Sources: European Commission, 2016; European Environment Agency, 2018.

Thus, the results show that despite the fact that all selected countries made significant efforts towards reaching the EU 80% targets 2050, the most visible progress towards them refers to Denmark (38% achievement), the UK (36% achievement) and Germany (31% achievement).

3.10. Revision of scenarios

In order to keep energy scenarios relevant and adaptive, they should be revised and re-published regularly. As a rule, no clear and detailed information about scenario revising process can be found in the national reports – who are the participants of such revision, what methodology is used, with what regularity, etc. The national scenarios have been developed, published and updated with spontaneous frequency. In Belgium, the long-term energy projections for different sectors and energy carriers have been published by the Federal Planning Bureau (Devogelaer, 2016, p. 2) every 3 years. In the rest countries (the Netherlands, France, Denmark, the UK) the frequency is once in 4-5 years or more rarely. Only in Germany the long-term scenario reports 2050 are available since 2014 (Mattes, 2016) and have been revised annually, which allows adapting to the changes in the frame conditions (e.g. fuel prices, policies) (PBL, 2016, p. 15). At the same time, the German climate protection scenarios should be updated annually for the period of 3 years (Öko-Institut/Fraunhofer ISI, 2016, p. 7).

Table 2.5 presents the results of an integrated assessment of the scenario policy settings in six north-west European countries. The final scores are calculated and then used for creating the radar diagrams (Figure 2.2). The maximum final score is 30. The higher the final score is, the more potential a country has to develop energy scenarios contributing to the EU 2050 targets' achievement. This potential can be considered as a possible input, since it is important to take into account that scenarios may help to formulate policies, but only putting into place strong policies may lead to achieving the EU long-term objectives. The results show that Germany has the highest final score (23 points) among six north-west European countries. This country is followed by the UK and Belgium (21 points each), and then by France and Denmark (20 points each). The lowest score goes to the Netherlands (19 points). Therefore, the scores for all countries lie in the range of 19-23 points out of 30 points possible.

Table 2.5. Integrated assessment of scenario policy settings in six countries

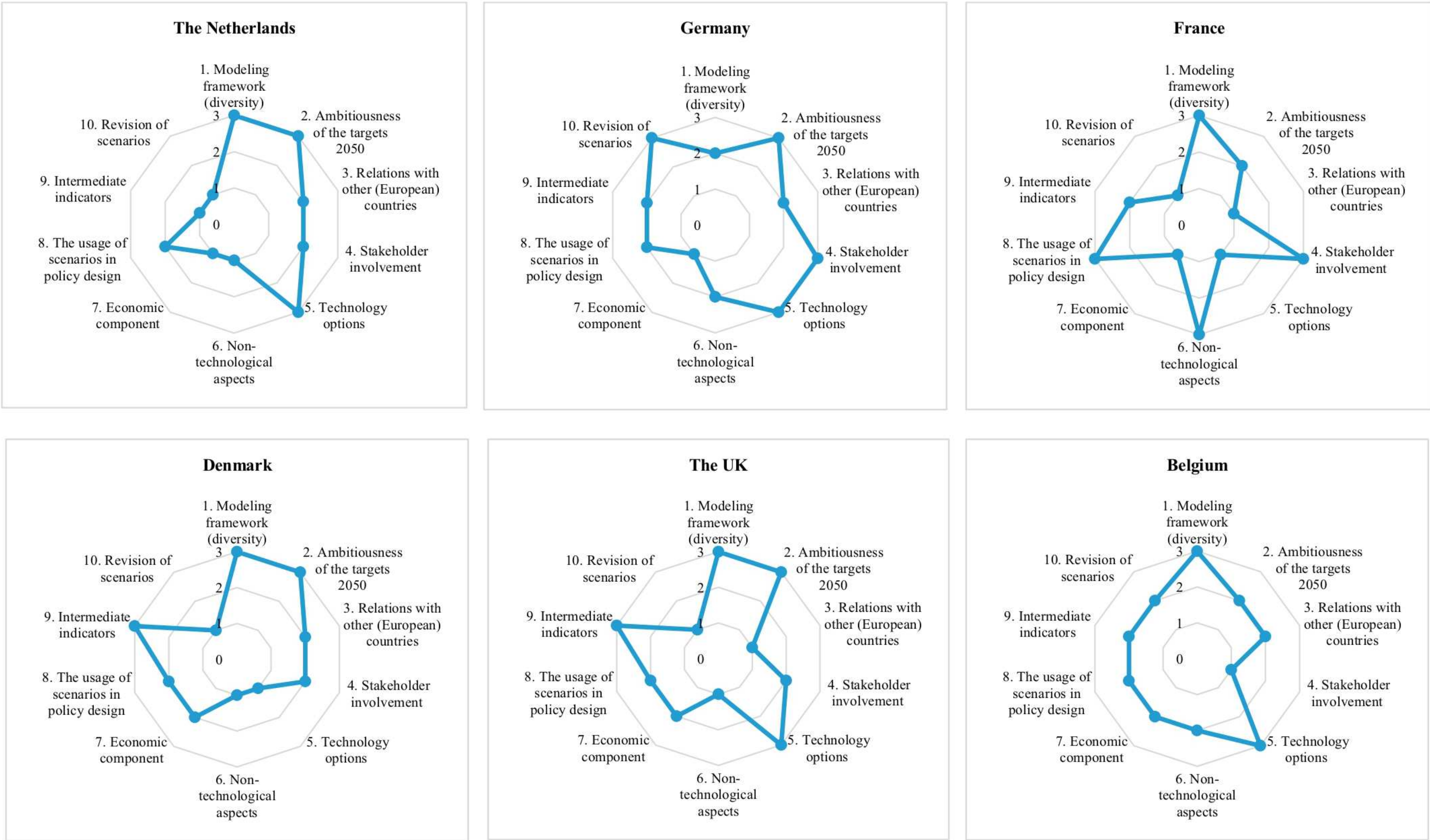
Characteristics	The Netherlands	Germany	France	Denmark	The UK	Belgium	Possible policy settings with the scale for assessment
1. Modelling framework (diversity)	**4 policy scenarios** 3 – Multiplicity of policy scenarios	**2 policy scenarios** 2 – Two policy scenarios	**4 policy scenarios** 3 – Multiplicity of policy scenarios	**5 policy scenarios** 3 – Multiplicity of policy scenarios	**4 policy scenarios (for 2050)** 3 – Multiplicity of policy scenarios	**3 policy scenarios** 3 – Multiplicity of policy scenarios	1 – One single policy scenario 2 – Two policy scenarios 3 – Multiplicity of policy scenarios (range of pathways)
2. Ambitiousness (targets 2050)	**-80%** 3 – High ambitiousness (80-95%)	**-95%** 3 – High ambitiousness (80-95%)	**-75%** 2 – Medium ambitiousness (50-79%)	**-95%** 3 – High ambitiousness (80-95%)	**-80%** 3 – High ambitiousness (80-95%)	**-65%** 2 – Medium ambitiousness (50-79%)	1 – Low ambitiousness (0-49%) 2 – Medium ambitiousness (50-79%) 3 – High ambitiousness (80-95%)
3. Relations with other (European) countries	**Focus on international and inter-regional approaches** 2 – Medium TRD inclusion (integrated scenario)	**The electricity exchange with European countries** 2 – Medium TRD inclusion (integrated scenario)	**TRD are not mentioned** 1 – Low TRD inclusion (isolated scenario)	**The regional differences in electricity prices and biomass prices** 2 – Medium TRD inclusion (integrated scenario)	**TRD are not mentioned** 1 – Low TRD inclusion (isolated scenario)	**Focus on international and inter-regional approaches** 2 – Medium TRD inclusion (integrated scenario)	1 – Low TRD inclusion (isolated scenarios) 2 – Medium TRD inclusion (integrated scenarios) 3 – High TRD inclusion (fully-fledged integrated scenarios)
4. Stakeholder involvement	**Government, external experts, ministry representatives** 2 – Governmental bodies and municipalities, business, academic community	**Federal states, municipalities, associations, research institutes, citizens** 3 – Governmental bodies and municipalities, business, academic community, the general public	**1. Environmental NGOs** **2. Consumer associations** **3. Trade-unions** **4. Industry** **5. Local authorities** **6. Parliament** **7. Administration** **+ Expert group** **+ Citizen group** 3 – Governmental bodies and municipalities, business, academic community, the general public	**Governmental bodies and municipalities, business representatives** 2 – Governmental bodies and municipalities, business, academic community	**Governmental bodies and municipalities, business representatives** 2 – Governmental bodies and municipalities, business, academic community	**Governmental bodies and municipalities** 1 – Governmental bodies and municipalities	1 – Governmental bodies and municipalities 2 – Governmental bodies and municipalities, business, academic community 3 – Governmental bodies and municipalities, business, academic community, the general public
5. Technology options	Scenario 1: 6/6 Scenario 2: 6/6 Scenario 3: 6/6 Scenario 4: 6/6 → **Average: 6/6** 3 – High transparency (5-6 technology options out of 6 are justified)	Scenario 1: 5/6 Scenario 2: 5/6 → **Average: 5/6** 3 – High transparency (5-6 technology options out of 6 are justified)	Scenario 1: 3/6 Scenario 2: 4/6 Scenario 3: 3/6 Scenario 4: 3/6 → **Average: 3/6** 1 – Low transparency (0-3 technology options out of 6 are justified)	Scenario 1: 4/6 Scenario 2: 3/6 Scenario 3: 3/6 Scenario 4: 3/6 Scenario 5: 3/6 → **Average: 3/6** 1 – Low transparency (0-3 technology options out of 6 are justified)	Scenario 1: 5/6 Scenario 2: 5/6 Scenario 3: 5/6 Scenario 4: 5/6 → **Average: 5/6** 3 – High transparency (5-6 technology options out of 6 are justified)	Scenario 1: 6/6 Scenario 2: 6/6 Scenario 3: 6/6 → **Average: 6/6** 3 – High transparency (6 technology options out of 6 are justified)	1 – Low transparency (0-3 technology options out of 6 are justified) 2 – Medium transparency (4 technology options out of 6 are justified) 3 – High transparency (5-6 technology options out of 6 are justified)

6. Non-technological aspects	**Non-technological aspects are not mentioned** 1 – Low inclusion (without social acceptance)	**Social acceptance** 2 – Medium (implicit) inclusion (only social acceptance)	**Social acceptance, carbon pricing, lifestyle / consumption patterns, urban planning policies, institutional changes** 3 – High (explicit) inclusion (social acceptance and other aspects)	**Non-technological aspects are not mentioned** 1 – Low inclusion (without social acceptance)	**Without social acceptance** 1 – Low inclusion (without social acceptance)	**Social acceptance, taxes, subsidies, tradable permits or certificates** 2 – Medium (implicit) inclusion (only social acceptance)	1 – Low inclusion (without social acceptance) 2 – Medium (implicit) inclusion (only social acceptance) 3 – High (explicit) inclusion (social acceptance and other aspects)
7. Economic component	**Only economic impact is analysed (no cost-benefit analysis)** 1 – Low description	**Only economic impact is analysed (no cost-benefit analysis)** 1 – Low description	**Only economic impact is analysed (no cost-benefit analysis)** 1 – Low description	**Calculations of the total costs for scenarios** 2 – Medium description (without details)	**Calculations of the total costs for scenarios** 2 – Medium description (without details)	**Cost-benefit analysis without details, calculations based on PRIMES model, etc.** 2 – Medium description (without details)	1 – Low description 2 – Medium description (without details) 3 – High description (with details)
8. The usage of scenarios in policy design	**Strategic thinking** 2 – Medium usage (only for strategic thinking)	**Strategic thinking** 2 – Medium usage (only for strategic thinking)	**Actively used in policy (e.g. in Energy Transition for Green Growth Act)** 3 – High usage (for strategic thinking and making tactical decisions)	**Strategic thinking** 2 – Medium usage (only for strategic thinking)	**Strategic thinking** 2 – Medium usage (only for strategic thinking)	**Strategic thinking** 2 – Medium usage (only for strategic thinking)	1 – Low usage (not at all) 2 – Medium usage (only for strategic thinking) 3 – High usage (for strategic thinking and making tactical decisions)
9. Intermediate indicators of targets' (2050) achievement[16]	*Target achieved (2015): -7% *The EU target (2050): -80% **→ 9% of the EU 80% target (2050) achieved** 1 – Low consistency (0-15% of the maximum national target 2050 achieved)	*Target achieved (2015): -25% *The EU target (2050): -80% **→ 31% of the EU 80% target (2050) achieved** 2 – Medium consistency (16-30% of the maximum national target 2050 achieved)	*Target achieved (2015): -14% *The EU target (2050): -80% **→ 18% of the EU 80% target (2050) achieved** 2 – Medium consistency (16-30% of the maximum national target 2050 achieved)	*Target achieved (2015): -30% *The EU target (2050): -80% **→ 38% of the EU 80% target (2050) achieved** 3 – High consistency (more than 30% of the maximum national target 2015 achieved)	*Target achieved (2015): -29% *The EU target (2050): -80% **→ 36% of the EU 80% target (2050) achieved** 3 – High consistency (more than 30% of the maximum national target 2015 achieved)	*Target achieved (2015): -15% *The EU target (2050): -80% **→ 19% of the EU 80% target (2050) achieved** 2 – Medium consistency (16-30% of the maximum national target 2050 achieved)	1 – Low consistency (0-15% of the EU 80% (2050) achieved) 2 – Medium consistency (16-35% of the EU 80% (2050) achieved) 3 – High consistency (36-100% of the EU 80% (2050) achieved)
10. Revision of scenarios	**The most recent WLO scenarios were published in 2006** 1 – Low frequency (every 4-5 years or more rarely)	**Annually** 3 – High frequency (annually)	**The most recent scenarios were published in 2015** 1 – Low frequency (every 4-5 years or more rarely)	**The most recent scenarios were published in 2014** 1 – Low frequency (every 4-5 years or more rarely)	**The most recent UKERC scenarios were published in 2013** 1 – Low frequency (every 4-5 years or more rarely)	**Every 3 years** 2 – Medium frequency (every 3 years)	1 – Low frequency (every 4-5 years or more rarely) 2 – Medium frequency (every 3 years) 3 – High frequency (annually)
Final score (max = 30 points):	**19 points**	**23 points**	**20 points**	**20 points**	**21 points**	**21 points**	**30 points**

Sources: CPB/PBL, 2015; Criqui and Hourcade, 2015; Danish Energy Agency, 2014; FPB, 2015; Öko-Institut/Fraunhofer ISI, 2016; UKERC, 2013.

[16] In terms of total GHG emissions reduction.

Figure 2.2. Radar diagrams for six countries



Summing up the results of analysis, the possibilities and limitations of this study, as well as the controversial issues and the lessons learned are discussed further in Section 4.

4. Results and discussion

The analysis has shown that the policy settings in the low-carbon energy scenarios are different in six north-west European countries. The research results can be helpful for understanding the factors that may influence the efficiency of energy scenario development in the European countries.

First, *collaboration and joint efforts* are needed on the regional level to provide higher consistency and transparency of policy, which may contribute to achieving the EU 2050 targets. The high ambition for the EU 2050 targets implies significant contribution from each country (the targets should be ambitious for all). In addition, taking into consideration the relationships with other European countries is important for the joint success.

Second, scenario development process needs to be *more interactive* on the national level. Active involvement of key stakeholders (governmental bodies, business, academic community, the general public) may encourage the fruitful dialog and speed up the acceptance of new technology pathways by the citizens.

Third, *new renewable technologies* play an important role in emissions reduction, however, technology favouring is different. In all scenarios the need for energy efficiency and massive electrification of industry and other sectors (such as transport, residential and services sectors, etc.) is mentioned, but is expected to be achieved through various low-carbon technologies. Nevertheless, not only technological options should be explored. *Non-technological aspects* (such as social acceptance of technologies) are sometimes even more important, since they may serve as a stimuli or a barrier for further scenario implementation in a specific country. In this case, addressing the social acceptance challenges requires a high degree of public engagement.

Fourth, the scenarios should account for *economic aspects* (costs and benefits) in order to be feasible and more adaptable to the future changes. Moreover, the strategy developed should be effectively incorporated into the national policy: not only into strategic thinking, but also into short-term decision-making.

Finally, *constant monitoring* is needed on both national and regional level to regularly measure the success of each country and the EU as a whole. For example, the progress in target achievement should be assessed and monitored on a constant basis to ensure the consistency of national scenarios with the European goals.

Intermediate indicators, such as the progress in GHG emissions reduction, may be used for this purpose. In general, more harmonised policy settings for scenario development with a set of requirements and monitoring milestones need to be established on the European level. First steps towards harmonisation have been taken under the Governance Regulation of the European Energy Union (2018b), which aims at harmonising the presentation in the frame of the National Energy and Climate Plans (NECPs). Although most of the Governance Regulation addresses the 2030 frame, Article 15 and Annex IV require a structured approach to a general framework for long-term strategies up to 2050. Nevertheless, these requirements are more formal in nature, focussing on the specific areas (energy efficiency, renewables and climate strategies), sectors and financing aspects, rather than on central characteristics as discussed in this paper. These characteristics may serve as an initial input to such a harmonised framework to present them at the EU member state level.

Discussing the research results, some limitations of this study need to be presented:

First, *the limitations of the methodological scale* should be taken into account. The list of ten characteristics was created based on literature review and consultations with national experts and should be considered as a starting point for further scenario comparison. The possible limitations of each characteristic are presented in Table 2.1. In general, those ten characteristics were selected for this research after literature review and consultations with the experts, because from the authors' point of view, their importance for scenario design (advantages) prevail over their limitations (disadvantages) (see Table 2.1). More sophisticated analysis and revision of the scales can be needed on the next stages of research, through additional literature review and expert discussions.

Second, one of the limitations of this study is *a comparative lack of data*. The information for the assessment part has been found in several documents, in which the figures sometimes were contradicting and required additional verification by the experts. Currently there is no unified framework for the scenarios' design, which satisfies the EU requirements. This once again emphasises the need for development of a more harmonised structure of energy scenario development in the European countries in order to make them more unified and comparable.

Third, the research results are visualised using *radar diagrams*, which have some limitations as equal weight is given to all characteristics. They just serve as a graphical representation and allow to make the results visible and assess the general potential of the countries in their possible contribution to achievement of the EU 2050 targets. The aim of this representation is not to compare the countries and judge who is the best, but understand what policy settings they have in their scenarios and how the scenario design may be improved in the future in order to speed up the 2050 energy transition.

Finally, another limitation is related to *expert involvement*. A limited number of national experts were engaged in discussing the research results. Expert consultations and a survey were conducted in order to get additional data about energy scenarios. To ensure deeper understanding of the details more active expert involvement is needed in the future for revising the methodology and verifying the findings.

Based on analysis of the results, as well as possibilities and limitations of this study, conclusions are made in Section 5 on the benefits that this approach brings to the harmonisation of the European energy scenarios.

5. Conclusions and policy implications

The main purpose of this paper was to propose a transparent approach allowing to compare and evaluate the policy settings of low-carbon energy scenarios 2050 in six north-west European countries (the Netherland, Germany, France, Denmark, the UK, Belgium) aiming to achieve the EU 2050 targets. In this study a conceptual framework including ten characteristics was developed for their comparison and then used to assess the policy settings of energy scenarios under research. For this, qualitative (literature review, expert questionnaire) and quantitative methods (statistical analysis, trend monitoring) were applied. The results can be of interest to economists (analysis of economic indicators), business (understanding the low-carbon targets in industries) and academic representatives (scenario development, trends monitoring, technology roadmapping, etc.), and especially policy makers involved in the long-term energy scenario development and assessment on the international, regional and national level. Although only six selected countries were analysed in this paper, this approach can be scaled for other European countries and for the whole European Union.

Apart from the methodological contribution, the following practical lessons have been learnt from this study. First, *collaboration and joint efforts* are needed on the regional level to provide higher consistency and transparency in achieving the EU 2050 targets. Second, the scenario development process on the national level needs to be *more interactive*, with active involvement of key stakeholders (e.g. government, business, academia, NGOs, the general public). Third, *new renewable technologies* play an important role in achieving the EU 2050 targets. However, not only technological options, but also *non-technological aspects* (such as social acceptance, lifestyle and consumption patterns, institutional changes, etc.) should be explored in more detail.

The analysis of the scenarios' ***modelling framework*** shows that almost all countries start from a reference scenario and have several normative scenarios with additional measures (from 2 to 5 policy scenarios) in order to satisfy the long-term EU targets (80-95%).

However, on the national level there are significant differences in the modelled GHG emissions reduction compared to 1990 and therefore in ***the ambitiousness (targets 2050)***. Most countries set up highly ambitious targets of 80-95% reduction (the Netherlands, Germany, Denmark, the UK), while the targets ambition of others (France and Belgium) is medium (75% and 65% respectively).

Taking into account the ***relations with other (European) countries***, four out of six countries under research (the Netherlands, Germany, Denmark and Belgium) have integrated scenarios, while two countries (France and the UK) have isolated ones (in them trans-border developments are mentioned but not addressed in practice).

Discussing ***stakeholder involvement***, most countries (apart from Belgium) engage not only governmental, but also non-governmental stakeholders in scenario development (the Netherlands, Germany, France, Denmark, the UK). For example, they may include the environmental NGOs, consumer associations, trade unions, businesses, research institutes, as well as the general public. The scenarios may focus on diverse (the Netherlands, Germany, France, the UK, Belgium) or a limited set of technologies (Denmark).

Selection of ***technology options*** may have a national character and be determined by the availability of natural resources, social acceptance issues and other factors. The analysis shows, that technology transparency also differs in scenarios: with high justification of technology options (5-6 out of 6) in the Netherlands, Germany, the UK and Belgium and low transparency (0-3 out of 6) in France and Denmark.

The possible **non-technological aspects** are weakly addressed in a half of scenarios under investigation (the Netherlands, Denmark, the UK), while included in the others – implicitly (Germany, Belgium) or explicitly (France). The examples are: social acceptance (Germany, France, the UK, Belgium), carbon pricing (France), taxes / subsidies / tradable permits or certificates (Belgium), lifestyle / consumption patterns (France), urban planning policies (France), appropriate institutions to be developed (France). Although these aspects are mentioned in energy scenarios, they are not investigated in detail.

Economic component is missing in a half of scenarios (the Netherlands, Germany, France) and bound by high uncertainties (such as changes in fuel prices, electricity prices and technology costs, including costs of energy savings, etc.). There have been the attempts to perform a cost-benefit analysis (Denmark, the UK, Belgium), but the detailed analysis can be considered more as an exception.

The usage of scenarios in policy design is still limited in all six countries. In most cases scenarios have been used for developing a long-term strategy (the Netherlands, Germany, Denmark, the UK, Belgium), and only in France their integration into the short-term measures (tactical decisions) is discussed.

In addition, the north-west European countries under research differ in ***intermediate targets achieved by 2015*** in comparison to the maximum national targets set by 2050. All countries made have a progress in reducing GHG emissions by 2015, and a half of them have achieved more than 30% of the EU 80% reduction targets 2050 in this year, with the most significant progress made by Denmark (38% achievement), the UK (36% achievement) and Germany (31% achievement).

The revision of scenarios is still spontaneous. In most countries (the Netherlands, France, Denmark, the UK) they are updated every 4-5 years or rarely, in Belgium – every 3 years, and only in Germany the energy scenarios have been revised on a regular basis (annually).

Thus, although the European countries have a joint vision of the energy future to 2050, the energy scenario development in these countries is still rather spontaneous and disjoint. According to the statistical data, the EU member states have different progress in reaching the GHG emissions reduction targets 2050. The calculations have shown that all six north-west European countries are very close to each other in the scores received as a result of scenario design assessment, and they range from 19 to 23 points out of 30 possible. Germany has the highest final score (23 points) among six north-west European countries under investigation. It is followed by the UK and Belgium (21 points each), and France and Denmark (20 points each). The lowest score goes to the Netherlands (19 points), but it is still close to the leader (Germany). Therefore, although these countries are still quite far from the maximum score (30 points), they all have a potential to improve their scenario policy settings, which in its turn, may influence the efficiency of national energy policy in the future. The results of this study may be applied for discussing the requirements for all European countries as a part of a more harmonised approach to achieve the EU 2050 targets, opening the possibilities for constant monitoring of the progress on the European level.

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Chapter 3. Global technology trends monitoring: theoretical frameworks and best practices[17]

Abstract

Monitoring and accurate interpretation of the data on technological trends is a key prerequisite for the gaining competitive advantages in various economic sectors. Validation of expert assessments via quantitative methods helps reveal inexplicit signs of technological change based on the analysis of large data sets. Synthesis of qualitative and quantitative methods enables identification of global technological trends, formalisation of their criteria and creation of automated information processing tools. This paper presents an analytical review of international practices for monitoring global technology trends (based on the reports of international organisations, national research centres, universities and research organisations, companies and consultancy agencies), as well as the key theoretical approaches and methods (from scientific publications), which have been developed in this field[18].

1. Introduction

Alongside the accelerating pace of technological progress and the shortening of the innovation cycle, we are faced with the task of identifying and systematically monitoring trends that are capable of having a significant impact on long-term social and economic development. Systematic monitoring of prospective science and technology (S&T) trends is necessary for flexible and timely strategic decision-making in response to technological changes.

Numerous studies aimed at uncovering these technological trends interpret this very term variously and make use of associated concepts. These studies differ in the emphasis they place on varying effects, the life cycle stage of the technologies, and the scale and methods used. The expected impact is one of the most significant characteristic of a technological trend. Thus, the unique feature of *disruptive innovations* lies in the fact that they endow technology with fundamentally new consumer properties, which are capable of fully changing the structure of markets

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[18] This paper was published in 2014 and analysed the literature that was relevant at that time. Therefore, further in the text, studies containing forecasts until 2020 may be indicated.

(Christensen, 1997). Where *emerging technologies*[19] are identified, intensively developing technological directions with high potential for inventions, innovations and associated significant economic and social consequences are the focus of attention (Gokhberg et al., 2013). There are also studies (Silberglitt et al., 2006), which put the emphasis on interdisciplinary technological fields that could have a major impact on social and economic development and change the lives of people around the world, and evaluate the prospects of *key technology applications*. Authors often include differing notions in the concept of technological trends depending on the technology's life cycle stage. For instance, *emerging technologies* fall under the research and development stage, while *technology applications and products* may already have been partially introduced in the market. Terminological preferences can be caused by the trends' scale. Thus, *mega-trends* are considered as stable trends on a global level that determine the future development of the global economy and society (Singh, 2012). Technology trends can also differ in the way they can be identified. In particular, dynamic and high-interest areas of S&T such as *research fronts* are defined as clusters of documents sorted on the basis of co-citation analysis (Upham and Small, 2010).

The main research question of this study is:

What methodological approaches (including qualitative and quantitative methods, data sources and software tools) can be used for technology trends monitoring?

2. Global practice in technology trends monitoring

Many projects on identifying technology trends are now being carried out worldwide by international organisations, national research centres, universities, companies and consultancy agencies. The aims of these studies vary. Technology monitoring by international organisations is necessary for supranational regulation of the S&T area, the development of joint programmes within country unions and effective integration and standardisation of activities in science, technology and innovation. Governmental institutions are faced with the task of understanding the overall state of global S&T and identifying a country's competitive advantages in key areas that are important from the perspective of national security and improving military potential (a portion of such data remains secret and inaccessible to the public). Monitoring projects by universities and research centres involve regular collection and analysis of information on new S&T directions, not only for scientific purposes, but also in the interests of businesses, and drafting

[19] Emerging technologies: (a) result from contemporary advances in a given field of knowledge; (b) are rapidly evolving; and (c) have high potential to result in inventions and innovations with significant societal and economic impacts (Gokhberg et al., 2013).

recommendations to governments on selecting certain national or regional priorities. Major corporations and private firms carry out their own monitoring of potential S&T breakthrough areas, which helps them adapt to changing market conditions and guarantee global competitiveness. Consultancy and audit companies engage in such initiatives to collect information needed by businesses to define strategic priorities.

Trends monitoring covers both certain sectors and the entire range of potential directions of technological development. The forecasting horizon, as a general rule, ranges from 10 to 30 years or more (the database of the German consultancy firm Z_punkt includes assessments up to 2030, while in some cases it is up to 2040-2050). These projects make active use of qualitative methods (literature review, expert surveys, interviews, developing scenarios, etc.) alongside quantitative methods (bibliometric and patent analysis, collecting and summarising web-data, etc.). Numerous attempts have been made to automate the processing of information on technologies (a semi-automated approach) and to use online tools to publish and discuss the results.

Figure 3.1 shows certain types of technology trends monitoring projects carried out by different organisations worldwide.

2.1. International organisations

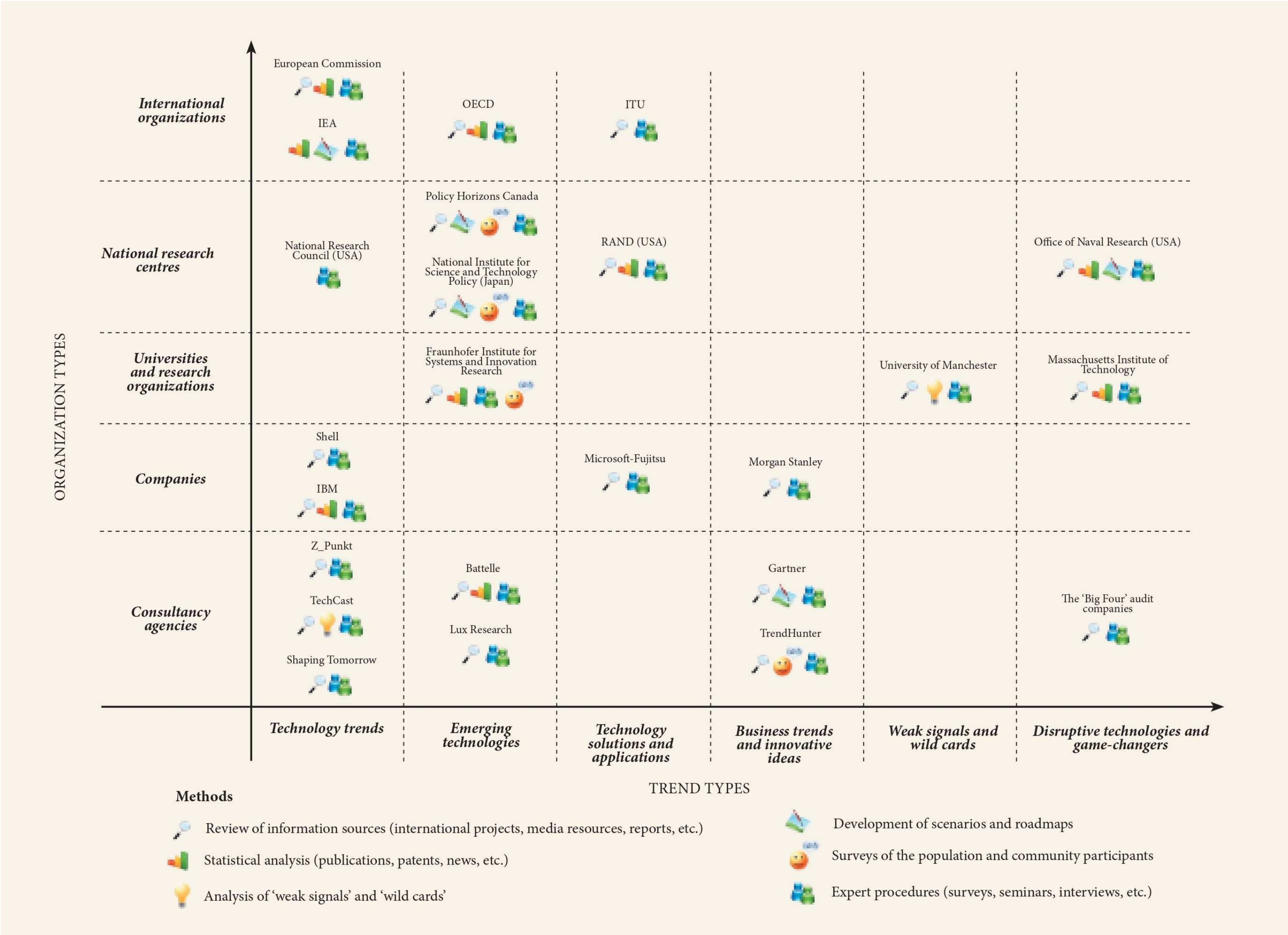
A number of international organisations carry out studies to identify prospective S&T directions and emerging technologies and to assess long-term development opportunities in certain areas. Generally, these projects result in the development of scenarios, a list of key technologies, trends and driving forces behind their development, as well as technological standards and policy recommendations for various countries. Examples of monitoring projects by international organisations are given in Table 3.1 below.

The European Commission implements various programmes to study global technology trends that have potential to influence the development of economy and society and publishes summary reports with recommendations to the European Parliament on S&T policy. For example, the “European Technology Watch” programme by the European Organisation for Security (European Commission, 2009) draws together the efforts of various participants (science, business, government) with a view to furthering existing competencies and raising the potential of European countries in S&T to secure the region’s leading positions in the world. This type of monitoring involves searching for potentially important technological fields and working on measures to stimulate their development in European countries.

The OECD conducts a large-scale analytical study on technology forecasting and a number of projects to monitor technology trends and drivers of growth in a diverse range of areas (space, energy, bioeconomics, etc.) For instance, in 2006-2007 the OECD published a series of "Infrastructure to 2030" (OECD, 2007) analysing the long-term opportunities and challenges faced by the global environment and setting out recommendations for the governments of the organisation's member states. In 2014, a report revealed the key challenges and trends, which could change the developmental trajectory of prospective fields such as nano-, bio-, space and information and communications technology, and incorporated the lists of key OECD reports in these areas (OECD, 2014).

The International Telecommunication Union's (ITU) "Technology Watch" project (ITU, 2014) looks at significant trends in information and communications technology and proposes the standards for new technological fields. The study aims to search for and study prospective S&T directions and measure their potential in terms of R&D standardisation. The ITU's reports offer an assessment of the impact of emerging technologies on the global competitiveness of developed and developing economies, analyse standardisation activity and trace the trajectory of information technology dynamics. As a whole, "Technology Watch" describes the broad current and future context of global S&T development and establishes a normative framework, within which to draft regulations and standards in information and communications technologies at national and international levels.

Figure 3.1. Typology of organisations and technology trends monitoring projects



Source: compiled by authors.

Table 3.1. Examples of technology trends monitoring projects by international organisations

Organisation	Project name	Project aim	Examples of trends	Methods	Results
European Commission	European Technology Watch (European Commission, 2009)	Early identification of emerging technologies in various fields, assessing their impact on the market to stave off any security threats to EU states	Robotic assistants	• Literature review (materials from joint European Commission projects – DEISA, PRACE, EGI, EMI) • Collecting and summarising expert assessments (interviews, expert panels, surveys, seminars, etc.)	Recommendations to EU state governments to guarantee security in Europe and globally
Organisation for Economic Co-operation and Development	"Infrastructure to 2030: Mapping Policy for Electricity, Water and Transport" (OECD, 2007)	Identifying long-term development opportunities for infrastructure around the world, drafting recommendations to improve infrastructure for OECD member states	Intelligent transport systems	• Reviewing studies by the OECD and member states of the organisation • Collecting and summarising expert assessments (involving specialists from government agencies, companies, research institutes)	• Report on opportunities to develop infrastructure in fields such as electricity production, water resources, rail freight transport, urban public transport, road transport • List of recommendations to OECD member states to improve infrastructure in the sectors under consideration
International Telecommunica-tion Union	"Technology Watch" (ITU, 2014)	Identifying emerging technologies to later set ICT standards in developed and developing countries	Ubiquitous sensor networks	• Literature review (various ITU reports) • Consultations with experts	• 27 reports on technology monitoring (for example, "Trends in Video Games and Gaming", "The Optical World", "Standards and e-Health", etc.) • TechWatch Alerts on technology development
International Energy Agency	"Energy Technology Perspectives 2012" (IEA, 2012)	Identifying technologies capable of reducing the negative effects of climate change and improving energy security	Carbon capture and storage	• Statistical analysis • Building roadmaps • Developing scenarios • Seminars with experts	• Energy development scenarios and strategies up to 2050 • 10 technologies potentially capable of having an impact on energy development • 25 energy recommendations to governments of various countries

Source: compiled by authors.

2.2. National research centres

Many national research centres are called upon by their governments to monitor prospective directions in technology development with a view to adjusting the country's domestic and foreign policy. Their projects describe technology trends, emerging technologies, prospective technology applications, driving forces and alternative technology development scenarios, as well as the most promising countries in terms of S&T collaboration. Table 3.2 shows several monitoring projects by national research centres.

The activities of the RAND Corporation – a strategic US research centre – focus on analytical support for science and education activity and health care and helping to strengthen national security and the stability of international relations. A range of technology trends are covered in the report "The Global Technology Revolution" (Silberglitt et al., 2006). The report presents four main S&T directions that are capable of having a radical impact on future development: bio-, nano-, information technologies and new materials. As part of the study, researchers looked at factors underlying the technology revolution and evaluated the prospects of 16 key technology applications, including hybrid vehicles, green manufacturing, targeted drug delivery, etc., and their most important effects.

The National Institute for Science and Technology Policy (NISTEP) was set up through the Japanese government to work on S&T policy, provide companies and associated organisations with analytical materials and assist in research activity in key technological areas. In 2010, NISTEP published "The 9th Science and Technology Foresight" (NISTEP, 2010), which was devoted to key directions to raise the competitiveness of the country in science, technology and innovation. The NISTEP Foresight centre publishes regular reports (Science and Technology Trends) (NISTEP, 2014) focusing on trends in technological areas (life sciences, ICT, ecology and energy, nanotechnology, etc.), which, if developed, could help to solve global and national problems. These trends are studied within expert networks made up of representatives from the science, business and the public sector.

Table 3.2. Examples of technology trends monitoring projects by national research centres

Organisation	Project name	Project aim	Examples of trends	Methods	Results
RAND Corporation	"Global Technology Revolution 2020" (Silberglitt et al., 2006)	Identifying key technology applications and analysing their impact on global social and economic development	Embedded sensors and computational devices in commercial goods	• Literature review (core S&T publications) • Assessment of R&D and investment dynamics • Interviews with experts	List and description of key technology applications
National Institute for Science and Technology Policy (Japan)	"The 9th Science and Technology Foresight" (NISTEP, 2010)	Analysing science, technology and innovation trends to increase the country's competitiveness in key S&T fields	Cloud computing	• Delphi surveys • Developing scenarios • Population surveys	• 12 scenarios • 120 key topics • List of countries for S&T collaboration with Japan • 13 areas with special importance to Japan
Office of Naval Research (USA)	"Science and Technology Text Mining" (ONR, 2014)	Analysing and mapping technology directions to plan and develop political programmes	Sensor networks	• Review of information sources (reports) • Statistical analysis (patents, scientific publications) • Web-mining • Collecting and summarising expert assessments (roadmaps)	• Global map of S&T development • S&T investment plan
National Research Council (USA)	"Technology Warning" (NRC, 2014)	Identifying key technologies and innovations from a military perspective, posing a potential threat to the US national security system	Supercomputing	• Review of information sources (materials from the "Joint Vision 2020" project and others) • Consultations with experts	• Description of key technologies in the form of reports on: "Technology Futures", "Technology Watch", "Technology Warning", "Technology Alert" and others

Source: compiled by authors.

Since 1998, the US Office of Naval Research (ONR) has been working on its "Science and technology text mining" programme (ONR, 2014). The aim of this project is to identify technology trends by processing textual data obtained from S&T databases (publications, patents, etc.) and using the results when planning and developing political initiatives. The programme looks for new interdisciplinary ways to overcome current challenges and identifies the key players and experts in specific S&T fields. In view of the importance of the programme to protect the country's national security, the results are presented to the US Navy command privately. At the same time, the authors behind the research regularly publish articles in academic journals and use their work as empirical evidence to support the accuracy of analytical conclusions (Kostoff et al., 2001; 2002; 2004).

The US National Intelligence Council (NIC) prepared a series of "Global trends" reports describing the factors and directions of technological progress that are capable of changing the trajectory of global development. Thus, the technology section of the report "Global Trends 2030: Alternative Worlds" (NIC, 2012) outlines the impact of new technologies on global development in such areas as ICT, automation and manufacturing, resource and health technologies and others. The document was drawn up on the basis of surveys carried out among company employees, members of academic institutes, governmental and non-governmental experts from the USA and other countries around the world. The study proposed four alternative global development scenarios, indicating the drivers, barriers and disruptive factors for them.

2.3. Universities and research organisations

Academic institutions, including non-governmental, make a significant contribution to technology trends monitoring. The emphasis here is placed on new technologies, "weak signals" and "wild cards"[20] that could have a major impact on global socio-economic development in the future. Such studies are carried out with the backing of national and international grants or as part of consultancy activity using vast information databases. They tend to develop databases (of trends, emerging technologies[21], "weak signals", "wild cards", etc.) that are widely accessible. Table 3.3 shows certain monitoring projects of this type.

[20] "Weak signals" are indicators of possible, but not obvious, changes in the future. "Wild cards" are less likely, but potentially highly important events that could bring about radical negative (e.g. terrorist attacks or natural disasters) or positive (e.g. the discovery of penicillin) consequences (Manchester IIR, 2013).

[21] Emerging technologies: (a) result from contemporary advances in a given field of knowledge; (b) are rapidly evolving; and (c) have high potential to result in inventions and innovations with significant societal and economic impacts (Gokhberg et al., 2013).

The iKnow project by the Manchester Institute of Innovation Research (Manchester IIR, 2013) is carried out with the support of the European Commission jointly with a number of international organisations and aims to identify "weak signals" and "wild cards". iKnow operates within an expert network bringing together decision-makers, researchers and participants in scientific and innovation activity. Every member of the community has access to a specialised database and can add information on existing or new technology trends. This project serves as an effective monitoring and long-term planning tool and is based on carefully studied conceptual and methodological principles to search for, classify and analyse "weak signals" and "wild cards", which have proven effective when assessing the potential impact of the latter on S&T development in Europe and the rest of the world.

A specialised division operates within the Fraunhofer Institute for Systems and Innovation Research (ISI) called the Competence Centre for Emerging Technologies (Fraunhofer ISI, 2014). Employees at this centre analyse developments in areas such as bioeconomy and life sciences, health system, data processing and communications, etc. Using a wide range of data, they study the developmental trajectories of emerging technologies and their impact on one another and they carry out assessments of the economic, environmental and social impacts of S&T progress. The institute involves economists, politicians and representatives of various scientific industries in its interdisciplinary projects, and its final recommendations are used in decision making on science, technology and innovation policy.

The "Technology Review" project (MIT, 2013) by the Massachusetts Institute of Technology (MIT) aims to identify prospective trends, business models and innovative solutions, as well as the directions of global development. In the project report (2013), information was presented on biomedicine and pharma, medical devices and digital health, the digital economy and mobile world, the new global energy map, advanced manufacturing, nanotechnology and new materials, "smart" cities and the mass market. These areas had a short description, a list of key trends and game changers, leading countries and forecast assessments of the future technology development. In addition, the report contained an analysis of mega-trends relevant to a wide range of sectors (nanotechnology and new materials, the power of the consumer, the automation of work, hyper-connectivity). As part of its "Technology Review" project, the Massachusetts Institute of Technology publishes annual reports on "Ten Breakthrough Technologies" (MIT, 2014) that provide additional information about many S&T fields.

Table 3.3. Examples of technology trends monitoring projects by universities and research organisations

Organisation	Project name	Project aim	Examples of trends	Methods	Results
Manchester Institute of Innovation Research	iKnow database (Manchester IIR, 2013)	Identifying, classifying and analysing "weak signals" and "wild cards"	Production of artificial organs	• Review of information sources (publications, blogs, news articles, EU technology monitoring projects) • Delphi surveys and interviews (panels involving scientists and research organisations) • Analysing "weak signals" and "wild cards"	• List of "weak signals" and "wild cards" according to the themes of the EU Seventh Framework Programme
Fraunhofer Institute for Systems and Innovation Research	"Emerging technologies" (Fraunhofer ISI, 2014)	Identifying technology trends in S&T fields and analysing the potential to introduce innovative technology applications into industry	Lithium-ion batteries	• Review of information sources • Monitoring R&D activity • Developing scenarios • Seminars with experts • Population surveys	• Reports on emerging technologies in various fields (bioeconomy and life sciences, health system, ICT and others)
Massachusetts Institute of Technology (MIT, 2013)	"MIT Technology Review" (MIT, 2013)	Analysing prospective technology fields selected at the Open Innovations Forum	Human brain modelling	• Review of information sources (scientific reports, news articles, etc.) • Statistical analysis • Surveys and consultations with experts	• List of key technology trends

Source: compiled by authors.

2.4. Companies

Large private companies carry out technology trends monitoring projects in the core sectors of their activity and related fields. Such studies allow them to detect innovation breakthrough areas at an early stage, thereby enabling them to improve the flexibility of their business and their market competitiveness. These projects result in alternative scenarios and lists of trends (innovative solutions) in the technological fields under investigation. Table 3.4 gives some examples of monitoring projects implemented by companies.

The goal of IBM's "Next Five in Five" monitoring project (IBM, 2014) lies in analysing key marketing and social trends that are capable of changing people's lives, as well as the new prospective technologies underlying these trends, over the next five years. In 2013, innovative trends were identified in five key fields: education, retail trade, healthcare, security and urban development. IBM uses the results when drafting strategic priorities and publishes them on its website for use by any interested parties. There is demand for this type of data from private firms, investors, research collectives, the media, etc.

A global alliance was signed between Microsoft and Fujitsu with a view to search for and apply innovative approaches to guaranteeing reliable long-term relationships with clients, involving consultancy services, business hardware and software solutions. In 2011, the alliance launched the "Insights Quarterly" research project aimed at identifying challenges and trends in ICT and searching for technological solutions that companies can rely on amid restrictions on budgets and high administrative risks. The "Key ICT Trends and Priorities" report (Microsoft-Fujitsu, 2011) gives a short review of technological trends in areas such as tablet computing, cloud computing, business intelligence and communications and also provides assessments of the significance of technologies and trust in them from representatives of leading ICT companies.

