Innovations towards low-carbon and resource efficient economies and the Climate, Land and Energy nexus - the case study of The Netherlands

Under the scope of the SIM4NEXUS project

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Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

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September 2019

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Abbreviations:

CLE	Climate Land and Energy
CLEWF	Climate Land Energy Water and Food
DPSIR	Driver Pressure State Impact Response
DH (or DHC)	District heating (or district heating and cooling)
ESCO	Energy Service Company
SIM4NEXUS	Sustainable Integrated Management for the NEXUS of Climate-Land-Energy-Water Food for a resource-efficient Europe (Research project)
UNFCCC	United Nations Framework Convention on Climate Change

Acknowledgements

I would like to express my sincere gratitude to all of those who supported me, virtually or in person, throughout the writing of this thesis.

Firstly, I would like to thank my supervisors, Eunice Pereira Ramos, Dennis Fokkinga and Duarte de Mesquita e Sousa. Without their willingness to let me define my own research and showing me the insides of their work, this thesis would not have been possible. Thank you Eunice, for providing me with the academic support I needed and taking me along on your impressively fast mind, while never forgetting to take care of the health of mine. Your motivational words have been appreciated as much as your explanations, ideas and always spot-on feedback. Thank you Dennis, for being brave enough to accept a thesis proposal so vague and broad at the start and helping me tackle the challenge of scoping and defining it. Thank you also, for urging me to balance academics with pragmatism, for always probing questions and transmitting your contagious desire to answer them. Thank you Duarte, for, from the very start, providing me with the freedom to follow my interests and pursue this work abroad.

A special word of appreciation goes to my colleagues at Driven by Values, who, from day one, made me feel like a full-fledged member of the team. Without the friendly and motivational environment they took me up in, the sincere interest in my work and the inspiring commitment to their own, this experience would have been completely different.

Furthermore, I would like to express my appreciation for my dear friends, whose support goes far beyond the direct contents of this study but is invaluable in the process. A special thank you goes to Carla, who created the online visualization of the outputs of this thesis and was always there to give me feedback or discuss ideas. Thank you furthermore for your convincingly strict reminders of the importance of taking proper breaks, regardless of the workload.

Finally, my appreciation and love goes to my parents, Jo and Natali, and my twin-brother, Niels, who dealt and deal with the side of me that arises when ambition and work-ethics collide with the finite number of hours in a day. Thank you, for always being proud of me and encouraging me to follow my dreams. Thank you also for consistently warning me not to lose other important aspects of life out of sight on the way to pursuing them.

Abstract (English)

Land scarcity challenges the ambition of the Netherlands, a densely populated country, to transition to a low-carbon economy. This issue not only affects sectors operating in the land system, e.g. agriculture, but also the energy sector, in particular due the large spatial requirements of renewable energy technologies. The competition for land permeates through the interlinkages between the Climate (C), Land (L) and Energy (E) domains - the CLE nexus. This study aims at identifying innovations that can contribute to improving the performance of the nexus by addressing the land scarcity challenge while supporting the low carbon economy transition. A framework for the identification of potential innovations applicable in a nexus context was developed. It derived from a literature review on innovation, the application of the Driver-Pressure-State-Impact-Response (DPSIR) framework to the land scarcity challenge, a benchmarking analysis of European countries, and several classifications of innovations. An inventory of innovations was prepared collecting examples from the Netherlands, the neighboring countries of Belgium and Germany, and a selection of countries (Denmark, Latvia and Sweden) that perform relatively well in terms of European-level energy and emissions targets. In The Netherlands' case study, three innovations were identified as particularly promising: district heating, Energy Service Companies, and peak shaving through water pumping. Furthermore, the DPSIR framework was used to identify elements that unify successful transition paths across countries. These were found to relate to long-term political commitments, context-specific geopolitical and economic drivers, and pioneering approaches, building from and towards national strengths.

Keywords: innovations, nexus science, DPSIR, systems thinking, the Netherlands

Resumo (Portuguese)

A escassez de solo desafia a ambição dos Países Baixos na transição para uma economia de baixo carbono. Esta questão não afeta apenas sectores que operam no sistema do uso do solo, p.e. agricultura, mas também o sector da energia, devido aos requisitos espaciais das tecnologias de energias renováveis. A competição por terra permeia as interligações entre os domínios Clima (C), Terra (T) e Energia (E) - o nexo CTE. Neste trabalho, um método para a identificação de possíveis inovações aplicáveis no contexto do nexo CTE foi desenvolvida, abordando o desafio da escassez de solo e apoiando a transição da economia de baixo carbono. O estudo incluiu uma revisão bibliográfica sobre inovação, da aplicação do método Processo Indutor-Pressão-Estado-Impacto-Resposta (PIPEIR) ao desafio da escassez de solo, uma análise de “benchmarking” dos países europeus e classificação de inovações. Um inventário de inovações foi preparado recolhendo exemplos da Holanda, Bélgica e Alemanha, e uma seleção de países (Dinamarca, Letônia e Suécia) que apresentam bom desempenho a nível das metas europeias de energia e emissões. No estudo de caso da Holanda, três inovações foram identificadas como particularmente promissoras: aquecimento urbano, empresas de serviços energéticos e abaixamento do pico por meio do bombeamento de água. Além disso, a estrutura PIPEIR também foi usada para identificar elementos que unificam trajetórias de transição bem-sucedidos entre os países. Verificou-se que estes se relacionam com compromissos políticos de longo prazo, motivadores geopolíticos e económicos de contexto específico, e abordagens pioneiras construindo a partir de, e para, as competências nacionais.

Palvras-chave: inovação, nexo ciência, Processo Indutor-Pressão-Estado-Impacto-Resposta (PIPEIR), sistemas inteligentes, Países Baixos

1. Background of the work

The Paris UNFCCC agreement that was signed in 2015 currently sets the scene for environmental policy globally. With its central aim of keeping the global temperature rise this century "well below 2 degrees Celsius" it puts pressure on all signatory countries to increase energy efficiency and renewable energy generation (United Nations Framework Convention on Climate Change [UNFCCC], 2015b). At the European level, the emission trading scheme and the Clean energy package, which includes the Renewable Energy Directive and Energy Efficiency Directive, are setting targets that require European Union member states to take more climate action (European Commission, 2009). In the Netherlands, the "klimaatakkoord" is leading the way regarding environmental policy (Rijksoverheid, 2019a). Among the signatory parties of this agreement are the Dutch national government, employers and financial institutions. It gives shape to the international targets, but also sets more ambitious national goals. For example, the Netherlands committed to a 49% reduction of greenhouse emissions in 2030 compared to 1990, while the European wide target is set at 40% (Sociaal-Economische Raad, 2018; European Commission, 2019a).

So far, progress towards a low-carbon society has been meagre in The Netherlands(Reijn, 2019). In 2016, the annual average CO_2 equivalent emissions per capita (12,200 kg/capita/year) decreased by only 15% compared to 2000 (14,400 kg/capita/year)(European Environment Agency [EEA], 2018). Part of the greenhouse gas (GHG) emission reductions can be obtained by increased renewable energy generation. At the European level, it has been agreed that by 2030 the share of renewable energy generation shall be 32% (European Commission, 2016b, 2019a). In 2017, the Netherlands reached 6.6% (Centraal Bureau voor de Statistiek [CBS], 2014). It is clear that there still is a long way to go for the Dutch to substantiate the ambitions voiced at the national level.

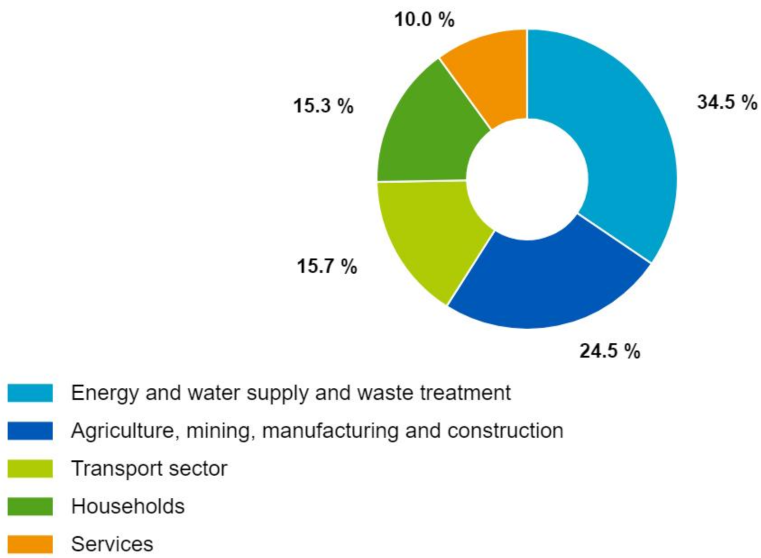

Figure 1 Contribution of CO2 emissions by households and industries for the second half of 2018 (CBS, 2018b).

The Netherlands is a small country, with a relatively large demand for energy, not the least because of its high population density. As can be seen from Figure 1, the energy, water supply and waste treatment sectors currently account for the largest share of CO_2 emissions in the Netherlands, see (CBS, 2018b). The energy sector in the Netherlands depends for the largest part on natural gas, mainly due plentiful and cheap availability, as a result of the exploitation of gas field in the North of the country (in the province of Groningen)(Schoots, Hekkenberg and Hammingh, 2017). Although renewable energy generation increased since 2006, it still makes up a very small share of the energy mix, see Figure 2 and 3 below (National Institute for Public Health and the Environment [RIVM], 2018).

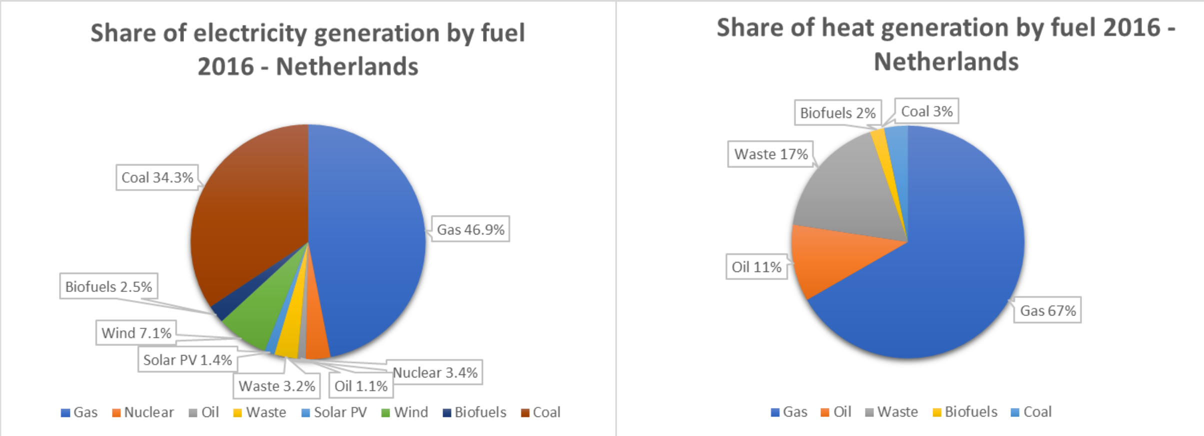

Figure 2 Share of energy production per fuel in the Netherlands in 2016 (IEA, 2017)(IEA, 2019c).