Table 3.4. Examples of technology trends monitoring projects by large companies

Organisation	Project name	Project aim	Examples of trends	Methods	Results
Shell	"Shell Energy Scenarios to 2050" (Shell, 2009)	Analysing factors affecting the business environment, development of global energy scenarios	Biofuels	• Review of information sources • Interviews with experts	• Trends in the energy industry • Alternative global energy scenarios
IBM	"Next Five in Five" (IBM, 2014)	Identifying technologies that have potential to change people's lives in future	Personalised medicine based on DNA technologies	• Collecting and analysing information on cutting-edge technologies developed at IBM laboratories • Analysing markets and social trends	• Regular reports describing five promising innovations over the next five years in fields such as education, retail trade, healthcare, security, urban development
Microsoft-Fujitsu	"Insights Quarterly" (Microsoft-Fujitsu, 2011)	Identifying the most important challenges and technological solutions in ICT	Tablet computing	• Review of information sources • Surveys of ICT company representatives	• Quarterly reports on challenges and technology trends in ICT
Morgan Stanley	"Morgan Stanley Blue Papers" (Morgan Stanley, 2014)	Analysing technological changes that could have a significant impact on the development of the global economy and business	Mobile commerce	• Review of information sources • Consultations with experts (analysts, economists, strategic management specialists)	• Reports on technology trends

Source: compiled by authors.

2.5. Consultancy agencies

Consultancy agencies offer an extremely broad range of technology monitoring services, although they are often highly specialised in nature and adapted to the needs of specific clients. Consultancy services tend to focus on business trends and emerging and breakthrough technologies in areas that are most attractive to their clients (Table 3.5).

The consultancy company Z_Punkt provides services to work on the development strategies of its client companies, including identifying technology trends in the corresponding fields. The "Z_Punkt Trend Radar 2020" database (Z_Punkt, 2014) covers technological development directions such as ICT, materials, life sciences, nanotechnology, robotics and artificial intelligence, transport and mobility, medicine, the environment, energy and others. It allows users to carry out a complex analysis of significant medium- and long-term social, cultural, economic, technological, political, and ecological events. The database includes approximately 240 trends with detailed descriptions of their time horizon, global development level, potential impact, etc.

Gartner carries out regular studies on the ICT market, offering consultancy services to developers, investors and software suppliers. An important strand of Gartner's studies is its forecasts of technology trends capable to influence prospective market dynamics. The aim of the "Top 10 Strategic Technology Trends" project (Gartner, 2014) is to search for and analyse strategic technologies that could have significant impacts for businesses in the coming three years. The potential of the technologies, investment demand and the risks caused by late implementation are all factors that affect their impact. Both existing and new directions in ICT that open up unique opportunities or have high disruptive potential for companies over the next few years are all considered strategic.

Table 3.5. Examples of technology trends monitoring projects by consultancy agencies

Organisation	Project name	Project aim	Examples of trends	Methods	Results
Battelle	Battelle.org (Battelle, 2014)	Identifying innovations and technology trends in various S&T fields	Membrane technology	• Review of information sources (reports, standards) • Statistical analysis • Collecting and summarising expert assessments • Laboratory experiments	• Emerging technologies in various fields (industry, energy and environment, healthcare, national security, pharmaceutical and medical devices, and others)
Z-Punkt	TrendRadar database (Z_Punkt, 2014)	Identifying and describing key technology trends in the medium and long term	Social networks and collective intelligence	• Review of information sources • Web-data collection and analysis • Interviews with experts	• Database of technology trends in fields such as ICT, materials, life sciences, nanotechnology, robotics and artificial intelligence, transport and mobility, medicine, environment, energy, nutrition
Lux Research	Luxresearchinc.com (Lux Research, 2014)	Identifying and describing emerging technologies for clients to select key technology directions to finance	Metamaterials	• Review of information sources (marketing surveys, company profiles, publications, etc.) • Interviews with company managers, clients, partners and external experts in more than 20 countries	• Database of discoveries and technology trends in various fields (advanced materials, agro innovation, alternative fuels, bioelectronics, water, and others)
Gartner	"Top 10 Strategic Technology Trends" (Gartner, 2014)	Identifying technology trends capable of affecting the activities of ICT companies in the next three years	Smart cars	• Review of information sources • Web-mining • Developing scenarios • Expert surveys	• Ten strategic technology trends in ICT
Deloitte	"Tech Trends" (Deloitte, 2012)	Identifying disruptive technologies, as well as technologies that contribute to S&T development in ICT	Gamification	• Review of information sources • Collecting and summarising expert assessments by science and industry representatives • Crowdsourcing of ideas[22] (global expert network)	• Annual reports on technology trends: five disruptors and five enablers
TechCast	Techcastglobal.org (TechCast, 2014)	Analysing topical technology trends for use in business planning and	The Internet of Things	• Review of information sources (S&T literature, web-data, the media, etc.)	• Summary map of technologies, published annually • 60 emerging technologies and 30

[22] In crowdsourcing, a solution to a problem is sourced from a large distributed group of community members, which helps to reduce spending on searching for and processing information.

		developing company policy		• Interviews with experts	"wild cards" in various fields • Technology forecasts by direction (energy and environment, information technology, digital economy, manufacturing and robotics, medicine and biogenetics, transportation, space, and others)
Shaping Tomorrow	Shapingtomorrow.com (Shaping Tomorrow, 2014)	Monitoring key trends, events and news in science and technology	Augmented reality	• Review of information sources (news feeds, materials from analytical centres, international reports, etc.) • Collecting and summarising expert assessments (in the form of interviews, expert panels, surveys, seminars, etc.)	• Reports on trends in various fields • Trend alerts • Information bulletins
Trend Hunter	TrendHunter.com (Trend Hunter, 2014)	Collecting information on innovations and cutting-edge technologies for start-up businesses and large-scale companies	Wearable fitness trackers	• Crowdsourcing and polling among community members • Collecting and summarising expert assessments	• 250,000 microtrends • 2,000 technology clusters • Summary reports on trends

Source: compiled by authors.

Deloitte's expert network brings together roughly 200 000 financial, audit and risk management specialists from around the world. Deloitte publishes annual reports on technology trends that will have the greatest impact on the future activities of ICT companies. After a round-up of a wide range of potential technologies, the analysis moves on to private surveys of clients, suppliers, researchers and analysts. In the final report, technology trends are classified into two categories: disruptors (causing stable positive changes in the ICT sector) and enablers (their development gives rise to new practices in the field). In particular, the "Tech Trends 2012: Elevate IT for digital business" report (Deloitte, 2012) describes five disruptive trends ("Social Business", "Gamification", "Enterprise Mobility Unleashed", "User Empowerment" and "Hyper-hybrid Cloud") and five enabling trends ("Big Data Goes to Work", "Geospatial Visualisation", "Digital Identities", "Measured Innovation" and "Outside-in Architecture").

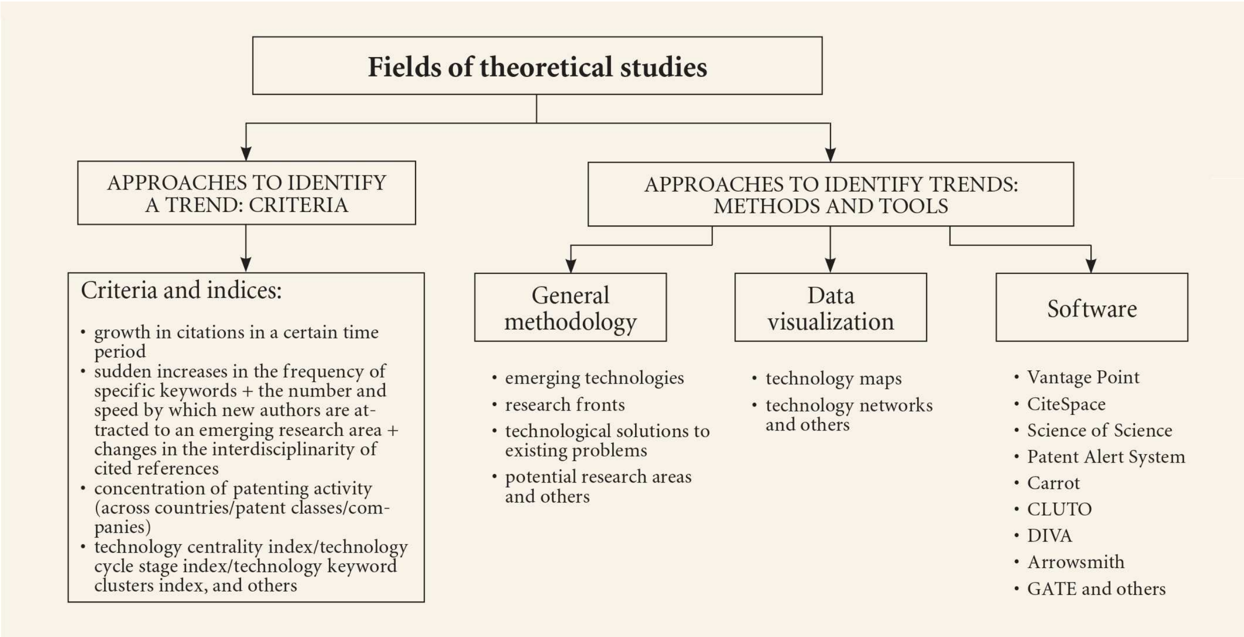
Trend Hunter is the largest global trends monitoring community covering various areas (fashion, technology, culture, design, social media, business, ecology and others) (Trend Hunter, 2014). The TrendHunter.com global network brings together more than 150 000 participants and serves as an important source of information on technologies and innovative ideas for start-up enterprises and large companies. Within this network, a methodology has been developed making it possible to codify information on emerging technologies, added by service users and to exchange opinions on their relevance using polls on the site. At present, the Trend Hunter database has thousands of reports on trends, technology clusters and new innovative ideas which private companies can use when developing their marketing and product strategies.

3. Quantitative approaches to technology trends monitoring

Contemporary approaches to technology monitoring propose a synthesis of qualitative and quantitative methods with the latter taking on an ever-growing role. Amid the current information overload, researchers are developing new analytical tools (software) to detect "hidden" knowledge using effective processing and interpreting methods for data collected from a broad range of sources.

The main research fields of theoretical studies devoted to identifying and revealing technology trends are shown in Figure 3.2 below.

Figure 3.2. Main research fields of theoretical studies on technology monitoring



Source: compiled by authors.

Several studies are devoted to classifying trends and developing criteria to identify them. Trends are grouped according to different parameters: growth in the number of highly cited publications on the topic (Upham and Small, 2010), keywords use statistics (Guo et al., 2011), etc. The study by Upham and Small (2010) analysed the change in the number of publications in research fronts[23] over a specified period of time, identifying the following types of research fronts:

- *Emerging* – fronts in the current dataset that contain no papers from the previous dataset;
- *Growing* – those that have more papers in the current period than the sum of all their contributing fronts in the previous period of analysis;
- *Stable* – those for which the sum of all contributing fronts yields the same number of papers;
- *Shrinking* – those that are smaller than the sum of all their contributing fronts in the previous time period;
- *Exiting* – fronts that existed in the previous period of analysis but have no papers in any front in the current period analysed.

Guo et al. (2011) propose a mixed model to describe and forecast emerging technologies involving three key indicators:

[23] Research fronts represent the most dynamic areas of S&T and the areas that attract the most scientific interest.

- sudden increases in the frequency of specific words indicating the emergence of new directions in scientific research;
- the number and speed by which new authors are attracted to an emerging research area;
- changes in the interdisciplinarity of cited references.

The authors note a correlation between these three factors: first, authors show up in emerging fields, then the number of interdisciplinary publications and citation levels starts to grow, which in turn gives rise to a spike in keywords use statistics (Guo et al., 2011). Besides, various technology trends indices are being developed. In particular, the study by Cobo et al. (2011) proposes using parameters such as centrality and density[24] to divide scientific subjects into the following types: highly developed and isolated; emerging or declining; motor; basic and transversal. Another study, by Corrocher et al. (2003) analyses emerging technology trends on the basis of concentration of patenting activity across countries, International Patent Classification (IPC) classes and companies[25]. The suggestion is that the newer the technology, the narrower the range of countries and companies that have access to it, and information on technology in the early stages of development is only provided for key patent classes.

3.1. Monitoring stages

In quantitative approaches, the important research task is developing the overall methodology to monitor technology trends. Methodologies can include methods to identify emerging technologies (Porter and Cunningham, 2005), technological solutions to existing problems (Kostoff et al., 2008; Kim et al., 2009), research fronts (Upham and Small, 2010), potential research areas[26] (Lee et al., 2009) and other trend types. On the whole, irrespective of the chosen focus and the tools used, the monitoring can be broken down into five main stages (Table 3.6).

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[24] “Centrality” describes the strength of the external links between the scientific subjects under consideration and other subjects. “Density” defines the strength of the internal links between keywords describing a particular scientific subject.

[25] The basis of the patenting activity concentration across countries lies in the hypothesis that the development of innovative products and applications takes place in a limited number of countries, the number of which gradually grows after standardisation of the technologies. The analogous concentration across patent classes stems from the hypothesis that in the early stages of development, emerging technologies are concentrated in certain IPC classes, and then information on these technologies spreads to other patent classes. The concentration across companies is based on the hypothesis that the development of emerging technologies is initially carried out by a narrow, albeit expanding over time, group of companies.

[26] Potential research areas can be identified as patent “vacancies”, which are created by the blank areas in the patent maps (Lee et al., 2009).

Table 3.6. Main stages of technology trends monitoring

№	Stage	Content
1	Setting objectives	Establishing the research objectives, selecting the subject area and methodology
2	Data collection	Selecting data sources for analysis and the search strategy determined by the research objectives; collecting materials
3	Data processing	Selecting the units of analysis (documents, keywords, authors, etc.) and methods (text mining, clusterisation, network analysis, citation analysis, etc.)
4	Drafting a preliminary list of trends	Defining candidate trends (integrating the results from the data processing)
5	Validation and interpretation	Validation of candidate trends (ensuring that the candidate trends meet the criteria of a trend)

Source: compiled by authors.

Porter and Cunningham (2005) introduce the notion of tech mining to refer to the step-by-step process of technology monitoring. At the stage of setting the objectives, the aim of the study is set and relevant data sources are selected. At the second stage, certain queries are formulated and data are collected from the selected sources. The next step – data processing – involves a basic (refining and filtering) and advanced (in-depth) analysis of the information gathered. The monitoring closes with the stage where the results are presented, interpreted and summarised.

The methodology of creating patent maps (Lee et al., 2009) to identify new prospective research fields is also packed into the presented technology monitoring outline. Based on the objectives, a collection of patents is formed, and the data processing stage involves the creation of a patent map to identify and describe candidate trends. The final stage of the monitoring is devoted to analysing, validating and interpreting the results obtained.

Differences in the technology monitoring process are caused not only by the objectives set, but also the sources of data and methods of analysis used. Figure 3.3 shows the possible choices at each stage of technology trends monitoring.

As Figure 3.3 shows, the monitoring process is dependent on the chosen trend type (emerging technologies, research fronts, technological solutions, potential research fields, etc.), the sources of information (databases of publications, patents, news, etc.), the data extraction methods (broad thematic inquiry such as "nanotechnology", list of keywords or a certain feature), the units of analysis (a certain document, structured or unstructured data), and the methods used to process and validate the trends identified (quantitative, qualitative or mixed).

3.2. Data sources

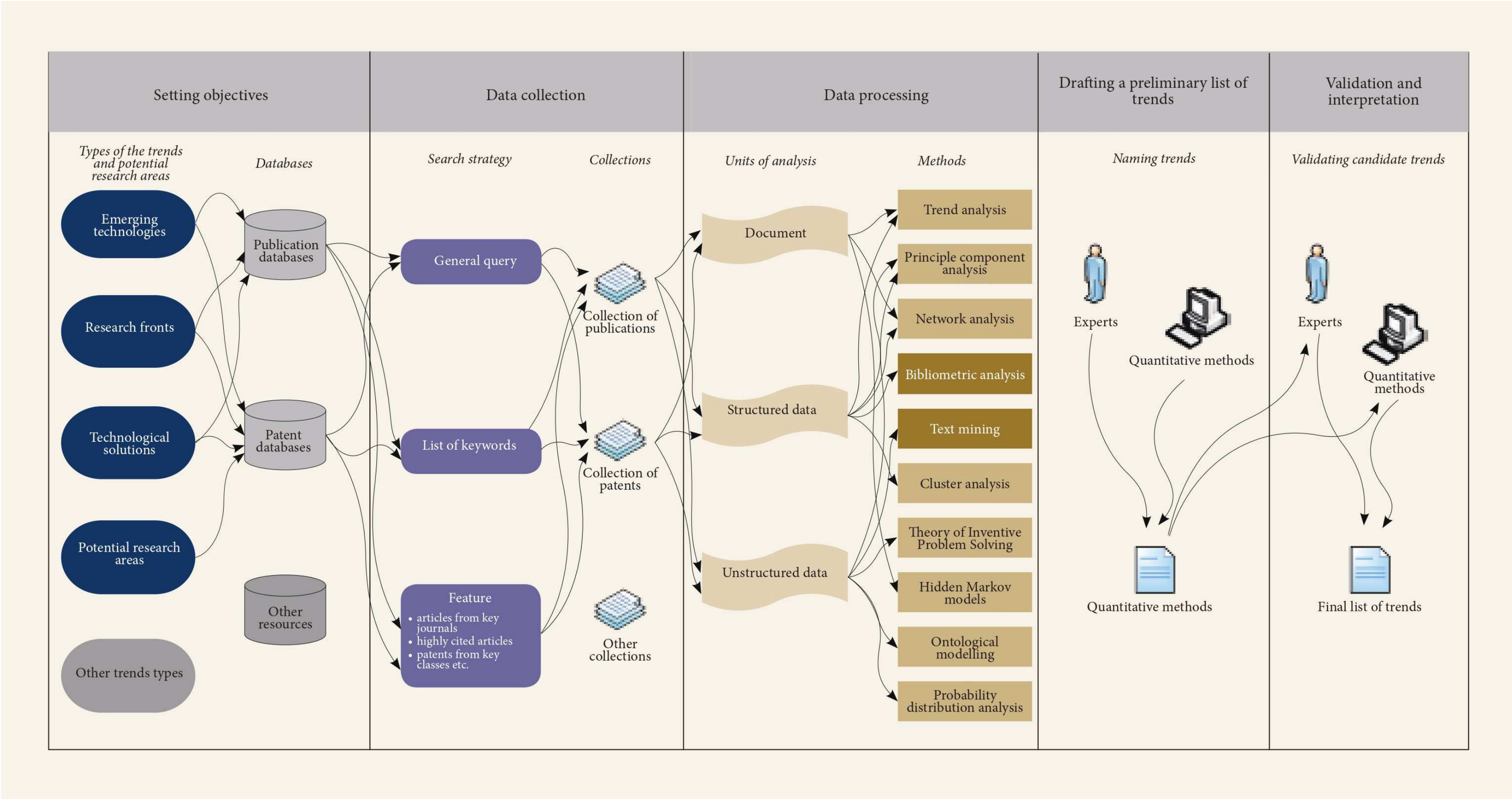
The selection of database is one of the most important stages of technology monitoring. The majority of authors give preference to bibliometric sources (either general e.g. Web of Science or Scopus; or specialised e.g. Medline, etc.) to monitor research fronts and emerging technologies or patent databases (e.g. the United States Patent and Trademark Office (USPTO), European Patent Office (EPO), Japan Patent Office (JPO) to search for information on technology solutions and applications in a particular subject area. Other data sources for technology monitoring might include: the news (Daim et al., 2006), business resources (in particular, the LexisNexis database) (Porter, Cunningham, 2005), and reports on activity by venture capital funds, start-ups, etc. (Cozzens et al., 2010)), conference materials (Porter and Cunningham, 2005) and others.

Collecting information from the sources selected is a separate task, solved by drawing up a list of keywords delineating the scope of the study. The specific tools used in the search include: one or more keywords combinations describing the subject field, a list of keywords selected on the basis of expert opinions (Lee et al., 2009; Morris et al., 2002) or from key documents (Kim et al., 2008), or combinations of these approaches (Kim et al., 2008; Porter and Cunningham, 2005). An alternative search strategy is to draw up a list of publications or patents based on a specific feature: articles from specialised journals (Cobo et al., 2011; Guo et al., 2011; Kajikawa et al., 2008; Kostoff et al., 2008), the most cited publications (Upham and Small, 2010), patents from corresponding IPC classes (Corrocher et al., 2003; Lee et al., 2011), patents in certain countries (Tseng et al., 2007), etc.

The data obtained forms collections[27] (of scientific publications, patents, etc.), which are then processed using certain qualitative or quantitative methods.

[27] A collection is an array of structured or unstructured data obtained from a specific source (database of publications, patents, news, dissertations, etc.).

Figure 3.3. Stages of technology trends monitoring



Source: compiled by authors.

3.3. Data processing methods

Data collections may be processed in one of three ways. The first involves taking a certain document as the unit of analysis and examining their quantitative dynamics within a set time interval (Campbell, 1983; Daim et al., 2006; Dereli and Durmusoglu, 2009; Lee et al., 2011) to assess publication activity in a specific subject area – a sufficiently narrow and potentially breakthrough direction. The second way is working with structured data from each text: the classification code determining which subject area the document falls under, keywords chosen by the author, citation statistics, etc. The third method uses unstructured information, i.e. analysing a full text after preliminary processing – removing duplicate documents, excluding stop words without individual meaning (prepositions, conjunctions, pronouns, etc.), stemming[28], etc.

The selection of the unit of analysis predetermines the methods that will be used during the technology monitoring. The main methods used to process the data under consideration involve citation analysis and text mining, which in many studies are combined with supporting methods such as network analysis, clusterisation, trend analysis and others. Figure 3.4 shows the methods used to identify technology trends. It goes without saying that their scope and the diverse ways in which they can be combined are not covered exhaustively in this diagram and can be supplemented by other methods, the use of which depends on the objectives set, the types of technology trends identified, and other factors.

Citation analysis as a bibliometric method is widely used to process structured data. The citation level of documents (publications, patents, etc.) can point to the emergence of research fields (fronts), opening up new directions for technological development (Chen, 2006; Igami and Saka, 2007; Kajikawa et al., 2008; Kim et al., 2008; Morris et al., 2002; Noma, 1984; Shibata et al., 2008; Upham and Small, 2010). In addition to citations when monitoring technology trends, structured data from bibliometric descriptions of documents can also be analysed: keywords (Cobo et al., 2011; Guo et al., 2011; Kim et al., 2008), the name of the organisation, author, title, and abstract (Morris et al., 2002), and classification category (Spasser, 1997), among others.

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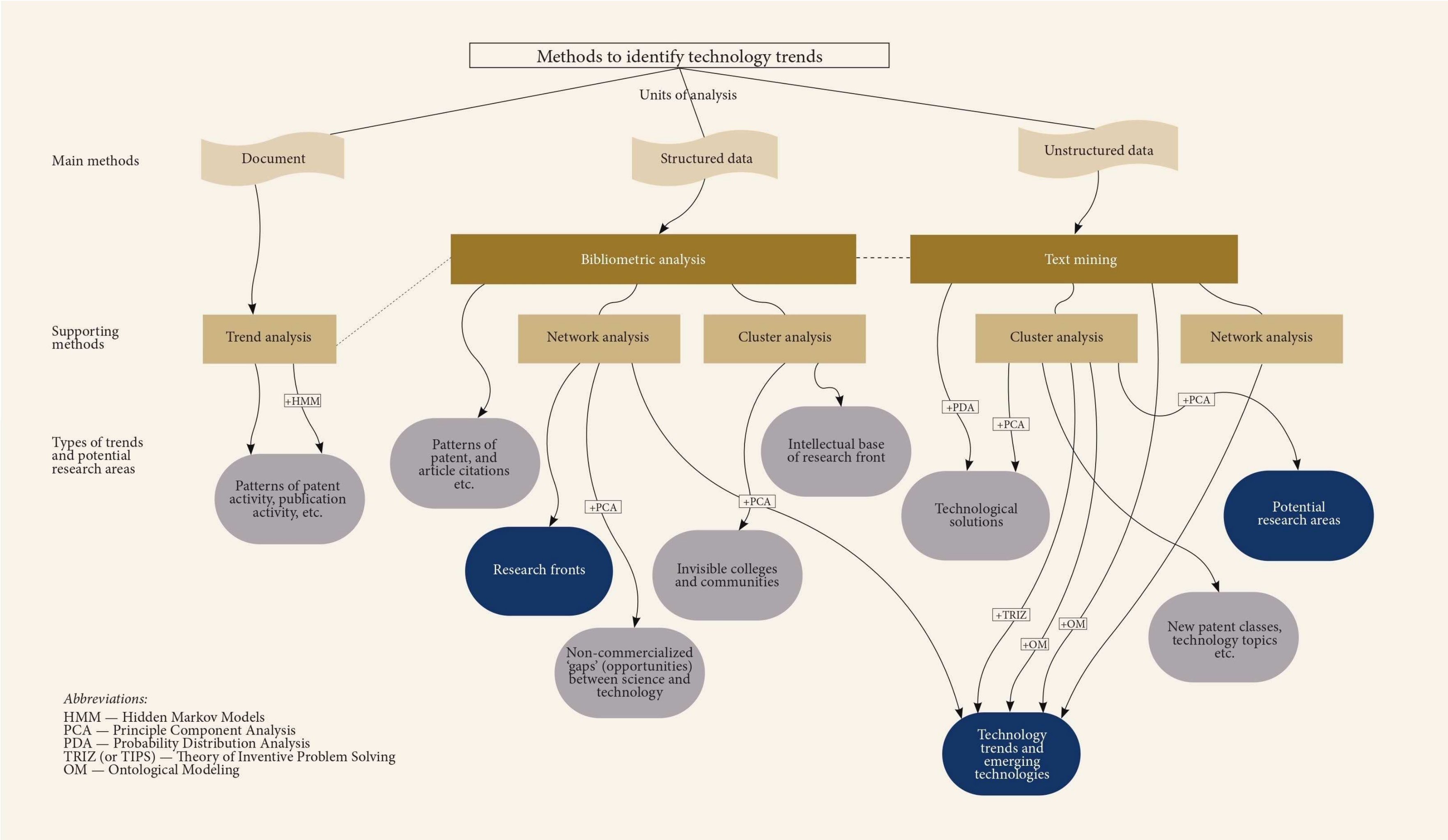
[28] Many words have the same lexical root but perform various syntactical functions, for instance computation and computing (Wang et al., 2010). During stemming, researchers look for the common lexical root of similar-sounding words for further normalization of a text.

Figure 3.4. Methods to identify technology trends



Source: compiled by authors.

One of the most widespread methods used to work with unstructured information is text mining[29]. Use of this method requires the structure of the document to be taken into account (Tseng et al., 2007) so that word combinations selected from the most relevant segments of the text can serve as data for clustering. Therefore, sentences or paragraphs in a text that include keywords, parts of headings or associated words selected by experts (for instance, goal, important, needed, problem, etc.) can have maximum weight. Some methods propose an analysis of keyphrase distribution throughout a text. Some authors work on the basis that keywords repeated throughout the entire document with a certain regularity can contain information on the nature of a technological problem in the subject field and can be used to search for solutions using linguistic analysis (Kim et al., 2009). The focus of the analysis might be the most (Corrocher et al., 2003; Lee et al., 2009) or least frequent but potentially significant word combinations (Li et al., 2009; Wang et al., 2010) to identify emerging technologies and promising research areas. Some works offer a mechanism to create automated annotations of documents (Trappey et al., 2006). For example, text mining of a patent generates a short abstract containing the most frequent keywords and parts of headings, phrases specific to the subject field, etc. In the future, this lexical material could serve to improve the speed and efficiency of patent analysis.

As mentioned above, text mining is based on large volumes of data. Many theoretical studies have been devoted to creating and using automated software to process data, including linguistic and statistical analysis and visualisation tools (for example: Chen, 2006; Dereli and Durmusoglu, 2009; Guo et al., 2011; Morris et al., 2002; Palomino et al., 2013; Porter and Cunningham, 2005). The faster information processing time significantly speeds up the sorting and filtering of data, analysis of trends and statistics, and the process of visualising results. During analysis, both online (Carrot, PAS and others) and offline software tools (Vantage Point (Porter and Cunningham, 2005), CiteSpace (Chen, 2006), DIVA (Morris et al., 2002), Sci (Guo et al., 2011), TextAnalyst (Wang et al., 2010), Arrowsmith (Smalheiser, 2001), PackMOLE (Fattori et al., 2003) and others) may be used. Many of the above tools have been developed by the authors themselves. Such applications, as a general rule, use information from electronic databases (publications, patents, news, etc.) and have a special user interface to make

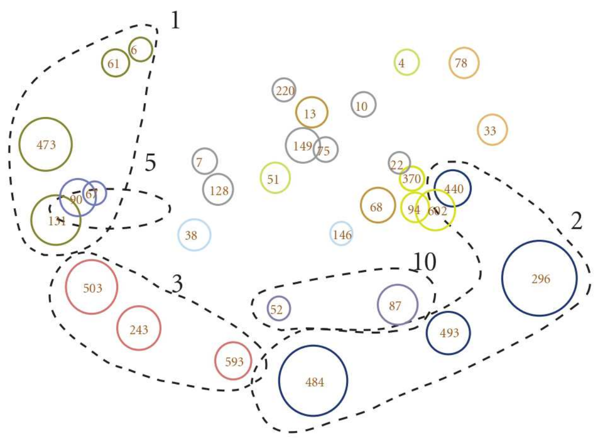
[29] The aim of text mining is to extract hidden, previously unknown meaning from a large volume of unstructured data (annotations and full-texts of documents, web content, etc.) As a complex approach, text mining is a combination of statistical and computational linguistic methods of data processing. It simplifies the technology data collection process by indexing the keywords encountered in the text of the documents and makes it easier to deal with these indexes afterwards (Yoon and Park, 2004).

queries, filter and visualise the results. Some programmes – Vantage Point, CiteSpace, DIVA – offer powerful data processing and visualisation tools in the form of tables, graphs, maps, clusters, etc.; others allow users to receive special alerts on changes in the developmental trajectory of technologies (for example, PAS notifies users of a marked increase in patent activity; and DIVA help users to generate integrated reports).

Specialised tools to group and visualise data on technology development play an important role in the processing of structured or unstructured information (Kim et al., 2008; Porter and Cunningham, 2005; Yoon and Park, 2004). Clusterisation or network analysis are often used for this purpose.

In the framework of technology monitoring, a clusterisation is used to separate the prepared data (documents, keywords, thematic areas, growth curves, etc.) into groups with similar characteristics reflecting the development of the most important technological directions in the subject field. Some of the most widespread clustering methods include the k-means (Kim et al., 2008; Trappey et al., 2006), hierarchical (Kostoff et al., 2008; Lee et al., 2011; Spasser, 1997) and topological (Kajikawa et al., 2008; Shibata et al., 2008; Shibata et al., 2010) clusterisation, and the k-nearest neighbours method (Tseng et al., 2007), among others. Figure 3.5 shows an example of data visualisation in the form of a cluster map serving as evidence of developing technological directions (clusters of a similar theme are highlighted in the same colour).

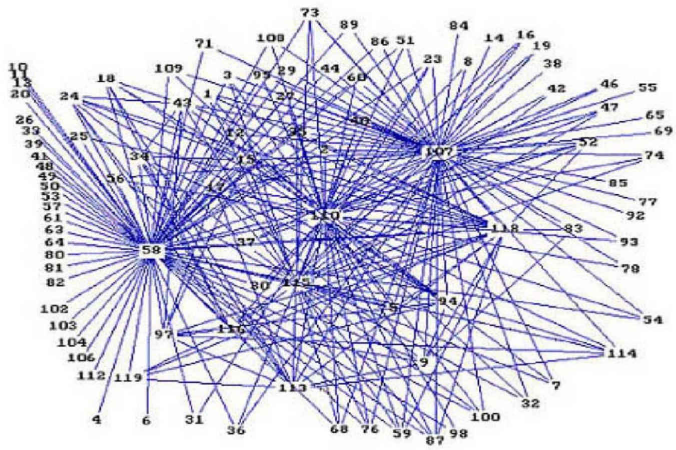
Figure 3.5. Example of a cluster map



Source: Tseng et al., 2007

In recent years, network analysis has generated serious interest, allowing researchers to identify, analyse and visualise the links at the heart of various processes. This quantitative method, based on graph theory, simplifies the analysis of the links between elements (nodes) of an emerging network. Documents, authors, thematic fields, countries, keywords, etc. can constitute nodes, as sources of information on emerging technology trends. When applied to technology monitoring tasks, network analysis is actively used to forge links between documents and create citation networks (Kajikawa et al., 2008; Shibata et al., 2008; Shibata et al., 2010; Small, 2006) and networks of semantically related keywords (Kim et al., 2008; Yoon and Park, 2004). Figure 3.6 gives an example of a constructed patent network based on semantic links between documents.

Figure 3.6. Example of a patent network



Source: Yoon and Park, 2004

Depending on the aims of the technology monitoring, basic processing methods for structured (bibliometric analysis) and unstructured (text mining) data can be combined, and they can be supplemented by supporting methods (Figure 3.4). The latter include network analysis, clusterisation, trend analysis, principle component analysis[30], probability distribution method[31], ontological modelling[32], the theory of inventive problem solving[33] (TRIZ or TIPS), and others. Varying combinations of these methods make it possible to identify different types of trends (emerging technologies, research fronts, invisible colleges, potential research areas, citation patterns, etc.) and expand the range of information sources, relying not only on

[30] The principle component analysis is most often used to supplement text mining, for example, to identify key factors (components) on a keywords map (Lee et al., 2009; Porter and Cunningham, 2005). It can be used in combination with citation analysis when forming citation networks (Chen, 2006; Kajikawa et al., 2008; Shibata et al., 2008), for which documents that do not have either incoming or outgoing citation links are removed from the network.
[31] An analysis of probability distributions can be used to identify keywords combinations that are encountered in documents with equal frequency i.e. they describe a certain important problem that various authors are working on in that particular technology field (Kim et al., 2009).
[32] In this approach, an ontological model of a trend is established, which is then used to analyse segments of a text containing external signs of the existence of a trend.
[33] TRIZ (or TIPS) can be used in combination with text mining to identify the maturity (or life cycle stage) of a given technology examined by comparing its characteristics with universal evolutionary patterns.

databases of scientific publications and patents but also on additional sources such as the news, information business resources, conference materials, etc.

4. Conclusion

Our review in this paper of the theory and practice of global technology trends monitoring shows that in a large number of studies carried out in this field different definitions and variations on this notion are used, with an emphasis on the most important effects of developing trends, life cycle stage, the scale of the trends and ways to identify them. However, the majority of authors predominantly show an interest in identifying, at the earliest possible stage, prospective technological fields with significant social and economic impacts and high potential for commercialisation.

Theoretical studies and applied projects on technology trends monitoring are carried out at different levels – global, national, industry and corporate. Interest in the results of these studies comes from international organisations, government bodies, business, research institutes and other structures involved in the process of developing and using long-term forecasts and shaping policy based on their recommendations.

Theoretical studies are focused on developing a substantiated methodology to identify emerging technologies (they also define the necessary criteria for this) and developing automated methods and software to process large volumes of data and visualise the results obtained, a critically important stage of the entire process.

Technology trends monitoring involves several stages (setting objectives, data collection, data processing, drafting a preliminary list of trends, interpreting results). The precise nature of these steps depends on the research objectives and the chosen trend type, sources of information, search strategy, units of analysis and methods used for further processing and validation. Alongside traditional sources of data for technology monitoring – scientific publications and patents – researchers often turn to news, business resources, conference materials, etc. The main methods tend to be text mining and bibliometric analysis at the data processing stage and cluster and network analysis at the data structuring and visualisation stage. In the majority of cases, they are combined with other supporting methods (principle component analysis, trend analysis, ontological modelling, etc.).

The combination of technology monitoring theories and practices aims to introduce a wider use of quantitative methods and automated procedures during large-scale applied projects, which, at present, are predominantly carried out on the basis of expert knowledge. The complexity of this task is caused by the highly resource-intensive nature of automated approaches when spread across the entire spectrum of technological fields. The expansion and increasing sophistication of software tools will make it possible to diversify the range of information sources used and, ultimately, increase the evidence base and effectiveness of technology trends monitoring.

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Chapter 4. Comparing data sources for identifying technology trends[34]

Abstract

This paper considers the strategies for working with different data sources for identifying technology trends. For this purpose, a comparative analysis of technology monitoring results using various data collections (scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations) is conducted. Guidance on how to use them to ensure the greatest output (the maximum number of trends retrieved from a specific information source) is presented. Green energy is taken as an example for comparative analysis and provides improvements in reducing inputs (time) and increasing output (coverage). The factors that affect data processing results are considered and discussed to more efficiently use quantitative and qualitative procedures for identifying, correcting and updating technology trends. The results of the study can be interesting for government bodies financing foresight studies and setting priorities in science and technology, for companies scanning disruptive innovations in the markets to support their corporate strategies and academic community developing the methodology for technology trends monitoring.

1. Introduction

Earlier identification and regular monitoring of technology trends, which have a key impact on social and economic development in the long term, provide stakeholders of different levels (global, national, corporate) with a distinct advantage for reacting quickly to technological changes and making strategic decisions in a timely manner. The timeliness and accuracy of technology monitoring depends on the right choice of a research methodology and data sources. Theoretical studies on technology monitoring are mainly based on the combination of qualitative and quantitative methods that complement each other. Along with extensive use of expert procedures, automated and semi-automated methods for extracting technology trends are increasingly being developed and becoming more important as evidence-based practice. A broad range of information sources can be used for processing such quantitative data: scientific publications, patents, media, business resources and others.

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In academic works that aim to discover technology trends, the most widely used data sources are scientific publications (e.g. Chen, 2006; Cobo et al., 2011; Daim et al., 2006; Guo et al., 2011; Kajikawa et al., 2008; Upham and Small, 2010) and patents (e.g. Daim et al. 2006; Lee et al., 2011; Trappey et al., 2006; Tseng et al., 2007; Wang et al., 2010; Yoon and Park, 2004). Some of these studies propose the general methodology for monitoring emerging technologies[35], research fronts[36], "white spots" and potential research areas[37]. The others discuss the advantages and disadvantages of using various methods and techniques for technology monitoring. In addition, a number of works apply the data visualisation methods, such as technology maps and technology networks, and develop and utilise the program software for data processing (e.g. Vantage Point, CiteSpace, Science of Science). Although many authors tend to choose one key information source – either scientific publications or patents – while processing data on technology trends, there have also been attempts to use a combination of them. For instance, Shibata et al. (2010) compare the structure of citation networks of publications and patents in order to discover the differences between the two and identify non-commercialised gaps between science (publications) and technology (patents).

The possibilities of using other information sources for identifying technology trends have also been discussed in the literature. For example, much useful data can be found in additional sources: specialised conferences (Porter and Cunningham, 2005); newspapers and social media (Farber, 2016; Krzywicki, et al. 2016); business-related resources, such as Lexis-Nexis (Porter and Cunningham, 2005); statistics on venture capital funds and start-ups (Cozzens et al., 2010); technical reports and "grey" literature (Porter and Cunningham, 2005) and others. Chen et al. (2012) study the evolution of data types used in business intelligence and analytics (BI&A). They distinguish three generations of BI&A: BI&A 1.0 – uses structured business-based commercial data, BI&A 2.0 – is based on unstructured web-based content, such as forums, online groups, web blogs, social networking sites, social multimedia sites (for photos and videos), and even virtual worlds and social games (O'Reilly, 2005); and BI&A 3.0 – employs mobile and sensor-based content: large- scale and fluid mobile and sensor data. In addition, specific data sources can be used for BI&A in science and technology (S&T): e.g. S&T instruments and system-generated data, sensor and network content. Jordan

[35] Emerging technologies: (a) result from contemporary advances in a given field of knowledge; (b) are rapidly evolving; and (c) have high potential to result in inventions and innovations with significant societal and economic impacts (Gokhberg et al., 2013).
[36] Research fronts represent the most dynamic areas of S&T and the areas that attract the most scientific interest.
[37] Potential research areas can be identified as patent "vacancies", which are created by the blank areas in the patent maps (Lee et al., 2009).

and Mitchel (2015) discuss the machine learning methods that have been developed for capturing and mining large quantities of data from the following sources: medical records, traffic data, crime data, large experimental data sets, etc. Segev et al. (2015) suggest the method for analysing technology trends through investigation their development over time, based on different information sources. They retrieve the trends not only from patents and academic articles, but also from web searches, news articles, book publications, and compare them with Gartner technology predictions. The research results show, that more research-oriented data sources such as academic articles and patents have a longer predictive time window and higher accuracy than news, books and web searches.

Nevertheless, investigation of the comparative efficiency of different data sources and the specificity of how they are selected is limited in the literature. Martino (2003) is one of the examples of such research, in which the author studies the differences in emphasis contained in technology trends based on the stage of their life cycle. According to this criterion, the data sources are divided into five categories (see Table 4.1).

Table 4.1. Choosing data sources based on the technology life-cycle stage

R&D stage	Typical source
Basic research	Basic research Science Citation Index
Applied research	Applied research Engineering Index (Compendex)
Development	Development USPTO patents database
Application	Application Newspapers Abstracts Daily
Social impact	Social impacts Business and popular press

Source: Martino, 2003.

Nevertheless, a technology life-cycle stage is not the one factor defining the ways of employing diverse information sources. The selection of them depends also on the purpose of a study, its methodology, available resources and other parameters of the project. In addition, this choice can be determined by what is understood as "a technology trend". Different authors propose various interpretations of this term and use other notions associated with it (Mikova and Sokolova, 2014). These concepts can differ depending on their expected effects (e.g. disruptive innovations, game-changers, emerging technologies, key enabling technologies, technology applications), the life-cycle stage (e.g. emerging technologies, technological applications and products), the scale (e.g. mega trends, micro trends). In addition, technology trends can differ in the way how they are identified. For example, research fronts are defined as clusters of documents detected on the basis of co-citation analysis (Upham and Small, 2010). The present study considers technology trends in more general terms, such as topical, cutting-edge and quickly developing technology areas that can significantly affect the development of the economy and society in the long term.

Therefore, taking into account the fundamental impact of the choice of data sources on technology monitoring outputs and significant underdevelopment of this issue in the scientific literature, the purpose of this paper is to conduct the exploratory study of the strategies for working with different information sources for technology trends monitoring, as well as of the factors that should be taken into account when choosing them.

The main research question is:

What strategies can be used for working with various data sources (publications, patents, media, foresight projects, conferences, international projects, dissertations, presentations) for technology monitoring in green energy area?

According to the integrated approach of UNDP (2016), the green (renewable) energy lies at the intersection of several development areas, such as achievement of climate targets, reduction of disaster risks associated with rising temperatures and better recovery from the disaster events. Green energy technologies contribute to a zero-carbon, risk-informed and sustainable development (UNDP, 2016). Selection of green energy as an example for comparing information sources has several advantages. First, green energy area has links with many disciplines and adjacent technologies, which can be also interesting to analyse. Second, based on this, the results largely depend on the correct strategy for extracting trends and this area gives more opportunities for exploring diverse search strategies. Third, the interest in green energy area is also caused by the difference in keywords used in various data sources, which enables one to further discuss the influence of the terminology on the choice of information sources and thus on technology monitoring results.

The paper is organised as follows. At first, the theoretical background of the specificity of different information sources in terms of their usage and possible data search strategies is provided. Next, the methodological approach is described. Subsequently, the case study of green energy is presented. Finally, the paper discusses the results and draws a conclusion.

2. Theoretical background: choosing information sources, collecting and processing data

The right choice of data sources for identifying technology trends has a crucial influence on the final outcome. One of the criteria for this selection is the goal and the tasks of the project. Table 4.2 illustrates the examples of correspondence between the information sources, the possible databases and the research tasks, which were identified based on review of scientific literature (Cozzens et al., 2010; Ena et al., 2016; Kostoff et al., 2008; Porter and Cunningham, 2005).

Another important issue is how to work with these information sources: how to select a database and what methods to use for collecting and processing data. While choosing a database, it may be necessary to account for its characteristics as a whole, ensuring that it meets a set of minimum standards in line with information objectives. Considerations may include suitability and comprehensiveness of coverage, biases, content quality, record structure and keywords availability (Porter and Cunningham, 2005).

When the database is identified, the important task is to form a search strategy and choose the methods for collecting data. Different options may be applied for this purpose. These can be *a broad query* that describes the subject area in general (for example, “green energy” or “sustainable energy”); *a list of keywords* (anything from one phrase to combinations of 30-50 keywords in order to describe the subject area in a complete manner) selected by experts (Lee et al., 2009; Morris et al., 2002); *the keywords from the most important documents* (Kim et al., 2008); or *a combination of these methods* (Kim et al., 2008; Porter and Cunningham, 2005). An alternative search strategy is to compile a set of documents based on *a nominal query*, such as articles from specialised journals (Cobo et al., 2011; Guo et al., 2011; Kajikawa et al., 2008; Kostoff et al., 2008), the most highly cited publications (Upham and Small, 2010), patents from specific classes of the International Patent Classification (Corrocher et al., 2003; Lee et al., 2011) or patents sponsored by a particular government agency (Tseng et al., 2007). The advantages and disadvantages of these search strategies are briefly summarised in Table 4.3.