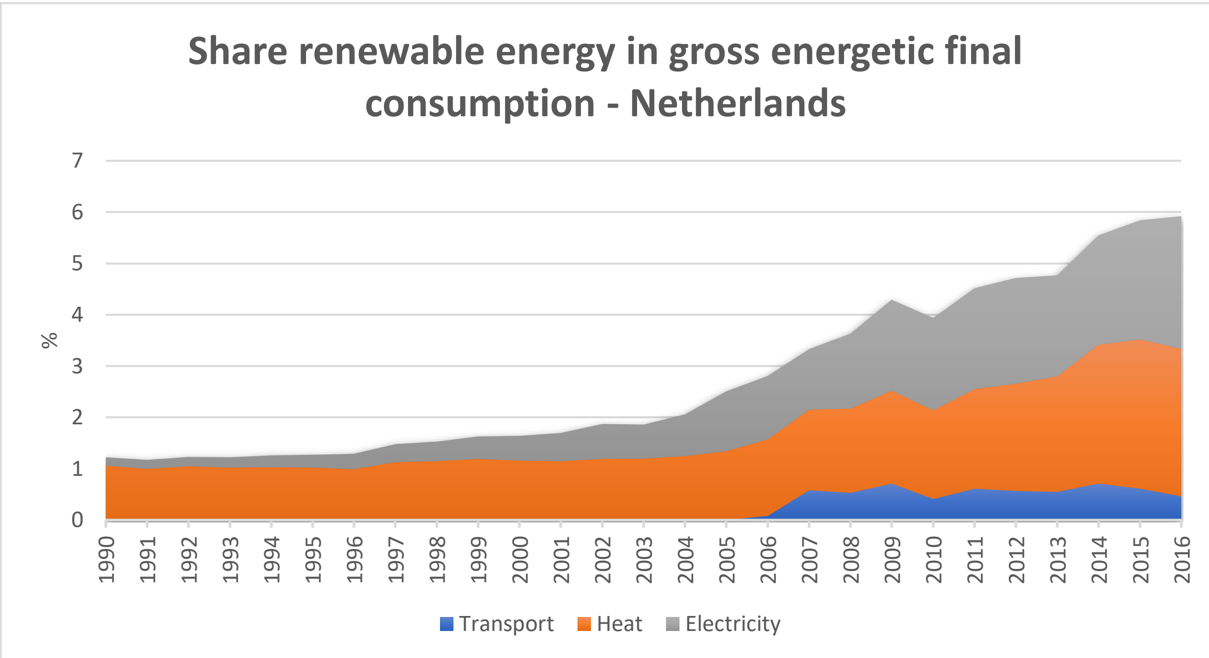

Figure 3 The share of renewable energy has remained low (IEA, 2017, 2019c).

As was mentioned before, the goals and ambitions mentioned above will, among other things, require a significant increase in renewable energy generation. Considering that renewable energy sources have a significantly lower power density than fossil fuels, an increase in renewable energy generation will require more space (van Zalk and Behrens, 2018). Making space for the energy transition, or dealing with land scarcity, albeit political or publicly perceived scarcity rather than absolute, is therefore particularly challenging for the Netherlands.

Moving beyond incremental improvements requires more radical change. As such, “innovation”, and how it should be created and developed has taken central stage in many research, strategy and policy documents, within but also outside of the Netherlands (OECD and Eurostat, 2018). After all, the urgency of transitioning to low-carbon economies is universal across Europe. However, the challenges that the energy transition evoke, as well as the opportunities, are to a larger extent specific to the characteristics of each individual country. In particular, challenges and opportunities exist in a network of interdependent domains that together make up a nexus. With regards to the transition to a low-carbon economy, the nexus consists of the domains Climate, Land, Energy, Water and Food. Over the course of this work, taking into account the (intermediary or especially interesting) findings, the focus shifted to mainly to the first three of these domains: Climate Land and Energy.

To reap the benefits of not being the only country that is confronted with the need to move towards a low-carbon economy, innovations from within as well as outside the Netherlands should be considered and evaluated for the Dutch context in particular. Characteristic to this context are, among other things, the high population density in the Netherlands and the extent to which renewable energy requires land.

1.1. Research Questions

The main aim of this study is to identify prospective innovations for the Netherlands in the context of the transition to a low-carbon economy,and assess their potential impact. More specifically, the aim is to answer the following two questions:

- *“Which innovations can have the largest impact on sustainability challenges for the interactions between the Climate Land and Energy nexus in the Netherlands, in particular to the challenge of land scarcity?”*
- *“Which innovations have the highest potential to be successfully implemented in the Netherlands, considering its political, historical and economic context as well as its most pressing CLE nexus trade-offs?”*

1.2. Objectives

In order to gain sufficient insights to provide satisfactory answers to the research questions, the concrete objectives of this study are to:

- Review the of state-of-the-art literature on innovations, particularly applicable to sustainability;
- Assess the performance of the Netherlands and other European countries on climate-indicators and select five countries that could serve as best-performance innovation examples for the Netherlands;
- Identify the CLEWF nexus trade-offs within the Netherlands, describe its political, historical and economic context, and assess the extent to which innovations are necessary to improve and support the integrated operation of the nexus;
- Create an innovation inventory with innovations from the best-practice countries and the Netherlands. The inventory will categorize the innovations according to the CLEWF nexus trade-

offs they address. The aim is also to include categories in this inventory that can aid to assess the extent to which they are influenceable at the regional level, so that regional actors and practitioners can directly use the insights.

- Assess the potential of innovations to be transferable to, or scalable within, the Netherlands. In a broader sense, the objective is to investigate how to leverage innovations and explore barriers to the successful implementation. Based on the findings the aim is also to create recommendations for actors at the regional level to foster innovative solutions to CLEWF nexus challenges.
- Assess the potential impact of the most promising innovations.

1.3. Structure of the thesis

The structure of the text chronologically follows the methodological steps taken when conducting the research. A summary of the most important content of each chapter is given here.

The details with regards to the used research methods, theories and frameworks will be explained in the chapter hereafter, chapter two.

In chapter three, the Dutch case study and the nexus approach are introduced. The most important characteristics of the Climate, Land and Energy domains of the Dutch nexus will be described in such a way that no other prior knowledge about the nexus approach or the country would be required to understand the rest of the research.

Chapter four provides a literature review on innovation in general and in particular on innovation for the transition to a low-carbon economy. The chapter reviews definitions and categorizations and clarifies which will be adhered to in the rest of the work. Also, several innovation theories are reviewed, parts of which will be used throughout the thesis.

In chapter five, the Driver-Pressure-State-Impact-Response (DPSIR) framework is introduced and applied to the nexus challenge of land scarcity in the Netherlands case study. This theoretical tool is combined with the nexus approach and used to analyse the challenge of scarcity of land in the Netherlands. Several related challenges are identified which will from there on be referred to as “DPSIR-challenges”.

Chapter six describes the benchmarking analysis that was performed on European Union member states. The starting points for the indicators to benchmark on were the topics for which targets are set at the EU level: GHG-emissions, renewable energy generation and energy efficiency. Five countries were selected that were used as sources of innovations in the subsequent part of the thesis.

In chapter seven, the approach taken to the development of an innovation inventory is described in detail. The categorizations are explained in detail and their purpose pointed out to facilitate the understanding of the transferability of the method. Also, the way in which the innovation list was populated for the purpose of this thesis is described briefly.

The results of the search for innovations are described in chapter eight. This chapter consists of two parts. The first half, section 8.1, describes the general transition paths of the selected countries and compares them to aspects of the Dutch transition. This section summarizes the consulted literature regardless of whether or not the encountered developments were innovative (and thus included in the innovation inventory). Here the DPSIR framework is applied for the second time, in order to understand the developments better and facilitate comparison. The second half of the chapter, section 8.2, describes the content of the innovation inventory making use of graphs, tables and charts. This part thus focusses only on the innovative developments of the analysed countries, those that were included in the inventory. Three promising innovations are selected and elaborated on further.

The most important conclusions and contributions of work are summarized in a separate chapter on conclusions. The final chapter describes the limitations and suggestions for future work.

2. Methodology

The identification of relevant innovations which can be implemented to improve the functioning of sectors in different nexus domains, requires the development of a method that can narrow down the broadness of a nexus analysis to what is essential. Additionally, it needs to account for the participation of relevant actors in the context of the nexus issue under analysis. This section describes the methodological steps followed in this thesis that enabled the development of a framework for the identification and selection of innovations with potential to address specific nexus challenges. The approach taken was a result of the performed analysis and application of the method to the land scarcity issue in the transition to a low carbon economy in The Netherlands.

An overview of the most important steps in the writing process of this thesis is provided in Figure 4 below.

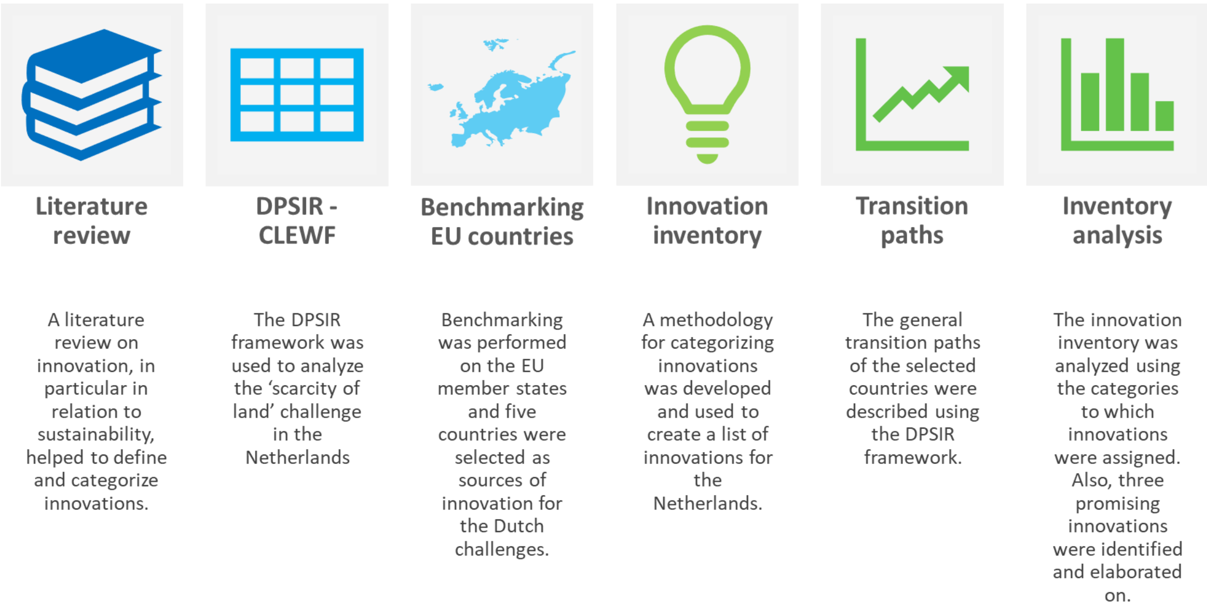

Figure 4 Overview of the most important steps of the research.

The development of the framework for the identification of nexus innovations was initiated by a literature review on innovation, in particular in relation to sustainability. This step served mainly to understand how to best define and categorize innovations.

The CLEWF nexus challenge of "scarcity of land" in the Netherlands was then analysed using the DPSIR framework. A table was created describing the DPSIR elements that characterize each nexus domain for the challenge of land scarcity. Review of statistical information (CBS, 2017, 2018a; Eurostat, 2019c, 2019b; CBS, 2019b, 2019c, 2019a; Eurostat, 2017b, 2018a, 2018c, 2018b; EEA, 2018; IEA, 2019d, 2019e), SIM4NEXUS project outputs (Brouwer, Avgerinopoulos, *et al.*, 2018; Brouwer, Vamvakeridou-Lyroudia, *et al.*, 2018; Laspidou *et al.*, 2019; SIM4NEXUS, 2019; Dekkers, Linderhof and Polman, 2020; Munaretto, 2020) and of academic and grey literature (CBS, 1998, 2016b, 2019c, 2019a; Butchart *et al.*, 2005; IUCN, 2009; Beets, 2011; ZEMBLA, 2017b, 2017a; McRae, Deinet and Freeman, 2017; Planbureau voor de Leefomgeving, 2018; Smits *et al.*, 2018; National Institute for Public Health and the Environment, 2018; Rijkdienst voor Ondernemend Nederland [RVO], 2019; Rijksoverheid, 2019b; Het

Voedingscentrum, 2019) served to elaborate the DPSIR table under the context described. In the table, the most important elements are explained and, where possible, supported by an indicator. Aspects identified as "Drivers", "Pressures", "States", "Impacts" and "Responses" were used to guide the search for innovations to be included in the innovations inventory.

The climate performance of the Netherlands and other European countries was assessed based on benchmarking using quantitative indicators. The starting point for the identification of the indicators were national, European and global targets. Five European countries were selected based on their performance as well as their expected relevance as best-practice examples for the Netherlands. For example, the geographical proximity and contextual similarities to the Netherlands were other criteria used for the selection of the countries for the benchmark analysis.