Table 4.2. Possible databases and research tasks for using different information sources

Sources	Possible databases	Possible tasks
Scientific publications	*Interdisciplinary:* • Web of science • Scopus • EI Compendex and INSPEC • Pascal • ResearchIndex, etc. *Specific:* • PubMed (MEDLINE) • Chem abstracts • Biological abstracts, etc.	• to study the dynamics of S&T development and growth of scientific interest in certain areas • to track research fronts and emerging technologies • to define "white spots" that are not yet developed but are potentially significant • to analyse leading countries and research groups engaged in S&T research • to identify exciting research activity and profile research and development (R&D) activity across a specific region to look for potential collaborators
Patents	• Questel-Orbit • Derwent World Patents Index • MicroPatent • Delphion • WIPS • Patbase • PatenCafe.com • IFI CLAIMS, etc.	• to search for information on technology problems and solutions in a subject area • to track the evolution of technology development in a specific area • to analyse leading countries, research groups and companies engaged in S&T research • to identify exciting research activity and profile R&D activity across a specific region to look for potential collaborators • to find information about technology applications and technology products developed in a specific area
Media	• Factiva • LexisNexis • Internet Securities, etc.	• to understand technology supply and demand dynamics in a wide variety of socio-economic areas • to monitor highly discussed topics in S&T areas (news from business sites, news channels, etc.) • to track public interests in general through newspaper article compilations • to find information about social acceptance of technologies and possible barriers for their development
Foresight projects	• European Foresight Monitoring Network (EFMN)	• to detect technology trends and priorities in different areas • to identify and analyse key emerging issues relevant for the future of S&T development

		• to analyse leading countries and research groups engaged in S&T research • to detect the main institutions sponsoring the future research around the world
Conferences	• Conference websites	• to identify key technology areas, which are of a great interest from representatives in specific areas of knowledge (scientists, business companies and others) • to assess dynamics and prospects for the implementation of novel technologies • to track research fronts and emerging technologies • to identify leading conferences on particular topics and highly active researchers to seek out • to analyse leading countries and research groups engaged in S&T research
International projects	• CORDIS Europe • European Framework Programs (FP) for Research and Technological Development, etc.	• to monitor political incentives and priorities in specific technology areas • to evaluate demand side and markets, S&T performance of different countries • to analyse possibilities for future cooperation in S&T areas • to detect the main institutions sponsoring the future research around the world • to track research funding emphases and research participation patterns
Dissertations	• ProQuest • EBSCO's Open Dissertations database • PQDT Open • EThOS, etc.	• to study the dynamics of S&T development and growth of scientific interest in certain areas • to track research fronts and emerging technologies • to analyse the state of art in a specific area • to count the number of scientists engaged in R&D • to identify leading research groups and relationships between them
Presentations	• SlideShare • Scribd, etc.	• to study the dynamics of S&T development and growth of scientific interest in certain areas • to identify key technology areas, which are of a great interest from representatives in specific areas of knowledge (scientists, business companies, etc.) • to collect the concentrated information about new innovation ideas, technologies and their applications • to detect individuals and research organisations who share their ideas, conduct research, connect with each other and generate decisions for their businesses

Sources: Cozzens et al., 2010; Ena et al., 2016; Kostoff et al., 2008; Porter and Cunningham, 2005.

Table 4.3. Advantages and disadvantages of possible search strategies

Possible search strategies	Advantages	Disadvantages
A broad query	(+) may save time at the stage of collecting data from the database (+) may be useful for the clearly defined areas (+) allows to capture many articles across multiple disciplines or fields (transfer of ideas)	(–) may retrieve too many documents (–) may provide less precision and risk to extract more results that are not pertinent to the subject of the analysis (more time needed to clean the data afterwards)
A list of keywords	(+) is more narrow query capturing fewer articles of a more specific nature (+) requires the use of the expert knowledge to create a list of keywords, which is an additional validation of them	(–) may not take into account all the synonyms (–) may require more deep involvement of experts, which increase time and the costs of getting information
The keywords from the most important documents	(+) represents the scope of research confirmed by the authors or the database administrators (+) may save time and reduce dependence on the experts during creating the data collection	(–) may not take into account the adjacent documents (from the other disciplines) (–) is limited to the analysis of only main documents, while important seeds of innovation from other documents may be neglected
A nominal query (e.g. articles from specialised journals, patents from specific classes, etc.)	(+) can be particularly important for competitive technological intelligence (+) saves time for creating “the right query” in order to determine the scope of the area more precisely (specific topics of investigation, specific countries, specific authors, etc.)	(–) requires compiling an initial list of specialised journals or patent classes for collecting data (–) narrows the search to the concrete topics, patent classes, etc., and therefore may not include the important documents from the other related areas (–) may not account for the problem of ambiguities of attribution of the documents (publications, patents, etc.) to different classes and possible classification errors
The most highly cited documents	(+) represents the “hot research topics” in a specific area (+) may be valuable in competitive technological intelligence, where it is important to determine the experts in a field through citation analysis	(–) requires citation information, which is presented in only few databases (–) may cause ‘the Matthew effect’, when the papers already cited become easier to find and more attractive to scientists looking for key references, and as a result ‘the rich get richer’ (–) requires suitable normalisation and expert review during citation comparisons among separated research communities

Source: based on Porter and Cunningham (2005).

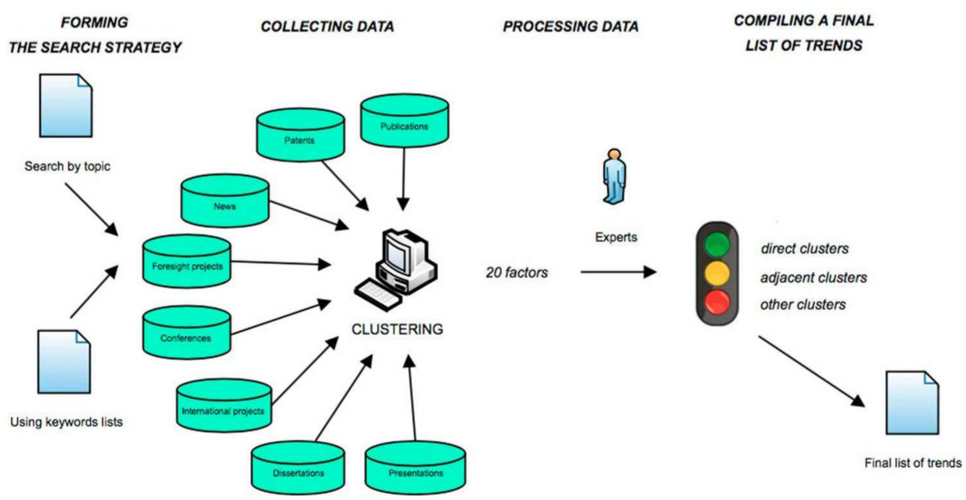
In the first two search strategies, a query can be applied to different data fields: title, abstract, keywords or full text. Each possibility has pros and cons. *Title* usually represents the compact information about the documents' content and often includes the main keywords, but some names of the documents serve more to attract the reader's attention and not precisely reflect the content. In *abstract* the authors describe essential ideas of work briefly and clearly, trying to incorporate the key terms. But at the same time, for example, patent applicants may not want to communicate their intents fully and directly (Porter and Cunningham, 2005). *Keywords* represent the concentrated and specific information about the documents' content, but usually are limited to the specific number of phrases, which may be not enough to fully describe a document. Full text gives more detailed and complete information about the content, but such "unstructured" materials may include a lot of noise and require more time and technical capabilities to process (Porter and Cunningham, 2005). Therefore, the final choice of the data fields depends on the project task, the methodology, the subject area, the information sources and other parameters.

During technology trends monitoring scientists may deal with both ***structured*** and ***unstructured data***. The most well-known methods for processing structured data are *bibliometric* and *patent analysis*, while *text mining* is a popular technique for handling huge amounts of unstructured textual documents. A number of theoretical works have been devoted to development and usage of automated software for processing unstructured data, including linguistic and statistical methods and visualisation tools (Chen, 2006; Dereli and Durmusoglu, 2009; Guo et al., 2011; Morris et al., 2002; Palomino et al., 2013; Porter and Cunningham, 2005). These programs may work online (e.g. Carrot, PAS) or offline (e.g. Vantage Point (Porter and Cunningham, 2005), CiteSpace (Chen, 2006), DIVA (Morris et al., 2002), Science of Science (Guo et al., 2011), TextAnalyst (Wang et al., 2010), Arrowsmith (Smalheiser, 2001), PackMOLE (Fattori et al., 2003)). As a rule, they use data from electronic databases (publications, patents, news, etc.) and have a special user interface for query creation, data filtration and visualisation. *Network analysis* and *cluster analysis* are frequently used in text mining. Network analysis is based on the graph theory and allows to detect, analyse and visualise relationships between the objects (documents, authors, thematic areas, countries, keywords, etc.). Clustering is applied to divide the prepared data into groups with similar characteristics. The most popular methods include: k-means (Kim et al., 2008; Trappey et al., 2006), hierarchical (Kostoff et al., 2008; Lee et al., 2011) and topological clustering (Kajikawa et al., 2008; Shibata et al., 2010), k-nearest neighbours algorithm (Tseng et al., 2007) and others.

3. Methodology

In this study comparative analysis of eight data sources (scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations) was started with extracting potential trends from each of them independently, using the same methodological approach (see Figure 4.1). After that these quantitative results were validated through the workshop with the experts from foresight and energy area in order to compile the final list of trends.

Figure 4.1. Research methodology



The methodology includes four stages:

- **Stage 1**. Forming the search strategy
- **Stage 2**. Collecting data for identifying technology trends
- **Stage 3**. Processing data
- **Stage 4**. Compiling a final list of trends

At the first stage, two main methods were chosen for collecting data about technology trends: *search by topic* and *using the keywords provided by experts*. These methods are combined in order to increase the consistency of collections. First, the main topics for data searching were selected (they differ in the various databases: "sustainable energy", "renewable energy", "alternative energy sources", etc.). Second, specific keywords were used for creating the sets of documents found in these chosen areas. A list of 30 keywords was created for the green energy area in consultation with experts. The experts from foresight and energy area were asked to compile the list of keywords, which outline the main scope of green energy area and include all important subareas. For example, this list includes such keywords as "wind energy", "solar energy", "biofuels", "geothermal energy" and others. The patent search was performed using *the specific patent classes*, which were preliminarily discussed with these experts, since due to more technical character of patent data, using the same list of keywords as for the other resources (publications, dissertations, etc.) did not help collect the relevant documents. In order to increase the technology monitoring efficiency, different ways of data collecting can be explored in detail at the next stages of the research.

At the second stage, eight data collections were compiled based on a combined search strategy described above. Table 4.4 shows the aggregated information: data sources, the number of documents and data fields being processed. Eight collections of English-language documents covering the period of the last 10 years were generated. The data field "keywords", which represents the concentrated information about the documents' content, was used as a priority field for processing data (scientific publications, dissertations). If it was not available in a database, the data fields "abstract" (for patents) and "title" (for media) were applied. To provide the same level of analysis, the field "claim" was not used for patents, since it contains the specification of the document in too technical terms. In the case of dealing with unstructured data (foresight projects, conferences and international projects) processing the full texts was the only option.

At this stage a total of 35 986 documents in different formats (*.txt, *.html, *.doc, *.pdf, *.ppt) were collected. The collections, including semi-structured data (title, abstract, keywords), were ready for uploading into Vantage Point software[38] using specialised import filters (for Web of Science, Questel-Orbit, Factiva). The collections with unstructured data (full texts) were preliminary converted into *.smart XML format for further processing.

Table 4.4. Aggregated data on the collections

Collections	Data sources	Number of documents	Data field for processing
Scientific publications	Web of Science	6222	Keywords
Patents	Questel-Orbit	7775	Abstract
Media	Factiva	21502	Title
Foresight projects	EFMN	40	Text
Conferences	Official websites	19	Texts
International projects	CORDIS Europe	129	Text
Dissertations	ProQuest	199	Keywords
Presentations	SlideShare	100	Text

[38] Since the research implies working with both structured and unstructured data, there was a need for a powerful software, which combines bibliometric techniques and text mining tools and offers the visualising possibilities. Vantage Point was chosen for this purpose, since it is designed to accept virtually any structured text content, supports for over 190 different import filters, has industry leading data manipulation capability and contains mapping and visualisation tools to help analyse complex relationships (Search Technology, 2016).

At the third stage, eight collections were processed in Vantage Point and the factor maps for each collection were created and analysed. To compare the results of dividing collections using different numbers of factors (clusters), the data from each collection were clustered into 5, 10, 15 and 20 factors. After the analysis of these clusters it was concluded that the data obtained by dividing into 20 factors is a subset for the data received by using 5, 10 and 15 factors. That is why the number of 20 clusters was chosen for further analysis.

At the fourth stage, the final list of technology trends was created. First, the analysis of 20 clusters for each collection was performed. During the expert workshop, the experts from foresight and energy area were asked to select the relevant technology trends from these clusters. A preliminary analysis of clusters was done to understand the core idea of them, based on studying their contributing keywords. When the lists of 20 clusters were created for each collection, the experts were asked to divide them into three groups: *direct clusters* (directly related to the subject area), *adjacent clusters* (indirectly related to the subject area) and *other clusters* (related to other areas), and the final list of technology trends was compiled on this basis. Using quantitative data obtained from analysis of different information sources for further expert analysis provided cross-validation of the results, since the experts' role was to validate the obtained clusters and choose the relevant ones, which represent technology mainstreams in the green energy area.

4. Results

The results for each data collection, obtained from division of 20 clusters into three cluster types, are presented in Table 4.5.

Table 4.5 shows that the highest number of direct clusters (related to green energy) belongs to the following sources: scientific publications, patents, media and conferences. The number of direct clusters represents the quality of a data collection and of a chosen search strategy (the higher the number of direct clusters, the more efficient is the data collection). The high number of adjacent clusters can serve as both an advantage and disadvantage of using a specific collection, which depends on the project goal, as they can be of a great interest for understanding the technology development in the border areas. The high number of other clusters indicates that a search strategy was too broad and not effective for a specific data collection. At the same time other clusters can provide additional relevant information, which is analysed at the end of this section.

Table 4.5. Aggregated data on the selected clusters

Collections	Direct clusters	Adjacent clusters	Other clusters
Scientific publications	10	5	5
Patents	8	6	6
Media	7	4	9
Foresight projects	4	1	15
Conferences	7	5	8
International projects	4	5	11
Dissertations	5	4	11
Presentations	6	2	12

Table 4.6 includes additional information about how the direct clusters are represented in the final list of trends. The names of the final (linked) trends were formulated in the following way. After automated data processing, the keywords for each cluster were retrieved from Vantage Point and then analysed and discussed with experts in order to correctly name the trends. In addition, Table 4.6 shows the names of the extracted trends for each collection, where the same trends from different collections are marked with the same sign (*, **, ***, etc.). For some collections the number of the linked trends is lower than the number of direct clusters, because not all direct clusters were validated and included into the final list of trends.

Through the procedures described above the lists of 20 trends obtained for each collection were studied. The analysis showed that the following topics are the best represented in the results of processing all eight collections: solar energy (especially the trend "Solar cells"), bioenergy (the trends "Biogas production", "Biodiesel production", "Bioethanol production"), hydrogen energy (the trend "Hydrogen storage"), hydropower (the trend "Large hydropower stations") and energy storage (the trend "Electrochemical cells"). Besides there are some trends that are extracted from only one particular collection (e.g. "Off-shore wind farms", "Geothermal power stations", "Hot dry rock geothermal power stations", "Pumped-storage power plants", "Molten carbonate fuel cells (MCFC)"). From this it can be concluded that using several collections could be more efficient than employing only one of them, since in the first case, technology monitoring covers a wide range of sources and information platforms where data on technology development could be represented.

Table 4.6. Aggregated data on the clusters and trends

Collections	Direct clusters (number)	Linked trends (number)	Linked trends (names)
Scientific publications	10	9	Solar thermal power stations* On-shore wind farms** Geothermal heat pumps*** Electrochemical cells**** Proton exchange membrane fuel cells (PEMFC)***** Solid oxide fuel cells (SOFC)****** Molten carbonate fuel cells (MCFC) Electrolysis of water******* Hydrogen storage
Patents	8	8	Solar cells# Solar thermal power stations* Off-shore wind farms Biodiesel production## Large hydropower stations### Geothermal heat pumps*** Solid oxide fuel cells (SOFC)****** Electrolysis of water*******
Media	7	5	Solar thermal collectors+ On-shore wind farms** Bioethanol production++ Small hydropower stations+++ Hydrogen storage++++
Foresight projects	4	4	Solar cells# Biogas production§ Bioethanol production++ Hydrogen storage++++
Conferences	7	6	Solar cells# On-shore wind farms** Large hydropower stations### Small hydropower stations+++ Geothermal power stations Hot dry rock geothermal power stations
International projects	4	4	Solar cells# Biogas production§ Biodiesel production## Bioethanol production++
Dissertations	5	5	Solar cells# Biogas production§ Electrochemical cells**** Proton exchange membrane fuel cells (PEMFC)***** Hydrogen storage++++
Presentations	6	5	Solar thermal collectors+ Bioethanol production++ Large hydropower stations### Electrochemical cells**** Pumped-storage power plants

The analysis of the other clusters shows that they can be divided into the following groups:

- *(1) Technical devices, technologies and models*

This group includes smaller-scale technology applications (at the level of sub-trends), specific technologies and models from green energy and adjacent fields, which can be used to study the process of energy transformation in different systems. Examples include the transmission electron microscope, self-propagating high-temperature synthesis and others. Clusters from this group are most widely represented in collections “Scientific publications”, “Patents” and “Dissertations”.

- *(2) Green energy related technology areas from the wider energy field (energy efficiency and energy saving), as well as the other related areas (such as the rational use of nature, nanotechnology and transport systems)*

The fact that the list includes not only the clusters from green energy and the wider energy area, but also the clusters from related disciplines, can point to the strong links between different technology fields. Examples of areas that are developing between adjacent disciplines include: interactive mapping technologies for connecting manufacturers and potential consumers of organic waste in order to produce biogas (green energy and the rational use of nature), using of environmentally-friendly heavy-duty plastics (green energy and nanotechnology) and others. The clusters from adjacent areas occur most frequently in the collections “Media”, “Conferences”, “International projects”, “Dissertations” and “Presentations”.

- *(3) Social, economic and political challenges*

This group includes clusters that involve information about the global problems (social, economic, political, etc.) that can be addressed by the technology solutions from green energy area and related fields. The examples of such trends include: the need to make life in the city more comfortable by using green technology, improving green energy education and making it more accessible in different regions of the world. Socio-economic clusters are detected in the collections “Foresight projects”, “International projects” and “Presentations”.

- *(4) Irrelevant clusters*

When analysing the list of clusters across all collections, a small number of clusters (around 2.5%), which are neither directly nor indirectly related to green energy, were discovered. Examples of irrelevant clusters include: the increased attention to weight loss and low-calorie foods (such as green tea); development of the ways for diagnosing and treating Alzheimer’s disease and others. Such clusters were discovered while processing the collections “Scientific publications”, “Patents” and “Media”.

Therefore, the information retrieved from the clusters, which were not included in the final trends list, is very useful. First, one can apply it for analysis of the specificity of different collections. Second, it may help identify the ground for selecting the best information sources. Finally, it can be used for further improvement of the methodology for monitoring and updating technology trends.

5. Discussion

Considering the case of green energy in detail, the possibilities and limitations of using different data collections and the lessons learned are discussed below.

The collection “*Scientific publications*” includes the greatest number of “contributing” trends (with a value added to the final list of trends) in comparison with the other collections. Such trends are: “Molten carbonate fuel cells (MCFC)”, “Solar thermal power stations”, “On-shore wind farms”, “Geothermal heat pumps”, “Proton exchange membrane fuel cells (PEMFC)”, “Solid oxide fuel cells (SOFC)” and “Electrolysis of water”. One should take into account the fact that in publications some emerging areas will obviously be the beginnings of the new scientific fields, not the new technologies. In order to use the possibilities of this collection more efficiently, a list of “more technological” terms could be used.

The collection “*Patents*” is the second leader in “contributing” trends, which are the following: “Offshore wind farms”, “Solar thermal power stations”, “Geothermal heat pumps”, “Solid oxide fuel cells (SOFC)” and “Electrolysis of water”. In general, patents can give detailed information on specific technical devices, technologies and models (sub-trends) in the subject area. At the same time, working with this collection, one should pay attention to a specificity of patenting in different disciplines and carefully choose the patent classes for collecting information, for example, with the help of experts.

The collection “*Conferences*” can also be considered as a collection with a great added value. It includes information about the following “contributing” trends: “Geothermal power stations”, “Hot dry rock geothermal power stations” and “Small hydropower stations”. In order to improve the results, one could refer to an expert opinion on a preliminary selection of the key conferences. In addition, as data about conferences is mostly unstructured (*.html, *.doc, *.pdf, *.ppt), the databases of conferences with more structured information could be explored.

A number of “contributing” trends are also presented in the collections “Media”, (“Small hydropower stations”), “Dissertations”, (“Proton exchange membrane fuel cells (PEMFC)"), "Presentations" ("Pumped-storage power plants"). In order to increase the efficiency of technology monitoring using these collections, one should be aware that the collection "Media" helps examine sources written by outside observers, analysts or journalists, and may reflect the relationships between technology trends and socio-economic impacts. That is why the keyword list for this collection could include some less technical, but more "trendy" terms like "sustainable energy", "environmentally friendly energy production" and others. At the same time, the terms for creating the collection "Dissertations" could be much more technical.

The collection *"Presentations"*, which could act as an additional business- and technology-oriented data source, includes the concentrated information about specific technologies, technology applications and innovative ideas, since the duration of a presentation is usually limited. However, while dealing with this source, one should take into account that some important data may be represented in pictures and graphs. Therefore there is a need to convert them into a structured format for further analysis.

Being the future-oriented data sources, the collections "Foresight projects" and "International projects" help reveal information on the priorities in technology fields and focus on prospective mainstreams of technology development. As in case of "Media", one could use some more specific keywords for creating these collections, without using difficult technical terms. Since the very projects already include the structured information about technology trends in the subject area, in some cases it could be more beneficial to process this data manually in order to increase the added value of this collection.

By comparing the results of processing different data sources for identifying technology trends in green energy, it can be concluded that the opportunities offered and the results obtained by using any of the eight represented collections may depend on the following factors:

- *The specificity of a subject area*

For example, political factors can play an important role in the area of green energy, and therefore a large portion of useful information can be contained in the projects and programs for development of energy industry in individual countries and across the globe.

- *The technology life-cycle stage*

The collections "Scientific publications", "Patents" and "Dissertations" can be used to analyse fundamental and applied research. "Media", "Conferences" and "Presentations" can be helpful in discovering the application. At the same time, “Foresight projects”, “International projects” and “Presentations” can be suitable for evaluating the social and economic impact of technology development.

- *The choice of information resources*

For example, while using electronic databases it is necessary to take into account the time required to present information in a structured format. The analysis of online content makes it possible to process information in real time.

- *The search strategy*

Searching using a broad query may be applied while studying the mainstreams of technology development in a specific area, while searching by topic or using a keywords list can be more effective when analysing technology trends on a deeper level.

- *The difference in terminology*

Diverse keywords can be used for describing technology trends in the subject area, for example, more scientific terms like “environment and energy” in the publications, and more “trendy” terms like “sustainable energy” in media.

- *The choice of data fields to be processed*

Information from some data fields, such as title or abstract, may be enough to search for mainstream technological trends, while processing the full text may be helpful for detecting more specific technology applications.

An important step in interpreting the results of data processing is the separation between supply side and demand side of the technology development. In order to identify these two types of trends, different data collections created by using specific keywords lists, can be applied. For instance, the collections “Foresight projects”, “International projects” and “Presentations” can be more suitable for monitoring demand side (socio-economic trends), while “Scientific publications”, “Patents”, “Media”, “Conferences” and “Dissertations” could be more helpful for discovering supply side (technology trends).

6. Conclusion

This study compares the results of identifying technology trends extracted from various data sources (scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations) in order to analyse the strategies for working with different collections, as well as the factors that may influence the technology monitoring results. The proposed approach is applied for green energy area connected with the different fields of knowledge. The analysis shows that comprehensive coverage of data sources can be more efficient than employing only one resource, since this makes it possible to discover technology trends at the earliest stage of their development, for example, using the latest news published online or the materials from the recent conferences. Taking into consideration the specificity of the subject area and each data collection, as well as the accurate formulation of a research goal, can help select the most relevant information sources for identifying different types of technology trends. Therefore, provided that the factors, which affect the results of data processing, are taken into account as much as possible, such systemic analysis of the results can be used as an important tool for further improvement of the methodology for technology trends monitoring.

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Chapter 5. Green energy prospects: trends and challenges[39]

Abstract

The transition of energy systems moving from non-renewable fossil-nuclear to renewable sources is a key challenge of climate mitigation and sustainable development. Green energy technologies can contribute to solutions of global problems such as climate change, growth of energy consumption, depletion of natural resources, negative environmental impacts, and energy security. In this article the prospective directions of technology development in green energy are studied and analysed using a combination of qualitative and quantitative methods. Qualitative research involves participation of experts from the green energy area, while quantitative analysis includes collecting and processing data from different information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, and presentations) with a help of Vantage Point software[40]. In addition, key challenges for green energy as well as its relationships with other technological and non-technological areas are identified and briefly described on the basis of qualitative and quantitative analysis.

1. Introduction

Energy is an important component of global social and economic infrastructure. The effective use of natural resources and the potential of the energy sector contribute to providing sustainable economic growth, a higher quality of life, and strengthening foreign economic positions. Currently, the development of the energy sector is associated with such global challenges as climate change, growth of energy consumption, depletion of natural resources, negative environmental impacts and energy security. These challenges are widely discussed in various reports at the global level (European Commission, 2007; European Commission, 2011; Glenn et al., 2011; IEA/OECD, 2011; IPCC, 2007; National Intelligence Council, 2012; OECD, 2012). To reduce negative effects connected with these challenges and to move towards sustainable energy infrastructure, national governments need to be aware of the key technologies, which can help address the problems identified. Development of green energy technologies can be one of the ways to increase an economy's energy efficiency. These technologies can make an

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[40] This chapter links to the findings of Chapter 4 related to the possibilities of using various data collections for trends monitoring.

appreciable contribution to the sustainable development of the energy sector and economy as a whole through the production of clean and inexhaustible energy.

This paper investigates the main trends in green energy development by using two principal approaches to technology forecasting: qualitative (expert) and quantitative methods. The expert approach compiles a list of technology directions, based on the opinions of leading specialists in the subject area. The quantitative procedures involve automatic processing of quantitative data from different sources using a specialised computer software (for example, Vantage Point). In theoretical works devoted to identifying technology trends the most frequently used sources of data are scientific publications (Chen, 2006; Cobo et al., 2011; Daim et al., 2006; Guo et al., 2011; Kajikawa et al., 2008; Kostoff et al., 2008; Morris et al., 2002; Porter and Cunningham, 2005; Shibata et al., 2008; Smalheiser, 2001; Upham and Small, 2010) and patents (Campbell, 1983; Corrocher, 2003; Daim et al., 2006; Dereli and Durmusoglu, 2005; Fattori et al., 2003; Kim et al., 2008; Kim et al., 2009; Lee et al., 2009; Lee et al., 2011; Li et al., 2009; Porter and Cunningham, 2005; Trappey et al., 2006; Tseng et al., 2007; Wang et al., 2010; Yoon and Park, 2004). However, in addition to publications and patents, technology forecasting can draw on information from news bulletins (Daim et al., 2006); business resources, such as the Lexis-Nexis database (Porter and Cunningham, 2005), venture capital funds and start-ups data (Cozzens et al., 2010)); information from thematic conferences (Porter and Cunningham, 2005), and others.

The main research question of this study is:

How can we analyse the prospective directions of technology development in green energy using qualitative and quantitative methods and different information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, and presentations)?

2. Methodology

The current study carried out expert analysis (qualitative) to identify the prospects of technology development in green energy. It also analysed a range of quantitative data sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, presentations) to find additional information about prospective technologies in green energy area. The expert analysis highlighted six key technology fields in green energy: solar energy, wind energy, bioenergy, electricity storage, fuel cells and green energy infrastructure. Next, eight data sources were analysed for containing information about green energy technologies developed from 2003 to 2012 (see Table 5.1).

Table 5.1. Information sources used to identify promising technology fields in green energy

Data collection	Data source	Methods
Scientific publications	Web of Science	Bibliometric analysis
Patents	Derwent Innovation Index	Text mining
Media (news)	Factiva	Bibliometric analysis
Foresight projects	EFMN, EFP	Text mining
Conferences	Official websites of conferences	Text mining
International projects	CORDIS Europe	Text mining
Dissertations	ProQuest	Bibliometric analysis
Presentations	SlideShare	Text mining

The quantitative approach to identifying key technology directions in green energy involved the following steps: 1) creating data collections (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations and presentations); 2) importing data into Vantage Point software; 3) pre-preparing data; 4) clustering keywords (factor analysis).

Table 5.2 shows aggregate data of eight collections created for green energy area: data sources, the number of documents, the names of bibliometric fields that are being processed, and also the format of collections before and after pre-preparation of data.

As a result, a total of 69 699 documents in different formats (*.txt, *.html, *.doc, *.pdf, *.ppt) were collected, most of which were converted into *.xml format for further processing in Vantage Point software.

Table 5.2. Aggregated data on collections created for green energy area

Data collection	Data source	Number of documents	Field for processing	Format before processing	Format after processing
Scientific publications	Web of Science	18 912	keywords	*.txt	*.txt
Patents	Derwent Innovation Index	5000	abstract	*.txt	*.txt
Media (news)	Factiva	44 310	title	*.html	*.xml
Foresight projects	EFMN, EFP	40	text	*.doc	*.xml
Conferences	Official websites of conferences	19	text	*.doc or *.pdf	*.xml
International projects	CORDIS Europe	129	text	*.doc	*.xml
Dissertations	ProQuest	1 189	keywords	*.html	*.xml
Presentations	SlideShare	100	text	*.ppt	*.xml

Vantage Point uses customised import filters for uploading data collections, which makes it possible to import data from most of the popular electronic databases

(Web of Science, Scopus, Derwent Innovations Index, Factiva, etc.). Next, at the stage of pre-preparing data, it is necessary to exclude irrelevant documents, undertake linguistic analysis, and remove words (stop-words) that carry no particular meaning on their own (such as prepositions, conjunctions and pronouns). Then selected keywords are grouped into clusters. In this case, the main parameter for clustering is co-occurrence of terms in the texts of documents. While clustering Vantage Point uses factor analysis, which allows to show the most meaningful clusters (the key technology fields) on a map.

3. Green energy technology development prospects

In this section, we discuss the results of qualitative and quantitative analysis of prospective technologies for each of six green energy technology directions (solar energy, wind energy, bioenergy, electricity storage, fuel cells and green energy infrastructure). For each of these technology directions we aim to find the quantitative evidence in eight data sources.

3.1. Solar energy

Currently there are two major technology directions in the field of converting solar energy into electricity: photovoltaic cells (or solar cells), designed for direct conversion of solar energy into electricity, and concentrated solar power stations, which use solar radiation as primary energy source. In the field of solar cells, the main work is focused on increasing energy conversion efficiency, providing long working life, minimising degradation of initial specifications, and reducing production costs. Key objectives in the field of concentrated solar power stations include reducing their costs and increasing energy conversion efficiency. This is intended to be achieved by designing a number of technical solutions, such as improving thermodynamic parameters of solar power plants; discovering new working masses; reducing heat losses in solar power plants' transmission channels; developing new coatings with high reflectivity and longer working life for solar concentrators; optimising technological structure and parameters of solar power plants, etc.

Application of solar energy technologies will allow to efficiently produce electricity directly at consumers' locations, and thus implement the concept of distributed generation. The use of solar energy would make a significant contribution to expanding the global fuel and energy resource base; saving non-renewable fossil fuel resources; reducing anthropogenic impact on the environment; reducing greenhouse gases emissions, and thus energy industry's negative impact on the climate; and creating new jobs, including in related industries.

Examples of technological products / solutions / applications in the field of solar energy include photovoltaic cells (crystalline silicon solar cells (first generation); thin film solar cells (second generation); organic solar cells (third generation)); concentrated solar power stations; evacuated tubular collectors for residential, commercial, and industrial buildings; cascade photovoltaic cells for aerospace solar power plants, etc.

Solar energy has a high disruptive potential. Large-scale development of solar energy can reduce demand for conventional fossil fuels, traditional mechanical engineering products, and human resources specialising in development and application of conventional energy technologies. Solar energy prospects will be largely determined by advances in and timeframes of developing new semiconductor materials, as well as solar cells' and solar concentrators' assembly technologies.

The leaders in development of advanced solar energy technologies are the USA, Germany, and Japan. Solar power plants have already found industrial application in these countries. Now they improve the already implemented technological solutions and develop new technologies. Solar power plants' operational characteristics may be significantly improved by 2025, while mass application of next-generation solar energy technologies can be expected after 2025.

Key characteristics of solar energy technologies are described in Table 5.3. Table 5.4 describes key technology directions in solar energy, presented in various information sources.

Table 5.3. Characteristics of solar energy technologies (expert-based)

Technology field	Objectives	Products / Services / Solutions / Applications	Probable application date
Solar cells	• increasing energy conversion efficiency • providing long working life • minimising degradation of initial specifications • reducing production costs	• crystalline silicon solar cells (first generation) • thin film solar cells (second generation) • organic solar cells (third generation) • evacuated tubular collectors for residential, commercial, and industrial buildings • cascade photovoltaic cells for aerospace solar power plants	2020-2025
Concentrated solar power stations	• reducing costs • increasing energy conversion efficiency	concentrated solar power stations	

Table 5.4. List of key technology directions in solar energy

Technology direction (from expert list)	**Key directions (from various information sources)**	**Information source**
SOLAR ENERGY	*Development of thin film technologies based on zinc oxide, silicon oxide, etc., for application in solar cells *Use of ultraviolet rays as an inexhaustible energy source; application of polycondensation processes for intermolecular energy transfer	Scientific publications
	*Development of technologies for production and application of photovoltaic devices (e.g. solar cells) *Development of organic electronics for green energy	Patents
	*Application of highly efficient crystalline silicon solar cells, roof tiles and solar panels for residential, commercial, and industrial buildings *Application of solar cells for reducing concentration of greenhouse gases in the atmosphere	Media (news)
	*Development of aerospace energy generation, to produce electricity from solar energy (building a power plant on the Moon or on the Earth orbit) *Use of alternative energy sources (solar cells, evacuated tubular collectors, etc.)	Conferences
	*Production of semiconductors using gallium phosphide	Dissertations
	*Need to develop solar energy production (application of a mechanism for concentrating sun rays on heliotubes; development and dissemination of solar cells; construction of energy-efficient buildings/structures, etc.) *Need to develop solar power engineering (production of solar cells, modular components, application of thin film solar cells, construction of solar power stations) *Application of thin film solar cells in solar power engineering	Presentations

Analysis of scientific publications shows that thin film technologies currently is the most relevant and actively discussed topic. In patents, organic electronics technologies command the highest interest. News normally cover the most striking socio-economic challenges, and application areas for solar energy technologies such as use of solar cells for reducing concentration of greenhouse gases in the atmosphere. At conferences, the most actively discussed topics are space-based energy generation technologies. Authors of dissertations deal with issues relevant to more specific technological solutions, such as production of semiconductors using gallium phosphide. Presentations include information about important socio-economic challenges (construction of energy-efficient buildings / structures), which promote development of solar energy, and about major application areas for relevant technologies (e.g. thin film solar cells).

As a result of comparing qualitative (expert-based) and quantitative data, both of the promising technology fields in solar energy identified by the experts were strengthened with information from quantitative data sources (such as scientific publications, patents, news, dissertations and presentations). In these data sources special attention is paid to space-based energy generation technologies for producing electricity from solar energy at power plants built on the Moon or on the Earth orbit.

3.2. Wind energy

Wind energy is currently developing in two major directions: onshore and offshore wind power generation. The following objectives are believed by experts to be the most important ones: reducing costs, increasing power, efficiency, reliability and safety, as well as reducing negative impacts on the environment. Various technology solutions are applied to these ends, including development of new materials and coatings for wind turbine blades; technologies for their production and application; better utilisation of wind potential; improving the blades' aerodynamic properties; reducing hydrodynamic losses; reducing mechanical losses; increasing hardware reliability; development of stronger and less expensive devices for fastening wind turbines at large depth; development of systems for optimised automatic control of wind power plants' operation modes; development of more precise techniques and systems for measuring wind potential and forecasting wind parameters.

Application of next-generation wind turbines will allow to efficiently produce electricity in regions with high costs of transporting conventional organic fuel, and implement the concept of distributed generation. Like in the solar energy case, application of new wind technologies will allow to significantly expand the global fuel and energy resource base; save non-renewable fossil fuel resources; reduce anthropogenic impact on the environment; reduce greenhouse gases emissions, and thus energy industry's negative impact on the climate; reduce losses of electricity in electric grids; reduce the costs of development and running of major power grids; and create new jobs, including in related industries.

Examples of technological products / solutions / applications in the wind energy field include wind turbines, their components (blades, generators, converters), offshore platforms, onshore and offshore wind power plants, etc.

Wind energy's disruptive potential is determined by the fact that its large-scale development could reduce demand for conventional fossil fuels, traditional mechanical engineering products, and human resources specialising in development and application of conventional energy technologies. Wind energy prospects will be largely determined by advances in and timeframes of developing new materials for blades and magnets; new hardware and technologies for increasing conversion ratio of wind's kinetic energy into mechanical energy; reducing energy losses in various wind turbine elements; and new designs and materials for offshore wind power plants.

The leaders in development of advanced wind energy technologies are the USA, Germany and Denmark. Wind power plants have already found industrial application in these countries. Now they improve the implemented technological solutions and develop new technologies. Wind power plants' operational characteristics may be significantly improved by 2025, while mass application of next-generation wind energy technologies can be expected after 2025.

Key characteristics of wind energy technologies are described in Table 5.5. Table 5.6 describes key technology directions in wind energy, presented in various information sources.

Table 5.5. Characteristics of wind energy technologies (expert-based)

<table>
<tr><th>Technology field</th><th>Objectives</th><th>Products / Services / Solutions / Applications</th><th>Probable application date</th></tr>
<tr><td>Onshore wind power plants</td><td rowspan="2">• reducing costs
• increasing power, efficiency, reliability and safety
• reducing negative impact on the environment</td><td>• wind turbines, components (blades, generators, converters)
• onshore wind power plants</td><td rowspan="2">2020-2025</td></tr>
<tr><td>Offshore wind power plants</td><td>offshore wind power plants and platforms</td></tr>
</table>

Table 5.6. List of key technology directions in wind energy

Technology direction (from expert list)	Key directions (from various information sources)	Information source
WIND ENERGY	*Need to measure peak power of wind installations (e.g. wind turbines) for efficient use of generated energy (measuring pulses' length and frequency, single pulse's energy, analysing intracavity photon density, application of solid-state lasers, etc.)	Scientific publications
	*Bringing together users of wind energy under a single "label"	Media (news)
	*Development of next-generation wind energy conversion systems *Use of alternative energy sources (wind energy, etc.)	Conferences
	*Need to assess reliability of alternative energy sources (wind energy, etc.)	Dissertations

The table shows that scientific publications provide information about secondary technology solutions for wind energy generation, such as techniques for measuring installations' peak power. News reflect the need for bringing together organisations using wind energy under a single "label". Participants of conferences discuss overall wind energy development trends, and specific technological applications such as wind turbines, etc. Meanwhile dissertations contain information about such problems as estimating wind power plants' reliability.

Comparison of qualitative (expert-based) and quantitative results revealed that quantitative data sources (scientific publications, news, conferences, dissertations) mainly include information about technologies applied at onshore wind power plants, while only secondary information was discovered regarding the other field (offshore wind energy generation), without specifically mentioning them in the documents' contents.

3.3. Bioenergy

The next generation of energy-related biotechnologies are being developed now, first of all to produce motor fuels. The main objectives of such developments are more efficient utilisation of solar radiation for biomass production; efficient biomass production based on other kinds of energy (in addition to solar); increasing the speed of atmospheric CO2 fixation in biomass; and increasing organic compounds' concentration in biomass, easily extractable and convertible into high-quality liquid motor fuels (hydrocarbons and spirits). The main accent is placed on creating new highly efficient microorganisms via bioengineering techniques, to fix atmospheric CO2 and transform it into motor fuel components. Major bioenergy technology development tasks include increasing energy efficiency of CO2 bioconversion into motor fuels; reducing biofuels' production costs; and increasing their quality (stability and environmental neutrality). Important bioengineering and technological solutions being developed include creation of new highly productive microorganism strains; new CO2 biofixation processes using other energy sources in addition to solar energy (electricity, chemical energy, e.g. hydrogen); development of new technologies for converting biomass into high-quality motor fuels; application of new materials for bioreactors (with longer working life, and less expensive); reducing energy consumption at all bioconversion stages; and development of new technologies for purification of bioconversion products.

Application of next-generation energy biotechnologies will allow to efficiently produce motor fuels without using fossil hydrocarbons. Like with solar and wind energy, application of new biofuel production technologies will allow to significantly expand the global fuel and energy resource base; save non-renewable fossil fuel resources; reduce anthropogenic impact on the environment; reduce greenhouse gases emissions, and thus energy industry's negative impact on the climate; and create new jobs, including in related industries.

Application of new energy biotechnologies would lead to supplying high-quality motor fuels on the market, such as biogasoline, biodiesel and bioethanol.

Bioenergy has a high disruptive potential. Large-scale development of bioenergy could reduce demand for conventional fossil fuels, traditional mechanical engineering products, and human resources specialising in development and application of conventional energy technologies.

Development prospects of technologies for motor fuel production will be largely determined by advances in and timeframes of developing new bioengineering techniques and technologies for creating new high-performance microorganism strains, safe to the environment and to people.

The leaders in development of advanced bioenergy technologies are the USA, Germany and the UK. Next-generation bioenergy technologies for production of motor fuels suitable for industrial application may emerge by 2030, while mass application of bioenergy technologies for motor fuel production can be expected after 2030.

Key characteristics of bioenergy technologies are described in Table 5.7. Table 5.8 describes key technology directions in bioenergy, presented in various information sources.

Table 5.7. Characteristics of bioenergy technologies (expert-based)

Technology field	**Objectives**	**Products / Services / Solutions / Applications**	**Probable application date**
Biogas production	• increasing energy efficiency of bioconverting CO_2 into motor fuels • reducing biofuel production costs, increasing its quality (stability and environment neutrality)	biogasoline	2025-2030
Biodiesel production		biodiesel	
Bioethanol production		bioethanol	

Table 5.8. List of key technology directions in bioenergy

Technology direction (from expert list)	Key directions (from various information sources)	Information source
BIOENERGY	*Use of photosynthetic organisms, e.g. green plants, algae and certain bacteria, to produce biofuels	Scientific publications
	*Use of biomass, e.g. algae, as an alternative energy source (biofuel production)	Patents
	*Promoting bioenergy crop production (e.g. annual tilled crops such as corn, sugar beet, sugar cane, cotton plant, potato), perrenial herbaceous plants (e.g. millet), and fast-growing trees (poplar) *Application of organic substances' formation process from carbon dioxide and water in the light, with participation of photosynthetic pigments *Production of synthetic diesel fuel – biodiesel (e.g. from waste) *Use of sugar cane as a renewable energy source	Media (news)
	*Use of biomass as a renewable energy source (e.g. forestry and agricultural waste, solid municipal waste, energy woods (poplar, acacia, eucalyptus, etc.), crops (timber waste, straw, corn shells, etc.), fuel pellets, oil plants (e.g. use of oil algae to produce biodiesel), sugar- and starch-containing products (cereals, potato, sugar beet), cellulose-containing plant-based raw materials (timber, straw, plant waste) *Use of algae for biomass production (microalgae – single-cell "factories" converting solar energy and carbon dioxide into biofuel; food stuffs; forage; and highly valuable biologically active components) *Use of industrial waste as a renewable energy source and reducing pollution of soil or water bodies	Foresight projects
	*Use of biomass and bioenergy (forest industry waste, manure, chicken dung, waste water sediments, etc.) *Use of biofuel in hybrid cars *Use of alternative energy sources in cities (biomass, forestry waste, etc.)	Conferences
	*Development of microbiology to produce fuels and generate energy (e.g. biocatalysis, application of bacteria to produce stable enzymes, etc.)	International projects
	*Application of integrated hydropyrolysis for petrol and diesel production and mixing biomass components; development of standards for renewable energy sources *Application of enzyme encapsulation techniques; production of ethanol from cellulose; use of silicon-based hybrid organic compounds	Dissertations
	*Development of environmentally friendly biofuel production technologies (production of pure ethanol, use of geothermal heating systems, use of biogas (produced by hydrogen- or methane-based biomass fermentation), production of biodiesel for cars)	Presentations

Analysis of scientific publications shows that technologies for application of photosynthetic organisms in bioenergy, e.g. green plants, algae and bacteria, currently is the most interesting and actively discussed topic. In patents the accent is also placed on use of biomass (algae) as an alternative energy source. News contains information about use of various bioenergy crops (tilled crops, herbaceous plants, and trees) and waste to generate energy; also noted is the need to develop a concise bioenergy policy. Similarly, foresight studies are focused on use of biomass as an energy source (forestry and agricultural waste, solid municipal waste, high-energy woods (poplar, acacia, eucalyptus, etc.), crops (timber waste, straw, corn shells, etc.), fuel pellets, oil plants (e.g. use of oil algae to produce biodiesel), sugar- and starch-containing products (cereals, potato, sugar beet), cellulose-containing plant-based raw materials (timber, straw, plant waste). Technologies for application of microalgae (single-cell "factories" converting solar energy and carbon dioxide into biofuel) are also noted in this information source. Participants of conferences discuss use of biofuel in hybrid cars, and use of alternative energy sources in cities. Projects implemented by international organisations offer information about development of microbiology to produce fuels and generate energy (e.g. biocatalysis, application of bacteria to produce stable enzymes, etc.). Dissertations reflect the general need to develop standards for renewable energy sources, and describe certain specific technological solutions in the bioenergy field, e.g. application of hydropyrolysis for petrol and diesel production; mixing biomass components; enzyme encapsulation techniques, etc. Presentations are mostly devoted to development of environmentally friendly biofuel technologies (production of pure ethanol, use of geothermal heating systems, use of biogas, production of biodiesel for cars).

Comparison of qualitative (expert-based) and quantitative data on bioenergy revealed that information about all three promising technology directions (production of biogas, biodiesel, and bioethanol) identified by the experts was also found in various quantitative data sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, presentations). However, some of these sources also mention technologies for use of waste as a renewable energy source – which are insufficiently represented in the expert-based materials.