The previous steps enabled the creation of an innovation inventory that could be used in other case studies and by relevant stakeholders, when applied to a specific nexus challenge. For this thesis, the inventory was filled with innovations from the selected countries, as well as the Netherlands, using a combination of online searches, field research in the form of an internship at a Dutch regional energy-transition consultancy (Driven By Values[1]) and expert-knowledge of SIM4NEXUS researchers in the countries part of the project. Categories were created to facilitate the interpretation and analysis of important characteristics of the innovations. These categories were based on the literature review, the CLEWF approach, the insights from the DPSIR-CLEWF of scarcity of land in the Netherlands, the aims of the thesis, and the interests of local level actors and practitioners.

The general transition paths of the selected countries were described using the DPSIR framework and compared to the transition path of the Netherlands. This was done to explain differences in performance that cannot (exclusively) be assigned to innovations, and to identify contextual factors that are important for emergence and successful implementation of innovations. For several elements, qualitative indicators were used to support the analysis.

The innovations in the inventory were analysed by producing several graphical visualizations per categorization. This allowed the identification of three promising innovations to address the land scarcity issue in the Netherlands. Recommendations were made for implementation of these, building from experiences from abroad and within the Netherlands.

[1] Driven by Values is a consultancy that develops and supports projects related to the energy transition in the Netherlands. More information can be found on https://www.drivenbyvalues.nl/.

3. Introduction to the Dutch Case Study

3.1. Introduction to the CLEWF nexus

Climate, Land, Energy, Water and Food together make up the nexus that is of interest for innovations for a low-carbon economy. Each domain of the CLEWF nexus is defined below (Laspidou, 2017):

- Climate is: The long-term pattern of the weather.
- Land is:
  - The land and soil system of nutrient and organic matter cycles as an ecosystem and habitat for species.
  - A natural resource that is affected quantitively (land-use) and qualitatively (depletion/land footprint) by human intervention (either purposefully or as a side-effect).
  - A geographical phenomenon, “space” for living, working and transportation.
- Energy is: a socioeconomic domain, consisting of
  - Energy production,
  - Energy transformation from one form to another, distribution and retail, and
  - energy consumption.
- Water is:
  - The water system with its hydrological cycle, as an aquatic ecosystem and as a habitat for species.
  - A natural resource that is affected quantitively (discharges) and qualitatively (emissions) by human intervention (either purposefully or a s aside-effect).
  - A geographical phenomenon, consisting of lines (canals/rivers) and surfaces (lakes/seas) that connect and are used for transportation and other activities.
- Food is: a socioeconomic domain, consisting of:
  - Food production,
  - Supply chains and retail, and
  - Food consumption.

The five domains of the nexus are related through a complex net of both direct and indirect interlinkages (see Figure 5). Direct interlinkages describe how the status of one domain is altered by a change in the status of another one, without interference of any other domains. Indirect interlinkages describe how a change in one domain of the nexus causes a change in another through a third domain, which functions as a mediator (Laspidou, 2017). For example, global warming will accelerate the hydrological cycle, therefore displaying a direct link between Climate and Water. The accelerated hydrological cycle will in turn affect seasonal patterns of precipitation and evapotranspiration. Also, it will intensify extreme weather events like storms, periods of drought, heavy rains and flash floods. This will have an effect on agriculture and food production. As such there is also an indirect link between Climate and Food (Laspidou, 2017).

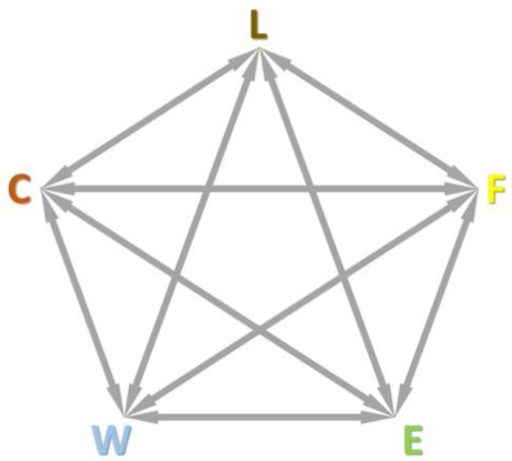

Figure 5 The interlinkages between the different domains of the CLEWF nexus (Laspidou et al.*, 2019).*

3.2 Nexus trade-offs in the Netherlands

The strength of interlinkages between nexus domains partly depend on the considered context. Factors such as the available resources and desired products may create challenges in one region while they provide opportunities in others. Take for example the direct link running from Water to Land: shortages of water can limit land productivity, while widespread availability can boost it. An example of an indirect link that can form a major challenge in certain contexts is given by the phenomenon known as "Indirect Land Use Change" (ILUC). ILUC refers to the case where increases in biofuel production cause changes in land use with an extra impact on climate. As such, the Energy domain influences the Climate domain indirectly, through the Land domain. This happens when for instance the price of agricultural land increases and induces the conversion of non-agricultural land that on average is carbon-rich to relatively carbon-poor agricultural land (when forests or grasslands are exchanged for agricultural fields, because the food is produced elsewhere).

It is therefore important to specifically investigate the trade-offs and challenges that are most important in the case of the Netherlands. As was explained before, one important challenge within the CLE domains of the nexus in the Netherlands, is related to land scarcity and the extent to which, especially renewable, energy requires it. It should be noted that "scarcity" is a popular term that has been used in several largely different narratives (Scoones *et al.*, 2019). Land scarcity, here, refers to political or perceived land scarcity in the sense that land use decisions are a serious source of discussion at every level of Dutch policy making and in the public discourse. Although the transition to renewable energy sources will require increased allocation of land to energy production anywhere in the world (Gordijn, Verwest and van Hoorn, 2003), this is particularly critical in the Netherlands. One square kilometer of Dutch ground is home to an average of 501 people, a population density that within Europe is only preceded by Malta. Although the west of the country (Amsterdam, Rotterdam, Utrecht) is more densely populated than the regions adjacent to the borders, there are no large areas that are uninhabitated. Only 22 municipalities (of the 390) have a population density of below 100 people per square kilometer (CBS, 2016a).