3.4. Electricity storage

Rechargeable batteries are currently widely used in numerous fields, including in mobile devices and in energy production as stationary installations, mainly to provide uninterrupted energy supply for devices, and for relatively long-term electricity storage. The last application area is becoming increasingly popular. In distributed generation systems, storage batteries may play an important role in providing an operational reserve, stabilising electro-physical parameters of local electric energy system, and improving the quality of electricity supply, e.g. by adjusting frequency and voltage. Key objectives of storage batteries' further development include increasing their specific capacity, power and working life, as well as reducing production costs. Major technological solutions for development of storage batteries include production of new electrode and electrolyte materials; providing a high number of charge / discharge cycles; reducing internal energy losses; and increasing batteries' safety through using new materials and monitoring systems.

Application of next-generation electrochemical batteries would allow to efficiently use electricity generated from both conventional and renewable sources; increase efficiency of installations based on renewable energy sources; store electricity and create power reserve directly at consumers' locations; and implement the concept of distributed generation. Application of next-generation electrochemical batteries would allow to increase renewable energy's competitiveness; save non-renewable fossil fuel resources; increase the quality of energy supply to end users; reduce anthropogenic impact on the environment; reduce greenhouse gases emissions, and thus energy industry's negative impact on the climate; lower losses of electricity in electric grids; reduce the costs of development and running of major power grids; and create new jobs, including in related industries.

The main product in this area is represented by electrochemical storage batteries, which can store extra electricity, cover peak electrical loads, and provide standby power supply.

Production of storage batteries has a high disruptive potential. Large-scale development of next-generation electrochemical batteries could reduce demand for conventional fossil fuel, traditional mechanical engineering products, and human resources specialising in development and application of conventional energy technologies. Development prospects of next-generation electrochemical batteries will be largely determined by advances in and timeframes of developing new electrode and electrolyte materials, and new battery control technologies.

The leaders in development of advanced electrochemical batteries are the USA, Germany, the UK and Japan. Electrochemical storage batteries have already found industrial application in these countries. Currently the implemented technological solutions are being improved, and new technologies developed. Significant improvement of electrochemical batteries' parameters can be achieved by 2030, while mass application of next-generation electrochemical storage batteries can be expected after 2030.

Key characteristics of electricity storage technologies are described in Table 5.9. Table 5.10 describes key technology directions in batteries, presented in various information sources.

Table 5.9. Characteristics of electricity storage technologies (expert-based)

Technology field	**Objectives**	**Products / Services / Solutions / Applications**	**Probable application date**
Electrochemical batteries	• increasing specific capacity, power, and working life • reducing costs	electrochemical storage batteries	2025-2030
Storage power plants		storage power plants	

Table 5.10. List of key technology directions in batteries

Technology direction (from expert list)	**Key directions (from various information sources)**	**Information source**
ELECTRICITY STORAGE	*Construction of buildings, which would use solar energy in various climatic zones; more efficient use of solar energy; development of long-lasting lithium-ion batteries capable of storing extra energy generated by solar cells or wind turbines at peak energy generation times, for subsequent supply as required	Media (news)
	*Application of green technologies in transport (development of energy-efficient and environmentally friendly power-supply systems, electricity generation during exploitation of vehicles, development of environmentally friendly batteries, development of efficient energy consumption management systems for vehicles, etc.) *Use of alternative energy sources in cities (storage batteries, etc.)	Conferences
	*Need to develop alternative energy generation to reduce negative impact of factors affecting geological history of Earth (use of rechargeable batteries, etc.)	Presentations

The table shows that news offer detailed information about development of long-lasting lithium-ion batteries for efficient management of electricity generated from solar and wind energy sources. The participants of business conferences discuss application of storage batteries in urban transport vehicles. Presentations reflect the need to apply rechargeable batteries to neutralize factors negatively affecting the Earth climate.

Comparative analysis of qualitative (expert-based) and quantitative data on energy storage revealed that quantitative data sources (news, conferences, and presentations) provide detailed information about technologies related to electrochemical batteries and have practically no data on storage power plants.

3.5. Fuel cells

Key objectives of fuel cells development include increasing energy conversion efficiency, reducing costs, increasing reliability and working life, easing requirements to fuel quality, achieving good manoeuvrability characteristics, as well as developing efficient monitoring and power management systems. The following technology solutions are being developed to achieve these objectives: membrane materials; new electrode materials with minimal content of expensive catalysts; new highly efficient fuel pre-processors; technology solutions to achieve high manoeuvrability characteristics; and new monitoring and power management systems.

Application of next-generation fuel cells would allow to efficiently supply electricity to end users; create power reserve directly at consumers' locations; implement the concept of distributed generation; and increase efficiency of installations based on renewable energy sources. In terms of expected effects, application of next-generation fuel cells would allow to increase energy conversion efficiency of fuel usage; save non-renewable fossil fuel resources; increase the quality of energy supply to end users; increase competitiveness of renewable energy's sources; reduce anthropogenic impact on the environment; reduce greenhouse gases emissions, and thus energy industry's negative impact on the climate; lower losses of electricity in electric grids; reduce the costs of development and running of major power grids; and create new jobs, including in related industries.

Fuel cells are the main product in this area (e.g. proton-exchange membrane fuel cells, solid-oxide fuel cells, and molten carbonate fuel cells). Key services supporting application of new fuel cell types include electricity generation at end users' locations; covering peak load periods; and creating power reserves.

Fuel cells have a high disruptive potential. Large-scale development of next-generation fuel cells could reduce demand for conventional fossil fuels, traditional mechanical engineering products, and human resources specialising in development and application of conventional energy technologies. Development prospects of next-generation fuel cells will be largely determined by advances in and timeframes of developing new electrode and electrolyte materials, and new power control technologies.

The leaders in development of advanced next-generation fuel cell technologies are the USA, Japan, Germany and Korea. Fuel cells have already found industrial application in these countries. Currently the implemented technology solutions are being improved, and new technologies developed. Significant improvement of fuel cells' parameters can be achieved by 2030, while mass application of next-generation fuel cells can be expected after 2030.

Key characteristics of fuel cell technologies are described in Table 5.11. Table 5.12 describes key technology directions in fuel cells, presented in various information sources.

Table 5.11. Characteristics of fuel cell technologies (expert-based)

Technology field	Objectives	Products / Services / Solutions / Applications	Probable application date
Proton-exchange membrane fuel cells	• increasing energy conversion efficiency • reducing costs • increasing reliability and working life • easing requirements to fuel quality • achieving good manoeuvrability characteristics • developing efficient monitoring and power management systems	proton-exchange membrane fuel cells	2025-2030
Solid-oxide fuel cells		solid-oxide fuel cells	
Molten carbonate fuel cells		molten carbonate fuel cells	

Table 5.12. List of key technology directions in fuel cells

Technology direction (from expert list)	Key directions (from various information sources)	Information source
FUEL CELLS	*Application of green technologies in transport (development of energy-efficient and environmentally friendly power-supply systems, electricity generation during exploitation of vehicles, development of environmentally friendly batteries, development of efficient energy consumption management systems for vehicles, etc.)	Conferences
	*Use of graphene to manufacture fuel cells' electrodes	International projects

Key sources of quantitative data about fuel cells technologies include conferences and projects implemented by international organisations. Proceedings of conferences reflect fuel cells' application prospects in the transport sector, such as development of energy-efficient and environmentally friendly power-supply systems, efficient energy consumption management systems for vehicles, etc. Some of the projects funded by the European Commission include application of graphene to manufacture fuel cells' electrodes.

Comparison of qualitative (expert-based) and quantitative data on fuel cells revealed that quantitative data sources (such as conferences and projects of international organisations) normally offer general information about such technologies, without subdividing them into three groups (protonexchange membrane fuel cells, solid-oxide fuel cells and molten carbonate fuel cells). In these materials, however, specific attention is paid to technologies for application of graphene in fuel cells.

3.6. Green energy infrastructure (smart grids)

Key objectives of smart grid development include increasing reliability and safety of energy supply; improving quality of supplied electricity; increasing automation of technological processes; application of digital technologies and microprocessor-based devices in monitoring and management systems; and reducing running costs. Major technology solutions currently under development in this area include: development of smart monitoring, diagnostics, and automated tools for managing hardware and operational modes, for use in real time in complex energy supply systems; automatic reconfiguration of energy supply system to match the current consumption level (implementing the concept of smart self-adjusting system); development of information and computer technologies, techniques, and tools for transferring large data arrays, mathematics-based adaptive management techniques; development of hardware-software solutions to integrate smart energy production and smart end-user electricity consumption management systems (the concept of “energy internet”); development of tools to increase reliability and safety of power supply by monitoring the state of the installed equipment in real time, taking into account actual operational conditions and automatic reconfiguration of the system in case of emergencies (implementing the concept of self-recovering system); development of hardware-software tools to identify the trends and forecast energy consumption, and characteristics of renewable sources energy, including price-related ones, and creating conditions for managing energy consumption based on economic criteria; development of hardware-software tools to implement the concept of “virtual power plant” based on distributed energy generating and energy storage installations, including mobile ones (electric cars); development of tools to support safety of smart energy grids and smart end-user hardware; preventing unauthorized remote control of them; development and adoption of data transfer standards and protocols for smart grids and smart meters.

Application of smart grids would allow to efficiently supply electricity to end users; create power reserve directly at consumers’ locations; implement the concept of distributed generation; and increase efficiency of energy installations based on renewable sources. In terms of expected effect, application of smart grids would allow to increase reliability and quality of electricity supply to end users; lower energy losses in grids; reduce power grids' development and running costs; increase competitiveness of renewable energy sources; increase energy conversion efficiency of organic fuel usage; save non-renewable fossil fuel resources; reduce anthropogenic impact on the environment; reduce greenhouse gases emissions, and thus energy industry's negative impact on the climate; and create new jobs, including in related industries.

The main services supporting application of smart grids include increasing reliability and quality of electricity supply to end users.

Smart grids have a high disruptive potential. Large-scale development of smart grids could reduce demand for conventional power engineering products, and human resources specialising in development and application of conventional energy technologies. Smart grids' development prospects will be largely determined by advances in and timeframes of developing new technologies for real-time automated management of major (both technologically and spatially) power systems employing complex operation modes, relevant hardware, equipment, devices and software for smart monitoring and management.

The leaders in development of advanced smart grid technologies are the USA, Germany, Japan, and Korea. Pilot smart grid projects are already being implemented in these countries, and are expected to be completed by 2030. Mass application of smart grids can be expected after 2030.

Key characteristics of smart grid technologies are described in Table 5.13. Table 5.14 describes key technology directions in smart grids, presented in various information sources.

Table 5.13. Characteristics of smart grid technologies (expert-based)

Technology field	**Objectives**	**Products / Services / Solutions / Applications**	**Probable application date**
SMART GRIDS	• increasing reliability and safety of electricity supply • improving quality of supplied electricity • increasing automation of technological processes • application of digital technologies and microprocessor-based devices in monitoring and management systems • reducing running costs	smart grids	2025-2030

Table 5.14. List of key technology directions in smart grids

Technology direction (from expert list)	Key directions (from various information sources)	Information source
GREEN ENERGY INFRASTRUC TURE	*Construction of buildings, which would use solar energy in various climatic zones; more efficient use of solar energy; development of long-lasting lithium-ion batteries capable of storing extra energy generated by solar cells or wind turbines at peak energy generation times, for subsequent supply as required *Construction of data centres operating on renewable wind energy *Large-scale construction of ecological (green) hotels, to minimise damage to the environment	Media (news)
	*Need to monitor efficiency of various energy installations, based on meteorological and other data (power coefficient, torsion coefficient, smoke emissions, etc.) *Development of software to control energy supply and consumption *Development of energy-efficient heating, ventilation, and air conditioning systems; application of artificial intelligence technologies in energy	Conferences
	*Application of green information technologies (green data centres, etc.)	International conferences
	*Building green data centres (which would sink heat generated by thousands of computers, and thus reduce heat emissions into the atmosphere); managing traffic load, redistributing queries to maintain balanced load	Dissertations

Analysis of news shows that the most promising green energy infrastructure technologies are technologies for construction of buildings (residential houses, hotels, etc.), which would inflict minimum possible damage to the environment, and data centres working on renewable wind-generated energy. Participants of conferences most frequently discuss the need to develop efficient heating, ventilation, and air conditioning systems; monitor efficiency of various energy installations based on meteorological and other data (power coefficient, torsion coefficient, smoke emissions, etc.); and develop specialised software to control energy supply and consumption. Projects implemented by international organisations, and dissertations frequently reflect active discussion of green information technologies (e.g. green data centres), which would reduce heat emissions into the atmosphere.

Comparative analysis of qualitative (expert-based) and quantitative data on green energy infrastructure revealed that the promising technology area (smart grids) identified by the experts was sufficiently supported by information from different sources (news, conferences, projects of international organisations, dissertations).

However, in quantitative materials special attention is being paid to technologies needed to construct and operate green data centres, increase energy saving and energy efficiency.

4. Challenges for green energy technology; links between green energy and other technological and non-technological areas

Application of expert-based and analytical techniques allowed to identify the following key challenges related to green energy: climate change; growth of energy consumption; depletion of natural resources; negative impact on the environment and people's activities; and energy security.

Dealing with the *climate change* problem involves reducing emissions of greenhouse gases into the atmosphere, and development of systems for their capture and storage. This requires coordination of such activities as mining of resources, production of energy, and limiting atmospheric emissions destroying the ozone layer. From this point of view the major objectives are optimising companies' operations to achieve efficient production; reduction of harmful emissions; development of systems for monitoring production activities and their environmental impact. Accomplishing these objectives requires government support of environmentally friendly production (e.g. subsidies, tax breaks, etc.).

In recent decades *global energy consumption* was growing at a high rate, hindering sustainable development of the world economy. This challenge creates demand for development of energy-saving technologies, energy production from renewable sources, and distributed energy generation – which involves managing end users' demand for electricity. Orientation towards the concept of energy efficiency and energy saving determines the need to monitor energy installations' efficiency based on meteorological and other data (power coefficient, torsion coefficient, smoke emissions, etc.), achieve sustainable development of energy sectors, and primarily of the non-renewable ones (resources, equipment, geography of reserves, mining and transportation capacities, etc.).

The issue of *depleting natural resources* is closely connected with the global growth of energy consumption. Implementing the concept of sustainable development involves saving the limited reserves of fossil fuels. Accordingly, there is a need to use alternative energy sources (solar, wind, geothermal, hydrogen, bioenergy, etc.) and develop an effective government policy to regulate the green energy sector.

Negative impact of energy production on the environment and people's activities is also a major problem. The need to solve it leads to growing interest to environment protection research (including reconstruction of ecosystems, microbiology, water treatment, reduction of toxic waste, pollution, and wood cutting, etc.), and also involves the need to regulate companies' activities (certification) and to balance saved profitability and reduced negative impact on the environment. An important objective here is to improve the quality and the standards of life in cities, through application of green technologies (living environment safety, air pollution control, planting of trees and shrubs, fighting environment-related diseases, use of alternative energy sources, reduction of noise, etc.).

The need to achieve *energy security (political, socio-economic and industrial)* is directly connected with highly volatile prices of conventional fuels in global markets. The political aspect of this problem is related to achieving energy security of countries importing fuels and energy, and their orientation towards implementing and disseminating green technologies (solar cells, green transport, biofuels, etc.). The socio-economic aspect reflects the need to adopt common international standards for green technologies, to limit use of non-renewable energy sources (e.g. through regulation of transport system, etc.), and the need to take into account security issues associated with use of biomass as an alternative energy source (which could lead to exacerbating the food supply problems due to use of agricultural lands for growing biomass).

Analysis of data from various information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, and presentations) revealed that solving the above problems is based on developing of green energy and related technology areas closely linked with it. These related areas include the following:

- ***Biotechnologies***

Bioengineering techniques and technologies to produce new highly productive microorganism strains (plants, algae, bacteria, etc.), safe to the environment and to people; bioenergy technologies for making motor fuels, etc.

- ***Rational use of nature***

Use of industrial waste as a renewable energy source and reducing pollution of soil or water bodies; development of environmentally friendly biofuel production technologies, etc.

- ***Transport and aerospace systems***

Production of biofuels (petrol, diesel) and mixing biomass components for use in hybrid cars; development of space-based solar energy generation, etc.

- ***New materials and nanotechnologies***

New semiconductor materials for solar energy generation; hardware and technologies to increase conversion ratio of wind's kinetic energy into mechanical energy; new materials for large-scale hydrogen storage, including lightweight high-strength construction materials, etc.

- ***Information and communications technologies***

Technologies for measuring power plants' peak capacity; mapping organic waste; sensory technologies for monitoring state of the environment and energy efficiency of buildings; hardware and software for smart grids; green data centres (managing traffic load, redistributing queries), etc.

In addition, analysis of different information sources helped identify certain non-technological aspects and areas of knowledge (integrated monitoring and modelling; security; green management; public initiatives and health promotion; green business and production; education and labour market; and international standards and licensing), which can make a significant contribution to development of green energy. For example, *integrated monitoring and modelling* can be used for measuring efficiency of various power plants; efficiently use of generated energy; sensory control of buildings' energy and environmental efficiency; building optimal models of natural resources' use (such as land, biofuel resources, etc.), to ensure sustainability of the environment and estimate reliability of alternative energy sources (hydrogen, wind, etc.). The *security* aspects of green energy development may involve using save and environmentally friendly materials for construction of energy installations; solving the problems of energy and food security (which is connected with using agricultural lands to grow biomass); and environmental problems affecting people's activities (saving living environment, planting trees and shrubs, improving health services, etc.). Development of green energy promotes the concept of *green management*, which involves changing the society's attitude to green technologies (increased attention to ecology, application of new materials, etc.) to overcome social barriers hindering development of green energy, change urban environment, promote eco-design and eco-construction. Application of green energy technologies also affects the sphere of *public initiatives and health promotion*, which implies involving public associations and organisations in solving environmental problems (improving air quality; checking statements on environmental-related advantages of various products / services / technologies; efficient use of floor space in retail centres, offices, etc.), and supporting sustainable (environmentally oriented) lifestyle (promoting consumption of clean energy at households; measuring concentration of pollutants in the atmosphere; disseminating environmental knowledge and literacy among senior citizens; monitoring people's health; planting trees and shrubs; regulating the transport sector; using social media to promote healthy lifestyle, etc.). The concept of *green business and production* involves reorientation of companies towards sustainable business development models based on use of renewable energy resources, and promotes development of high-tech industries (green information technologies, chemical engineering, sustainable management of forest resources, etc.). This concept implies an important role of using green technologies for construction and running of factories and plants, and analysing products' life cycle (estimating the products' environmental impact at all its stages). Development of green energy also affects the *education and labour market*, since it makes more available sustainable development-related education, promotes demand for highly skilled green professionals and creation of relevant jobs, including in related industries. The need to develop transparent global green energy policy requires development and adoption of common *international standards* to limit use of non-renewable energy sources (e.g. regulating the transport sector, etc.) to reduce toxic waste, and introducing a universal new production *licensing* system. Also important is adopting common international standards for health care, improving air quality and use of water resources.

5. Discussion and conclusion

This study analysed promising technology directions of green energy development, which have a potential to make significant contribution to solving socio-economic, political, environmental, and other problems hindering sustainable development (changing climate, increasing energy consumption, depleting natural resources, negative environmental impacts, energy security). Using qualitative (expert workshop) and quantitative (analysing data with the help of specialised software – Vantage Point) techniques, six green energy fields (solar energy, wind energy, bioenergy, electricity storage, fuel cells and green energy infrastructure) were studied, which include thirteen key technologies capable of significantly affecting green energy's long-term development.

For solar energy generation, identified promising technology development areas included solar cells and concentrated solar power stations; for wind energy – onshore and offshore wind power plants; for bioenergy, key technologies included biogas, biodiesel, and bioethanol production; for energy storage – electrochemical batteries and storage plants; for fuel cells – proton-exchange membrane fuel cells, solid-oxide fuel cells, and molten-carbonate fuel cells; for green energy infrastructure, smart grid technologies were identified as offering the highest potential. Comparison of qualitative (expert-based) and quantitative materials has shown that most of the expert-identified technology development areas were supported, to a greater or lesser extent, by quantitative data from various information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations, and presentations). However, these six technology fields were represented in quantitative materials unevenly.

For example, the highest match of technologies was noted in solar energy and bioenergy. As to other areas, some technologies were reflected in expert-based materials but not in quantitative ones. For example, regarding offshore wind power plants (wind energy), only indirect data was found in quantitative sources, without any direct mentioning of such technologies in the documents' contents. In bioenergy, some of the quantitative sources mention use of waste as a renewable energy resource – which in effect was ignored in the expert-based materials. Regarding energy storage, quantitative sources contained detailed information about electrochemical batteries technologies, while data on storage plants was almost totally absent. In the field of fuel cells, technologies for application of graphene were specifically mentioned in quantitative materials. As to green energy infrastructure, technologies for building and operating green data centres received particular attention in quantitative sources, to increase energy saving and energy efficiency.

Firstly, this can be explained by different degree of maturity of technologies and the scale of discussion of these technologies in scientific literature, media and other sources. Secondly, the experts attempted to propose a general (relatively homogeneous) overview of trends in green energy, while quantitative data were collected heterogeneously from different sources (for example, depending on the search strategy: the keyword "green energy" can be suitable for collecting data from news, but is too vague for collecting data from patents). Third, the expert analysis may not fully take into account early emerging technologies, which have been already widely discussed in the media (f.e. use of waste for bioenergy production, use of graphene in fuel cells, etc.), but do not yet have technological products and applications. These and other possible factors were discussed earlier in Chapter 4.

Application of qualitative (expert-based) and quantitative techniques allowed to find out that several of the above technology areas include information relevant not just to green energy, but also to related topics. Close links were identified between green energy and such technological areas as biotechnology, rational use of nature, transport and aerospace systems, new materials and nanotechnologies, and information and communications technologies. Moreover, information from quantitative data sources helped identify non-technological spheres and knowledge areas (integrated monitoring and modelling; security; green management; public initiatives and health promotion; green business and production; education and labour market; international standards and licensing), which can significantly influence long-term sustainable development of the energy sector.

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Chapter 6. Understanding interrelationships between new societal trends to inform policy-making for the European energy transition[41]

Abstract

New societal trends (such as prosumaging, circular economy, digitalisation, economy, etc.) are understood as societal developments arising from general megatrends, which can have potentially large controversial (increasing or decreasing) impacts on energy consumption as well as cross-sectoral demand shifts because they are not simply the extrapolation of already presently observed trends ("continuous" or "linear" trends) but may take up speed when they are embraced by larger parts of the society or accompanied by policy instruments ("disruptive" or "non-linear" trends). In this paper, we analyse the interrelationships between the new societal trends that may influence future energy demand in the European countries. Through a desk research and three expert workshops energy relevant new societal trends are selected, clustered and their potential importance and disruptiveness are assessed using a three-dimensional metric (degree, scale, direction). An expert survey and network analysis provide a better understanding of the interrelationships between these trends, which can help designing European energy demand-side policy instruments that may have simultaneous major impacts on the new societal trends, avoiding the development of demand increasing patterns. This will lead to a better understanding of potential non-linear developments of future energy demand and how energy (efficiency) policies could be designed to take these trends and their connections meaningfully into account.

1. Introduction

Climate change as an existential threat to our planet, significantly affects opportunities for sustainable development in Europe and the whole world. To address this challenge, the European Commission has approved the European Union's (EU) strategic plan "The European Green Deal" aiming to transform the EU into a modern, resource-efficient and competitive economy and make Europe the first climate neutral continent in the world by 2050 (European Commission, 2019a), in line with the Paris Agreement (UNEP, 2014). This plan includes actions to boost the efficient use of resources by moving to a clean, circular economy and

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stop climate change, revert biodiversity loss and cut pollution (European Commission, 2019a). In 2020, the European Commission adopted a set of proposals to reduce the EU's net greenhouse gas emissions (GHG) by at least 55% by 2030, compared to 1990 levels (European Commission, 2020a). Besides, the European Parliament proposed even more ambitious target of a 60% reduction in 2030, compared to 1990 levels, while all individual member states must become climate-neutral by 2050, including "negative emissions" to compensate for emissions elsewhere (European Parliament, 2020). Russia's invasion of Ukraine has added new urgency to European climate action. The REPowerEU plan, proposed by the European Commission in May 2022, implies increasing share of renewables in final energy to 40-45% in 2030 and reducing final energy consumption to 750 Mtoe instead of the 787 Mtoe included in the "Fit for 55" package from July 2021. In total, this would result in emissions of between 57-62% below 1990 levels in the year 2030 (Climate Action Tracker, 2022).

The long-term strategy 2050 developed by the EU in 2020, assesses different pathways to achieve greenhouse gas emissions reductions between minus 80% (compared to 1990) up to net zero greenhouse gas emissions by 2050. This strategy is mainly based on exploiting the full potential of technologies, while other scenarios assume an increase in climate awareness of EU citizens translating into lifestyle changes and consumer choices, as well as a more circular economy (European Commission, 2020b). EU Member States still have partly to catch up with similarly ambitious scenarios for climate neutrality (Mikova et al., 2019). The achievement of the EU long-term climate goals requires the ongoing progress towards a low-carbon society, while both technological and non-technological factors having a broader framing as *New Societal Trends (NSTs)*, significantly contribute to the success of reaching national and regional targets (Fraunhofer ISI, 2022).

This research is being done under the newTRENDs project (Fraunhofer ISI, 2022), which aims to increase the qualitative and quantitative understanding of controversial impacts (decreasing, increasing or shifting) of new societal trends on energy consumption in the European countries and to improve the modelling of energy demand, energy efficiency and corresponding policy instruments. By *New Societal Trends* (which we call shortly also "*trends*" in the following) we understand societal developments arising from general megatrends (such as globalisation, climate change, technological progress, urbanisation, etc.), which can have potentially large (increasing or decreasing) impacts on energy consumption as well as cross-sectoral demand shifts (Brugger et al., 2021). Such trends include among others (Fraunhofer ISI, 2022):

- transition of consumers to “prosumagers” (consumers, producers and managers of energy);
- move towards a circular economy and a low-carbon industry;
- digitalisation of the economy and of private lives;
- trends towards a sharing economy.

Currently, European low-carbon energy scenarios by 2050 have been assuming that the general social context (e.g. population, GHG intensity, average standard of living, education level, etc.) plays a large role in the energy transition (Mikova et al., 2019). However, non-technological factors that influence energy consumption are rarely integrated in these scenarios. A number of studies present a major step forward by integrating new societal trends, such as digitalisation (e.g. IEA / OECD, 2017; European Commission, 2017; EUSEW, 2019), sharing economy (e.g. EU Calc, 2017; Perboli et al., 2018; UKERC, 2011), circular economy (e.g. Material Economics, 2018; SITRA, 2018), or prosumaging (e.g. European Commission, 2018a). However, more progress is necessary to quantitatively analyse new societal trends and their representation in scenarios, in particular covering energy demand. There have been attempts to study the controversial impact of new societal trends on energy consumption, for example by developing a narrative of future change based on observable trends that result in low energy demand (Grubler et al., 2018). Nevertheless, a full quantitative and consistent investigation of new societal trends in energy demand modelling, including the analysis of data and modelling gaps to quantification, is still missing (European Commission, 2019b). Such an analysis can help reveal the energy increasing and decreasing mechanisms under various trends and thus inform policy makers to address unintended effects of new societal trends as well as potentially disruptive trends early as they unfold (Fraunhofer ISI, 2019; EUSEW, 2019).

However, not only individual new social trends give rise to research questions. So far, little research has been devoted to investigating interrelationships between new societal trends to better understand how they may reinforce or contradict each other (i.e., one trend mitigates the impact of another). Further, the analysis of existing and emerging policy measures needed to ensure that new societal trends contribute positively to energy transition remains an open room for research. Therefore, the main goal of this paper is to analyse the interrelationships between new societal trends, to better understand their controversial impact (decreasing, increasing or shifting) on future energy demand in the European countries and how environmental policies can be designed to stir new societal trends in synergy towards energy demand decreasing developments.

The research presented in this paper is based on the combination of qualitative and quantitative methods. Qualitative methods are: desk research, expert workshops and consultations, impact assessment of trends, online expert survey and review of policy instruments; while quantitative methods include network analysis and statistical analysis. As a result, first, 15 new societal trends are identified, described and analysed through three expert workshops. Second, the network of interrelationships between 11 priority trends is created based on the online expert survey. And third, the list of policy instruments is created for two exemplary trend dyads ("Digitalisation" and "Sharing economy", "Digitalisation" and "Circular economy") that may have synergetic impacts on the trends in order to enhance their energy demand decreasing character.

This paper is organised as follows. Following the introduction, Section 2 will provide the review of the studies related to investigating the impacts of new societal trends on future energy demand to identify the research gaps and formulate the main research question. Then, Section 3 will describe the methodological approach used in this paper, which includes two main stages (identification and analysis). Next, based on this methodology, the results obtained on each of two stages will be presented in Section 4. Subsequently, these results will be discussed in Section 5. Finally, Section 6 will formulate an answer to the research question and draw conclusion.

2. Theoretical background

In this section, first, we research the studies investigating the impacts of new societal trends on energy demand in different areas. Second, we study foresight methods used to identify and analyse trends related to the European energy transition. Third, we review the works investigating these trends and their relationships to get additional information about their controversial impacts (decreasing, increasing or shifting). Finally, we identify the gaps in literature and formulate a research question for this paper.

The studies investigating the impacts of new societal trends on energy demand, are conducted on global, regional and country level, and have different aims, among which are the following: to reveal societal and technological factors influencing energy demand (f.e. Kramers et al., 2014; Werner, 2015; Barbu et al., 2018; Czibere et al., 2020; Figueroa and Lah, 2020; Lange et al., 2020); to establish impact indicators potentially contributing to energy transition (Kylili et al., 2020) and to measure the influence of specific trends on energy demand (f.e. Woods et al., 2017; Ertz et al., 2018; Zhang and Mi, 2018; Mrówczyńska et al., 2020; Fabiani et al., 2021); to outline the key priorities (Noussan and Tagliapietra, 2020) and possible scenarios for energy transition (Bartholdsen et al., 2019; Tagliapierta et al., 2019) and provide a guideline for the European transition to renewable-based power supply systems (Pleßmann and Blechinger, 2017); to develop a conceptual framework of specific societal trends (Gadenne et al., 2011) and investigate the role of the messages from government, enterprises and media in changing consumer behaviour and reducing energy demand (Ferdousi and Qiang, 2016; Chen and Kim, 2019). These studies apply qualitative methods, such as literature review, scenario development and impact assessment, conducting surveys, interviews and site-visits, etc., as well as quantitative methods including statistical analysis, energy modelling, data mining, cluster analysis and others.

Table 6.1 presents the examples of studies investigating the impacts of new societal trends on future energy demand in different countries.

Table 6.1. Examples of studies investigating the impacts of new societal trends on future energy demand

Author (year)	Main goal	Methods	Governance level
Barbu et al., 2018	To discuss the possibility for the sharing economy to bring about profound changes in consumer behaviour towards products and services and to highlight the factors that drive consumers' shift towards the sharing economy	Model based on consumer questionnaire data, in which the change in consumer mind-set is based on the satisfaction with the services of the sharing economy and the intention to access such products and services	Global
Bartholdsen et al., 2019	To describe three possible scenarios for the transformation of the German energy system until 2050, taking into account current climate policies on a global, European and German level, and also including different demand projections, technological trends and resource prices	Linear cost-optimising model (GENeSYS-MOD) to calculate the cost-efficient paths and technology mixes for scenario development	EU (Germany)
Chen and Kim, 2019	To develop the coordinated circular economy-energy transition approach, which brings in synergistic effects, such as promoting circular economy activities among industries, reducing energy demand and attaining additional greenhouse gas mitigation potential	Literature review of the circular economy and energy transition frameworks	Global
Cheshmehzangi, 2020	To explore the impacts of COVID-19 (associated with longer-term energy demand changes or temporary) on household energy use/demand	Statistical analysis (household energy use)	Asia (China)
Czibere et al., 2020	To analyse the social factors influencing energy use and energy efficiency in four different European countries, using the data from the PENNY research (Psychological social and financial barriers to energy efficiency-Horizon 2020)	Online interviews in cooperation with service providers in three countries; survey of households in four European countries (Italy, The Netherlands, Switzerland, Hungary) to compare environmental self-identity, values and attitudes towards the energy use of European citizens	EU (Italy, The Netherlands, Switzerland and Hungary)
Ertz et al., 2018	To investigate the extent, to which collaborative consumption enthusiasts are significantly more likely to engage into specific forms of socially responsible consumption, in contrast to regular consumers	Online questionnaire survey of consumers and cluster analysis combined with analyses of variance in social engagement	America (Canada)
Fabiani et al., 2021	To use dedicated survey campaign for investigating the potential pros and cons of remote working	Logistic regression and generalised linear models for capturing the effect of several independent variables on user acceptance of remote working	EU (Italy)
Ferdousi and Qiang, 2016	To investigate whether any awareness creating messages either from the government, enterprises or media influences consumer behaviour towards buying green products	Online and offline questionnaire, among respondents living in Wuhan, capital of Hubei Province, in China. Descriptive statistics, correlation and regression analysis to analyse the data	Asia (China - Wuhan, capital of Hubei Province)

		(based on SAS 9.1.3 version)	
Figueroa and Lah, 2020	To investigate factors and solutions needed to avoid creating a gap between technological mobility systems and human dimensions (including policy alignment and social innovation can strengthen feasibility of a fast transformation of transport energy use)	Literature review, statistical analysis	Global
Gadenne et al., 2011	To develop a conceptual framework of consumer environmental behaviour and its antecedents, and test hypotheses within the framework by means of a survey of green consumers	Online survey with customers of three ‘environmentally friendly’ firms that sold green products and services in the Sunshine Coast region of Australia	Australia (Sunshine Coast region)
Kramers et al, 2014	To explore the opportunities of using ICT as an enabling technology to reduce energy use in cities	Analytical framework, which builds on a combination of household functions and ICT solutions for sustainable cities to reach their climate targets	EU (Sweden)
Kylili et al., 2020	To establish impact indicators that demonstrate the contribution of remote working models in tackling energy and environmental challenges for the transition of European cities to smart energy regions	Scenario development and impact assessment (impact indicators)	EU (Cyprus)
Lange et al., 2020	To investigate four effects of digitalisation on energy demand (direct effects, energy efficiency increases, economic growth, sectoral change/tertiarisation)	Literature review (debates on ICT for sustainability), analytical modelling to investigate the potentials and risks of ICT for decoupling	Global (EU and other countries)
Mrówczyńska et al., 2020	To estimate the potential for reducing energy demand depending on socioeconomic factors (household standard and its location in the city) based on built-in scenarios and searching for the optimal way of conducting development policy at the local level	Modelling based on real and estimated data on the diversity of energy demand (minimum and maximum achievable energy saving potential), scenario development with a modelling method based on radial artificial neural networks	EU (Poland, Zielona Gora city)
Noussan and Tagliapietra, 2020	To propose a scenario analysis for the future of European passenger transport, by evaluating the potential effects of digitalisation on mobility demand, energy consumption and CO_2 emissions	Energy modelling (multiple indicators through European statistics: final and primary energy demand, CO_2 emissions, share of renewable energy sources, other pollutants emissions, etc.), scenario development	EU
Pleßmann and Blechinger, 2017	To provide a guideline for European stakeholders for transition from conventional to renewable-based power supply systems	Linear model (elesplan-m) to simulate a techno-economically optimised decarbonisation pathway for 18 interconnected European regions	EU
Tagliapierta et al., 2019	To outline the key priorities that should drive the EU energy and climate policy making for the new institutional cycle 2019-2024	Literature review (European policy documents on policies and regulations)	EU
Werner, 2015	To reveal factors and spatial patterns of dissemination of ICT technology and comparison of their electrical energy consumption	Statistical analysis of spatial data using shift and share analysis, factor analysis and visualisation using GIS tools	EU
Woods et al., 2017	To identify how user behaviour, in particular owners, managers, tenants and customers, influences energy performance in European shopping centres	Cross-methodical approach, including web-based questionnaires (to get statistical data on energy efficiency and sustainability in shopping centres), interviews, site-visits and literature reviews	EU (Norway, Spain, Italy, Germany and Austria)
Zhang and Mi, 2018	To quantitatively estimate the environmental benefits of bike sharing	Big data techniques for estimating the impacts of bike sharing on energy use and CO_2 and NO_x emissions	Asia (China, Shanghai)
Zink and Geyer, 2017	To define circular economy rebound, explain the mechanisms that drive it, and propose suggestions for avoiding rebound so that the promise of the circular economy can be fulfilled	Literature review (articles on circular economy rebound from 2000-2012 years)	Global

Source: compiled by authors.

Foresight methods are frequently applied to identify and analyse future trends and challenges related to European energy transition. Such methods are used for working with different data sources (Mikova and Sokolova, 2019) and include among others:

- horizon scanning of the key trends, factors and uncertainties (Saritas and Proskuryakova, 2017; Cuhls, 2019);
- organising expert workshops (Ansari and Holz, 2019), interviews and surveys including Delphi methods (Obrecht and Denac, 2016; Kattirtzi and Winskel, 2020);
- bibliometric analysis (Kajikawa et al., 2008; Mockel et al., 2019), patent analysis (Li et al., 2019; Linares et al., 2019; Cao et al., 2021) and data mining (Li et al., 2019);
- scenario development and modelling (Ansari and Holz, 2019; Mockel et al., 2019; Ghasemian et al., 2020);
- life-cycle analysis, text mining and clustering (Rezaeian et al., 2017);
- analysis of indicators (Steblyanskaya et al., 2021);
- network analysis (Linares et al., 2019; Saritas and Nugroho, 2012);
- cross-impact analysis (Ghasemian et al., 2020).

Using foresight and other methods, a number of studies investigate controversial impacts of trends from specific areas on future energy demand (decreasing, increasing or shifting) taking into account their relationships. For example, Gadenne et al. (2011) investigate the influence of consumers' environmental beliefs and attitudes on energy saving behaviours and conclude that both intrinsic and extrinsic environmental drivers together with social norms and community influence are associated with environmental attitudes, but cost barriers may have a negative influence. The aim of the study by Werner (2015) is to reveal factors and spatial patterns of dissemination of ICT technology in EU households and compare their electrical energy consumption. The study is based on the comparison of partial indices of the information society, an explanation of the energy rebound effect (take-back effect) and statistical analysis of spatial data using shift and share analysis. The goal of the research by Pelau and Acatrinei (2019) is to analyse the impact of digitalisation on household energy consumption, with the intent to understand trends, anticipate future changes as well as the impact on energy efficiency. The results of the panel regressions based on the quantity of consumed energy and the popularity of several internet activities have revealed an inverse relation − the increased number of consumers doing certain online activities, such as internet calling, reading online newspapers, activities on social media networks and uploading content online, determine a lower energy demand. Lange et al. (2020) use an analytical model to investigate four effects of digitalisation on energy consumption and conclude that digitalisation can only boost sustainability when it fosters two effects (energy efficiency increases, sectoral change/tertiarisation) without promoting two other effects (direct effects from the production, usage and disposal, economic growth from increases in labour and energy productivities). Noussan and Tagliapietra (2020) analyse the possible impact of digitalisation on energy demand in European passenger transport in two opposite scenarios. This research illustrates that the penetration of digital technologies can lead to opposite effects with regard to both energy demand and emissions, and the likelihood of these two possible pathways is related to multiple drivers, including users' behaviour, economic conditions and transport and environmental policies. Court and Sorrell (2020) conduct a systematic literature review of the direct and indirect impacts of digitalisation of goods on energy demand. They notice that most of the current studies assume that digital goods substitute for material goods and all of them neglect rebound effects-which suggests that they overestimate energy savings. Given the diversity and context-specificity of the available evidence, the optimistic assumptions that are frequently used (e.g. perfect substitution) and the neglect of rebound effects, the authors cannot conclude that e-materialisation has delivered significant energy savings to date or is likely to do so in the future. The paper by Santarius (2020) examines whether digitalisation helps or hinders an absolute decoupling of environmental throughput from economic growth. Comparing the mitigating and the aggravating impacts of digitalisation, we conclude that a more active political and societal shaping of the process of digitalisation is needed to make ICT work for global environmental sustainability. Zink and Geyer (2017) investigate the "circular economy rebound" effect and argue that circular economy activities can increase overall production, which can partially or fully offset their benefits. They argue that the "circular economy rebound" occurs when circular economy activities, which have lower per-unit-production impacts, also cause increased levels of production, reducing their benefit. Ghasemian et al. (2020) use cross-impact analysis to investigate the interrelationships between STEEPV[42] trends mentioned in the global energy scenarios by 2040. The study applies mathematical principles to quantify the rational judgments of an expert panel in social, technological, economic, environmental and political framework through cross-impact analysis.

Nevertheless, there are the following challenges that are identified in the previous studies. First, the current studies focus mostly on global scenarios and investigate the influence of broad trend clusters on development in specific areas (such as digitalisation, transport, consumer behaviour, circular economy, etc.), without establishing clear connections with future energy demand. Second, the research in this area is quite fragmented (f.e. they may cover only one main trend without analysing its connections with other trends) and lacking assessment details, so a

[42] STEEPV stands for: social, technological, economic, environmental, political, values trends.

more systemic approach covering many energy-related areas with possible estimations of such impacts is needed. A quantification (assessment) of the influence of societal trends on energy demand exists only for a number of trends and the relationships between them are not obvious. Third, the controversial (multidirectional) impact of trends is understudied. Although there are attempts to measure not only positive, but also negative impact, the development of more detailed narratives for specific trends is needed, that can provide additional information and be helpful to understand the multidirectional impact of new societal trends on energy demand (decreasing, increasing or shifting) in a particular sector. Fourth, in previous studies interrelationships between new societal trends are mentioned but not actively taken into account in the scenarios. Finally, based on this additional information about the trends interrelationships, it could be helpful to analyse the demand-side policy instruments that influence the development of these trends and get insights into what additional policies need to be designed in the appropriate sectors to enhance their decreasing impacts on energy demand in the European countries.

Therefore, the main research question of this study is:

How information about interrelationships between new societal trends and their controversial impact on future energy demand can support the formulation of environmental policies in the European countries?

3. Methodology

Section 3 presents the methodological approach to identify and analyse energy-related new societal trends and their interrelationships. This approach includes two main stages (*identification* and *analysis*) and five consecutive steps (see Figure 6.1).

The methodology combines qualitative (foresight) methods, such as environmental scanning, expert workshops and surveys, impact assessment, review of policy instruments, as well as quantitative methods (network and statistical analysis). Such combination is not widely applied and is a strength of the newTRENDs project (Fraunhofer ISI, 2022). The results obtained from this research (the list of 15 new societal trends with assessment, network of interrelationships between 11 priority trends and the list of the policy instruments for two trend dyads ("Digitalisation" and "Sharing economy", "Digitalisation" and "Circular economy")) are to be further integrated in the next stages of the newTRENDs project, namely into the quantitative models frequently used by the EU for long-term forecasting.

The workshop series (see Figure 6.1) is designed to leverage expert knowledge to identify important societal trends, issues, events and conditions with the strongest potential to affect future energy demand in the European countries, as well as the interrelationships between these factors. Over the course of three workshops, the experts in energy-related fields (such as green energy, sustainable urban development, sharing economy and others) and the newTRENDs team members work to define clusters of factors whose impact on energy demand is the most important. The experts come from the European countries and have academic, business or policy background. Given the ongoing COVID-19 pandemic and the accompanying restrictions on travel and person-to-person meetings, the workshops are designed to take place using two online platforms. Microsoft Teams[43] is used for audio and visual communication and Miro[44] – as an online whiteboard application for interactive exchanges (Fraunhofer ISI, 2022).

The experts actively participate in this research (participatory expert workshops and surveys), so it is crucial to take into account possible foresight biases (information bias, end-of-history illusion bias, hindsight bias, optimistic bias, confirmation bias, ambiguity aversion bias, groupthink bias, etc.). For example, Schirrmeister et al. (2020) identified 17 biases that influence one foresight method alone – the scenario development process. These biases affect the smoothness of information processing during the scenario process, the influence of belief on information processing, the selection and integration of data, and interaction within groups.

In our study we take the following steps to overcome the biases:

Identification stage:

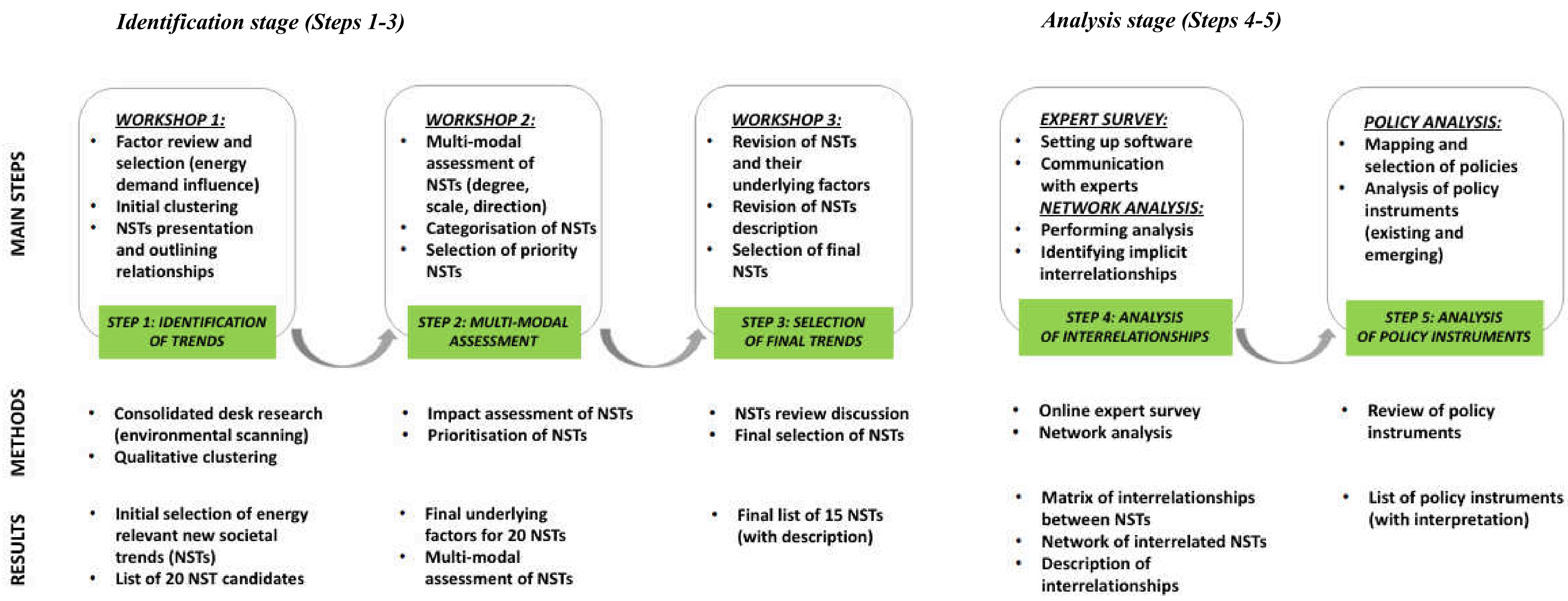
- expanding viewing angle to collect insights from internal community and signals from external sources (f.e. the future of mobility versus the future of car sharing);
- using various sources of data (qualitative and quantitative) and involving different stakeholders (academia, business, etc.);
- encouraging people to work in small groups, interact and collaborate using Miro workspace;

Analysis stage:

- inviting internal and external experts to analyse factors, trends, technologies and key uncertainties;
- sharing the results for open discussion with customers and partners.

[43] https://teams.microsoft.com
[44] https://miro.com

Figure 6.1. Research methodology



3.1. Step 1: Identification of trends (the 1st workshop)

Environmental scanning (Slaughter, 1999; Toivonen and Viitanen, 2016) and horizon scanning (Cuhls, 2020; Könnölä et al., 2012) methodologies are essential to the discovery and identification of new societal trends candidates in Step 1. To better facilitate the newTRENDs workshops 1-3 (Figure 6.1) conducted in 2021, initial research focuses on identifying key factors[45] − defined as individual trends, social conditions, emerging issues, events − that create societal change and could influence future energy demand in European countries taking into account socio-economic context (COVID-19 pandemic). In this way, 241 initial factors are gathered from a review of previously published foresight research, including holistic assessments of changes affecting the futures of the EU (European Commission, 2020c; Gaub, 2019), global systems of governance (Rosa and Roess, 2019) and social innovations (Warnke et al., 2019; Zweck et al., 2015).

In Step 1, 22 trend candidates are composed from these underlying factors in three working groups during *the first expert workshop*: "Society and lifestyle" (6 trends), "Business and industry" (8 trends) and "Politics and governance" (8 trends). During the plenary discussion, these 22 trends are condensed into 20 priority trends based on how their underlying factors are connected to each other.

3.2. Step 2: Multi-modal assessment (the 2nd workshop)

The second expert workshop produces a more detailed understanding of the composition and internal relationships of the previously identified new societal trends. The activities include a multi-modal assessment of each underlying factor, with respect to its impact on future energy demand at three dimensions: "Impact degree" (high, medium, low), "Impact scale" (macro, meso, micro) and "Impact direction" (decreasing, increasing, shifting)[46].

To facilitate a streamlined and productive meeting in the third workshop, the products of the assessment activities are reviewed and trend candidate "narratives" are written to explain identified dynamics and relationships. These descriptive narratives describe high impact compositional factors, their interrelationships and potentials for disruptive change through combinations or dynamic environmental

[45] We further use two main terms in the paper: "trends" are the new societal trends themselves and "factors" are the underlying factors they consist of.

[46] "Impact degree" indicates the potential disruptiveness of a trend's impact (high, medium, low). A trend has a high impact degree if it would change the whole socio-economic system at one of three scales in the next 5-10 years. "Impact scale" determines at what level the influence of the trend extends: global or supranational level (macro), national or regional level (meso) and individual or community level (micro). "Impact direction" shows whether the development of a trend leads to the increase, decrease or shift of energy demand between sectors.

conditions. These narratives become the centrepiece for the third workshop, as they summarise the efforts of two previous workshops into approachable texts that can be quickly read, expanded and utilised (Fraunhofer ISI, 2022).

3.3. Step 3: Selection of final trends (the 3rd workshop)

The first part of *the third workshop* is a review of the trend narratives written by the project team. Each narrative provides details about underlying factors within each trend as derived from the assessment matrix results of the second workshop. These descriptive narratives outline the relationships between factors and describe expert assessments regarding the conditions that can make the trend more disruptive to future energy demand. The second part of this workshop evaluates the initial prioritisation results of the 20 new societal trends, when candidates are combined and reprioritised based on project goals and consortium discussion (Fraunhofer ISI, 2022).

As a result, the third workshop produces a final list of 15 trends, divided into "universal" (7 trends), "nice to have" (4 trends), "optional" (3 trends) and "future research" (1 trend). In order to make the further expert survey and trends analysis more precise and manageable, the 241 factors are condensed into 96 factors, removing duplicates and combining overlapping and similar ones[47]. As a result, each of the 15 trends includes from 4 to 9 underlying factors important for its development (see Table 6.2 in Section 4). The final narratives for these trends are further developed and revised according to the feedback received from experts (see Appendix 6.1).

3.4. Step 4: Analysis of interrelationships

3.4.1. Expert survey

Around 150 experts from the European countries are invited to participate in an online survey to assess the interrelationships between the factors and trends. The survey website is open to the participants for three weeks (January-February 2021), and during this period 30 experts from research institutes and universities (20 persons), business companies (7 persons), governmental bodies (3 persons) and other organisations, participate in the survey. These people have expertise in energy-related fields including but not limited to energy (efficiency) policy, economic development (in primary, secondary and tertiary sectors), modelling, circular economy, foresight studies, digitalisation and sharing economy. They

[47] For example, the factors "Rise in the number of urban settlements", "Increased urbanisation" and "Increasing land area of cities" are combined and form together one factor "Increased urbanisation (rise of population and number of urban settlements)".

include scientists, analysts, modellers and other professionals and have a master's or doctorate degree.

To focus only on the most relevant trends and reduce the time required for answering the questions, the survey is conducted for 11 priority trends[48], the 7 "universal" and the 4 "nice to have" trends identified in Step 3 (see also Table 6.2 in Section 4), each including between 4-9 factors. For each trend the experts are requested to assign its underlying factors to one other trend, which they found the most relevant. To provide flexibility in the time spent on the survey, the participants are first requested to evaluate the 7 "universal" trends. They are then given the option to either end the survey or further evaluate one or more of the remaining 4 trends. All the questions included in the survey are optional, meaning that the respondents could skip evaluating one or the other trend. To avoid similar response patterns, the trends are shuffled in the survey randomly.

3.4.2. Network analysis

After collecting the experts' opinion on connections between the factors and trends, the strength of interrelationships between the 11 new societal trends is analysed taking into account the underlying factors, through which they are connected. The wealth of information provided in the expert survey regarding the factors that compose each new societal trend, allows for performing a network analysis.

Based on the results of the expert survey, the matrix of interrelationships between the 11 new societal trends is created and used as the foundation for further network analysis, which aims to understand explicit and implicit relationships between trends and their connecting factors that may influence future energy demand in the European countries. We recall that each of these trends is a cluster of several of the 241 initial factors identified before and during the first expert workshop. The network is developed to visualise interrelationships between the trends through their common underlying factors (see Figure 6.3 in Section 4.2.1).

[48] It is important to note that this research was done in 2021, before the outbreak of the Russia's war against Ukraine. At that time we made an attempt to take into account the context and consequences of the global COVID-19 pandemic through analysing such related trends as digitalisation, decentralised work, sharing economy and others, but in the light of the current events, the new societal trend "Geopolitics and Global Forces" has become more important. We are currently identifying ways how this trend can meaningfully be integrated into the project logic and what energy policy measures should be taken into account in a low-demand / low-gas energy scenarios.

3.5. Step 5: Analysis of policy instruments

Climate, energy, and environmental policies may influence new societal trends or their combinations (trend dyads)[49], amplifying their positive and/or mitigating negative contribution to energy transition. Knowledge about the factors (parameters) derived from network analysis, which may simultaneously influence both trends in a dyad (decreasing, increasing or shifting energy demand), gives insights into what additional policies need to be developed in the appropriate areas.

In our exploratory study we take two examples of trend dyads: (1) "Digitalisation" and "Circular economy"; (2) "Digitalisation" and "Sharing economy", and analyse energy demand-side policy instruments related to their development. These two dyads were selected due to their priority for the newTRENDs project, availability of experts and input material. Nevertheless, such a methodological approach can be applied to any other dyads of trends under investigation. In this research we focus on key connecting factors (from Step 4), which are influential for both trends in a dyad. To provide homogenous and comparative results, we follow a common framework that includes mapping and analysis of the EU policy instruments, which have or are expected to have simultaneous major impacts on both trends in each dyad. To this end, we study: (1) the existing EU policy instruments, i.e. instruments that are legally binding as of June 2022; (2) the emerging policy instruments, i.e. instruments that have been formally proposed in official preparatory documents, produced during the various stages of the EU legislative and budgetary processes, including in particular the European Commission's legislative proposals.

4. Results

4.1. Identification stage (Steps 1-3)

Steps 1-3 provided the final list of 15 new societal trends (see Figure 6.2 and Table 6.2) divided into the categories, with 7 trends identified as "universal", 4 trends identified as "nice to have", 3 trends identified as "optional" and 1 trend placed into the "parking lot" for future research. This included the creation of one entirely new trend "Circular Economy" and three amalgamated clusters: "Sustainable Cities" now includes also the trend candidate "Urbanisation". "Socio-Economic Dynamics" was combined from the candidates "Energy Poverty", "Socio-Economic Equality", "Rebound Effect" and "Growing Middle Class". Lastly, the cluster "Demographic Change" was created based on "Healthy Aging", "Growing Youthful Population" and "Migration and Displacement".

[49] The dyads such as: "Digitalisation" and "Sharing economy", "Digitalisation" and "Circular economy" or others.

Table 6.2 presents these 15 final new social trends with short description. The descriptive narratives were developed for these trends to understand the potential mechanisms of their impact and disruptiveness for future energy demand (the full list of narratives is presented in Appendix 6.1). The claims in these narratives should be considered as hypothetical and yet to be tested, as they illustrate the core dynamics and effects of each cluster as highlighted during expert review and are meant to guide future modelling efforts. However, these narratives may ultimately turn out to be only partially true, or even false, since they represent a record of current expert discussions, but not statements of empirical facts (Fraunhofer ISI, 2022).

Figure 6.2. The final list of new societal trends

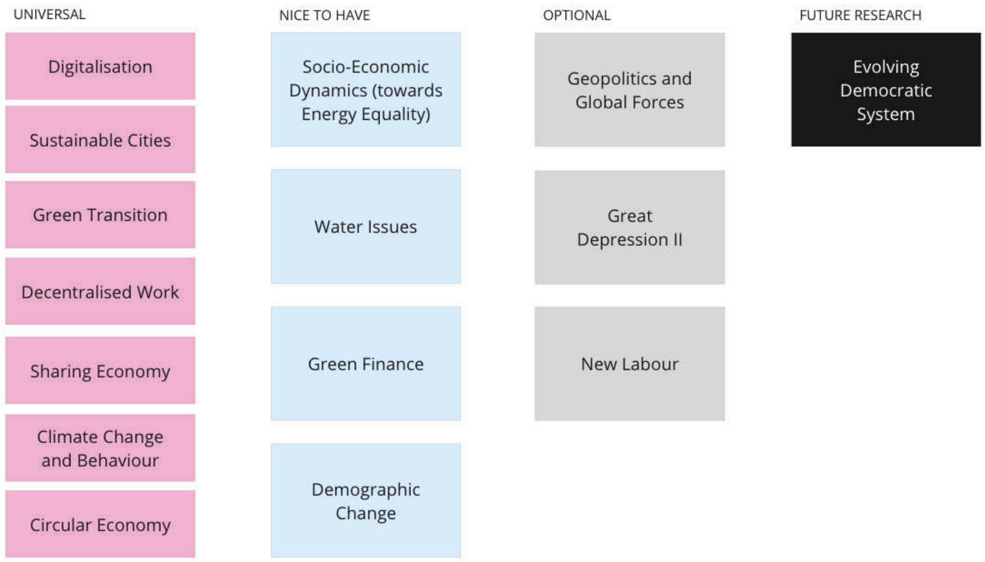


Table 6.2. Short description of 15 final new societal trends

Trend	**Short description**	**Number of underlying factors**	**Category**
1. Digitalisation	New challenges and requirements of the progressing digitalisation	8 factors	Universal
2. Sustainable Cities	The development of urban living spaces to meet future challenges	9 factors	Universal
3. Green Transition	Determining an appropriate policy mix for relevant challenges	5 factors	Universal
4. Decentralised Work	Remote working allowing workers to operate from anywhere	4 factors	Universal
5. From Owning to Sharing	The growing sharing culture enabling innovative ideas in exchange of knowledge and promoting sharing platforms	5 factors	Universal
6. Climate Change and Behaviour	Increasing climate change concerns requiring changing consumer behaviour	7 factors	Universal
7. Circular Economy	Building an autonomous and sustainable socio-economic system in line with environmental challenges	6 factors	Universal
8. Socio-Economic Dynamics	Socio-economic systems involving various aspects of human activities and complex factors of living environment	9 factors	Nice to have
9. Water Issues	Increasing water scarcity affecting multiple aspects of society	7 factors	Nice to have
10. Green Finance	Increasing recognition of behavioural impact leading to new financial services	6 factors	Nice to have
11. Demographic Change	Demographic developments including the birth and mortality rates, age structures, as well as mobility, urbanisation and quality of life	8 factors	Nice to have
12. Geopolitics and Global Forces	Role of the geopolitical dimension in trade, social aspects, demand/supply sides	5 factors	Optional
13. Great Depression II	Depression affecting the financial situation in the countries and increasing migration	5 factors	Optional
14. New Labour	Increasing relevance of labour for societal participation	6 factors	Optional
15. Evolving Democratic System	Political systems adapting to social platforms, data streams, changing demographics	6 factors	Future research

4.2. Analysis stage (Steps 4-5)

In this stage we analysed first, the interrelationships between the 11 priority new societal trends and second, policies that may have synergetic impacts on the trends in order to enhance their energy demand decreasing character and to impede energy demand to increase under the impact of new societal trends. To illustrate the whole analysis process, we took the first trend dyad "Digitalisation" and "Sharing economy" as an example, and as mentioned before, added on the analysis of energy demand-side policy instruments for the second dyad "Digitalisation" and "Circular economy".

4.2.1. Analysis of interrelationships

As mentioned in Section 3.4.1, for each of the 11 trends the experts were asked to assess their connections to the underlying factors of the other trends[50]. Based on this, a matrix of interrelationships was created, including the 11 trends in the rows and the values of the entries describing the number of underlying factors of each of these trends that connect them with the rest 10 trends (in the columns). Figure 6.3 presents the final network[51], which includes 11 new societal trends and their interrelationships.

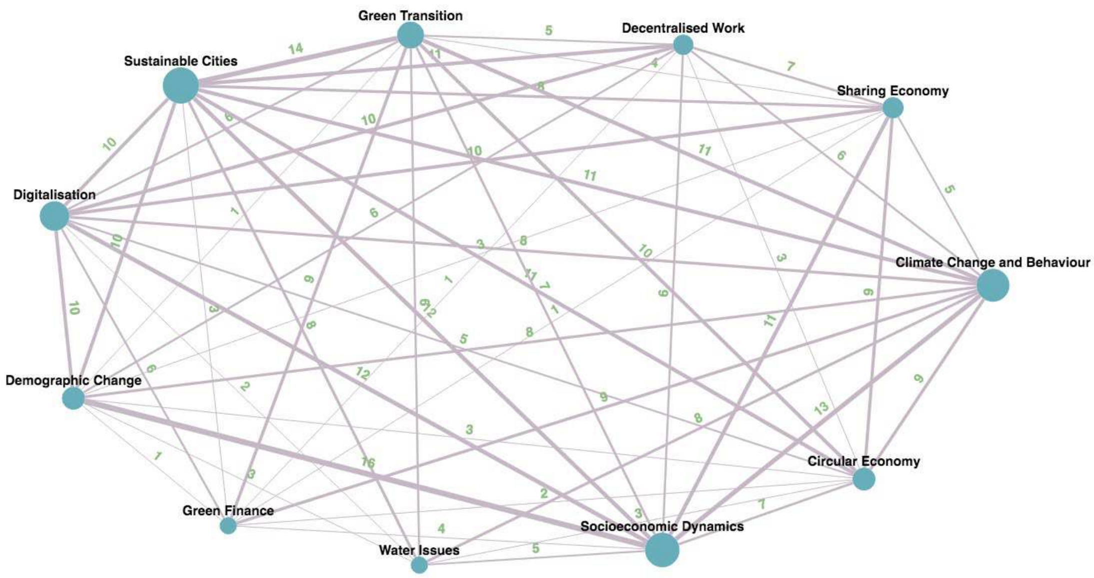
As seen from Figure 6.3, almost all trends have connections, but in our study we investigate the strength of these connections and also how the combinations of trends can create the new areas for research. The biggest nodes (trends) in the network are: "Sustainable Cities", "Socioeconomic Dynamics", "Climate Change and Behaviour", "Digitalisation" and "Green Transition". The information on the

[50] For example, the trends in the dyads "Digitalisation" and "Sharing economy" are interrelated through ten underlying factors. The factors for analysis are taken from the list of 96 factors created from the original 241 factors (see Step 3 in Section 3). Five factors from "Digitalisation", which are related to "Sharing economy", are the following: *e-government* to foster transparency; *technology governance* including science, technology and innovation policy; *open access to knowledge* freely available and free of charge for all; *digital currencies* gaining in variety, including crypto-currency; and *digital technology business models* including gamification. Five factors from "Sharing economy", which are connected to "Digitalisation", include: a new *"sharing culture"*, which is characterised by co-production, co-management and sharing resources, time, services, knowledge, etc.; the transition from ownership models to *"collaborative consumption"*; online and offline sharing communities; *data sharing*, which implies open access to information by individuals, organisations and governments; and *collaborative innovation spaces*, such as shared offices and living labs, which can be used for co-creation, information exchange, knowledge sharing, social interaction, etc.

[51] The network was created by the authors using the Graphonline software (www.graphonline.ru).

connections between new societal trends can be used to derive parameters that can express or translate their interconnectedness[52].

Figure 6.3. The network of connections between 11 priority trends[53]



In Appendix 6.2, we present the 10 dyads of the most interconnected new societal trends in more detail. For example, based on the results of network analysis, we can analyse the area so-called "digital sharing economy", the development of which can have a controversial impact on future energy demand in the European countries. "Digital sharing economy" can have a decreasing impact, as data sharing can be considered as "a way to optimise highly-relevant data, generating more robust data and analytics to solve business challenges and meet enterprise goals" (Gartner, 2021). But at the same time, increasing impact can be caused by the need to provide quality, transparency and privacy in this process. The two trends ("Digitalisation" and "Sharing economy") together may influence energy demand in the European countries in different directions (decreasing, increasing or shifting). Table 6.3 includes three connecting factors, which were considered by the experts as the most important for "Digitalisation" and "Sharing economy"

[52] In this exploratory study we use the number of connecting factors to illustrate the interrelationships between trends. More detailed analysis of these interrelationships can be further required, taking into account different number of underlying factors within the trends, the number of expert votes for the connection, the number of experts voted for the trends, etc.

[53] The size of each of the 11 nodes (trends) does hereby not represent its overall importance, but its connectedness. The larger the node is depicted, the more it is connected with other trends through underlying factors. The values on the lines provide the number of underlying factors, through which the trends are interrelated. For simplicity, in this exploratory study, we count that Trend A and Trend B have a connection through a specific factor if at least one expert voted that this factor from Trend A is related to the Trend B. For example, the trend "Digitalisation" (with 8 underlying factors) and the trend "Sharing economy" (with 5 underlying factors) are connected through 10 factors (5 factors from "Digitalisation" and 5 factors from "Sharing economy").

(open access to knowledge, online and offline sharing communities and a new "sharing culture") and presents the examples of their possible controversial impact on future energy demand. In the expert workshop the main discussion was about the decreasing impact of these three factors. Taking this into account, we attempt to analyse not only the decreasing impact, but consider the broader context and also give the examples of possible increasing or shifting potential. It is important to emphasise that these connecting factors were the findings from the expert survey, so they may not be all-encompassing and should, therefore, be considered as a starting point for future research.

Table 6.3. Connections between the trends "Digitalisation" and "Sharing economy" with their possible impacts on energy demand

Key factors connecting the trends "Digitalisation" and "Sharing economy" and *other related factors	**Impact degree (High / Medium / Low)**	**Impact scale (Macro / Meso / Micro)**	**Impact direction (Decreasing / Increasing / Shifting)**	**Additional context: examples of other possible impacts**
based on expert discussions				*based on literature review*
1. Open access – knowledge freely available and free of charge for all	Low	Macro	Decreasing	**Increasing/Shifting energy demand:** • While new end-user devices are more and more energy-efficient and energy demand per transferred gigabyte has significantly decreased, people spend more time and consume more data via their mobile devices than ever before (Pihkola et al, 2018). • Data centres and data transmission networks are responsible for nearly 1% of energy-related GHG emissions (IEA, 2022).
*Open source software / hardware	Low	Macro	Decreasing	
*Digitalisation of knowledge: move from physical to electronic publications (already a mature trend)	Low	Macro	Decreasing	
*Increase awareness of energy inputs (more conscious consumption)	Low	Macro	Decreasing	
*Less duplication of work	Medium	Meso	Decreasing	
*More efficient use of resources	Medium	Meso	Decreasing	
2. Online and offline sharing communities	High	Micro	Decreasing	**Increasing / Shifting energy demand:** • In order to prevent that consumers move away from public transport systems to car sharing, some measures need to be taken to change the competitive relationship between the two modes (Luan et al., 2018). • The case of rebound effects occurring within the same resource or service system. F.e. affordable accommodation provided by Airbnb enables guests to use more of the platform's services (Pouri and Hilty, 2021).
*Urban planning and energy demand in buildings	High	Micro	Decreasing	
*Parking space for bike parking or sharing	High	Micro	Decreasing	
*Sharing physical objects (tools, etc.)	High	Micro	Decreasing	
*Sharing physical spaces (e.g. more cycle friendly public space)	High	Micro	Decreasing	
*Uber and other sharing models	High	Micro	Decreasing	
3. A new "sharing culture"	High	Micro	Decreasing	**Increasing / Shifting energy demand:** • There is a concern that some companies may use the "sharing economy" as a marketing gimmick to disguise excessive profit-motivation and exploitation, while arguing they make society a better place (Zhifu and Coffman, 2019).
*Urban and rural sharing systems	High	Micro	Decreasing	
*Honesty boxes	High	Micro	Decreasing	

Source: compiled by authors.

Based on discussions with experts, all three connecting factors have a potential to decrease energy demand on macro-, meso- and micro-level. However, technological progress related to "digital sharing economy" may not be enough for eliminating negative environmental impacts and can play a significant role in creating environmental challenges and concerns (Bleys et al., 2018). For example, "car sharing" may have controversial impact on energy demand. On the one hand, with car sharing fewer vehicles are needed to cover an equal traffic demand, less parking space and facilities are needed, owning a private car becomes less necessary, which leads to a decrease in production materials. In addition, car sharing may promote using electric vehicles and contribute to GHG emissions reduction. On the other hand, car sharing may make it more difficult to use electric vehicles because of infrastructural challenges and also increase the rate of car usage due to low cost of mobility (Lazarus et. al, 2018), intensive shared car use may require much repair cost (Weber, 2018), affordable car sharing may lower interest in public transport (Pouri and Hilty, 2018). Therefore, while the "sharing economy" has the potential to encourage shifts in collective consumption patterns, better governance models and strategies are required to support this process. For example, the EU's Sharing Cities project aims to develop affordable, integrated, commercial-scale smart city solutions with a high market potential by fostering international collaboration between industry and cities (Sharing Cities, 2022). Such policies can positively contribute to the energy transition by offering the ways of more efficient resource allocation and additional frameworks for citizen engagement and collaboration.

4.2.2. Analysis of policy instruments

In this section we discuss for two exemplary trend dyads ("Digitalisation" and "Sharing economy", "Digitalisation" and "Circular economy") the EU policies that may have synergetic impacts on the trends in order to enhance their energy demand decreasing character.

As policy instruments we understand all rules and regulations, both formal (laws, regulations, policy incentives) and informal (bottom-up initiatives, soft measures), which shape and determine the environment of the investigated trends. We analyse three categories of policy instruments in the European countries: a) regulation; b) economic and financial instruments; and c) soft instruments. *Regulations* include legal acts and other formal documents, such as standards, that should be followed by EU market actors. *Economic and financial instruments* mean mechanisms that provide financial incentives (e.g. grants, subsidies) for given activities. *Soft instruments* cover informal movements, bottom-up voluntary initiatives and approaches that aim at influencing people's behaviour and consumers' choices. To narrow down the scope of our analyses and provide sound and useful results, we exclude country-level policy instruments.

4.2.2.1. Policy instruments for the dyad "Digitalisation" and "Sharing economy"

The list of existing and emerging policies for the dyad consisting of "Digitalisation" and "Sharing Economy" is presented in Table 6.14 (Appendix 6.3). According to the experts' opinion, these two trends have ten connecting factors. The following three were ranked highest by the experts: "Data sharing", "Online and offline sharing communities" and "A new "sharing culture". The policy mix analysis shows that all three factors are closely interrelated and covered well with policy measures from all three categories:

- *regulation*, e.g., addressed by the European Commission's Proposals: for a Regulation on "Digital Services Act" (European Commission, 2020d) and for a Directive on improving working conditions in platform work (European Commission, 2021a);
- *economic and financial instruments*, e.g., "Horizon Europe", in particular Pillar II "Global Challenges and European Industrial Competitiveness", especially under Cluster 5: Climate, Energy and Mobility (European Commission, 2022a);
- *soft instruments*, e.g., Connected Collaborative and Automated Mobility (CCAM) Partnership between the CCAM Association and the European Commission in the context of the Cluster 5 of "Horizon Europe" (CCAM, 2022).

At the same time, other factors are less regulated by EU policies. For example, the factors "Disruption of ownership models" and transition to "collaborative consumption" and "Collaborative innovative spaces" are covered only by *product and sectoral standards*, such as Regulation (EU) 2019/1150 on promoting fairness and transparency for business users of online intermediation services (European Parliament and Council of the European Union, 2019). The factor "Digital currencies including crypto-currency" is mentioned in Regulation (EU) 2022/858 on a pilot regime for market infrastructures based on distributed ledger technology, and amending Regulations (EU) No 600/2014 and (EU) No 909/2014 and Directive 2014/65/EU (European Parliament and Council of the European Union, 2022). There are also factors, such as "E-government" and "Digital technology business models" that are covered by policies to a lesser extent.

Therefore, the analysis of policy mixes reflecting the agenda for the connecting factors of new societal trends may give additional information about how they are covered by existing and emerging policy instruments and what are possible gaps that can be filled with appropriate policy measures in order to foster the EU's energy transition.

4.2.2.2. Policy instruments for the dyad "Digitalisation" and "Circular economy"

Table 6.15 (Appendix 6.3) presents the policy instruments (existing and emerging) at the intersection of "Digitalisation" and "Circular economy". Based on the network analysis results, these two trends are connected through five factors: "Reindustrialisation (digitalisation and sustainability)"; "Technology governance (science, technology and innovation policy)"; "Digital currencies including crypto-currency"; "Digital technology business models (including gamification)"; and "Circular electronics (laptops, phone, e-books, etc.)". As seen from Table 6.15, "Reindustrialisation (digitalisation and sustainability)", being a broad area that touches upon various economic, social and political aspects of organising natural resources for re-establishing industries, as well as "Circular electronics", which was voted by a largest number of experts, are covered by many policy instruments from all categories. Among them are:

- the European Commission's Regulation (EU) 2019/424 laying down ecodesign requirements for servers and data storage products (European Commission, 2019c),
- the European Commission's proposal for a Regulation establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC ("Sustainable Products Initiative") (European Commission, 2022b),
- Green Public Procurement requirements for: (1) data centres, server rooms and cloud services (European Commission, 2020e); (2) computers, monitors, tablets and smartphones (European Commission, 2021b).

At the same time, some factors are mentioned only in specific categories. For example, the factor "Technology governance (science, technology and innovation policy)" is mostly discussed under economic and financial measures, such as the European Regional Development Fund and Cohesion Fund (European Parliament and Council of the European Union, 2021a). Another example is the factor "Digital technology business models (including gamification)", which is mostly addressed by EU soft instruments, such as Processess4Planet Partnership aiming to develop sustainable circular business models through digitalisation (Processes4Planet, 2022). However, the factor "Digital currencies including crypto-currency" is given less attention and discussed in policy documents only fragmentarily.

5. Discussion

Different policy coverage and possible gaps. The analysis of policy mixes for two exemplary dyads of trends (Tables 6.14-6.15 in Appendix 6.3) illustrates that their connecting factors are presented differently in the European energy policy agenda. Some of the trends or their combinations (trends dyads) are already considered in the legislation, while other trends are not yet substantially covered by policies. The four most important connecting factors [54] have been covered mostly by *regulation* [55] and *economic and financial instruments* [56]. At the same time, much fewer *soft instruments* [57] were or are expected to be implemented at the EU level. At the same time, the factor "Digital currencies including crypto-currency", which links both dyads, has only very recently come to the attention of the EU policy makers (European Parliament and Council of the European Union, 2022). The reason can be that digital currency has been developing not so long ago and its influence is not fully examined yet. Nevertheless, crypto-currency and blockchain technology can play a significant role in the development of the "Circular economy", helping obtain more knowledge on material cycles and processes through the value chain and enabling to share data in a secure environment (European Policy Centre, 2018). In the "Sharing economy", they can be used to coordinate activities of large groups of people at once who can organise themselves through directly communicating with one another. Therefore, the results of this study can be used to identify the possible gaps that can be covered with appropriate policy measures to foster the EU's energy transition.

Design of policies at the trends intersections. The findings from this research suggest that additional information about interrelationships between new societal trends can be helpful for the design of accompanying policy measures at their intersection. If we know that two new societal trends are closely interrelated through their common underlying factors, the energy efficiency policies can be designed in such a way that they focus especially on the connections between trends. Aiming to develop policy measures at the trends intersections, it is important to distinguish what specific policy instruments are meant only for one trend under investigation and what are meant for both trends at their interplay. This additional information may help understand how the European energy policies may

[54] These four factors have been selected by a largest number of experts during the survey. Connecting factors in the dyad "Digitalisation" and "Sharing economy" are (1) "Data sharing", (2) "Online and offline sharing communities" and (3) "A new "sharing culture". "Circular electronics" is a connecting factor in the dyad "Digitalisation" and "Circular economy".
[55] For example, the Circular Electronics Initiative, the Digital Services Act and the proposal for requirements on working conditions.
[56] Such as Green Public Procurement requirements for data centres and computers and Horizon Europe (Pillar II, Cluster 5).
[57] For example, the WEEE label or the Connected Collaborative and Automated Mobility (CCAM) Partnership.

be improved in terms of their potential impact on simultaneous development of several trends in a more synchronic manner.

Analysis of crossover policy impacts. Analysis of crossover policy impacts may also be helpful. For example, if we analyse two trends that are connected through three common underlying factors, we can get additional information from the policy analysis on how the policies may influence both trends and what should we look forward from this connection future wise. For example, aiming to design policies for the "Digitalisation", we have to also assess not only the impact on the "Digitalisation" itself, but also on the "Sharing economy" or the "Circular economy" if they are connected, trying to analyse the crossover effects from such policies. Therefore, more detailed analysis of the related trends in a dyad and their connecting factors can be useful to study their controversial impact on future energy demand in a more complete way and make suggestions on appropriate simultaneous policy measures at the EU level.

Limitations. This exploratory study comes with some limitations that need to be taken into account. Firstly, under a limited time frame, we analysed only 11 priority trends out of 15 trends, which were considered by the experts as the most important for the newTRENDs project[58]. Secondly, a limited number of experts (30 persons) took part in the workshops and survey, raising the issue of involving both "generalists" (interdisciplinary experts) and "specialists" from energy-related areas. Thirdly, due to limited resources for data collecting and processing, in our survey experts were asked to identify only "single" connections, but we did not analyse "multiple" connections[59], which could be also helpful to investigate. Fourthly, network analysis was mainly used for investigating the direct connections between trends and can be explored in more detail to analyse the roles of the various trends in the whole network, for example by analysing trend clusters and the trends, which are building the "bridges" between them, thus connecting otherwise unconnected clusters. Furthermore, to narrow down the scope of the study and provide sound and useful results, we excluded country-level policy instruments from the analysis of policy mixes. This does not neglect the fact that national policy instruments that work at the intersection of new societal trends do exist[60]. In this context, the results of our analysis of policy instruments could have

[58] See explanation on the trends selection in Section 3.4.1.

[59] "Single" connection means that a specific factor from Trend A is connected to one Trend B), while "multiple" connection means that a specific factor from Trend A is connected to several Trends: B, C, D.

[60] For example, at the intersection of "Digitalisation" and "Circular economy", Finland adopted a new strategic programme to promote a circular economy (Finnish Ministry of Economic Affairs and Employment and Ministry of the Environment, 2021). In this programme, the Finnish

been more comprehensive under wider analytical conditions. Further investigation of specific existing or emerging policies at the trends' intersections, also at a national level, is required to identify the areas where additional policy measures are needed to be developed or improved at the EU, country and regional level.

6. Conclusion and policy implications

Taking into account substantial and potentially disruptive impacts of new societal trends on energy demand (such as circular and sharing economy, digitalisation of economic and private life, prosumaging etc.), this paper aimed to study interrelationships between such trends, their controversial impact on the European future energy demand and policy measures that may influence their development in a synergetic way. This can help better understand how demand-side energy policies in specific areas at the trends intersections could be designed to maximise their contribution to energy transition.

Based on the results of the expert survey, the explicit and implicit relationships between new societal trends were identified through their connecting factors (parameters) that may influence future energy demand. This created a basis to study the policy instruments associated with two trend dyads as examples: "Digitalisation" and "Circular economy", "Digitalisation" and "Sharing economy". The analysis has shown that a number of factors are covered by many policy instruments from all categories (regulation; economic and financial instruments; soft instruments). The examples include: "Reindustrialisation (digitalisation and sustainability)", "Circular electronics" and "Online and offline sharing communities". At the same time, a number of connecting factors, such as "E-government", "Digital currencies including crypto-currency", "Digital technology business models", are underrepresented in the policy mixes, which means that there seem to be potential gaps, which can be filled by appropriate policy measures, such as the Markets in Crypto-Assets (MiCA) Regulation, aiming to establish harmonised rules for crypto-assets at the EU level.

The results of this study can be helpful to inform EU policy-makers how energy policies have to be designed to reduce energy demand by stirring synergetic new societal trends. First, network analysis allows to see the overall picture of interrelationships between new societal trends and study what policy measures are being taken at their intersection. For example, the factor "Circular electronics" connecting two trends "Digitalisation" and "Circular economy", is not fully

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government expects digitalisation to be a key enabler for circular economy. This will be implemented thanks to creating digital marketplaces and interoperable digital circular economy solutions that track material data, product information as well as analyse impacts of industry's and consumers' choices.

covered by policy instruments and can be considered as an area for potential policy adjustments, especially soft measures, such as information campaigns, voluntary projects and product labels. Second, the areas where policy gaps are identified (f.e. "Technology governance (STI)", "Digital technology business models" and "Digital currencies including crypto-currency"), can be explored more in detail to discover new emerging trends that are not yet covered but already require policy action. Additional investigation of these gaps can help inform the policy makers about the measures that are missing and can be put on the policy agenda. Third, some new societal trends may be connected with a group of factors (for example, the trends "Digitalisation" and "Sharing economy" are connected through the triad of factors – "Data sharing", "Online and offline sharing communities" and "A new "sharing culture"), which are closely interrelated and may require simultaneous policy actions in several areas. For example, for the development of a "digital sharing economy" in cities it can be accomplished by formulating regional strategies, which combine different policy actions (improving the living environment, reducing energy costs through managing city data, promoting sharing practices and solutions, etc.) to coordinate smart sharing cities in multiple countries (Sharing Cities, 2022). Fourth, the analysis of policies at the intersection of two trends allows to determine additional policy measures associated with their development (e.g. "Circular electronics" is related through policy instruments to "Reindustrialisation (digitalisation and sustainability)" and "Technology governance (science, technology and innovation policy)") and how the policy agenda should be redesigned to maximise their positive environmental impact. Furthermore, more studies on individual trends, as well as their controversial impact on each other and ultimately on future energy demand in the European countries, are further needed to gain more certainty on the policies required.

This paper investigates the interrelationships between new societal trends based on expert discussions and analyses how this may inform the enhancement of energy policy instruments, which aim to contribute to the energy transition being discussed in the European energy scenarios. This will allow a better understanding of potential non-linear developments of future energy demand and how the European energy policies can be designed to take new societal trends and their connections meaningfully into account.

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Appendix

Appendix 6.1. Narratives for 15 new societal trends[61]

“Universal” trend clusters

Digitalisation

This cluster summarises all kinds of trends, which are related to digitalisation. Digitalisation is seen as an enabler for a sustainable energy transition. At the same time, it is a driver of increasing energy demand in itself. This trend includes both developments. On one hand, including the rise of digital data storage and traffic and its corresponding increase in energy demand of data centres and networks as well as the increase in digital hardware production. On the other hand, it includes changes in the sectoral energy demand through digitalisation and enables energy and resource efficiency (e.g. in the transport sector through the trend of increasing virtual work or in the industrial sector through industry 4.0 and an increasingly circular economy).

Acceleration of virtual work (COVID-19) may have high or medium impact at macro level, contributing to decreasing energy demand in different sectors (transportation, urban infrastructure, work spaces, etc.). Digital literacy plays an important part in how energy demand is impacted as work and education shift to greater digitalisation − with some digital practices causing greater demand for energy inputs than others.

Sustainable Cities

In this cluster, different trends aiming at overcoming future challenges (e.g. food supply, transportation and urbanisation) of urban living spaces were gathered. Focusing on urban settlements, these trends are expected to have a low to medium impact on decreasing future energy demand, mostly on the meso scale.

A notable exception is the hyper connectivity trend (closely related to the “Digitalisation” trend cluster), which will have a disruptive impact on data transport quantities as well as infrastructure needs and consequently, increase the energy demand on the macro level. Furthermore, new transportation models will have a higher impact on the macro level by decreasing energy demand from this sector.

The general trends of increased urbanisation, growing population size of urban settlements, and the rise in the number of urban settlements, are expected to shift the energy demand on the meso level. A focus on the local food supply and car-

[61] Based on Fraunhofer ISI (2022).

free cities will have a decreasing impact on the energy demand, and can counter increased energy demands from growing urban populations. Particularly, the car-free city can have a disruptive impact because land use changes enable other strategies for decreasing energy demand like greening urban areas and fostering localised food systems.

Green Transition

The EU's green transition requires fairly intense initial energy requirements to build out new systems, infrastructure and capacities. Rebound effects of these efforts will have to be monitored closely and accounted for in other policies and financial instruments. The macro scale impact will initially be increased energy demands through increased (re)building of infrastructure to achieve the transition, with reduced energy demand over the long term. Net zero policies do not necessitate reduced energy demand, if ample emissions free energy sources can be tapped and upfront energy costs can be accounted for over time. Nevertheless, improving energy efficiency (including the objectives aimed at decreasing energy demand compared to the PRIMES reference scenario) is one of the main policies directions (see for example the Energy Efficiency Directive and the Energy Efficiency First principle implemented therein). EU regulatory power will play a strong role in shaping the different impacts of the green transition at meso and micro scales − though the same initial energy increases are likely if no incentives are set in place to counteract this development.

Decentralised Work

The digitalisation of many forms of work is seen as having the highest impact on energy demand and is operating at a macro scale (supranational or global). Data centres are at the core of this energy demand growth, and they are impacted by limits of efficiency gains − an exponential growth of data use creates significant new energy demand.

Decentralised work also impacts energy demand in transportation systems and domestic lives, as people engage in work from home (initially energy intensive with slow reduction in energy demand), and move outside of city centres − increasing commute time, but reducing the frequency of work-related travel, the net effects of which are yet uncertain.

Finally, multigenerational living arrangements to save costs (including reduced energy demand), may also impact healthy aging and reducing energy demand from people who might be isolated (elderly or people with restrictions, etc.). Health care energy demands might also be reduced by fostering trans-generational living communities.

Sharing Economy

The disruption of ownership models has a high impact on energy demand, but operates at the micro scale. In particular, it decreases energy demand in the material extraction, production and transportation. Fewer "things" (tools, cars, equipment, etc.) with less idle time lead to a more efficient use of material and human resources.

Open access of knowledge was an important part of this cluster, including the move to all digital publications, open-source software and standards, and creative commons products. Overall open knowledge was seen as a reduction of energy demand − fewer material inputs for publishing, fewer systemic costs and demands for OSSS and Creative Commons (CC). However, in some cases, CC models for 3D printing for example, the open access could create an influx of individual production with accompanying material and energy costs increases.

The concept of shared living spaces (community kitchens for example) was a participant-generated topic that also led to questions regarding links between social and personal health as related to energy demand − do people who participate in healthier activities (cycling, sharing meals) require more or less energy in the rituals and routines?

Climate Change and Behaviour

The activities and behaviours of individual consumers play an important role in shaping future energy demand. These behaviours can be shaped by strong national policy that incentivise decisions and actions that reduce various types of systemic energy demand (extraction, production, transport, domestic use, etc.). High impact can be expected at the micro scale.

Strong regional governance can also shape future generations from an earlier age with concerted education programs, creating social rewards for responsible consumption, and shaping perception of climate and energy sensitive behaviour and attitudes. High impact can be expected at the meso scale.

Supranational and global compacts to address climate change (and affect energy demand) also encourage large-scale social reorientation − if those compacts are viewed as potent and reliable. Medium impact can be expected at the macro scale.

Circular Economy

This cluster of factors and trends was not one of those created in the workshop series, and, therefore, was not subject to the assessment matrix workshop.

The transition to a circular economy implies numerous systemic changes to socio-economic structures and industrial operations and processes. While circular economy is often reduced to recycling, it also includes reduction and reuse. The former implies significant energy inputs and a likely rise in energy demand in the near term. In contrast, the latter two can potentially reduce energy demand and associated emissions.

These initial energy inputs for recycling could come in the form of designing, testing, implementing and scaling new systems of production, reclamation, recycling and repurposing. This includes new or restructured transportation systems of materials and products, construction of new facilities and machines for various operations, and other initial needs for systemic change.

However, if the circular model includes the material reduction and reuse, and defines the majority of recycling systems within a social, economic and industrial context, energy demands are expected to decrease, given the new material efficiencies. The energy efficiency promise of the circular economy, in combination with lowered emissions and decreased environmental impacts, is a major driving force in the model's adoption by policy-makers pushing for its implementation.

"Nice to have" trend clusters

Socio-Economic Dynamics (towards Energy Equality)

There are a number of areas, in which deepening inequalities are spurring momentum for societal shifts. The COVID-19 pandemic has highlighted the varying capabilities of healthcare systems across the EU, and simultaneously underscored the economic disparities that exist between member states and regions within each state. These are just two contemporary examples of how social inequalities can redirect investments and development − both of which imply short term increases in energy demand for infrastructure, increased operational capacities, and additional services. While addressing some of these inequalities may eventually lower energy demand through optimising people's health or access to more energy efficient lifestyles − these energy gains may be a long time in coming.

Rebound effects must be considered for many of the proposed socio-technological solutions to address GHG emissions, resource intensive food and products, and other efforts to create a "green society" through economic stimulus and incentives. Rebound effects are when (energy) savings generated through a change in one aspect of a system initiate increases in energy demand in other parts of the system that lead to demands similar to initial conditions (or sometimes worse). For example, implementing more energy efficient technologies, or systems that encourage more energy aware behaviours, in search of solutions to address energy poverty, might in turn increase utilisation of the newer more efficient technology − increasing overall energy usage. This is not to say that addressing energy poverty will inevitably lead to increased energy demand, but that direct and indirect rebound effects of all kinds should be taken into account, as soon as they can be anticipated.

The rising middle class is where we can see important dynamics playing out in concert. On one hand, rising middle class signals more affluence, and (hopefully) less socio-economic inequality. This is to be applauded, if it also signals that others are being raised out of poverty and other dire circumstances. However, one effect of a growing middle class is an increase in disposable income, which often signals increases in consumption, and inherent increases in energy demand (somewhere along the value chain of goods and services). Middle class growth in much of the developing world was showing signs of acceleration prior to the COVID-19 pandemic, and should be anticipated to begin again, as economies begin recovery processes.

Water Issues

Water is intractably linked to every aspect of human living − from direct consumption, to food production, to its hygienic necessity, to its use in various modes of energy production (as a medium, coolant, and water flow as a source of power). Its integrated nature across so many human systems amplifies the effects of disruptions to water sources − low rainfall, draughts, floods, urbanisation and pollution, among others. The disruptions can generate increases in energy demand working at many scales but become more obvious at the meso level, when a region or nation experiences a significant (often prolonged) shift in water availability. When more overall energy is needed to extract and transport water from one source to cover shortages in another, this can add up very quickly.

Water scarcity can also directly and indirectly create larger numbers of refugees, displaced peoples and migrants − which in turn shifts energy demands (often across borders or rural/urban dividing lines). Additionally, middle class lifestyles are increasingly water (and thus energy) intensive, and the global middle classes grow, so too does water/energy/food demand increase.

Green Finance

Financing transition (financial systems) is going to be one of the main drivers to energy efficiency and electrification of services at macro level, decreasing or shifting energy demand between fossil fuel to electricity in the transport and other sectors. At the same time, at micro level, increasing recognition of climate risks among private sector actors (e.g. Task Force on Climate-related Financial Disclosures (TCFD)) may also foster decrease of final energy demand.

Crowdfunding established as an alternative financing model, as well as ethical and value-based financial services, may also decrease energy demand at macro, meso and micro level. The impact of ethical financial services was assessed as low, because it is hardly seen in any scenario.

Citizen perceptions of environmental impacts of behaviours, which are closely related to the personal footprint (more responsible consumption) issues, together may decrease energy demand at micro level. Citizens are willing to be part of the transition but they face significant barriers. It may be barriers in financial sector, political ones, as well as the lack of trust in the institutions.