Behrens en van Zalk (2018) systematically reviewed the electrical power produced per horizontal square meter, the power density, of nine energy sources and many sub-types of these, see Figure 6. Sub-types of solar energy are, for instance, solar photovoltaics and concentrated solar power. For biomass, some examples of sub-categories are sugar cane, bamboo, wood chips and rape oil. They concluded that renewable energy systems have lower power densities than non-renewables, and increasing the share of renewable energy production will increase land use. They also emphasize that this will present challenges for agriculture and the protection of biodiversity. Choosing the most energy dense renewable options and using land for multiple purposes are suggested as strategies to deal with these challenges. (van Zalk and Behrens, 2018)

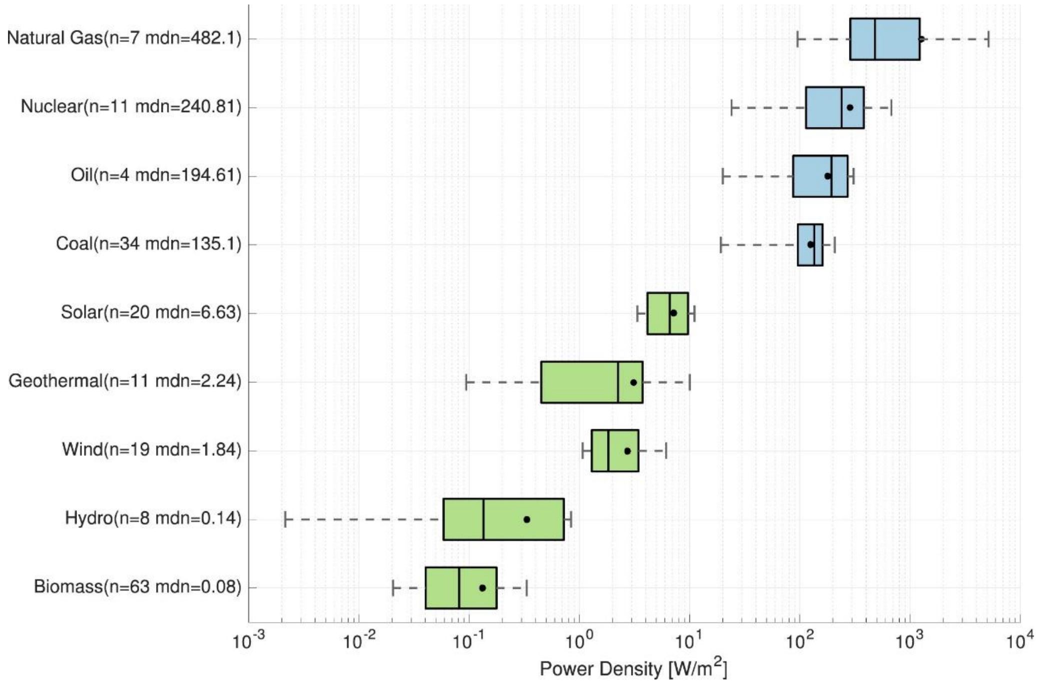

Figure 6 Power densities of different energy types on a logarithmic scale. The n and mdn values indicate respectively the number of values found for each energy type and the median power density. The black dots indicate the mean of each type. Blue and green boxes were used for non-renewable and renewable energy sources respectively (van Zalk and Behrens, 2018).

To make the logarithmic scale of Figure 6 more illustrative, I visualized the size of land required to provide for only the Dutch electricity demand using the different energy sources in Figure 7.[2]

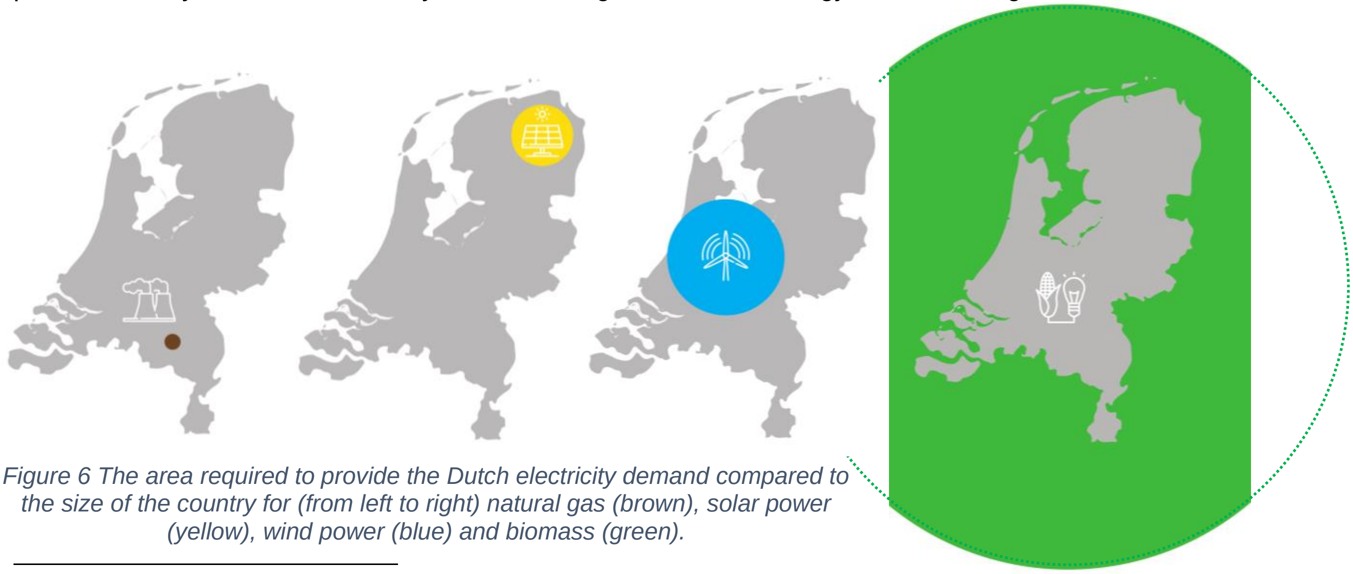

Figure 6 The area required to provide the Dutch electricity demand compared to the size of the country for (from left to right) natural gas (brown), solar power (yellow), wind power (blue) and biomass (green).