Demographic Change

Some regions in the world still see population growth, with a demographic phenomenon called a “youth bulge” − a statistically significant concentration of overall population being under the age of 25. Currently, there are nearly 3 billion humans on earth that fit into this definition of youth, with developing nations harbouring this trend to a greater extent than more wealthy nations. This cluster could have a particularly strong impact on increasing energy demand within those regions where the youth bulge is most prominent (large parts of Africa, some nations in the Middle East, SE Asia, and South and Central America). Where regions are able to meet the increasing demand, there will be energy inputs into energy system buildouts (infrastructure, etc.) as well as continuous energy demand. In regions that are not able to meet energy demands, youthful populations may have more incentive to migrate in search of locations that can meet their demands − shifting increase from one region to another. Overall, this cluster may have a macro level increase in energy demand, though its meso level impacts will be pronounced in some areas.

Displacements are happening at global and regional level, and could also be affecting the energy demand at both scales. Although migrations can be caused by several reasons (working opportunities, climate, conflicts, social mobility), they are all considered to result in a moderate increase in energy demand. Increasing water scarcity as one stimulus for migrations is seen to have the highest impact on energy demand at a macro level. Migrating might also have an effect on the specific energy demand, e.g. migration from poor infrastructure with higher specific energy demand to the more developed infrastructure and vice versa. Among the trends attributed to this cluster, solidarity is considered to have a minor positive effect on energy demand, although depending on the definition, it might have a higher impact. If we consider the role of the young generation in learning new communication and solidarity skills, we can see a large impact on energy demand.

Aging populations in the Global North could have a medium impact on energy demand at the supranational or global scale, depending on the energy intensity of the activities that older populations engage in and their overall physical health. While the impact manifests at a large scale, the size of the impact will rely on meso and micro factors − community (and infrastructure) design for aging populations and their needs, personal wealth, social factors that affect the activities people engage. The growth of the global health market − one way that healthy aging might be approached − will almost certainly increase energy demand. At the global scale, and at the meso scale, various types of health system development require infrastructure, technological investments, and rely on stable and redundant energy sources. Depending on how these newer systems are designed, the initial energy demands might be later recouped, but that is contingent on mesoscale policy decisions. The digitalisation of health systems is another strong driver of future energy demand produced by healthcare system growth in response to aging populations.

"Optional" trend clusters

Geopolitics and Global Forces

Geopolitical developments can have major impacts on the EU energy system and the future energy demand. The trends are operating mostly at a macro scale and mainly either increase the energy demand or shift the consumption between sectors. Factors included among many others:

The fuel dependency of the EU can play a major role in the future development of the energy demand and the energy sources selected.

The increase in the global population and in the middle class in BRICS states is considered to have a high increasing impact on energy demand.

The relations between the Global North and South as well as the technological confrontation of US and China.

Social disparities have a similar, but stronger impact on energy demand.

Great Depression II

This cluster, consisting of different aspects in relation to migration, such as the rising financial burden of industrial countries and social disparities on global level, is expected to be effective on the meso- and the macro-scale (similar to the cluster

“Migration”). Based on the typically increasing life standards following migration, this impact will potentially increase the energy demand.

Depending on the impacts of the depression on the global economy, there may be a decrease in total energy demand (fewer goods, less disposable income). However, longer-term energy impacts might see an overall increase in energy demand as national and regional entities attempt to restart economies with inefficient experiments and large infrastructure build outs.

New Labour

In this cluster, relevant trends for the development of labour are covered. Eye-catching is on the one hand the necessity of new competences for working and on the other hand the increasing societal relevance of working.

The lack of skilled workers is becoming increasingly relevant. On one hand, many new competences are needed in the economy as a whole and in the energy sector in particular. One reason for this development is the increasing importance of digital skills in all areas, including in trades, such as heating installers, which play a crucial role in the transition process. New forms of job trainings as well as incentives are needed to transform the skill set of workers. On the other hand, there is a general shortage of skilled workers needed e.g. to perform thermal insulation of buildings. Much effort is needed to address both: sharpening the skill set and increasing the number of workers in these areas.

Furthermore, the societal relevance of work is mirrored in the factors covering the general aspect of job and market losses and the resulting factors covering loss of trust in government and populism. Those factors will have an impact on the macro scale and can potentially have a high impact on the energy demand depending on the new political agenda.

“Future research” trend clusters

Evolving Democratic System

EU regulatory power and massive investment in green transition may have a high impact at macro level, decreasing energy demand in different sectors.

At the same time, at macro level, such trends as right-wing populism and the denial of equal rights, as well as populism and nationalism, may increase energy demand significantly (also a high impact).

Rising global burden of disease as a complex issue closely connected with aging population, may decrease energy demand, as people are on average going to consume more energy at home than at work or while traveling. These may lead to the need to have more care-givers and this would impact the health system as a whole. The impact on energy demand might be relatively small. At the same time, a growing share of healthy share of retirees might lead to more travel activities than in younger generations, which may increase energy demand or shift it to other sectors.

Loss of trust in government and media may significantly increase energy demand at meso and micro level. This will not trigger investments, so people will not reduce their energy demand as much as needed. On the contrary, active citizen participation may decrease energy demand at the meso level.

Appendix 6.2. Dyads of the most interconnected new societal trends

Table 6.4. Connections between trends "Green Transition" and "Green Finance"

Trend A	**Trend B**
Green Transition	Green Finance
Connection degree = 68%[62] **Top connecting factors[63]:** • B: Fossil fuel divestment (including putting public pressure on companies that are currently involved in fossil fuel extraction to invest in renewable energy) (15%) • B: Green (sustainable) finance: taking into account environmental, social and political considerations (13%) • A: Massive investment in green transition (12%) • B: Emerging framework for governance of sustainable finance (EU, Asia, US) (8%) • B: Massive green investment and development of green finance products (green bonds, blockchain technology, smart contracts, etc.) (8%)	

Description: Green (sustainable) finance, taking into account environmental, social and political considerations, is becoming increasingly important in the process of green transition. Emerging framework for governance of sustainable finance serves as a basis for massive green investment and development of green finance products (green bonds, blockchain technology, smart contracts, etc.) in Europe and other regions.

Table 6.5. Connections between trends "Green Transition" and "Climate Change and Behaviour"

Trend A	**Trend B**
Green Transition	Climate Change and Behaviour
Connection degree = 57% **Top connecting factors:** • A: "Net-zero" policies (13%) • A: EU regulatory power for energy transition (10%) • A: Rebound effect: underestimated paradox of sustainability policy (6%) • B: Social acceptance of the climate change mitigation goals (6%)	

[62] Here and below: Connection degree is calculated based on the percentage of expert votes that these trends are connected.
[63] Here and below: Top connecting factors are the factors with the occurrence >=5%.

• A: Massive investment in green transition (5%) • B: Sustainability education and training options (5%) • B: Citizen transition to more responsible consumption (5%)

Description: Green transition requires from citizens to significantly change their consumption behaviour patterns. Social acceptance of the climate change mitigation goals and citizen perceptions of environmental impacts and more responsible consumption, supported by the EU regulatory power, as well as education and training options, can be considered as the key factors contributing to the transition to a more sustainable energy systems from the citizen perspective.

Table 6.6. Connections between trends "Digitalisation" and "Decentralised Work"

Trend A	**Trend B**
Digitalisation	Decentralised Work
Connection degree = 47% **Top connecting factors:** • B: Digitalised and decentralised workforce (18%) • A: Rise of digital traffic and acceleration of virtual work (COVID-19) (9%) • B: Changes in the nature of work (increasing importance of service sector and knowledge work) (9%)	

Description: The spread of COVID-19 and political measures taken to address this challenge have revealed the areas, which were digitalised less effectively than needed: commerce, education, public administration, healthcare, as well as everyday office work. Rise of digital traffic and acceleration of virtual work may enforce transition to more digitalised and decentralised workforce. So, digitalisation plays a great role in changing the nature of work, with the increasing importance of service sector and knowledge economy.

Table 6.7. Connections between trends "Climate Change and Behaviour" and "Socioeconomic Dynamics"

Trend A	**Trend B**
Climate Change and Behaviour	Socioeconomic Dynamics
Connection degree = 44% **Top connecting factors:** • Cluster A: Unconditional basic income allowing a secure livelihood for all people (9%) • Cluster A: "Don't tread on me" response to government policies (fighting for personal freedom and individualism) (9%)	

Description: Addressing climate change needs to be done in an all-encompassing manner. On one hand, the systems, in which we operate, have to change: e.g. how energy is generated, how mobility and cities are designed in a sustainable manner. On the other hand, individual behaviour plays an important role within these changing systems as well. The connections between these two clusters are heavily oriented towards the role of the individual and community/cultural conditions. These connections, therefore, emphasise the role of changing behaviour.

Table 6.8. Connections between trends "Green Transition" and "Circular Economy"

Trend A	Trend B
Green Transition	Circular Economy
Connection degree = 43% **Top connecting factors:** • B: Green batteries: clean power storage for new electric cars (EU targets for the collection and recycling of batteries) (11%) • B: Sustainable production: using materials and components (e.g. plastic) suitable for recycling, upcycling or reuse processes (8%) • B: Sustainable construction: sustainable materials and technologies for circular buildings (6%) • B: Circular electronics: a make-or-break moment for the twin green and digital transitions (laptops, phones or e-books actually become more circular) (6%) • B: Sustainable packaging (6%)	

Description: The European Commission's new Circular Economy Action Plan (CEAP) adopted in March 2020 is one of the main building blocks of the European Green Deal 2050. Circular economy implies using new emerging business models and operations as well as novel concepts of production and consumption. Massive investment in circular economy aims at reducing pressure on natural resources and creating sustainable growth and jobs. The EU regulatory policy is needed to achieve the EU's 2050 climate neutrality target and stop biodiversity loss.

Table 6.9. Connections between trends "Sustainable Cities" and "Socioeconomic Dynamics"

Trend A	Trend B
Sustainable Cities	Socioeconomic Dynamics
Connection degree = 40% **Top connecting factors:** • B: Car-free cities creating a space of community inclusion (9%) • A: Urban-rural divide and infrastructure difficulties (6%) • A: The global urban middle class and its impact on sustainable urban development (5%)	

Description: Increasing urbanisation and the growth of the middle class, particularly in underdeveloped areas, fuel the construction of new urban and suburban settlements. This provides an important leverage to construct these new areas in a sustainable manner, including but not limited to the areas of energy, materials and mobility. Due to energy inequalities, people having fewer means to travel to their workplace may suffer from social isolation and vulnerability. The concept of a "car-free city", with more efficient public transport, better cycling infrastructure, car-sharing options etc., may help local governments tackle or mitigate transport poverty in urban areas.

Table 6.10. Connections between trends "Sustainable Cities" and "Green Transition"

Trend A	**Trend B**
Sustainable Cities	Green Transition
Connection degree = 37% **Top connecting factors:** • B: Noise (from traffic, airports, wind farms, etc.): the ignored environmental and health problem (11%) • A: Greening urban areas (including green urban planning, community gardening, etc.) (5%)	

Description: Urbanisation and climate change call for new solutions to maintain and improve the quality of life in cities. Public green space has a positive impact on biodiversity, climate and health. They play an important role in the sustainable development of cities, not only for the natural environment, but also as an urgent need to improve the lifestyle of urban dwellers. Greening urban areas contribute to a larger extent to a sustainable city and the improvement of its environment.

Table 6.11. Connections between trends "Digitalisation" and "Sharing Economy"

Trend A	**Trend B**
Digitalisation	Sharing Economy
Connection degree = 36% **Top connecting factors:** • B: Data sharing: open access to information by individuals, organisations and governments (15%) • B: Online and offline sharing communities (7%) • B: A new "sharing culture" is becoming established (co-production, co-management and sharing resources, time, services, knowledge, etc.) (5%)	

Description: Digital technology is a driving force of the sharing economy. The large-scale sharing or collaboration networks (online and offline sharing communities) are based on a data sharing digital platform with open access to information by individuals, organisations and governments, in which available resources are efficiently redistributed by matching supply and demand. In addition to such platform, the successful implementation of the sharing economy is also influenced by government policies, government oversight and existing infrastructures.

Table 6.12. Connections between trends "Digitalisation" and "Socioeconomic Dynamics"

Trend A	**Trend B**
Digitalisation	Socioeconomic Dynamics
Connection degree = 33% **Top connecting factors:** • A: Digital competence (digital literacy and skills) as a social organisational task (6%) • A: E-government to foster transparency (5%) • A: Open access – knowledge freely available and free of charge for all (5%)	

Description: Digitalisation may contribute to the reduction of poverty and the digital divide between people of various social groups through providing access to knowledge freely available and free of charge. Currently, digital technologies have been transforming the relationships between economic actors in energy, construction, banking, transportation, retail trade, education, healthcare, the media and security. Digital competences, such as digital literacy and skills are becoming more important as a social organisational task.

Table 6.13. Connections between trends "Socioeconomic Dynamics" and "Demographic Change"

Trend A	**Trend B**
Socioeconomic Dynamics	Demographic Change
Connection degree = 33% **Top connecting factors:** • B: Healthy aging (including psychological health) (9%) • B: Global aging population (Global North): work and retirement, family structure, housing, social security, caregiving and the burden of disease and disability (8%) • B: Forced and reluctant migration (for social, economic or political reasons) (8%) • A: Gender inequalities (including sexism, discrimination, gender pay gap, etc.) (7%) • A: Universal health coverage (equal access to essential health services) (7%) • A: Unconditional basic income allowing socio-economic equality (6%) • B: Shift of (geopolitical) power: colonisation, exploitation of Global South (6%) • B: Voluntary migration (for work and better living conditions) (6%)	

Description: The EU has been an aging population for decades, implying that youthful populations are coming from outside of the EU. The main connection outlined here is future energy demand as a result of learning and awareness raising, particularly with respect to individual and community behaviour and practice. It is worth noting that youthful populations are also seen as a source of social innovations and solidarity – a wealth of ideas that might be focused on climate related community behaviour.

Appendix 6.3. EU-level policy instruments with simultaneous implications for dyads

Table 6.14. EU-level policy instruments with simultaneous implications for “Digitalisation” and “Sharing Economy”

Policy instrument category		**Policy instrument name**	**Policy instrument status (existing / emerging)**	**Policy implications for “Digitalisation” and “Sharing Economy”**	**Connecting factors covered by policy instruments**
Regulation	Product and sectoral standards	Regulation (EU) 2019/1150 on promoting fairness and transparency for business users of online intermediation services	Existing (adopted on 20/06/2019) (European Parliament and Council of the European Union, 2019)	Rules for ensuring transparency, fairness and effective redress possibilities for users of online intermediation services, such as online collaborative e-commerce market places.	*7. Disruption of ownership models and transition to “collaborative consumption”: the shift from ownership to access to a particular product/service* ***8. Online and offline sharing communities*** *10. Collaborative innovation spaces (physical location, information exchange, co-creation, knowledge sharing, social interaction, etc.)*
		Regulation (EU) 2022/858 on a pilot regime for market infrastructures based on distributed ledger technology, and amending Regulations (EU) No 600/2014 and (EU) No 909/2014 and Directive 2014/65/EU	Existing (adopted on 30/05/2022) (European Parliament and Council of the European Union, 2022)	Requirements for infrastructures and operators of distributed ledgers, i.e. digital information repositories that keep records of transactions and that are shared across, and synchronised between network nodes using a consensus mechanism.	*4. Digital currencies gaining in variety (including crypto-currency)*
		Proposal for a Regulation on a Single Market For Digital Services (Digital Services Act) and amending Directive 2000/31/EC	Emerging (proposed on 15/12/2020) (European Commission, 2020d)	Responsibilities and obligations of collaborative economy platforms, aimed at protecting consumers and their rights online.	***6. A new “sharing culture” (co-production, co-management and sharing resources, time, services, knowledge, etc.)*** *7. Disruption of ownership models and transition to “collaborative consumption”: the shift from ownership to access to a particular product/service* ***8. Online and offline sharing communities*** *9. Collaborative innovation spaces (physical location, information*

					exchange, co-creation, knowledge sharing, social interaction, etc.)
		Proposal for a Directive of the European Parliament and of the Council on improving working conditions in platform work	Emerging (proposed on 09/12/2021) (European Commission, 2021a)	Requirements for working conditions at digital labour platforms, i.e. internet-based companies, which provide an online service ensuring the supply of on-demand work, e.g., ride-hailing by Taxify and Uber.	*3. Open access – knowledge freely available and free of charge for all* ***8. Online and offline sharing communities*** ***9. Data sharing: open access to information by individuals, organisations and governments***
	Auditing	Commission Delegated Regulation (EU) 2019/1681 amending Regulation (EU) No 692/2011 of the European Parliament and of the Council concerning European statistics on tourism, as regards the transmission deadlines and adaptation of Annexes I and II	Existing (adopted on 01/08/2019) (European Commission, 2019d)	Measuring online accommodation and transport services offered through online platforms of sharing economy, such as Airbnb.	***8. Online and offline sharing communities***
		Evaluation of Regulation (EU) No 181/2011 concerning the rights of passengers in bus and coach transport	Existing (adopted on 10/12/2021) (European Commission, 2021c)	Review of compliance of emerging carriers (e.g., Blablacar, Flixbus) with the EU law establishing rights of passengers. It was found that online vending of shared travel services that are actually performed by other carriers can cause confusion to passengers to understand, with which party they are contracting and whom to complain to in case of an issue.	***6. A new "sharing culture" (co-production, co-management and sharing resources, time, services, knowledge, etc.)*** ***8. Online and offline sharing communities***
Economic and financial instruments	Government procurement	Green Public Procurement requirements for road transport	Existing (adopted on 18/10/2021) (European Commission, 2021d)	Criteria for procurement of mobility services by contracting authorities across the EU, including commissioning of car sharing and combined mobility services, supported of digital interface that the customer can use (app, web-based service, etc.).	***8. Online and offline sharing communities***

	Grants and subsidies, including RD&D funding	Regulation (EU) 2021/694 of the European Parliament and of the Council of 29 April 2021 establishing the Digital Europe Programme and repealing Decision (EU) 2015/2240	Existing (established on 29/04/2021) (European Parliament and Council of the European Union, 2021b)	Creation of digital technical infrastructure and governance mechanisms for sharing the mobility and transport data relevant for mobility.	*3. Open access – knowledge freely available and free of charge for all* ***9. Data sharing: open access to information by individuals, organisations and governments***
		Horizon Europe, in particular Pillar II Global Challenges and European Industrial Competitiveness, especially under Cluster 5: Climate, Energy and Mobility	Existing (established on 28/04/2021) (European Commission, 2022a)	European demonstrators for integrated shared automated mobility solutions for people and goods, innovative shared mobility solutions, including testing of key enabling technologies such as sensors, connectivity, cybersecurity, AI.	***6. A new "sharing culture" (co-production, co-management and sharing resources, time, services, knowledge, etc.)***
Soft instruments	Negotiated Agreements (Public-private sector)	Connected Collaborative and Automated Mobility (CCAM) Partnership between CCAM Association (association of European mobility industries) and the European Commission in the context of the Cluster 5 of Horizon Europe	Existing (adopted on 23/06/2021) (CCAM, 2022)	Research and innovation agenda enabling mobility industries to develop and deploy new shared, automated mobility and freight services integrated with public transport.	*2. Technology governance (science, technology and innovation policy)* ***8. Online and offline sharing communities***

Digitalisation:
1. E-government to foster transparency
2. Technology governance (science, technology and innovation policy)
3. Open access – knowledge freely available and free of charge for all
4. Digital currencies gaining in variety (including crypto-currency)
5. Digital technology business models (including gamification)
Sharing economy:
6. A new "sharing culture" (co-production, co-management and sharing resources, time, services, knowledge, etc.)
7. Disruption of ownership models and transition to "collaborative consumption": the shift from ownership to access to a particular product/service
8. Online and offline sharing communities
9. Data sharing: open access to information by individuals, organisations and governments
10. Collaborative innovation spaces (physical location, information exchange, co-creation, knowledge sharing, social interaction, etc.)

Table 6.15. EU-level policy instruments with simultaneous implications for "Digitalisation" and "Circular Economy"

Policy instrument category		Policy instrument name	Policy instrument status (existing / emerging)	Policy implications for "Digitalisation" and "Circular Economy"	Connecting factors covered by policy instruments
Regulation	Product and sectoral standards	Regulation (EU) 2019/424 laying down ecodesign requirements for servers and data storage products	Existing (adopted on 15/03/2019, amended on 23/02/2021) (European Commission, 2019c)	Requirements for energy consumption, reparability, reusability, upgradeability and recyclability of servers and data storage products.	*1. Reindustrialisation (digitalisation and sustainability)*
		Regulation (EU) 2019/1020 on market surveillance and compliance of products and amending Directive 2004/42/EC and Regulations (EC) No 765/2008 and (EU) No 305/2011	Existing (adopted on 20/06/2019) (European Commission, 2019e)	Online sellers are required to ensure compliance with the extended producer responsibilities (concerning packaging waste, waste electrical and electronic equipment and batteries) also for non-EU manufacturers selling on their websites.	*1. Reindustrialisation (digitalisation and sustainability)* ***5. Circular electronics (laptops, phones, e-books, etc.)***
		Circular Electronics Initiative – proposed within "A new Circular Economy Action Plan"	Emerging (proposed by the EC on 11/03/2020) (European Commission, 2020f)	Electronics and ICT (including mobile phones, tablets and laptops) required to be designed for durability, reparability, upgradability, maintenance, reuse and recycling.	*1. Reindustrialisation (digitalisation and sustainability)* ***5. Circular electronics (laptops, phones, e-books, etc.)***
		Radio Equipment Directive: common charger for electronic devices – Proposal for a Directive of the European Parliament and of the Council amending Directive 2014/53/EU on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment	Emerging (proposed by the EC on 17/09/2021) (European Parliament and Council of the European Union, 2021c)	Universal charger for mobile phones and similar electronic devices, which should contribute to reducing the e-waste, extraction of raw materials and the CO_2 emissions generated by the production, transportation and disposal of chargers.	*1. Reindustrialisation (digitalisation and sustainability)* ***5. Circular electronics (laptops, phones, e-books, etc.)***
		Sustainable Products Initiative – Regulation establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC	Emerging (proposed by the EC on 30/03/2022) (European Commission, 2022b)	Digital product passports to electronically register, process and share product-related information (e.g., on product's guaranteed lifetime, ease of repair, recycling, re-use, refurbishment, use of recycled	*1. Reindustrialisation (digitalisation and sustainability)*

				materials) amongst supply chain businesses, authorities and consumers.	
	Auditing	Monitoring Framework for the Circular Economy	Existing (published on 16/01/2018) (European Commission, 2018b)	Monitoring of circular economy progress, including recycling rate of e-waste.	*1. Reindustrialisation (digitalisation and sustainability)*
Economic and financial instruments	Government procurement	Green Public Procurement requirements for: (1) Data centres, server rooms and cloud services; (2) Computers, monitors, tablets and smartphones	Existing (published on 11/03/2020 and 05/03/2021) (European Commission, 2020e; European Commission, 2021b)	Circular economy and energy efficiency criteria for green ICT products commissioned by contracting authorities across the EU.	*1. Reindustrialisation (digitalisation and sustainability)* ***5. Circular electronics (laptops, phones, e-books, etc.)***
	Grants and subsidies, including RD&D funding	Regulation (EU) 2021/694 establishing the Digital Europe Programme and repealing Decision (EU) 2015/2240	Existing (established on 29/04/2021) (European Parliament and Council of the European Union, 2021b)	Prototypes of digital product passports, supporting the goals of the Sustainable Product Initiative, Circular Electronics Initiative.	*1. Reindustrialisation (digitalisation and sustainability)*
		Horizon Europe, in particular Pillar II Global Challenges and European Industrial Competitiveness, under Cluster 4: Digital, Industry and Space and Cluster 5: Climate, Energy and Mobility	Existing (established on 28/04/2021) (European Commission, 2022a)	Research and innovation towards new class of green digital devices that radically improve circular approaches and a high degree of recyclability.	*1. Reindustrialisation (digitalisation and sustainability)* *2. Technology governance (science, technology and innovation policy)* ***5. Circular electronics (laptops, phones, e-books, etc.)***
		European Regional Development Fund and Cohesion Fund	Existing (regulation adopted on 24/06/2021) (European Parliament and Council of the European Union, 2021a)	Funding for ICT and low-carbon transitioning towards a net zero carbon economy and resilient Europe.	*1. Reindustrialisation (digitalisation and sustainability)* *2. Technology governance (science, technology and innovation policy)*
	Loans	Innovation, Digital and Human Capital (IDHC) lending programme of the European Investment Bank	Existing (established in 2000, recent orientation 2021-2027 published on 15/12/2021)	Loans for digitally enabled circular business models and production models for improved energy and material efficiency.	*2. Technology governance (science, technology and innovation policy)* *4. Digital technology business models (including gamification)*

			(European Investment Bank, 2021)		
Soft instruments	Negotiated Agreements (Public-private sector)	Processes4Planet (P4Planet) Partnership between A.SPIRE (association of European process industries) and the European Commission in the context of the Cluster 4 of Horizon Europe	Existing (adopted on 23/06/2021) (Processes4Planet, 2022)	Research and innovation agenda enabling process industries to develop and deploy sustainable circular business models through digital materials design, digital process development and engineering, digital plant operation, digitalisation of industrial-urban symbiosis.	*4. Digital technology business models (including gamification)*
	Information campaigns	European Circular Economy Stakeholder Platform	Existing (started in March 2017) (European Commission / European Economic and Social Committee, 2019)	A joint virtual initiative by the European Commission and the European Economic and Social Committee, aimed to support the transition to a circular economy, e.g. by promoting online marketplaces for verified circular products.	*1. Reindustrialisation (digitalisation and sustainability)*
	Voluntary approaches – Unilateral Commitments of Private sector	European Green Digital Coalition	Existing (established on 19/03/2021) (European Commission, 2021e)	Voluntary commitment to private sector to invest in green digital solutions with significant energy and material efficiency and to engage in developing standardised assessment methodologies for the impact of green digital solutions on the environment and climate.	*1. Reindustrialisation (digitalisation and sustainability)*
	Product labels	Directive 2012/19/EU on waste electrical and electronic equipment (WEEE) (recast) – WEEE label (crossed out wheeled dustbin symbol)	Existing (introduced on 04/07/2012) (European Parliament and Council of the European Union, 2012)	A symbol placed on any electronic and electrical equipment meaning that at the end of life, it should not be disposed to municipal waste and must be taken to a separate collection facility for recovery and recycling.	***5. Circular electronics (laptops, phones, e-books, etc.)***

Digitalisation:
1. Reindustrialisation (digitalisation and sustainability)
2. Technology governance (science, technology and innovation policy)
3. Digital currencies gaining in variety (including crypto-currency)
4. Digital technology business models (including gamification)
Circular economy:
5. Circular electronics: a make-or-break moment for the twin green and digital transitions (laptops, phones or e-books actually become more circular)

Chapter 7. Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries?[64]

Abstract

New societal trends are unfolding, such as digitalisation, sharing economy and consumer awareness. They will highly influence future energy demand and, depending on their realisation, enhance or counteract projected energy efficiency gains. Therefore, these trends have to be accompanied by policies with a strong focus on reducing energy demand (including Energy Efficiency First). This work analyses quantitatively for all sectors how new societal trends interact with energy efficiency (policies). An extensive consultation with European experts identified 12 new societal trends that are likely to shape future energy demand. Based on these, four energy demand scenarios were developed for 2050. Using literature review and expert consultations, the impacts on all sectors were evaluated taking these trends explicitly into account. The results show that new societal trends can have a crucial impact on future energy demand beyond mere techno-economic potentials. In the best case scenario, "New Trends Efficient", they can reduce final energy demand by 67% compared to the EU "Baseline" scenario in 2050. While in the "Worst Case" scenario, they could increase final energy demand by 40%. This paper opens up the discussion on how new societal trends will shape future energy demand and emphasises the crucial role of policy-making therein.

1. Introduction

The central aim of the 2015 Paris Agreement is to strengthen the global response to the threat of climate change by keeping the global temperature rise within this century well below 2 ◦C above preindustrial levels and to pursue efforts to limit the temperature increase even further to 1.5 ◦C (United Nations, 2015). To reach this ambitious goal, two central strategies are pursued by the European Union (EU) and its Member States concerning the energy system: (1) enhancing energy efficiency (EE) and (2) decarbonising energy supply, in particular via large diffusion and wide-use of renewable energy sources. While both strategies are necessary for maintaining the chance to reach the targets, they might not be sufficient. The past has shown that in many areas energy efficiency gains were counteracted by societal trends that increased corresponding activities, leading to much smaller

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decreases (or even increases) of energy demand than technologically feasible. Examples of this process are found in all sectors, such as the utilisation of larger vehicles in private transport (IEA, 2019), increasing internet traffic and energy demand from servers, data centres and information technology infrastructure (Masanet et al., 2020) or the increase in the living area per person (Odyssee-Mure, 2018)[65]. Therefore, it is important to access current and (foreseeable) future societal trends concerning the impact that they might have on future energy demand. By "new societal trends" in this paper we understand trends, which – though they may have been around for quite some time in the form of "niche trends" – may suddenly gain considerable momentum due to new technologies supporting them and/or new views of larger parts of society on the values behind those trends. It lies in the nature of these new societal trends that assessing their impact is linked to high degrees of uncertainty. This makes increasing awareness towards their potential impact – which may not simply be linear extrapolations of past trends – even more crucial, since in many areas policies and (consumer) awareness might play a major role in shaping how these impacts will actually unfold.

The arising new societal trends can often be linked to general megatrends, which in turn can have potentially large increasing or decreasing impacts on energy demand (Wadud et al., 2016). Within this work these arising trends were clustered into the four following trend clusters (for the detailed process, see Section 3): (1) the *digitalisation* of the economy and of private life; (2) *new social and economic models*, including the *sharing economy* and *prosumaging* (combination of producing, consuming and managing of energy); (3) the *industrial transformation*, including *decarbonisation of industrial processes* and the *circular economy* (including a stronger focus on material efficiency); and (4) *changes in the quality of life*, including *health effects*, *urbanisation* and *regionalisation*. The trend towards digitalisation may also act as a facilitator for all other trends. The diffusion of cell phone apps for example facilitates car sharing. Table 7.1 presents an overview of the four trend clusters and their corresponding trends.

[65] The concept of energy sufficiency gains increasing importance in this context. Energy sufficiency is defined as "a state in which people's basic needs for energy services are met equitably and ecological limits are respected" (ECEEE, 2018). It places the needs of the people at the centre and focuses on how these needs can be met (e.g. need for a comfortable home or need for mobility), rather than solely focusing on technological enhancements of the energy services. Energy sufficiency therefore plays a crucial role in mitigating direct and indirect rebound effects of energy efficiency gains.

Table 7.1. The four societal trend clusters and the detailed trends they encompass

Cluster	Trend
Digitalisation of life	Human-Machine / Shift towards smart products and services
New social and economic models	Sharing economy Prosumer society Awareness (of personal carbon footprint) Social disparities / Energy poverty New forms of funding – Public spending towards greener and more efficient options
Industrial transformation	Reindustrialisation Circular economy – New requirements for material flows for consumer goods Decarbonisation of the industry
Quality of life	Increasing importance of health (e.g. air quality, noise, heat) Regionalisation – Urban governance solving global challenges locally in cities Urbanisation – Global trend towards larger shares of the population living in cities

The European Commission (2016a) emphasises the role of new societal (mega) trends in their "A Clean Planet for all" communication and particular in their corresponding long-term strategic vision (European Commission, 2018a). Therefore, it is not surprising that many studies analyse the effect of these new societal trends on future energy demand. Yet, most existing studies concentrate on a single or very few trends or only cover specific sectors (see literature overview below, one valuable and recent exemption is provided by Grubler et al., 2018). However, new societal trends have (1) the potential to shift energy demands between sectors[66] and (2) might reinforce or diminish one another when they occur at the same time. Therefore, the here provided approach – starting from a systematic foresight analysis of new societal trends and investigating the potential impact of such trends on future energy demand in a systemic manner – provides an important addition to the recent emerging literature in this area.

The main research question of this study is:

How may new societal trends (e.g. digitalisation, sharing economy, prosumaging, etc.) influence energy demand in different sectors in the European Union until 2050?

[66] For example increasing online sales leads to a shift of energy demand away from the tertiary sector towards the transport sector or the trend toward more home office inducing a higher energy demand in private households while at the same time decreasing energy demand in the transport sector.

Following the introduction, Section 2 will present an overview of the knowledge in present literature on the four new societal trend clusters introduced in Section 1. In Section 3 a systematic methodological approach will be followed to establish these four clusters by identifying and clustering new societal trends that are likely to shape future energy demand in European countries (and worldwide). In addition, a modelling approach to identify how the new societal trends can be represented in an energy system model and with which key parameters will be described. Section 4 will present the analysis of the new societal trends in the different scenarios and provides a first quantitative estimate of how they might interact with energy efficiency gains as well as the development of energy demand in different sectors. Section 5 will discuss limitations of the proposed approach. Finally, Section 6 will formulate an answer to the main research question and draw a conclusion.

2. Theoretical background

Section 2 presents the analysis of the literature findings for the four clusters of new societal trends introduced in Section 1: (1) *digitalisation*, (2) *new social and economic models*, (3) *industrial transformation*, and (4) *changes in the quality of life*.

The impact of new societal trends on energy demand is gaining attention in the academic literature (see for example Grubler et al., 2018; Wadud et al., 2016; Pfaffenrot, 2017; Hamari et al., 2016; Urbach and Röglinger, 2019; Walter and Sillanpää, 2018; Debref, 2018) as well as in applied projects and reports (see for example "Pathways for Carbon Transition" from the European Commission (2010a; 2010b; 2010c; 2011); "Digitalisation and energy" from IEA / OECD (2017); "Study on national policies reported in the transport sector for 2021-2030" by Ricardo (2017)).

The proposed approaches have different aims, among which are the following: to analyse long-term scenarios until 2050 and the paths of renewable energy development (for example in the 95% scenario of Öko-Institut et al. (2016)); to describe a specific trend itself, the technologies it implies and the impact of this trend on the development of different sectors and the low-carbon society as a whole (BAMB, 2016; European Commission, 2010a; European Commission, 2010b; EU Calc, 2017; IEA/OECD, 2017; Material Economics, 2018; UKERC, 2011); to identify and quantify how a specific trend may drive the competitiveness of the EU in the specific industry, including cost and productivity gains (European Commission, 2017); to understand the specific policies needed to achieve energy savings in different sectors and the potential contribution that national policy measures could make in the future (Ricardo, 2017); to describe how trends might unfold beneficially to reach a 1.5◦ scenario (Grubler et al., 2018); to outline what a sustainable post-carbon society would look like in the next 50 years (European Commission, 2010c) and to analyse the consumer engagement in the development of a specific trend (European Commission, 2018b). Different qualitative and quantitative methods have been used in recent studies separately or in combination. Qualitative methods include literature review (IEA/OECD, 2017), expert and stakeholder workshops and interviews (EU Calc, 2017), surveys and behavioural experiments (European Commission, 2018b), scenario development (European Commission, 2010a; European Commission, 2010b; Ricardo, 2017). Quantitative methods, commonly applied to access the impact of new societal trends, amongst others are the analysis of statistical data (UKERC, 2011; Wadud et al., 2016), linguistic (semantic) analysis (European Commission, 2010c), energy modelling (UKERC, 2011), integrated assessment models (Grubler et al., 2018), cost-benefit analysis and economic modelling (European Commission, 2017; Material Economics, 2018).

In Table 7.2 a number of studies analysing strong climate reduction scenarios from a techno-economic perspective are introduced, which contain more or fewer elements linked to the new societal trends mentioned above.

Table 7.2. Examples of studies related to the influence of new societal trends on energy consumption

Trend cluster	Author (year)	Location	Time frame	Methodology	Main findings
Digitalisation of life	IEA/OECD (2017)	International	2040-2050	Qualitative (scenario development, expert consultations). Quantitative (economic modelling).	The authors summarise how digitalisation may increase efficiency, productivity and energy savings in three sectors (transport, buildings and industry), qualitatively assessing the magnitude of potential impacts and associated barriers. They conclude that digital technologies and applications face a variety of barriers to adoption and use and that their impacts on energy demand differ substantially across demand sectors and within different scenarios.
	European Commission (2017)	EU	2030 and beyond	Qualitative (scenario development, expert consultations). Quantitative (economic modelling).	The analysis reveals important findings on the opportunities and costs that the automotive industry will likely face in the context of rapid technological changes and an uncertain global regulatory environment. Based on these findings and associated conclusions, recommendations are proposed on how the EC can support the automotive industry in the EU in this period of change, focusing on M1/N1-category vehicles, L-category vehicles and the automotive supply chain.
	BAMB (2016)	EU	2020-2030	Qualitative (desk research, expertise from BAMB consortium). Quantitative (statistical analysis).	Twelve main opportunities (grouped into: policy opportunities, R&D opportunities, business opportunities and creation of building qualities for users and owners) and ten key barriers (grouped into: policy barriers, commercial barriers and communicative

					barriers) have been identified when Materials Passports and Reversible Building Design Protocols – as part of the integrated BAMB output – should be fully implemented.
New social and economic models	European Commission (2018b)	EU	2020-2030	Qualitative (literature review, stakeholder interviews (semi-structured), consumer focus groups and online survey, behavioural experiment). Quantitative (data mining, statistical analysis).	The European Commission (2018) aims to analyse consumers' engagement in the circular economy focusing on five main products: smartphones, televisions, vacuum cleaners, dishwashers and clothing. They investigate consumer willingness to engage in the circular economy; consumer expectations and experiences with durability and reparability; the drivers, barriers and trade-offs faced by consumers and the effects of product information on purchasing decisions.
	EU Calc (2017)	EU	2050	Qualitative (the EU calculator expert workshop on lifestyles and lifestyle changes in Europe).	The report analyses how the sustainable lifestyle changes (consumption choices and patterns) may influence the energy consumption in three sectors: buildings, transportation and food / diets. It is concluded that the energy system (energy supply and demand) covers everything from basic needs to economic desires and therefore, behavioural aspects, as well as structural, institutional and political conditions should be taken into account.
	UKERC (2011)	UK	2050	Qualitative (scenario development, expert consultations), quantitative (statistical analysis).	The authors study consumer awareness through analysing the role of pro-environmental lifestyle changes for the UK energy system up to 2050. The results indicate that energy use might be expected to fall in both the household and transport sectors by approximately 50% in each by 2050, which implies energy demand decreases of just below 2% annually.
Industrial transformation	Material Economics (2018)	EU	2050	Quantitative (statistical analysis, economic modelling).	The study shows how a more circular economy can contribute to cutting GHG emissions from heavy industry. Three circular economy strategies that make better use of materials and products to reduce GHG emissions in 2050 are discussed in the report. The findings suggest that a more circular economy can produce deep cuts to emissions from heavy industry. Demand-side measures thus can take us more than halfway to net-zero emissions from the EU industry and hold as much promise as those on the supply side.
	Öko-Institut/Fraunhofer ISI/IREES (2016)	Germany	2050	Qualitative (scenario development). Quantitative (statistical analysis, economic modelling).	The following three conclusions can be drawn from the scenarios: 1. From a technical and economic perspective, the ambitious targets of Germany's Energy Concept are achievable. 2. The minimum target path set out in Germany's Energy Concept is just about sufficient for 2020 to 2040 to achieve a reduction of 80 % by 2050. 3. With a 95 % reduction target, substantially more ambitious emission reductions have to be realised by all sectors than would be the case with an 80 % target.
	Wadud et al. (2016)	USA	2050	Qualitative (expert consultations). Quantitative (statistical analysis).	Wadud et al. (2016) identify and quantify specific mechanisms, through which automation may affect travel and energy demand and resulting GHG emissions. They assess the impacts of these mechanisms through a coherent energy decomposition framework. They conclude that automation might plausibly either reduce road transport GHG emissions and energy use by nearly half – or nearly double them.

Quality of life	European Commission (2010a)	EU	2050	Qualitative (scenario development). Quantitative (statistical analysis, spatial data analysis).	Focusing on the trend of urbanisation, the European Commission (2010a) studies the relationship between urbanised forms of living and energy needs respectively possibilities of energy supply – to envision future long-term energy scenarios for different imaginable settlements in Europe.
	European Commission (2010b)	EU	2050	Qualitative (scenario development). Quantitative (statistical analysis, modelling).	The European Commission (2010b) provides a qualitative overview of the technologies and lifestyles that would make up a low-carbon society in Europe in 2050. This research includes an initial assessment of the material intensity of current technologies in the areas of housing, transport and energy service, and links these technologies to the different urban schemes and land use clusters.
	European Commission (2010c)	EU	2050	Qualitative (literature review, expert interviews, web-based survey). Quantitative (semantic analysis, statistical analysis, modelling).	The most important findings of the report, both as regards the production of new knowledge on energy transition and the elaboration of scenarios for future development, are presented in a model called Sociological Predictive Operational Model on Energy Transition (SPROMET), which pursues an operational objective, namely to provide a sociological interpretation of energy transition that could form the basis for developing predictive analyses.

This brief literature overview of the new societal trends shows that all the trend clusters have the potential to decrease energy demand, but they might also drastically increase energy demand (some more than others) if trends unfold in unbeneficial circumstances (e.g. without guiding policies that put decreasing energy demand at the centres or without consumer awareness). While a wide range of studies on new societal trends exists, the literature review unveiled that several aspects in the analysis of the effect of new societal trends on energy demand have proven to be understudied. For many of the trends that are expected to have major impacts on future energy demand no previous studies exist, not even ones, which determine the qualitative effects of a trend on the energy demand. More specifically, a quantification of the effects of these trends on energy demand exists only for selected trends (such as digitalisation – IEA/OECD, 2017) and even in these cases only for selected subparts. Challenges that have been identified in the previous studies are: that these studies are often not transparent in their baseline assumptions, that parameters have to be meaningfully adapted to the EU context and that model parameters – in case of a model-based quantitative analysis of this trends – need to account for double-counting of certain mechanisms.

3. Methodology

Section 3 presents the methodology used to derive and quantify new societal trends. For this purpose, three expert workshops[67] were carried out in the period between January and September 2018, with 20-30 European energy experts each,

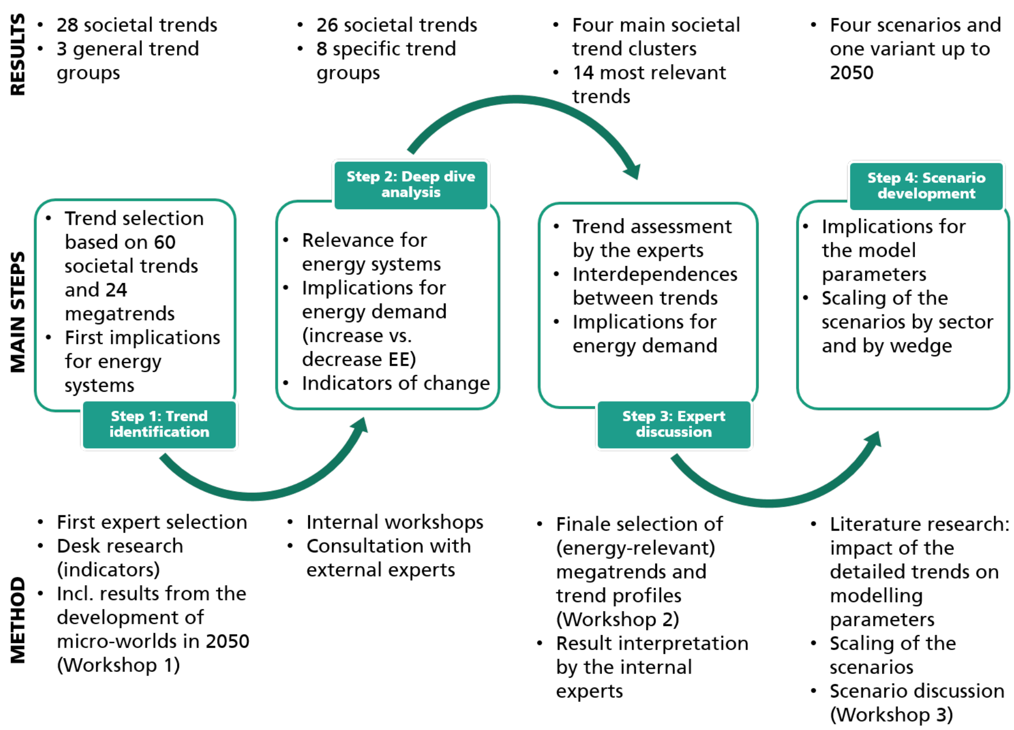
[67] These three workshops differ from the ones described in Chapter 6.

to explore the 2050 energy perspective, supported by analytical work. Experts came from across the EU with different professional backgrounds, ranging from representatives of industrial sectors to representatives of environmentalist organisations.

This study was performed in four consecutive methodological steps: (1) trend identification, (2) deep dive analysis, (3) expert discussion and (4) scenario development and model-based analysis. These steps are described in turn and the process is visualised in Figure 7.1. Afterwards, the developed scenarios are described.

Steps 1 to 3 focused on the identification of the societal trends that are expected to have a major impact on the realisation of energy efficiency potentials and might substantially increase or decrease energy demand. Step 4 focused on the analysis of the impact of these societal trends on the modelling parameters within the different scenarios developed.

Figure 7.1. Overview of the methodological process and its consecutive steps



3.1. Step 1: Trend identification

The trend identification was developed on the basis of a study executed by VDI-Technologiezentrum/Fraunhofer ISI (2017), in which a set of megatrends and detailed trend profiles was developed. The societal trends were selected based on (1) their *social relevance*, where the importance of a trend is determined by significant social and/or economic and in some cases also disruptive impacts; (2)

their *time dimension*, when impacts of the trend are relevant in a period of time extending from now until 2030 (all of the identified trends have proven to be relevant beyond the year 2030, however, additional societal trends are likely to become important in the interval leading up to 2050, which cannot be foreseen at the current point in time); (3) their *relationship to research and innovation (R&I)*, where the trend as a whole or in some aspects should clearly relate to research and innovation; and (4) the *degree of "novelty" of a social trend*, whether the social trend is wholly or partly new for the research and innovation system, or, in the opinion of the authors and experts involved, has received too little attention to date (VDI-Technologiezentrum/Fraunhofer ISI, 2017). Through this process, 60 societal trends and 24 megatrends were identified. The trend profiles were developed in the context of major changes, so-called megatrends, such as increased urbanisation, increased number of people 65-plus in age and increase in life expectancy or digitalisation, which has an influence on the employment structure. These 60 general trends were then evaluated for their (potential) impact on the energy system. 28 societal trends were evaluated to be of major relevance for the energy system (see full list in Appendix 7.1) and were included in the following steps.

3.2. Step 2: Deep dive analysis

A deep dive analysis was carried out to assess the relevance of the societal trends for the energy system. The implications for the increase or the decrease of energy efficiency and energy demand were discussed with experts and the specific indicators of change were identified (see example in Table 7.3 and the full list of the selected trends resulting from Step 2 in Appendix 7.1).

Table 7.3. Template for the expert feedback on the trends

Trend	**Describe relevance for the energy system**	**Describe how this can:**		**Indicators of change**
		increase EE	decrease EE	
Declining households size	• quicker uptake of new services • lower rate of ownership • impact on available income and consumption pattern	• If it leads to rapid uptake of EE services and solutions. • If it leads to urbanisation and less commuting.	• If it leads to more appliance and living space per capita. • If it leads to poverty (capital availability).	• Ownership rates and lifetime of appliances • Square meters • Passenger-kilometre

3.3. Step 3: Expert discussion

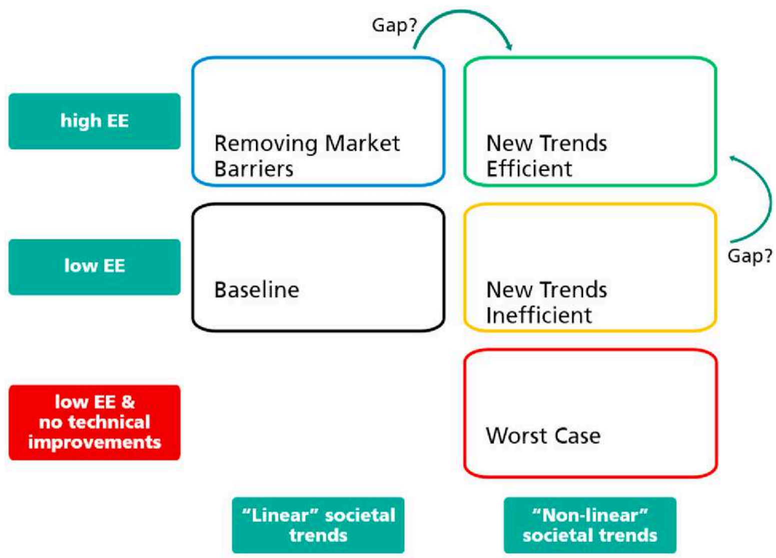
As the outcome of the second expert workshop, the list of trends was condensed to the 12 trends identified as being particularly relevant for future energy demand and the implementation of the EE1 principle. They were further clustered into the four main societal trend clusters presented in Table 7.1: “Digitalisation of life”, “New social and economic models”, “Industrial transformation” and “Quality of life”. Though the development of the clusters was an iterative process with significant stakeholder and expert involvement, their definition is not set in stone and might evolve in future work.

3.4. Step 4: Scenario development

3.4.1. Step 4a: Scenario development

Four scenarios to 2050 were developed with expert consultation (see Figure 7.2). They were designed in comparison to a “Baseline” scenario. The left-hand side of Figure 7.2 describes two techno-economic scenarios, which are distinguished by the impact and strength of energy efficiency policies (high/low efforts). New societal trends are present but rather as a linear extrapolation of past trends. The right-hand side of Figure 7.2 represents three scenarios with strong (non-linear) societal trends, which may either lead to increasing demand or be strongly influenced by EE policies, leading to a decreasing demand. These scenarios are described in the following section in more detail.

Figure 7.2. The scenarios developed for the analysis of new societal trends



The "Baseline" scenario [68] is based on the PRIMES projections from 2016 (European Commission, 2016b). This scenario provides the reference for the development of drivers of energy consumption. New societal trends happen in this scenario but as a rather smooth continuation of previous trends (linear societal trends).

The "Removing Market Barriers" (or "Techno-Economic") scenario focuses on the realisation of economic and near economic potentials for energy efficiency, mainly based on technical solutions. As in the "Baseline" scenario, new societal trends are included, but as a rather smooth continuation of previous trends (linear societal trends).

The following two scenarios are based on the "Removing Market Barriers" scenario. In these scenarios, the economic and near economic potentials for energy efficiency are realised such as in the "Removing Market Barriers" scenario, and, additionally, the potentials are either reduced or enhanced due to new trends.

The "New Trends Inefficient" scenario is characterised by strong non-linear societal trends due to penetration of the sharing and digital economy and strong rebound effects, i.e. energy-increasing impacts of the new societal trends. By "non-linear" we mean that those trends, although they may have been around in small niches for quite some time, suddenly receive a strong push and become part of society's mainstream.

The "New Trends Efficient" scenario is also characterized by strong non-linear societal trends. In this scenario policies are developed, which act upon the new societal trends, guiding them strongly to bring forward the energy reducing impacts.

The "Worst Case" scenario has been developed in a way that new societal trends (in their increasing form) operate directly on the "Baseline". This means that in the "Worst Case" scenario economic and near economic energy efficiency potentials

[68] The "Baseline" scenario is based on the most recent projections of the European Commission with the PRIMES model (at the time this study was conducted), for the sectors as well as for the overall final energy demand. Details of these projections can be found in European Commission (2016b). The main features of this scenario are (1) final energy demand stays relatively stable and even slightly increases after 2040; (2) gross inland consumption decreases somewhat, essentially due to the penetration of renewable energy sources; and (3) (energy-related) GHG emissions decrease by about 42% compared to 2010, also mainly due to the fuel switch towards renewable energy sources. Though the reduction in GHG emissions is already considerable in the "Baseline", overall, these projections are far from reaching the requirements of the Paris Agreement. Including all GHG emissions and comparing them with 1990, in 2050 a reduction of 48% of GHG emissions is achieved (European Commission, 2016b).

are not (fully) tapped by policies, while at the same time the new societal trends increase energy demand.

3.4.2. Step 4b: Quantifying the defined scenarios

This process included four main steps:

- i) Assessing the techno-economic potentials for the "Removing Market Barriers" scenario, in comparison to the predefined "Baseline" scenario (European Commission, 2016b) (see Section 4.1).
- ii) Assessing the impact of new societal trends on energy demand – for the "New Trends Inefficient", "New Trends Efficient" and "Worst Case" scenario – through a thorough literature research on pre-existing studies. Hereby, the magnitude of the quantification given in the various studies was assessed and thereby the impact of the detailed trends on important modelling parameters were evaluated. Both energy-increasing and energy-decreasing impacts were considered.
- iii) Translating the indicators of change into modelling parameters while estimating parameters that could not be obtained from the existing literature. In this step care was taken to use conservative estimates in order to not overestimate the effect of new societal trends on the energy demand in the various scenarios.
- iv) Finally, the energy demand in the scenarios was scaled by sector and by end-uses[69] with the estimated parameters.

Although in these scenarios we focus on the demand side of energy use, the potentials have a major effect on gross inland consumptions, including non-energy uses. Gross inland consumption potentials are the result of material efficiency, conversion efficiency as well as final energy-related efficiency measures. The savings in gross inland consumption are thus highly influenced by the shift towards a highly efficient electricity generation mix. For the "Baseline" scenario the electricity mix of the European Commission (2016b) study is implemented. In the other scenarios an electricity mix is applied with a more ambitious share of renewable energy sources, and which follows the EUCO 3030 Scenario (E3MLab/IIASA, 2016) up to 2030 and then a low carbon mix up to 2050 based on an update of BMU/Fraunhofer ISI (2012), which achieves a renewable energy sources (RES) share of 92% in 2050 (see Table 7.4).

[69] The eleven end-uses are: for private households and the tertiary sector (1) the building envelope, (2) heating and cooling, (3) lighting, (4) ICT, (5) household appliances; for the industrial sector (6) steam and hot water, (7) electric drives, (8) system optimisation; and for transport (9) technical improvements and (10) E-Mobility. All saving potentials not covered by the ten specific end-uses subsumed in the "estimated wedge".

Table 7.4. Low-carbon electricity generation mix

EU long-term	2010	2020	2030	2040	2050
RES (without Biomass)	17%	30%	45%	56%	66%
Biomass	4%	6%	9%	18%	26%
Heating Oil	3%	1%	0%	0%	0%
Natural Gas	24%	17%	11%	9%	8%
Solids	25%	23%	13%	7%	0%
Nuclear	28%	23%	22%	11%	0%

Note: The shares refer to gross electricity generation. Until 2030 this mix stays identical to the electricity mix in the EUCO 2030 scenario of E3MLab/IIASA (2016); afterwards it is extrapolated based on BMU/Fraunhofer ISI (2012).

Source: Compiled by authors.

The main indicators of the scenarios are presented in Table 7.5.

Table 7.5. Main indicators of the different scenarios

	Final energy demand in 2050 in Mtoe (% change compared to "Baseline")	Gross inland consumption in 2050 in Mtoe (% change compared to "Baseline")	Energy-related GHG emissions in 2050 in Mtoe (% change compared to "Baseline")
"Baseline" scenario	1085.9	1491.6	2175.5
"Worst Case" scenario	1545.7 (+42%)	1695.4 (+14%)	2866.5 (+32%)
"New Trends Inefficient" scenario	737.3 (-32%)	829.8 (-44%)	1076.4 (-51%)
"Removing Market Barriers" scenario	533.1 (-51%)	600.0 (-60%)	778.2 (-64%)
"New Trends Efficient" scenario	360.6 (-7%)	405.8 (-6%)	526.4 (-6%)

Source: Compiled by authors.

When analysing the studies care was taken to understand which parts of the trends were already included in the "Baseline" development and the "Removing Market Barriers" scenarios. Both scenarios already include a part of the new societal trends, which can be considered the continuation of developments of the past.

4. Assessing the techno-economic potentials and the impact of new societal trends on energy demand

This section presents an overview of energy efficiency potentials in the four non-baseline scenarios ("Removing Market Barriers", "New Trends Efficient", "New Trends Inefficient" and "Worst Case") and possible contributions of the new societal trends to an increase or decrease of the energy demand in the EU until 2050 and thereby to its emission reduction targets.

4.1. “Removing Market Barriers” (or “techno-economic”) scenario

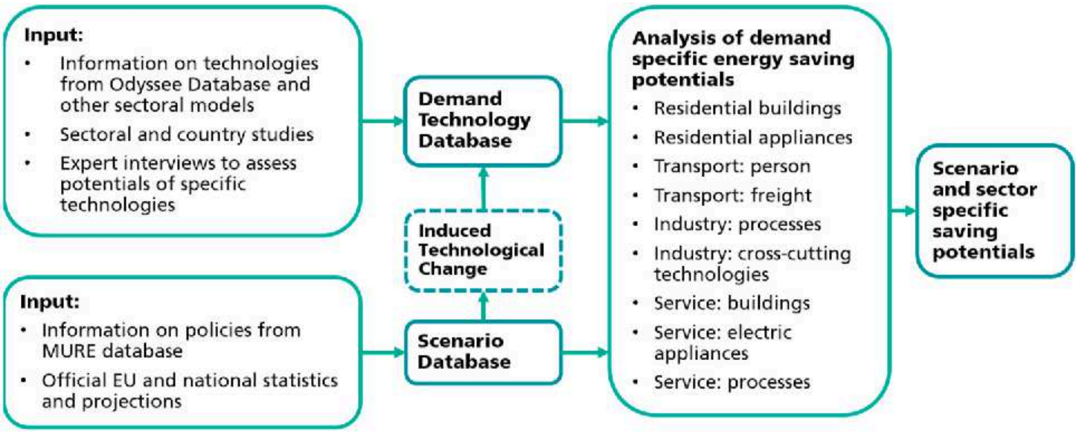
The “Removing Market Barriers” scenario is defined as a scenario, in which currently existing market barriers to implement the EE1 principle are removed and policies implemented in a way that the energy efficiency first principle is realised (European Commission, 2016b). This scenario is based on current projections for central drivers for energy demand (such as sectoral GDP, population growth and kilometres travelled (European Commission, 2016b)). Within this scenario techno-economic energy efficiency potentials are realised in all sectors. Techno-economic efficiency potentials are hereby defined as potentials, for which technical solutions already exist and which are, at the time of investment (nearly) cost-effective (i.e. additional investment and life-cycle costs are smaller than financial savings through avoided energy costs (Brugger et al., 2019; Fraunhofer ISI, 2009; Fraunhofer ISI, 2014). To assess the cost-effectiveness, assumptions were made based, amongst others, concerning the development of investment costs as well as energy prices over time. Furthermore, only “realistic techno-economic potentials”, rather than theoretical potentials were considered (e.g. considering the technology stock with lifetimes and reinvestments cycles of technologies for the time of adoption, rather than independent technology diffusion curves) (Fraunhofer ISI, 2009; Fraunhofer ISI, 2014). Additionally, this scenario includes a contribution of enhanced energy efficiency in energy conversion and in energy end-use to gross inland consumption savings by 2050 and utilises the electricity mix presented in Table 7.4.

4.1.1. Methodology for assessment

Figure 7.3 provides an overview for the methodological approach that was taken to evaluate the energy efficiency potentials. The techno-economic saving potentials are assessed in a bottom-up approach. Central inputs are the technological and policy database of the Odyssee-Mure (2021) project, as well as national and EU statistics on activity levels (European Commission, 2016b). Based on a detailed technological structure, the saving potentials that arise through energy efficient technologies (Demand Technology Database) under certain framework conditions, such as activity levels and policies (Scenario Database), were assessed bottom-up for each of the four demand sectors under study (residential, transport, industry and services)[70].

[70] The Odyssee-Mure database can be assessed online at www.odysee-mure.eu.

Figure 7.3. Scheme for the evaluation of energy efficiency potentials



Source: adapted from Fraunhofer ISI, 2009.

The potentials in the original study by Fraunhofer ISI (2009; 2014) were determined based on the baseline energy demand projection of the European Commission from the year 2008 (European Commission, 2008). To take into account the current projections of energy demand drivers up to 2050 and the fact that time has moved on (with parts of the energy efficiency potentials having been realised by policy measures and parts having been “lost” for energy efficiency purposes, as investments were made in less efficient technologies), two adjustments were made:

Firstly, the potentials were scaled to the projections of the “PRIMES reference scenario” of the European Commission (2016b). Here the saving potentials were adjusted considering the updated final energy demand as well as changes in activities and altered energy intensities per sector. Secondly, potentials that were already realised between 2009 and 2016 are deducted from the previously identified potentials. Thus, a decrease in potentials in some of the sectors is the result of a combination of decreasing activities and/or already realised potentials, while increasing potentials can be traced back to higher activity projections. Thirdly, in the original study by Fraunhofer ISI (2009), the quantification of energy saving potentials was assessed up to 2030. These potentials were extrapolated up to 2050.

The saving potentials identified are cost-effective, as well as nearly cost-effective technical potentials rather than theoretical potentials (see Fraunhofer ISI, 2009; Fraunhofer, 2014 for more details). Cost-effective energy-saving potentials depend on the future development of drivers such as the economic or social development (e.g. the future GDP, population growth, stock of existing buildings, etc.). The drivers underlying the present scenario are the ones underlying the reference scenario of the European Commission (2016b) study.

With regard to the cost-effectiveness of efficiency technologies, only economical technologies are selected (i.e. the financial savings that an investor or end-user can expect through the fuel savings exceed his or her additional investments required to implement the efficiency technology) or at least near-economical ones, in order to include only technologies that are likely to reach market maturity. The latter ones are chosen in such a manner that the energy system costs do not exceed the present energy system costs. The potentials are analysed for all eleven end-uses. Each of these end-uses includes specific energy efficiency options and the underlying technologies, which can be addressed by individual policy measures.

4.1.2. Overall saving potentials

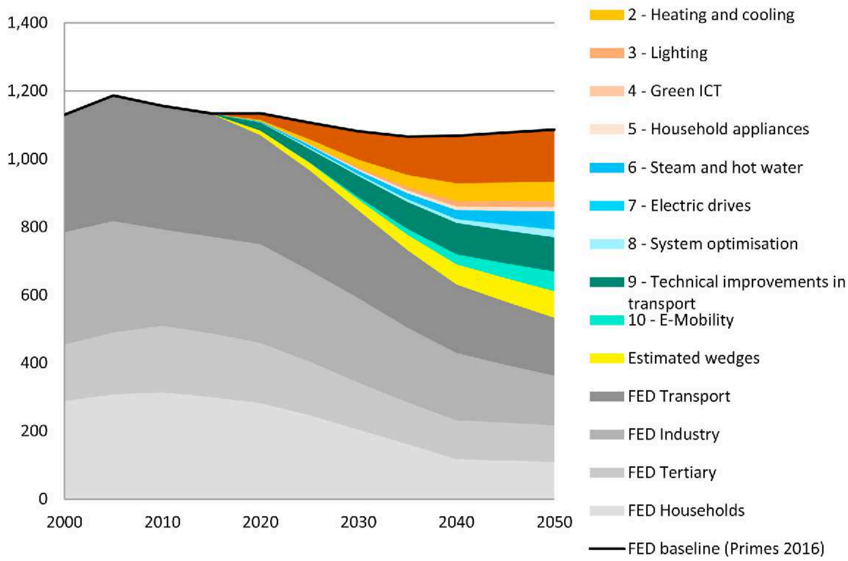
In the following section it will be shown how final energy demand and gross inland consumption (including non-energy uses) as well as energy-related CO2-emissions can be reduced when techno-economic potentials are realised in all sectors.

4.1.2.1. Overall final energy demand saving potential

The total final energy demand (FED) in the reference scenario ("PRIMES, 2016" baseline) of the European Commission (2016b) peaks in 2005 and decreases until 2030. Afterwards it is expected to increase slightly. Overall, between 2000 and 2050 a decrease of 4% is projected.

Compared to this baseline development, final energy demand could potentially be reduced through realising techno-economic potentials by 51% in the year 2050. Figure 7.4 shows that households and the tertiary sector could deliver 22% (end-uses 1-5), the industry sector contributes 7% (end-uses 6-8) and the technical improvements in the transport sector together with a notable shift towards electric vehicles (end-uses 9 and 10) – about 14%. Furthermore, the "estimated wedge" contributes about 7% to the savings and subsumes – among others – low impact industry savings, and certain appliances in the tertiary sector. Overall, 14% of final energy demand reduction (about 1/3 of the total savings) can be realised solely through building envelope measures. Here the agriculture sector is included in the remaining final energy demand in the tertiary sector.

Figure 7.4. "Baseline" (PRIMES, 2016) and "Removing Market Barriers" scenarios: Overall final energy demand (FED) and final energy savings (in Mtoe)



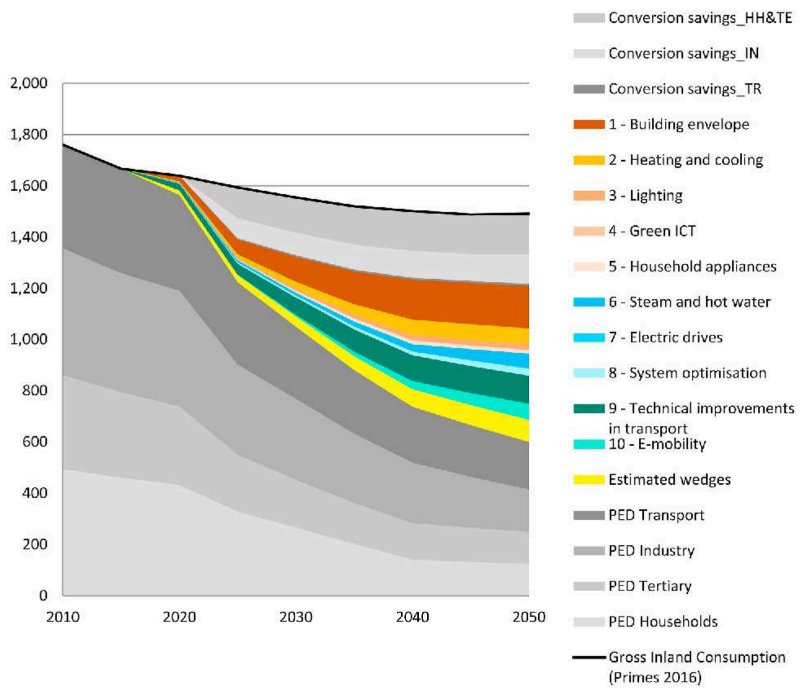
4.1.2.2. Overall gross inland consumption saving potential

Based on a decrease of final energy demand in the "PRIMES 2016" baseline, the gross inland consumption (including non-energy uses) will also decrease slowly but steadily. In the baseline scenario it is expected to be 15% lower in 2050 as compared to 2010.

The gross inland consumption saving potentials, as shown in Figure 7.5, are divided into "conversion savings" triggered by the shift towards a highly-efficient, mainly renewable energy-based electricity supply system (see Table 7.4) and "final energy savings" due to exploiting the final energy saving potentials described above.

Gross inland consumption can be reduced by up to 20% by 2050 due to conversion savings. The transport sector's contribution here is negligible since it does not benefit from an increase in conversion efficiency (e.g. for oil products). Final energy-related savings imply an additional 40% reduction in gross inland consumption, making a total of 60% of the gross inland consumption avoidable.

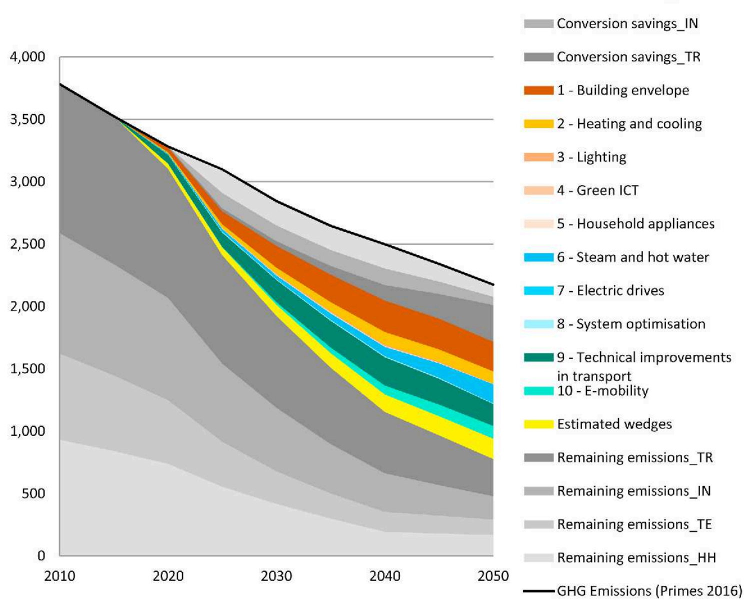
Figure 7.5. "Baseline" and "Removing Market Barriers" scenarios: Gross inland consumption (including non-energy use) and saving potentials for all sectors (in Mtoe)



4.1.2.3. Energy efficiency contribution in GHG emission reductions

In the "PRIMES 2016" baseline, GHG emissions are projected to decrease drastically by 43% between 2010 and 2050 (Figure 7.6). This is based on the fact that electricity is increasingly generated using low-carbon generation technologies. The additional emission reduction potential due to "conversion savings" lies at 21% in 2050 compared to the baseline, 13.5% of which are due to the increase of electric vehicles in passenger transport.

Figure 7.6. "Baseline" and "Removing Market Barriers" scenarios: Energy-related GHG emissions resulting from final energy savings (in Mt CO2-equivalent)



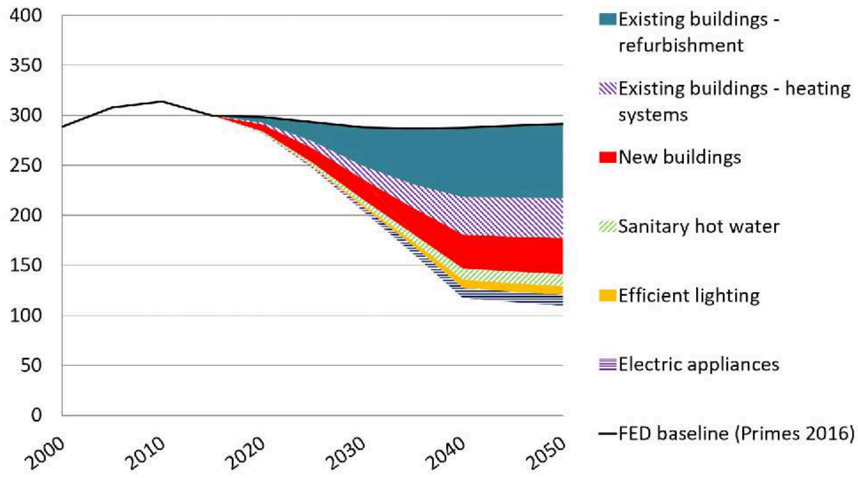
The overall contribution from energy efficiency measures related to final energy lowers GHG emissions by an additional 43% compared to the baseline emissions. This can be translated into a 79% emission reduction compared to the 2010 level and 81% emission reduction compared to the 1990 level. It has to be noted however, that these figures represent only energy-related GHG emission reduction potentials and do not reflect measures in other areas.

4.1.3. Analysing the sectoral saving potentials: the household sector as an example

The "Removing Market Barriers" scenario answers the question as to what extent final energy demand can be reduced via the realisation of (nearly) cost-effective energy efficiency potentials. The techno-economic potentials were modelled with a bottom-up approach (BMU/Fraunhofer ISI, 2012; Fraunhofer ISI, 2009; Fraunhofer, 2014), based on the FORECAST model family and have been updated in order to account for potentials realised and lost since the initial study. The results of the bottom-up modelling of the techno-economic potentials are explained using the household sector as an example.

According to "PRIMES 2016", the baseline final energy demand in the household sector is projected to have peaked in 2010 and to decline from 2010 until 2030, with a small increase afterwards. Final energy demand is projected to again reach the level of 2025 in the year 2050 (~290 Mtoe). However, major final energy saving potentials were identified, which can lead to a reduction in final energy demand of 63% in 2050 compared to the baseline development (Figure 7.7).

Figure 7.7. "Baseline" and "Removing Market Barriers" scenarios: Final energy demand and energy savings potentials by end-use in the household sector (in Mtoe)



More than half of these savings are related to the building shell refurbishment of existing buildings, with the refurbishment of old buildings (25%) and the refurbishment replacement of heating system in existing buildings (13%). Furthermore, 12% of savings can be realised in the construction of new buildings. The savings in sanitary hot water (4%), efficient lighting (3%) and electric appliances (4%) contribute to a significantly lesser extent to the overall savings.

4.2. "New Trends Inefficient", "Worst Case" and "New Trends Efficient" scenarios

The "New Trends Inefficient", the "Worst Case" and the "New Trends Efficient" scenarios complement the "Baseline" and "Removing Market Barriers" scenarios, which take structural and societal changes and their (increasing or decreasing) impacts on energy consumption more explicitly into account. They are contrasting scenarios: in particular, the "New Trends Inefficient" scenario and the "Worst Case" scenario combine the energy-increasing impacts of these trends while the "New Trends Efficient" scenario supposes that strong energy efficiency policies enhance the decreasing impacts of the trends concerning energy consumption. De facto, increasing and decreasing impacts may be observed at the same time.

4.2.1. Methodology for assessment

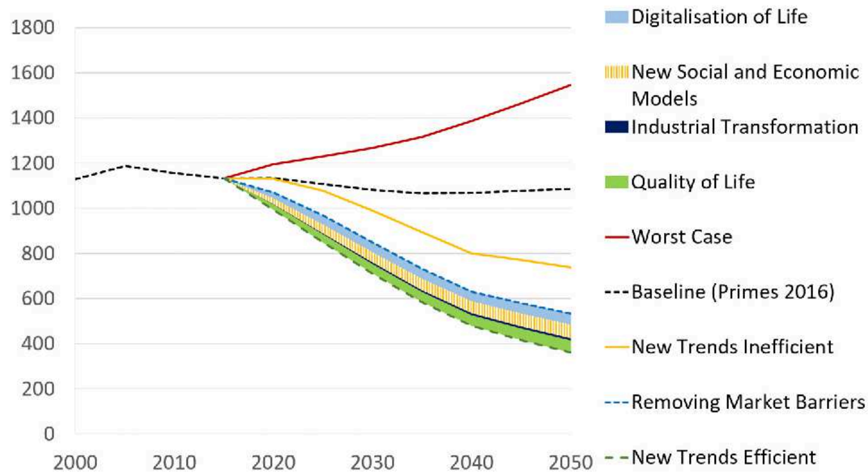
The assessment of energy efficiency potentials in "New Trends Inefficient", the "Worst Case" and the "New Trends Efficient" scenarios relies on the following steps: (1) analysing the impact of societal trends on energy consumption through a thorough literature review of existing studies. (2) Assessing the qualitative and quantitative impacts given in the various studies and thereby evaluating the impact of the detailed trends on important modelling parameters of the various end-uses set up in the “Removing Market Barriers” scenario. Both energy-increasing and energy-decreasing impacts were considered (see example in Table 7.3).

When analysing the studies, care was taken to understand which parts of the trends were already included in the “Baseline” and the “Removing Market Barriers” scenarios. It should be recalled that both already include parts of the new societal trends, which can be considered the continuation of developments of the past. The “Worst Case” scenario is building up the effect of energy-increasing impacts on the “Baseline” scenario, and is thus based on the assumption that the techno-economic potentials are not realised and that additionally trends will unfold in an energy-increasing manner. (3) Translating the impacts into modelling parameters. (4) Estimating open model parameters. Here conservative estimates as to the impacts of such trends were applied. Furthermore, the model parameters for the end-uses need to account for double-counting of certain mechanisms across end-uses. Care was taken here to eliminate instances of double-counting among the different societal trends, but more in-depth analysis could better separate such overlapping impacts. Finally, (5) scaling of the scenarios by sector and by end-use with the estimated parameters was implemented.

4.2.2. Overall saving potentials

Figure 7.8 shows the overall final energy demand within the various scenarios. In addition, it indicates to which extent the four main societal trend clusters contribute to the decreasing final energy demand from the “Removing Market Barriers” scenario (mere techno-economic potentials) to the “New Trends Efficient” scenario. Note that for example the low impact of the industrial transformation is due to the fact that most changes within this transformation are (nearly) cost-effective techno-economic changes, and thus already included to a large degree in the “Removing Market Barriers” scenario.

Figure 7.8. Final energy demand (EU28) in the four scenarios and the baseline (in Mtoe) and the contribution of four main trend clusters in the case of the "New Trends Efficient" scenario



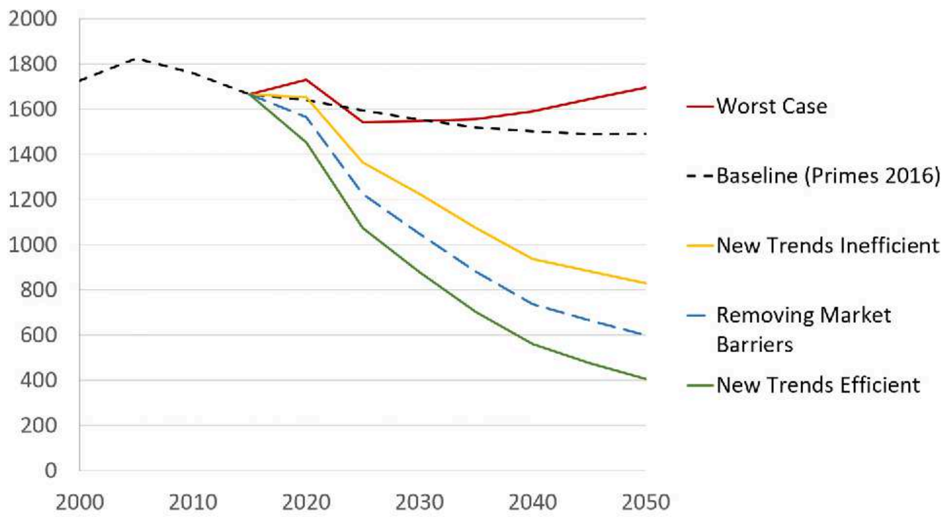
The main findings from the analysis of the total final energy demand are the following: new societal trends without any accompanying strong energy efficiency policies ("New Trends Inefficient" scenario) could diminish the effect of the realised techno-economic potentials for final energy demand to a 32% reduction (as compared to the "Baseline" in 2050). If, on the one hand, the new societal trends were to manifest the energy increasing trends without the realisation of the techno-economic potentials ("Worst Case" scenario), the final energy demand could be strongly increased by up to 42% above the "Baseline". On the other hand, new societal trends supported by strong energy efficiency policies ("New Trends Efficient" scenario) could decrease final energy demand further (decrease by 67% compared to the "Baseline" in 2050).

The four trend clusters hereby describe the difference between the "Removing Market Barriers" and the "New Trends Efficient" scenarios. "Digitalisation of life", "New social and economic models" as well as "Quality of life" each contribute to this further reduction of 172.5 Mtoe with a share of approximately 30%, while the "Industrial transformation" only contributes with a reduction share of 5% (for more details see Table 7.6 below). The gross inland consumption and the (energy-related) CO2-emissions are based on the final energy demand and the low-carbon electricity mix shown in Table 7.4. The resulting gross inland consumption and CO2-emissions within the four scenarios are visualised in Figure 7.9 and Figure 7.10.

Table 7.6. Contributions of the four trend clusters to the reduction of FED beyond techno-economic potentials in 2050

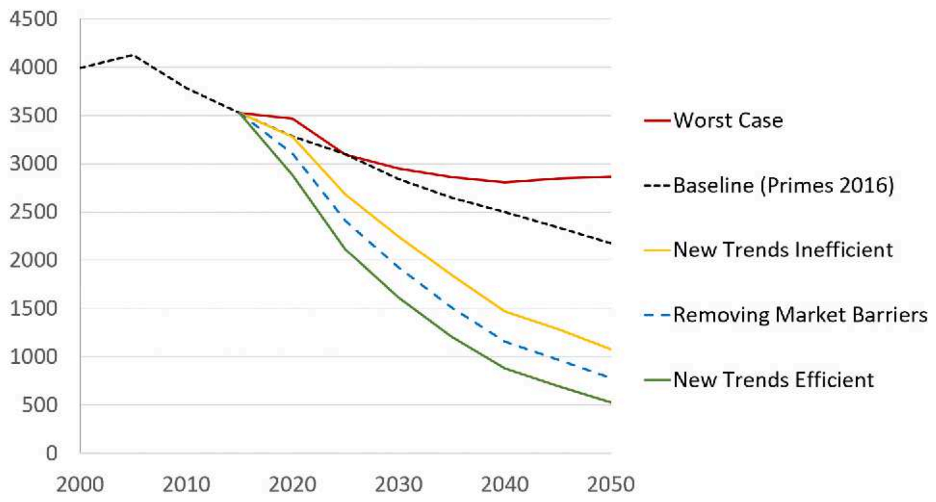
	Total[71]	Households	Services	Industry	Transport
FED in "Removing Market Barriers" scenario (in Mtoe)	533.1	109.5	82.0	145.8	170.2
FED in "New Trends Efficient" scenario (in Mtoe)	360.6	73.4	55.5	125.1	81.1
Difference between the two scenarios (in Mtoe)	172.5	36.1	26.5	20.7	89.1
Reduction contribution by trend cluster in Mtoe (in % of difference)					
Digitalisation of life	49.0 (28%)	8.1 (22%)	7.9 (30%)	3.9 (19%)	29.0 (33%)
New social and economic models	60.3 (35%)	13.3 (37%)	9.5 (36%)	7.4 (36%)	30.0 (34%)
Industrial transformation	9.3 (5%)	0.0 (0%)	0.0 (0%)	9.4 (45%)	0.0 (0%)
Quality of life	54.1 (31%)	14.8 (41%)	9.0 (34%)	0.0 (0%)	30.0 (34%)

Figure 7.9. Gross inland consumption (in Mtoe) in the four scenarios and the baseline (EU 28)



[71] Totals include the values for agriculture, which are not part of the sectoral analysis.

Figure 7.10. Energy-related GHG emissions (in Mtoe) in the four scenarios and the baseline (EU28)



4.2.3. Sectoral saving potentials: the household sector as an example

For the household and tertiary sectors the following main impacts of the new societal trends on energy consumption and scenario parameters were identified to be relevant, in addition to the realisation of techno-economic potentials:

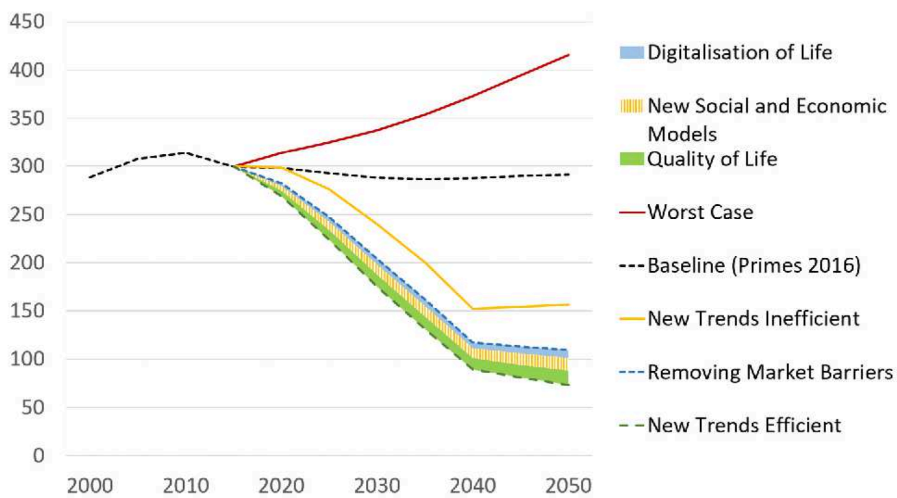
- in the *"New Trends Inefficient" scenario* (increasing impacts on energy consumption):
  - building automation and interconnection of appliances increase the energy demand of buildings;
  - despite a widespread awareness, consumers face increasing energy demands (e.g. due to changes in comfort levels).
- in the *"Worst Case" scenario* (increasing impacts on energy consumption and techno-economic potentials not realised):
  - the same energy-increasing effects as in the "New Trends Inefficient" scenario;
  - additionally, the techno-economic potentials are not realised (e.g. renovations that are economic were not implemented).
- in the *"New Trends Efficient" scenario* (decreasing impacts on energy consumption):
  - building automation increases consumer awareness;
  - decentral generation of electricity raises awareness regarding the value of energy;
  - urbanisation contributes to smaller (individual) living spaces and adapting them to the living context;

- awareness about personal carbon footprint impacts consumer choices on buildings and appliances.

Behavioural choices such as the adaptation of space to the living context, awareness of the personal carbon footprints and decentral generation of electricity (supported by policy settings) contribute to the "New Trends Efficient" scenario. Results for final energy demand (EU28) in the four scenarios are provided in Figure 7.11.

Figure 7.11 shows that the four trend clusters can lead to additional saving potentials that go beyond the mere techno-economic saving potentials of the "Removing Market Barriers" scenario. If all four trend clusters would unfold in a beneficial manner, the FED in the "New Trends Efficient" scenario could be below the FED in the "Removing Market Barriers" scenario. 22% of which can be attributed to the cluster of digitalisation, 37% to the cluster "New social and economic models" and 41% to the cluster "Quality of life". The cluster "Industrial transformation" does not lead to any additional potentials for the private households.

Figure 7.11. Final energy demand in the household sector (EU28) in the four scenarios and the baseline (in Mtoe) and the contribution of the four main trend clusters in the case of the "New Trends Efficient" scenario.



5. Main findings and limitations of the study

The main indicators of the different scenarios are summarised in Table 7.5. These findings suggest, that the new societal trends could indeed have a major impact on future energy demand. A large bandwidth of drastically increasing FED in the "Worst Case" scenario and substantial reductions beyond the techno-economic potentials in the "New Trends Efficient" scenario is observed. Furthermore, the results of the "New Trends Inefficient" scenario show, that new societal trends can substantially reduce energy savings due to direct and indirect rebound effects. This goes to show that new societal trends are often not inherently positive or negative for future energy demand, but that the impacts can substantially differ depending on the way they unfold, which (amongst others) highly depends on accompanying policies.

Table 7.6 summarises the contribution of the four trend clusters to the reduction of FED within the different sectors, beyond the techno-economic potential in the "Removing Market Barriers" scenario. Overall, the "Digitalisation of life" (28%), the "New social and economic models" (35%) and the "Quality of life" (31%) contribute with approximately equal shares to the reduction. While the "Industrial transformation" only contributes with 5%. Further we observe that the three former clusters contribute to relatively equal amounts to the reduction potential in the services and transport sector. While the "Quality of life" (41%) plays a distinctively more important role in the household sector, with the "Digitalisation of life" (22%) being still quite important, but not as prominent as for the total FED reduction (28%). Not surprisingly, in the industrial sector the "Industrial transformation" (45%) contributes by far the most to the reduction potential, followed by "New social and economic models" (36%) and "Digitalisation of life" (19%).

This exploratory work comes with some limitations that have to be kept in mind. Firstly, since European ambitions develop rather rapidly, the latest updates of the energy efficiency goals and the accompanying policy framework (notably the reviewed Renewables Directive) could not be taken into account. Secondly, this analysis is based on cost-effective potentials previously identified (BMU/Fraunhofer ISI, 2012; Fraunhofer ISI, 2009; Fraunhofer ISI, 2014). Although all potentials were updated considering structural changes, altered activities and updated energy intensities, some haziness cannot fully be excluded. Thirdly, the potentials were updated based on "PRIMES 2016". By doing so, the assumptions regarding structural and lifestyle changes (or the lack of the same) as well as the changing extent of activities and energy intensities are adopted from "PRIMES 2016" as well. Fourthly, limitations arise due to the current availability of data and studies. For many trends no previous studies exist, not even ones, which determine the qualitative effects of a trend on the energy consumption (e.g. consumer, financing, urbanisation) and had to be completed by own expert estimates regarding impacts. Specifically, there is quite often no quantification of these trends yet, in some cases because their most important features may be more suited to qualitative analysis. A sensitivity analysis considering differences of the estimated parameters would be an important next step, until the data is more comprehensively available. Fifthly, existing studies are often not transparent in their baseline assumptions. Some trends were assessed on other jurisdictions, e.g. the US or single EU member states. Therefore, parameters needed to be adopted to the EU context. Specific EU studies may enhance the validity for the European context. Furthermore, as mentioned previously, the assessment of the effects on energy demand of the various mechanisms has to account for double-counting. A multiplication of the effects (rather than an addition) was chosen as a more conservative calculation method in order to minimise remaining double-counting effects. More studies on individual trends, and especially their interplay, are required in the future to gain more certainty concerning the quantitative impacts.

6. Conclusion and policy implications

Efficiency gains play a crucial role in realising the EU climate goals. However, these efficiency gains do not by themselves lead to a reduction of energy demand. One example is the transport sector, in which the potential reduction of energy demand by increasing efficiency is counteracted by an ever-growing demand of private car transport and larger vehicles (IEA, 2019). The same can currently be observed in the area of digitalisation, in which major efficiency gains in data centres are currently only able to offset the rising demand (Masanet et al., 2020).

This paper aimed at opening up the discussion of how energy demand might change through new societal trends. Based on these trends, it analysed four energy demand scenarios developed for 2050 ("Baseline", "Removing Market Barriers", "New Trends Efficient", "New Trends Inefficient" and "Worst Case"). As the various scenarios depict in a stylized manner, new societal trends could unfold in a way that would further substantially decrease energy demand beyond merely realising the techno-economic potentials if strong energy efficiency policies, expressed through the Energy Efficiency First (EE1) principle, guide individual and policy decision-making in a beneficial way. However, the effects of the new societal trends could also counteract efficiency gains in a way that leads further away from achieving the EU goals for energy efficiency and climate neutrality in 2050.

The EU proposed EE1 as a fundamental principle applied to policymaking, planning and investment in the energy sector. The EE1 principle is now gaining increasing visibility in European energy and climate policy (European Climate Foundation, 2016). Put briefly, the concept of EE1 prioritizes investments in customer-side efficiency resources (including end-use and supply side energy efficiency and demand response) whenever they would cost less, or deliver more value, rather than investing in energy infrastructure, fuels and supply alone

(Enefirst, 2019; European Commission, 2016b). Although the Energy Union Strategy has recognized energy efficiency as a resource in its own right at the same level as generation capacity and the EE1 as a guiding principle has been brought forward, previous studies suggest that numerous barriers still impede this principle from being streamlined and the benefits of energy efficiency from being adequately taken into account in financial and political planning and decision-making (BMU/Fraunhofer ISI, 2012; Fraunhofer ISI, 2009; Schleich, 2009; Schleich and Gruber, 2008). The results of this study show that the path that final energy demand will take in the years to come is less than certain and will depend not only on the realisation of techno-economic potentials, but also to a vital degree on how societal trends will unfold. These trends can have an impact on energy efficiency improvements and contribute to a decrease or increase of energy consumption beyond the linear trends. In particular, an increase in energy consumption might be the result of new societal trends that are not accompanied by policies strongly implementing the EE1 principle. While the current paper aims at raising awareness of the large effects that the new societal trends might have on future energy demand, it will be crucial to further intensify the endeavour of studying not only the cost-effective potentials, but also to further quantify the effects, including cross-sectoral effects, that societal trends will have on future energy demand. This might ultimately inform policy-makers how European policies have to be designed in order to shape political, commercial and individual decision-making in a way that further decreases energy demand rather than counteracts efficiency gains.

To summarise: the work presented in this paper is pioneering work. It collects information on the relationship of new societal trends to the best of present knowledge and closes the gaps with estimates. More studies on individual trends, as well as on the interplay between them, are required in the future to gain more certainty on the quantitative impacts. Estimates, both upward and downward, are carried out in a conservative way to not overestimate the impacts of the new societal trends, for which data availability is still challenging.

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Appendix

Appendix 7.1. The list of new societal trends

The 28 trends resulting from Step 1 of the methodological process.

Cities

1. Villages as pioneers in shaping the post-growth society
2. The global urban middle class – tipping the scales of sustainable urban development?
3. The growing importance of the region in the global economy
4. Urban governance – solving global challenges locally in cities
5. Social cohesion – the cement of 21st-century societies?