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[2] The area calculation was based on the average power densities of the energy sources found by van Zalk and Behrens (2018), which include space required for mining and correction capacity factors (i.e. solar panels do not work during the night). The total final consumption of electric energy in the Netherlands was taken for 2016 as documented by the Dutch Statistics Agency (CBS, 2019b).

The challenge of land scarcity in the Netherlands, albeit perceived or political rather than absolute, will be analysed using the DPSIR framework in chapter 5. Here, the Climate Land and Energy domains of the Netherlands will merely be described.

3.3. Profile of the Dutch Climate Land and Energy nexus

The Netherlands is home to around 17 million people who, on average, enjoy a high living standard. It covers an area of around 41,000 km^2 of which about one fourth lies below sea level. The low-lying areas require artificial control of the water table and are surrounded by dikes. Located in the North-West of Europe, the Dutch borders touch the North Sea, Germany and Belgium. Historically the Dutch economy has been mostly dependent on trade. In the last century, the economy has also regularly been describes as a "knowledge economy" in which services and knowledge development are important (EURAXESS Netherlands, 2019).

3.4. Profile of the Dutch Climate

The Dutch climate is best described as temperate marine, with cool summers and mild winters. The average temperature ranges between 2 °C in January and 19 °C in July (World Weather and Climate information, 2019). Demand for space heating is therefore considerably larger than for space cooling (EURAXESS Netherlands, 2019). Rainfall is spread over the year, but is less prevalent from April to September(EURAXESS Netherlands, 2019). The average monthly temperature and rainfall in the Netherlands from 1901 to 2016 is shown in Figure 8 below.

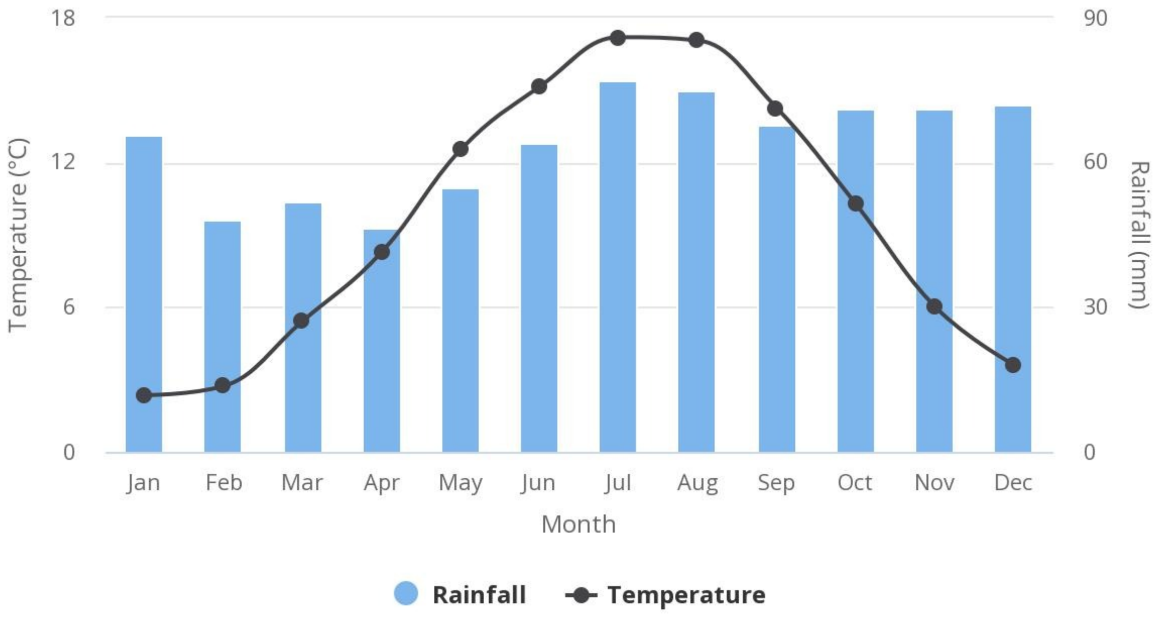


Figure 8 The average monthly temperature and rainfall in the Netherlands from 1901 to 2016 (The World bank Group, 2019).

3.5. Profile of Dutch land use

A very small proportion of the Netherlands is not used for anthropogenic activities such as agriculture, housing or infrastructure. Only 12% of the land consists of forests and nature and 19% of the territorial area is water. 54% Of the total land area is used for agricultural purposes. The remaining 15% are mainly used for built up and semi-built up area (which together make up 10% of the total), see Figure 9.

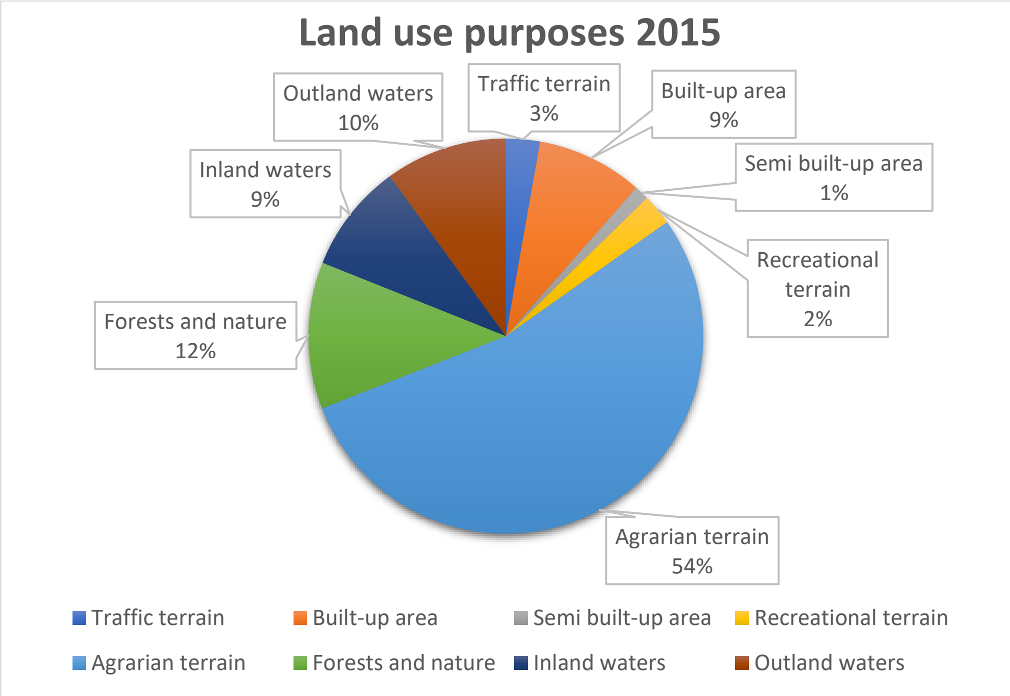


Figure 9 Land use purposes of the Netherlands in 2015 (CBS, 2018a)