Industries

6. Reindustrialisation
7. New paradigms of economic growth and social prosperity
8. Growing importance of enterprises in emerging economies
9. More attention being given to social innovations
10. Rebound effect: underestimated paradox of sustainability
11. Self-optimisation of people
12. Gamification – persuasive games in ever more areas of life
13. Do-it-yourself 2.0
14. A new culture of exchange is becoming established
15. Personal footprint – more responsible consumption
16. Slow consumption as a countertrend to fast fashion
17. Rediscovery of the commons
18. Social disparities – fault lines of global development
19. Future European integration scenarios

Health

20. Noise: the ignored environmental and health problem

Land use

21. Economic activity in extreme climatic regions is being stepped up

22. Reconquering the public space

Time use

23. Time sovereignty

Banks

24. Crowdfunding is becoming established as an alternative financing model

25. Ethical and value-based financial services

26. Impatient investors - the drying-up of long-term capital

27. Public finances: from voluntary commitment to paralysis?

28. New requirements for material flows for consumer goods have a delayed impact on the environment and disposal systems

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Chapter 8. Summary and conclusions

1. Summary of the results

The following six independent publications form the basis to investigate how technological and new societal trends may impact the European long-term sustainable energy transition.

Low-carbon scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets

In *Chapter 2* we proposed a structured framework that allows comparing and evaluating the policy settings in the European low-carbon energy scenarios in six north-west European countries (the Netherland, Germany, France, Denmark, the UK, Belgium) and serves as a step towards a more harmonised approach to achieve the EU 2050 climate neutrality targets. First, we presented the methodology including ten characteristics for scenario assessment: modelling framework (diversity); ambitiousness (targets 2050); relations with other (European) countries; stakeholder involvement; technology options; non-technological aspects; economic component; usage of scenarios in policy design; intermediate indicators of targets' achievement; revision of scenarios. Further, we used qualitative and quantitative methods to evaluate energy scenarios developed in six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium). The analysis has shown that all selected countries have the potential for modifying their energy scenarios, which may help to achieve the European climate neutrality targets 2050. Since these countries are socially and economically interrelated, a more harmonised approach to scenario development needs to be designed and introduced on the EU level. The proposed characteristics may serve as a starting point for such harmonisation.

Global technology trends monitoring: theoretical frameworks and best practices

In *Chapter 3* we presented an analytical review of international practices for monitoring global technology trends (based on the reports of international organisations, national research centres, universities and research organisations, companies and consultancy agencies), as well as the key theoretical approaches and methods (from scientific publications) that have been developed in this field and can be further applied for the analysis of non-technological trends. The theoretical studies and practical projects on technology trends monitoring are carried out at different levels – global, national, industry and corporate. Interest in the results of these studies comes from international organisations, government bodies, business, research institutes and other stakeholders involved in the process of developing and using long-term forecasts and shaping policy based on their recommendations. The analysis has shown that the theoretical studies on trends monitoring are focused on proposing a systemic methodology to identify technology trends and developing automated methods and software to process large volumes of data and visualise the results obtained. In most cases, this process involves the following stages: setting objectives; data collection; data processing; compiling a list of trends; validation and interpretation. The precise nature of these steps depends on the research objectives and the chosen trend type, sources of information, search strategy, units of analysis and methods used for further processing and validation. Based on literature review, the practical projects for technology trends monitoring actively use qualitative methods (e.g. literature review, expert surveys, interviews, scenario development) and quantitative methods (e.g. bibliometric and patent analysis, collecting and summarising web-data). Numerous attempts have been made to automate the processing of information about technologies (a semi-automated approach) and to use online tools to publish and discuss results. In theoretical (quantitative) approaches the main methods tend to be text mining and bibliometric analysis at the data processing stage and cluster and network analysis at the data structuring and visualisation stage. In the majority of cases, these are combined with other supporting methods (e.g. principle component analysis, trend analysis, ontological modelling).

The combination of technology monitoring theories and practices aims to introduce a wider use of quantitative methods and automated procedures during large-scale applied projects, which, at present, are predominantly carried out on the basis of expert knowledge. The complexity of this task is caused by the highly resource-intensive nature of automated approaches when spread across the entire spectrum of technological fields. The expansion and increasing sophistication of analytical tools (software) will make it possible to diversify the range of information sources used and, ultimately, increase the evidence base and effectiveness of technology trends monitoring.

Comparing data sources for identifying technology trends

In *Chapter 4* we aimed to compare the trends monitoring results obtained from diverse data sources, such as scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations, to analyse the strategies for working with different collections, as well as the factors that may influence the technology monitoring results. Further, we studied how these findings can be used for the analysis of non-technological trends. The proposed approach was applied for sustainable energy as an area connected with different disciplines and fields of knowledge. The analysis has shown that comprehensive coverage of data sources can be more efficient than employing only one resource, since this makes it possible to discover technology trends at the earliest stage of their development, for example, using the latest news published online or the materials from the recent conferences. Taking into consideration the specificity of the subject area and each data collection, as well as the accurate formulation of a research goal, can help select the most relevant information sources for detecting different types of technology trends. By comparing the results of processing different data sources for identifying technology trends in sustainable energy, it can be concluded that the opportunities offered and the results obtained by using any of the eight represented collections may depend on the following factors: (1) the specificity of a subject area, (2) the technology life-cycle stage, (3) the choice of information resources, (4) the search strategy, (5) the difference in terminology, (6) the choice of data fields to be processed. These factors affecting data processing results were considered and discussed to more efficiently use quantitative and qualitative procedures for identifying, correcting and updating technology trends. The results of the study are interesting for government bodies financing foresight studies and setting priorities in science and technology, for companies scanning disruptive innovations in the markets to support their corporate strategies and academic community developing the methodology for technology trends monitoring.

Green energy prospects: trends and challenges

In *Chapter 5* we used a combination of qualitative and quantitative methods to analyse the promising technology directions of green energy development, which have the potential to significantly contribute to solving socio-economic, political, environmental and other problems hindering sustainable development (i.e. climate change, increasing energy consumption, depletion of natural resources, negative environmental impacts, energy security). Qualitative analysis was based on participation of the experts in the field of green energy, while quantitative analysis included collecting and processing data from different information sources (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations and presentations).

The quantitative approach to identifying key technology directions in sustainable energy involved the following steps: 1) creating data collections (scientific publications, patents, news, foresight projects, conferences, projects of international organisations, dissertations and presentations); 2) importing data; 3) pre-preparing data; 4) clustering keywords (factor analysis). As a result, six sustainable energy areas (solar energy, wind energy, bioenergy, electricity storage, fuel cells and sustainable energy infrastructure) were studied, which included thirteen key technologies capable of significantly affecting sustainable energy's long-term development.

Application of qualitative (expert-based) and quantitative techniques revealed that several technology areas include information relevant not only for sustainable energy, but also for related topics. Close links were identified between sustainable energy and such technological areas as biotechnology, rational use of nature, transport and aerospace systems, new materials and nanotechnologies, and information and communications technologies. Moreover, information from quantitative materials helped investigate non-technological aspects and knowledge areas (integrated monitoring and modelling; security; green management; public initiatives and health promotion; green business and production; education and labour market; international standards and licensing), which can significantly affect long-term sustainable development of the energy sector.

Understanding interrelationships between new societal trends to inform policy-making for the energy transition

In *Chapter 6* we aimed to analyse the interrelationships between the new societal trends that may influence future energy demand in the European countries. Through a literature review and three expert workshops energy relevant new societal trends were selected, clustered and their potential importance and disruptiveness were assessed using a three-dimensional metric (impact degree, impact scale and impact direction). An expert survey and network analysis provided a better understanding of the interrelationships between these trends, which helps designing European energy demand-side policy instruments that may have simultaneous major impacts on the new societal trends, avoiding the development of demand increasing patterns.

Based on the results of the expert survey, the explicit and implicit relationships between new societal trends were identified through their connecting factors (parameters) that may influence future energy demand. This created a basis to study the policy instruments associated with two trend dyads as examples: "Digitalisation" and "Circular economy"; "Digitalisation" and "Sharing economy". The analysis has shown that a number of underlying factors of these trends are covered by many policy instruments from all categories (such as regulation, economic and financial instruments, soft instruments), while the others were underrepresented in the policy mixes, which means that there seem to be potential gaps, which can be filled by appropriate policy measures taken at the EU level. This will lead to a better understanding of potential non-linear developments of future energy demand and how energy (efficiency) policies could be designed to take these trends and their connections meaningfully into account.

Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries?

In *Chapter 7* we aimed at opening up the discussion of how energy demand might change through new societal trends and emphasising the crucial role of policy-making therein. An extensive consultation with European experts identified 12 new societal trends that are likely to shape future energy demand. Based on these, four energy demand scenarios were developed for 2050 ("Baseline", "Removing Market Barriers", "New Trends Efficient", "New Trends Inefficient" and "Worst Case"). Using literature review and expert consultations, the impacts on all sectors were evaluated taking these trends explicitly into account. The results have shown that new societal trends can have a crucial impact on future energy demand beyond mere techno-economic potentials. In the best case scenario, "New Trends Efficient", they can reduce final energy demand by 67% compared to the EU "Baseline" scenario in 2050. While in the "Worst Case" scenario, they could increase final energy demand by 40%.

The results show that the path that final energy demand will take in the years to come is less than certain and will depend not only on the realisation of techno-economic potentials, but also to a vital degree on how societal trends will unfold. These trends can have an impact on energy efficiency improvements and contribute to a decrease or increase of energy consumption beyond the linear trends. In particular, an increase in energy consumption might be the result of new societal trends that are not accompanied by policies strongly implementing the EE1 principle.

The findings suggest, that new societal trends could have a major impact on future energy demand. A large bandwidth of drastically increasing FED in the "Worst Case" scenario and substantial reductions beyond the techno-economic potentials in the "New Trends Efficient" scenario is observed. Furthermore, the results of the "New Trends Inefficient" scenario indicate, that new societal trends can substantially reduce energy savings due to direct and indirect rebound effects. This goes to show that new societal trends are often not inherently positive or negative for future energy demand, but that the impacts can substantially differ depending on the way they unfold, which (amongst others) highly depends on accompanying policies.

2. Answers to the research questions

This thesis is dedicated to the central research question:

How can technological and new societal trends impact the European long-term sustainable energy transition?

In order to answer this research question, the following sub-questions are addressed in the thesis:

- **RQ 1:** What insights can be derived on the similarities and differences in policy settings of European low-carbon energy strategies (taking six north-west European countries as the examples), as well as the potential for their improvement in order to achieve the EU 2050 climate neutrality targets?
  Chapter 2
- **RQ 2:** What methodological approaches (including qualitative and quantitative methods, data sources and software tools) can be applied to monitor technological trends in the sustainable energy area and what can we learn for the analysis of non-technological trends?
  Chapters 3, 4
- **RQ 3:** How can information about (inter) relationships between technological and non-technological trends and their controversial impact on future energy demand support the formulation of environmental policies in the European countries?
  Chapters 5, 6
- **RQ 4:** How would new societal trends (e.g. digitalisation, sharing economy, prosumaging, etc.) influence future energy demand and the realisation of the European long-term energy strategies?
  Chapter 7

In the following sections, the results of the individual chapters are combined to answer these research questions.

> ***RQ 1: What insights can be derived on the similarities and differences in policy settings of European low-carbon energy strategies (taking six north-west European countries as the examples), as well as the potential for their improvement in order to achieve the EU 2050 climate neutrality targets?***

The role of non-technological trends in achieving the EU climate neutrality targets. In order to achieve long-term climate neutrality targets in 2050 (or earlier), comprehensive and detailed long-term strategies need to be developed and scaled up, considering both technological and non-technological factors and policies. The stocktaking of low-carbon energy strategies and scenarios in six north-west European countries shows that, although a number of European countries have developed long-term low-carbon energy scenarios, only a part of them consider projections to 2050 and take into account both technological and non-technological factors and policies. At the same time, non-technological aspects (such as social acceptance of technologies) are sometimes even more important, since they may serve as a stimuli or a barrier for further scenario implementation in a specific country. Such non-technological factors and policies influence the progress in reaching the national and regional targets in energy area (for example, the structural changes may require strong support from the general public). Nevertheless, the role of these trends in the strategies and their contribution to the energy transition is understudied.

Low integration of non-technological trends into scenarios. New renewable technologies play an important role in emissions reduction, while technology favouring is different among European countries under research. In all scenarios the need for energy efficiency and massive electrification of industry and other sectors (such as transport, residential and services sectors (e.g. heating of buildings), etc.) is mentioned, but expected to be achieved through various low-carbon technologies. Nevertheless, in addition to reliance on prevailing technologies, non-technological aspects have been fragmentally mentioned in the energy scenarios. Examples are: social acceptance (Germany, France, the UK, Belgium); carbon pricing (France); taxes, subsidies, tradable permits or certificates (Belgium); lifestyle/consumption patterns (France); urban planning policies (France); appropriate institutions to be developed (France). Therefore, non-technological trends and changes needed to achieve the EU 2050 climate neutrality targets, are not yet integrated into energy strategies on a systemic level.

The lack of a systemic methodology to monitor non-technological trends. The cross-cutting insight in strategy development is related to the lack of analysis of non-technological factors and policies for their effective integration into low-carbon energy strategies. Although advanced technologies play an important role in achieving the EU 2050 targets, non-technological aspects (e.g. social acceptance, lifestyle and consumption patterns, institutional changes) need to be explored in more detail. Taking into account that energy strategy development in the European countries having a joint vision of the energy future to 2050, is still rather disjoint, it is important to ensure that the EU framework for strategy development includes a systemic methodology to identify and analyse non-technological factors and policies.

RQ 2: What methodological approaches (including qualitative and quantitative methods, data sources and software tools) can be applied to monitor technological trends in the sustainable energy area and what can we learn for the analysis of non-technological trends?

Learning from methodologies developed for monitoring technological trends for analysis of non-technological ones. The review of international practices and theoretical approaches used to monitor global technology trends at different levels (global, national, industry and corporate) provides important insights on the methodologies that can be potentially useful for identifying and analysing non-technological trends. Taking into account that there is no comprehensive systemic approach for such analysis, some best practices can be borrowed from technology trends monitoring. For example, the methodology for monitoring non-technological trends may also include the following main stages: setting objectives; data collection; data processing; compiling a list of trends; their validation and interpretation. These methodological steps can be used and adapted depending on the objectives of the study, search strategies, available data sources, etc. Different methods can be taken for analysis of non-technological trends. Qualitative methods include e.g. literature review, expert surveys, interviews, scenario development, while quantitative methods involve e.g. bibliometric analysis, collecting and summarising web-data, text mining, network analysis, factor analysis. It can be also helpful to automate the processing of large volumes of data about non-technological factors and apply software tools to visualise and discuss the results.

Choosing appropriate data sources for monitoring non-technological trends. Technology monitoring approaches use a wide variety of information sources, including scientific publications, patents, media, foresight projects, conferences, international projects, dissertations and presentations, which can be also relevant for studying non-technological trends, since most technological trends are interlinked with a technological basis (e.g. the sharing economy is connected with digital technologies to organise the sharing). Taking into account the distinction between technological and non-technological trends, different data sources can be applied to their analysis. For instance, foresight projects, international projects and presentations can be more suitable for monitoring non-technological (socio-economic) trends, than scientific publications, patents, media, conferences and dissertations, which can be more helpful to discover technological ones. Taking into consideration the specificity of the subject area and each data collection, as well as the accurate formulation of a research goal, can help select appropriate information sources for monitoring non-technological trends. Therefore, provided that the factors, which affect the results of data processing, are taken into account as much as possible, such systemic analysis of the results can be used as an important tool for further improvement of the methodology for monitoring of non-technological trends.

Linking trend analysis and scenario development. While systemic methodologies to monitor technological trends include important steps for identification and analysis, the transparent process of translation of the key messages arising from technology monitoring into policies and actions is still missing. The most advanced approaches to analysing the role of low-carbon technologies in energy transition, aim to link trends monitoring to scenario development activities in order to understand how policies may stir technological advances in a favourable way to contribute positively to climate neutrality. Learning from these approaches developed for monitoring technological trends and linking this activity with the implementation of the results, it is also essential to develop the ways for the efficient integration of non-technological trends into energy scenarios and models. Therefore, it is important to place the analysis of non-technological trends into a wider policy context to make use of the outcomes for the purpose of policy-making processes.

> ***RQ 3: How can information about (inter) relationships between technological and non-technological trends and their controversial impact on future energy demand support the formulation of environmental policies in the European countries?***

Mapping of interrelationships between different types of trends. In order to efficiently integrate the new societal trends into energy scenarios and strategies, it is important to know not only the characteristics of the trends and their potential controversial impact on future energy demand (decreasing, increasing, shifting), but also their connections to other trends, in order to develop policies that may have synergetic impacts on them, which helps enhance their energy demand decreasing character and impede energy demand to increase under the impact of new societal trends. Therefore, it is important to study different types of connections: (inter) relationships between technological trends; between non-technological trends, as well as between technological and non-technological trends. It also implies investigating not only explicit, but also implicit connections between trends, which are not obvious without sophisticated network analysis. This information can be helpful to see a complete picture of the interplay and intersections between new societal trends, in order to understand what policies can support their development in combinations (dyads).

Learning from methodologies for analysis of trends interrelationships and their controversial impacts on future energy demand. Methodological approaches proposed to analyse technological trends in sustainable energy and their connections to other trends, can be applied for the analysis of interrelationships between new societal trends and the evaluation of their impact on energy demand. The potential importance and disruptiveness of new societal trends can be assessed using a multi-modal assessment of their underlying factors, with respect to their possible controversial impact on future energy demand at three dimensions: "Impact degree" (high, medium, low), "Impact scale" (macro, meso, micro) and "Impact direction" (decreasing, increasing, shifting). Combination of qualitative (literature review, expert surveys and workshops, impact assessment) and quantitative (text mining, statistical analysis, clustering (factor analysis), network analysis) methods can be used for this research, as well as different information sources, from which particularly helpful can be media (news), foresight projects, international projects and presentations.

Using knowledge about trends interrelationships for policy analysis. Climate, energy and environmental policies may influence new societal trends or their combinations (dyads), amplifying their positive and/or mitigating negative contribution to energy transition. Knowledge about the factors (parameters) derived from network analysis of trends interrelationships, which may simultaneously influence both trends in a dyad (decreasing, increasing or shifting energy demand), gives insights into what additional policies need to be developed in the appropriate areas. To this end, the analysis can cover: (1) existing EU policy instruments, i.e. instruments that are legally binding at the moment; (2) emerging policy instruments, i.e. instruments that have been formally proposed in official preparatory documents. Therefore, the analysis of policy mixes reflecting the agenda for the connecting factors of new societal trends may give additional information about how they are covered by existing and emerging policy instruments (such as regulation, economic and financial instruments, soft instruments) and what are the potential gaps that can be filled with appropriate policy measures in order to foster the EU's energy transition.

> ***RQ 4: How would new societal trends (e.g. digitalisation, sharing economy, prosumaging, etc.) influence future energy demand and the realisation of the European long-term energy strategies?***

Controversial impact of new societal trends depending on accompanying policies. The analysis of the influence of new societal trends shows that they are often not inherently positive or negative for future energy demand, but that the impacts can differ substantially depending on the way they unfold, which (amongst others) highly depends on accompanying policies. These trends have the potential to decrease energy demand, but they might also drastically increase energy demand if trends unfold in unbeneficial circumstances (e.g. without guiding policies that put decreasing energy demand at the centre or without consumer awareness). As the various scenarios depict in a stylised manner, new societal trends could unfold in a way that would further substantially decrease energy demand beyond merely realising the techno-economic potentials if strong energy efficiency policies, expressed through the Energy Efficiency First (EE1) principle, guide individual and policy decision-making in a beneficial way. However, the effects of new societal trends could also counteract efficiency gains in a way that leads further away from achieving the EU goals for energy efficiency and climate neutrality in 2050.

Quantitative assessment of impacts of new societal trends on future energy demand. While developing low-carbon energy strategies and scenarios for 2050, it is highly necessary to evaluate the controversial impacts of new societal trends on energy consumption (increasing, decreasing or shifting) and analyse quantitatively how these might interact with energy efficiency (policies). There is a need to develop a systemic approach for assessment of the implications for increase or decrease of energy efficiency and energy demand in all sectors and identification of the specific indicators of change based on qualitative (discussions with experts) and quantitative (statistics) data. More studies on individual trends, and especially their interplay, are required in the future to gain more certainty concerning their quantitative impacts. Knowledge about "Impact degree" (high, medium, low), "Impact scale" (macro, meso, micro) and "Impact direction" (decreasing, increasing, shifting) can provide additional substantial information for further scenario development.

Integration of new societal trends into energy scenarios and models. The development and quantification of four energy-demand scenarios ("Removing Market Barriers", "New Trends Efficient", "New Trends Inefficient", "Worst Case") give insights in how new societal trends may affect future energy demand in the European countries, taking into account different pathways of technological and societal development, as well as accompanying policy measures. For more efficient integration of new societal trends into scenario development, it is important to analyse their role in the different scenario pathways and provide quantitative estimations of how they might interact with energy efficiency gains and changes in energy demand in different sectors. It emphasises the need to create an interface between trends monitoring and policy and strategy making process, increasing the impact of the activity on action. Ideally, the next step would be the evaluation of the findings and re-iteration of the complete process "closing the loop" in analysis of how new societal trends influence future energy demand and the realisation of the European long-term energy scenarios.

3. Conclusions and recommendations

3.1. Added value of the research

Addressing how technological and new societal trends – in their interaction – may influence the sustainable energy transition, three perspectives are taken in this thesis: ***policy***, ***methodology*** and ***impacts***. The added value of this research regarding these perspectives is presented below.

Policy

As was mentioned above, only a part of the European low-carbon energy strategies and scenarios consider long-term projections (2050) and take into account *both technological and non-technological aspects* (such as social acceptance of technologies), which may *play a great role in achievement of the EU climate neutrality targets (Chapter 2)*. Nevertheless, the role of these trends in the strategies and their contribution to the energy transition is still understudied. *Non-technological aspects* (such as social acceptance, lifestyle and consumption patterns, etc.) are fragmentally mentioned in the energy scenarios, but *are not yet considered in energy strategies on a systemic level*. *Understanding the interrelationships between the new societal trends and their simultaneous influence on energy demand* (i.e. decreasing, increasing or shifting), may give insights into how they are covered by existing and emerging policy instruments (i.e. regulation, economic and financial instruments, as well as soft instruments) and *what additional policies need to be developed to accelerate the EU's energy transition (Chapter 6).* Analysis of the role of new societal trends in different scenario pathways and quantitative assessment of their impact on energy efficiency gains, can be helpful for *more efficient integration of these trends into scenario development (Chapter 7)*.

Methodology

To incorporate both types of trends (technological and non-technological) into energy scenarios *a systemic methodology* including a combination of qualitative (literature review, expert surveys, interviews, etc.) and quantitative methods (bibliometric and patent analysis, clustering, network analysis, etc.) *is needed to identify and analyse such trends and their interrelationships*. As was noted previously, given the lack of a systemic approach for analysis of non-technological trends, *methodological learning can be taken from existing international practices* *and theoretical approaches used for technology monitoring (Chapter 3)*, which cover a wide variety of information sources (e.g. scientific publications, patents, media, foresight projects, conferences, international projects, dissertations, presentations). Taking into account the specificity of the subject area and each data source, as well as the accurate formulation of a research goal, can help *to select the most relevant information sources to monitor new societal trends (Chapter 4)*. It is also important to learn from the approaches *linking trends monitoring to scenario development activities* to understand how policies may support climate technologies that contribute positively to energy transition. This can be helpful *to develop the ways for the efficient integration of new societal trends into energy scenarios and models (Chapter 7).*

Impacts

To effectively integrate the new societal trends into energy scenarios, it can be important to know not only the potential impact of these trends on future energy demand (i.e. decreasing, increasing, shifting), but also their connections with other trends, in order to develop policies that may have synergetic impacts on them. As mentioned above, *different types of connections can be investigated through mapping using network analysis*, which may help to see a bigger picture of the interrelationships between new societal trends and understand *what policy measures can support their development in combinations (dyads). Methodological approaches proposed to analyse technological trends in sustainable energy and their connections with other trends (Chapter 5), can be applied for analysis of interrelationships between new societal trends and assessment of their potential impact on energy demand in three dimensions: impact degree, impact scale and impact direction (Chapter 6)*. It is essential *to evaluate the controversial impact of new societal trends on future energy demand and analyse quantitatively how they might interact with energy efficiency (policies) (Chapter 7)*. Therefore, *a systemic approach is needed* to assess the implications of an increase or decrease of energy efficiency and energy demand in all sectors and *develop the specific indicators of change* based on qualitative (expert) and quantitative (statistical) data.

3.2. Limitations in the research

Discussing the results presented in this thesis, some limitations have to be taken into account. Firstly, limitations arise due to the *current availability of data and studies*. For example, analysing the European low-carbon energy scenarios *(Chapter 2)*, the information for the assessment has been found in several documents, in which the figures sometimes were contradicting and required additional verification by the experts. Investigating the impacts of new societal trends *(Chapter 7)*, for many of them no previous studies existed, not even ones, which determine the qualitative effects of a trend on the energy consumption (e.g. consumer, financing, urbanisation) and had to be completed by expert estimates. Therefore, a sensitivity analysis considering differences of the estimated parameters would be an important next step, until the data is more comprehensively available. Secondly, *a limited number of experts* were engaged in discussions. Expert workshops, surveys and consultations were conducted in order to get additional information about the impact of technological and new societal trends on the future energy demand. To ensure deeper understanding of the details more active expert involvement is needed in the future, with participation of both "generalists" (interdisciplinary experts) and "specialists" from energy-related areas. Thirdly, due to *the limited resources for collecting and processing data*, we analysed only 11 priority trends out of 15 trends, which were considered by the experts as the most important for the newTRENDs project *(Chapter 6)*. Next, in the survey, experts were asked to identify only "single"[72] connections between new societal trends, while "multiple" connections were not analysed, but could also bring valuable information. Further, to narrow down the scope of the research and provide sound and useful results, we excluded country-level policy instruments from the analysis of policy mixes, but we assume that national policy instruments exist at the intersection of new societal trends and are important to be investigated in further research. Fourthly, *network analysis* was used to analyse the direct connections between trends and *needs to be explored in more detail* to investigate the role of the specific trends in the network, for example by analysing the factors, which are building the "bridges" between them, thus connecting otherwise unconnected trends. Fifthly, the assessment of the impacts of the new societal trends on energy demand was based on the information available in 2018-2020 *(Chapter 7)*, and since European ambitions develop rather rapidly, *the latest information about the energy efficiency goals and the accompanying policy measures were not taken into account* and need to be further updated on a regular basis.

[72] "Single" connection means that a specific factor from Trend A is connected to one Trend B), while "multiple" connection means that a specific factor from Trend A is connected to several Trends: B, C, D.

3.3. Recommendations

3.3.1. Recommendations for scientific research (theory)

- **Combination of qualitative and quantitative methods for analysing technological and new societal trends**

More evidence-based approaches for monitoring of technological trends

The analysis of theoretical approaches and international practices on technology trends monitoring shows that recently, qualitative methods (interviews, surveys, seminars, etc.) have been actively used to carry out such large-scale projects. At the same time, there is a growing demand for an evidence-based approach to monitoring trends, capable of verifying expert assessments and revealing implicit signs of technological changes using large volumes of data. That is why theoretical studies increasingly focus on improving quantitative technology monitoring methods and developing automated data processing procedures during large-scale applied projects, which have been predominantly carried out on the basis of expert knowledge. The complexity of this task is caused by the highly resource-intensive nature of automated approaches when spread across all technological fields related to sustainable energy. The expansion and increasing sophistication of analytical tools (software) will make it possible to diversify the range of information sources used and, ultimately, may increase the evidence base and effectiveness of technology trends monitoring.

More quantitative estimations to analyse the impacts of new societal trends

The results of this study show that the path that final energy demand will take in the coming years is less than certain and will depend not only on the realisation of techno-economic potentials, but also to a vital degree on how societal trends will unfold. These trends can have an impact on energy efficiency improvements and contribute to a decrease or increase of energy consumption beyond the linear trends. In particular, an increase in energy consumption might be the result of new societal trends that are not accompanied by policies strongly implementing the EE1 principle. While the current study aims at raising awareness of the large effects that the new societal trends might have on future energy demand, it will be crucial to further intensify the endeavour of studying not only the cost-effective potentials, but also to further quantify the effects, including cross-sectoral effects, that societal trends will have on future energy demand. This might ultimately inform policy-makers how European policies have to be designed in order to shape political, commercial and individual decision-making in a way that further decreases energy demand rather than counteracts efficiency gains.

- **A more systemic approach integrating different types of trends and data sources**

Although the impacts of technological and new societal trends on future energy demand is the main focus of this thesis, other trends types may also be taken into account to see a more complete picture of how different trends and their combinations may influence the energy transition. The STEEPV[73] framework, which has been recently used in different foresight projects, explores not only social and technological trends, but also economic, environmental, political and values trends, which are becoming very important in the constantly changing global environment.

Hence, a more systemic approach is needed, starting with a broader horizon scanning phase in a wide variety of information sources and databases (identification), analysing results by using multiple tools and techniques in an integrated way (investigation) and generating results with a further discussion on their implications for public and corporate policy and strategy (integration). Such approach can serve as a "closing loop" between different analytical stages and can be applied on a regular basis to systemically investigate the contribution of different trends to the sustainable energy transition.

The analysis of theoretical and practical approaches to technology trends monitoring shows that comprehensive coverage of data sources can be more efficient than employing only one resource, since this makes it possible to discover trends at the earliest stage of their development, for example, using the latest news published online, the materials from the recent conferences or information from social networks. Taking into account the specificity of the subject area and each data collection, as well as the accurate formulation of a research goal, can help select the most relevant information sources for identifying different types of trends. Therefore, provided that the factors, which affect the results of data processing, are taken into account as much as possible, such systemic analysis of the results can be used as an important tool for further improvement of the methodology for trends monitoring.

- **Further analysis of interrelationships between trends**

Application of qualitative (expert-based) and quantitative techniques for identifying technology trends in green energy area shows that some technological trends are connected not only to green energy, but also to other related topics. The links are identified between green energy and such technological areas as biotechnology, rational use of nature, transport and aerospace systems, new

[73] STEEPV – social, technological, economic, environmental, political and values trends.

materials and nanotechnologies, and information and communications technologies. Moreover, a number of non-technological fields and knowledge areas are identified (such as integrated monitoring and modelling; security; green management; public initiatives and health promotion; green business and production; education and labour market; international standards and licensing) that can significantly affect long-term development of the energy sector. Therefore, further understanding of interrelationships between technological, societal and other trends can be helpful to obtain additional information on how these may influence energy demand. Furthermore, more studies on individual trends, as well as their controversial impact on each other and ultimately on future energy demand in the European countries, are further needed to gain more certainty on the policies required. This will lead to a better understanding of potential non-linear developments of future energy demand and how energy (efficiency) policies could be designed to take these trends and their connections meaningfully into account.

3.3.2. Recommendations for policy (practice)

- **A more harmonised approach with national requirements at the EU level**

Although the European countries have a joint vision of the energy future to 2050, the energy scenario development in these countries is still rather spontaneous and disjoint. According to the statistical data, the EU member states have different progress in reaching the GHG emissions reduction targets 2050 and a potential to improve their scenario policy settings, which in its turn, may influence the efficiency of national energy policy in the future. The results of this study can be applied to discuss the requirements for all European countries as a part of a more harmonised approach to achieve the EU 2050 targets, opening the possibilities for constant monitoring of the progress on the European level.

First, collaboration and joint efforts are needed on the EU level to provide higher consistency and transparency in achieving the EU 2050 targets. Second, the scenario development process on the national level needs to be more interactive, with active involvement of key stakeholders (e.g. government, business, academia, NGOs, the general public). Third, new renewable technologies play an important role in achieving the EU 2050 goals. However, not only technological options, but also non-technological aspects (e.g. social acceptance, lifestyle and consumption patterns, institutional changes) should be explored in more detail, with the specific requirements adapted to the EU context. Fourth, the scenarios should take into account economic aspects (costs and benefits) in order to be feasible and more adaptable to the future changes. Moreover, the strategy developed should be effectively incorporated into the national policy: not only into strategic thinking, but also into short-term decision-making. Finally, constant monitoring is needed on both national and regional level to regularly measure the success of each country and the EU as a whole.

- **Integration of different types of trends and their interrelationships into scenario development**

Taking into account substantial and potentially disruptive impacts of new societal trends, such as circular and sharing economy, digitalisation of economic and private life, prosumer society etc., it is important to investigate interrelationships between such trends, their controversial impact on the European future energy demand and policy measures that may influence their development in a synergetic way. This can help to better understand how demand-side energy policies in specific areas at the trends intersections could be designed to maximise their contribution to energy transition. The results can be helpful to inform EU policy-makers how energy policies have to be designed to reduce energy demand by stirring synergetic new societal trends. First, network analysis allows to see the overall picture of interrelationships between new societal trends and study what policy measures are being taken at their intersection. Second, the areas where policy gaps are identified can be explored more in detail to discover new emerging trends that are not yet covered but already require policy action. Additional investigation of these gaps can help inform the policy makers about the measures that are missing and can be put on the policy agenda. Third, some new societal trends may be connected with a group of factors, which are closely interrelated and may require simultaneous policy actions in several areas. Fourth, the analysis of policies at the intersection of trends allows to determine additional policy measures associated with their development and how the policy agenda should be redesigned to maximise their positive environmental impact. Furthermore, more information about individual trends, and especially their interplay, are required in the future to gain more certainty concerning the quantitative impacts on future energy demand in the European countries and can be helpful to formulate the appropriate policy measures.

- **Integration of the results into policy decision-making**

Although, in recent decades trend analysis has been used in development of low-carbon energy scenarios in the European countries, there is still the room for further improvement, particularly, in the ways of more efficient integration of the results into policy decision-making. While this research aims at raising awareness of the large effects that the technological and new societal trends might have on energy consumption, it will be crucial to further intensify the endeavour of studying not only the cost-effective potentials, but also to further quantify the impacts, including cross-sectoral effects that societal trends will have on future energy demand. This might ultimately inform policy-makers how European policies have to be designed in order to shape political, commercial and individual decision-making in a way that further decreases energy demand rather than counteracts efficiency gains. Further research is needed to design a process to explicitly link trend analysis into policies and strategies within a systemic framework. Such a framework should include analysis of emerging trends (e.g. technological, societal, as well as economic, political and others), along with their individual attributions and interrelationships, as well as the ways of their integration into energy (efficiency) policies.

Publications in this book

Mikova, N., Eichhammer, W., Pfluger, B. (2019). Low-carbon energy scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets. Energy Policy, 130, 448-460. https://doi.org/10.1016/j.enpol.2019.03.047

Contribution: literature review, methodology, expert procedures, formal analysis, writing

Mikova, N., Sokolova, A. (2014). Global technology trends monitoring: theoretical frameworks and best practices. Foresight and STI Governance, 8(4), 64-83. https://foresight-journal.hse.ru/data/2015/01/05/1106723543/5-Mikova-64-83.pdf

Contribution: literature review, methodology, formal analysis, writing

Mikova, N., Sokolova, A. (2019). Comparing data sources for identifying technology trends. Technology Analysis & Strategic Management, 31(11), 1353-1367. https://doi.org/10.1080/09537325.2019.1614157

Contribution: literature review, methodology, expert procedures, formal analysis, writing

Filippov, S., Mikova, N., Sokolova, A. (2015). Green energy prospects: trends and challenges. International Journal of Social Ecology and Sustainable Development, 6(3), 1-20. https://doi.org/10.4018/IJSESD.2015070101

Contribution: literature review, methodology, expert procedures, formal analysis, writing

Mikova, N., Brugger, H., Rosa, A., Eichhammer, W., Bagheri, M., Kochanski, M. (2023). Understanding interrelationships between new societal trends to inform policy-making for the energy transition. Energy Policy, 2023. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4455899

Contribution: literature review, methodology, expert procedures, formal analysis, writing

Brugger, H., Eichhammer, W., Mikova, N., Dönitz, E. (2021). Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries? Energy Policy, 152, 112216. https://doi.org/10.1016/j.enpol.2021.112216

Contribution: literature review, methodology, formal analysis, writing

Appendix

Appendix A. List of additional publications connected to this thesis

Mikova N., Sokolova A. (2014). Selection of information sources for identifying technology trends: a comparative analysis (preprint). HSE, Series WP BRP "Science, Technology and Innovation", 25/STI/2014. https://wp.hse.ru/data/2014/02/06/1329134064/25STI2014.pdf

Mikova, N. (2016). Climate change and our future: anticipating trends and challenges using media data (preprint). HSE, Series WP BRP "Science, Technology and Innovation", 65/STI/2016. https://wp.hse.ru/data/2016/09/30/1122184162/65STI2016.pdf

Mikova N. (2016). Recent trends in technology mining approaches: quantitative analysis of GTM conference proceedings. In: Anticipating future innovation pathways through large data analysis (book) / Ed. by Daim, T., Chiavetta, D., Porter, A., Saritas, O. Springer: 2016, 59-69. https://doi.org/10.1007/978-3-319-39056-7

Ena, O., Mikova, N., Saritas, O., Sokolova, A. (2016). A methodology for technology trend monitoring: the case of semantic technologies. Scientometrics, 108(3), 1013-1041. https://doi.org/10.1007/s11192-016-2024-0

Sokolova, A., Mikova, N., Gutaruk, E., Gokhberg, L., Saritas, O., Sokolov, A., Chulok, A., Kuzminov, I., Saigitov, R., Bakhtin, P., Yaroslavtsev, A., Osmolovsky, A., Matich, L., Reshetova, E., Koroleva, O., Zhukova, E., Sokolsky, V., Akimova, V., Kornilova, A., Merkulova, E., Kiseleva, L., Zalessky, N., Efimenko, V. (2016). Global technology trends (book) / Ed. by Gokhberg, L., Saritas, O., Sokolov, A., Sokolova, A. HSE: 2016.

Sokolova, A., Mikova, N., Gutaruk, E., Gokhberg, L., Saritas, O., Sokolov, A., Chulok, A., Kuzminov, I., Saigitov, R., Bakhtin, P., Yaroslavtsev, A., Osmolovsky, A., Matich, L., Reshetova, E., Koroleva, O., Zhukova, E., Sokolsky, V., Akimova, V., Kornilova, A., Merkulova, E., Kiseleva, L., Zalessky, N., Efimenko, V. (2017). Atlas of future technologies (book) / Ed. by Gokhberg, L., Saritas, O., Sokolov, A., Sokolova, A. Tochka: 2017.

Mikova, N., Brugger, H., Rosa, A., Eichhammer, W. (2021). Understanding the controversial impact of new societal trends on long-term energy demand in European countries (paper / report). ECEEE Summer Study Proceedings / The newTRENDs project: Deliverable 2.2. https://publica-rest.fraunhofer.de/server/api/core/bitstreams/30a243dd-3497-43db-9cb0-b08e4703bcbe/content

Rosa, A., Mikova, N., Brugger, H., (2022). Identifying new societal trends impacting future energy demand (report). The newTRENDs project: Deliverable 2.1. https://newtrends2020.eu/wp-content/uploads/2022/05/newTRENDs_D2.1_Identifying-New-Societal-Trends-impacting-future-energy-demand-1.pdf

Brugger, H., Eichhammer, W., Mikova, N., Döniz, E. (2023). Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries? (policy brief). The 8th STI forum for the sustainable development goals (United Nations). https://sdgs.un.org/sites/default/files/2023-05/C11%20-%20Mikova%20-%20Energy%20Efficiency%20Vision%202050.pdf

Appendix B. Surveys, interviews and workshops conducted in this research

- "Technology platforms, long-term science and technology forecasting and foresight" (2012), series of international expert workshops (multi-disciplinary)
- "Long-term foresight of scientific and technological development for 2030" (2014), international expert survey (multi-disciplinary)
- "Global technology trends: trend-letters" (2015), international expert survey (multi-disciplinary)
- "Sustainable energy: trends and challenges" (2015), series of interviews with experts (energy)
- "Development and testing of a methodology for creating and developing centres for interaction between universities and corporations" (2015), series of expert workshops
- "Methodology for technology trends monitoring" (2016), series of interviews with experts (information and communications technology)
- "Low-carbon energy scenarios 2050 in north-west European countries: towards a more harmonised approach to achieve the EU targets" (2019), international expert survey (energy)
- "The newTRENDs project: how will new societal trends influence future energy demand in the European countries?" (2020-2021), series of international workshops (energy):
    - 1st expert workshop (trend clustering with project partners)

    - 2nd expert workshop (cluster analysis and prioritisation with external experts)
    - 3rd expert workshop (final cluster analysis and prioritisation with project partners)
- "The newTRENDs project: understanding interrelationships between new societal trends to inform policy-making for the energy transition" (2022), online expert survey (energy)

Appendix C. Conference presentations

- International Conference on Future-oriented Technology Analysis (FTA) (European Commission):
    - 5th FTA Conference (2014) "Engage today to shape tomorrow": "Comparing information sources for identifying technology trends", Brussels (Belgium), November 2014
    - 6th FTA Conference (2018) "Future in the making": "Low-carbon energy scenarios in north-west European countries", Brussels (Belgium), June 2018
- International Conference on Anticipation (Global Futures Laboratory):
    - 1st International Conference on Anticipation (2015): "Climate change and our future: anticipating trends and challenges", Trento (Italy), November 2015
    - 3rd International Conference on Anticipation (2019): "Anticipation of low-carbon energy future 2050 in north-west European countries", Oslo (Norway), October 2019
- Global TechMining Conference (Georgia Tech):
    - 5th Global TechMining Conference (2015): "Tech mining for monitoring technology trends: related methods, sources and software tools", Atlanta (USA), September 2015
    - 6th Global TechMining Conference (2016): "Integration of tech mining into technology roadmapping: creating, validating and updating technology roadmaps", Valencia (Spain), September 2016
    - 7th Global TechMining Conference (2017): "Tech mining tools for technology roadmapping: their usage in trends monitoring and bibliometric analysis", Atlanta (USA), October 2017
- International Futures Conference (Finland Futures Research Centre):
    - 18th International Conference "Futures of a Complex World" (2017): "Integration of trends monitoring and bibliometric analysis into technology roadmapping", Turku (Finland), June 2017

  - 24th International Conference "Empowering Futures" (2023): "New societal trends: analysis of their interrelationships to inform policy-making for the European energy transition", Turku (Finland), June 2023
- EU Sustainable Energy Week (EUSEW):
  - EUSEW "Lead the clean energy transition" (2018): "Low-carbon energy scenarios in north-west European countries", Brussels (Belgium), June 2018
  - EUSEW "Clean energy for green recovery and growth" (2020): "Green energy prospects: trends and challenges", Brussels (Belgium), June 2020
  - EUSEW "Accelerating the clean energy transition – towards lower bills and greater skills" (2023): "Understanding interrelationships between new societal trends to inform policy-making for the energy transition", Brussels (Belgium), June 2023
- UN Multi-stakeholder Forum on Science, Technology and Innovation for the SDGs (United Nations):
  - 4th UN STI Forum "STI for ensuring inclusiveness and equality" (2019): "Low-carbon energy scenarios in European countries", New York (USA), May 2019
  - 8th UN STI Forum "Science, technology and innovation for accelerating the recovery from the coronavirus disease (COVID-19) and the full implementation of the 2030 agenda for sustainable development at all levels" (2023): "Energy Efficiency Vision 2050: how will new societal trends influence future energy demand in the European countries?", New York (USA), May 2023
- EU-SPRI 2020 "New horizons for science, technology and innovation policy" (2020): "European energy scenarios 2050: how new societal trends may influence future energy consumption in the European countries?", Utrecht (Netherlands), June 2020
- ECEEE Summer Study "Energy efficiency: a new reality?" (2021): "Understanding the controversial impact of new societal trends on long-term energy demand in European countries", Stockholm (Sweden), June 2021
- Green Tech Festival (2022): "Technological and new societal trends and their role in energy transition", Berlin (Germany), June 2022

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Curriculum Vitae

Nadezhda Mikova has a background in "World Economics" (BSc), "Sustainable Development and Environmental Governance" (MSc), and "Foresight and Science, Technology and Innovation Policy" (postgraduate studies).

In 2012-2015 she worked at the International Foresight Centre (Higher School of Economics) as a foresight expert and coordinator of the "Global Technology Trends" project, which contributed to the "Russian Science and Technology Foresight 2030" and focused on monitoring promising technologies, which have potential impacts on developments in different areas (energy, ICT, medicine, transport, new materials, rational use of nature, biotechnology).

After finishing her master's studies (2015-2017) at Leipzig University and Utrecht University, Nadezhda Mikova started her PhD program at Fraunhofer ISI and Utrecht University in 2018. She worked on the "newTRENDs" project (Horizon 2020) aiming to increase the qualitative and quantitative understanding of impacts of new societal trends on energy consumption and to improve the modelling of energy demand, energy efficiency and policy instruments in this frame.

Her PhD focuses on the influence of technological and new societal trends on the European long-term sustainable energy transition, in terms of three perspectives: policies, methodologies and impacts.

Although a number of European countries have developed *low-carbon energy strategies* and analysed them in the form of scenarios, only a part of them consider projections to 2050. No country so far provided a complex view on the role of *technological*, as well as *non-technological factors* (e.g. social acceptance of technologies, stakeholder participation, lifestyle and consumption patterns), and policies to address both aspects. *New societal trends* can often be linked to general megatrends, which could, potentially, affect energy demand. Such trends include e.g. the transition to a circular and sharing economy, digitalisation of economic and private life, and a prosumer society. The main goal of this thesis is to develop an approach to analyse European long-term strategies for climate neutrality with a focus on the role of technological and new societal trends that affect the sustainable energy transition. This research is based on using *qualitative* (e.g. literature review, expert procedures, impact assessment, scenario development) and *quantitative methods* (e.g. text mining, statistical analysis, clustering, network analysis, modelling), as well as various *data sources* (e.g. international reports, scientific publications, patents, media, foresight projects, statistical databases). To address how technological and new societal trends – in their interaction – may influence the energy transition, three perspectives are taken in this thesis: *policy*, *methodology* and *impacts*.