3.6. Profile of the Dutch Energy domain

3.6.1. Political context

As will be elaborated on in section 6.1., the Netherlands, like the other EU-member states, is currently drawing up a national climate policy plan (NECP's). The NECP's of all EU-member states should cumulatively increase the renewable energy consumption to 32% by 2030 and increase energy efficiency by 32.5% in that same year. For the reduction of GHG emissions, the effort sharing decision imposes a national goal of 36% by 2030 (in comparison to 2005) for the Netherlands (European Parliament and Council of the European Union, 2018).

The national "klimaatakkoord" (climate agreement), will form the basis for the Dutch NECP (Rijksoverheid, 2019a). It contains plans that were made in collaboration with organizations and companies but also citizens, for five sectors: Built environment, mobility, industry, agriculture and land-use, and electricity. Instead of aiming for a 36% decrease of GHG emissions by 2030 (compared to 2005), which is the target set by the EU, the agreement states an overall goal of reducing GHG emissions by 49%, but compared to 1990 (Sociaal-Economische Raad, 2018). Furthermore it lobbies for an increase in the European wide goal to 55% compared to 1990, instead of the current 40% compared to 2005 (Sociaal-Economische Raad, 2018; European Commission, 2019a).

It is important to note also that the Dutch political system consists of several levels. Whereas the national government decides on larger goals and commitments, the provincial and municipal governments take important decisions on the exact implementation and realization approaches. Given the more distributed nature of renewable energy generation, the role of local levels of government can be expected to become more important. Within the klimaatakkoord, the importance of regional action was acknowledged by explicitly requiring provinces, municipalities and water authorities to collaborate in 30 regions to create a regional energy strategy (RES), as is depicted in Figure 10 (Netbeheer Nederland, 2019).

Figure 7 The Netherlands will have regional energy strategies for each of the 30 regions colored on this map (Nationaal promgramma Regionale Energie Strategie, 2019).

3.6.2. Cultural and historical context

3.6.2.1. Biking culture

The Netherlands is flat and densely populated, two characteristics that could be underlying the existence of a strong biking culture. Alternatively, the popularity of biking might be due to the pragmatic attitude and tendency to dislike wasting time or money of the stereotypical Dutch citizen. Perhaps some combination of the before mentioned reasons is at play. To distil the direction of any presumed causal relationships between the Dutch biking culture and contextual factors, goes beyond the scope of this thesis. A brief descriptive text seems appropriate and important however, given the intrinsic connection between energy use and human behaviour.

The Dutch travel by bike for more than one quarter of all their trips (Harms and Kansen, 2018). This is shown in Figure 11. In fact, the Netherlands has more bikes (22.5 million) than people (17.3 million)(CBS, 2016a). According to the Netherlands Institute for Transport Policy Analysis, Dutch residents have a positive perception of biking particularly because it is cheap, it guarantees “arriving on time”, “being on your own” and it offers peace and quiet. Also it is associated with convenience and comfort. (Harms and Kansen, 2018)

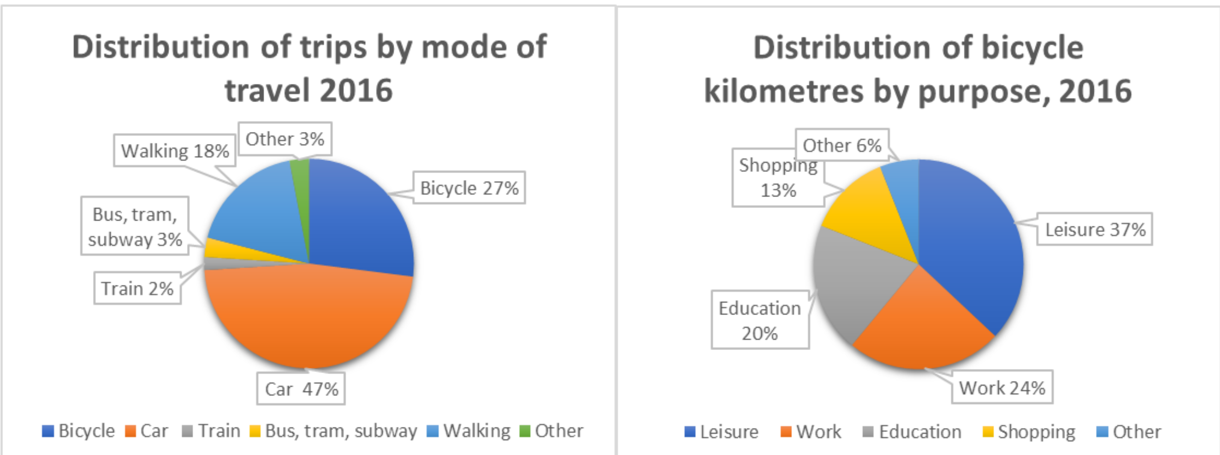


Figure 8 The Dutch biking culture in figures, adapted from “Cycling facts” by Lucas Harms and Maarten Kansen (2018).

3.6.2.2. Historical development of energy sources and infrastructure

With regards to energy use, the Dutch history is summarized in Figure 12. In the beginning of the 20th century, oil and coal were used for most energy applications. With the discovery of large national gas reserves in the 1960's, natural gas became the most used fossil fuel (Hölsgens, 2016). In recent years, renewables have started to emerge as sources of energy in the electricity, heating and transport sector (see Figure 3). Still, the most important source of energy is natural gas, albeit partly imported from other countries, see Figure 12.

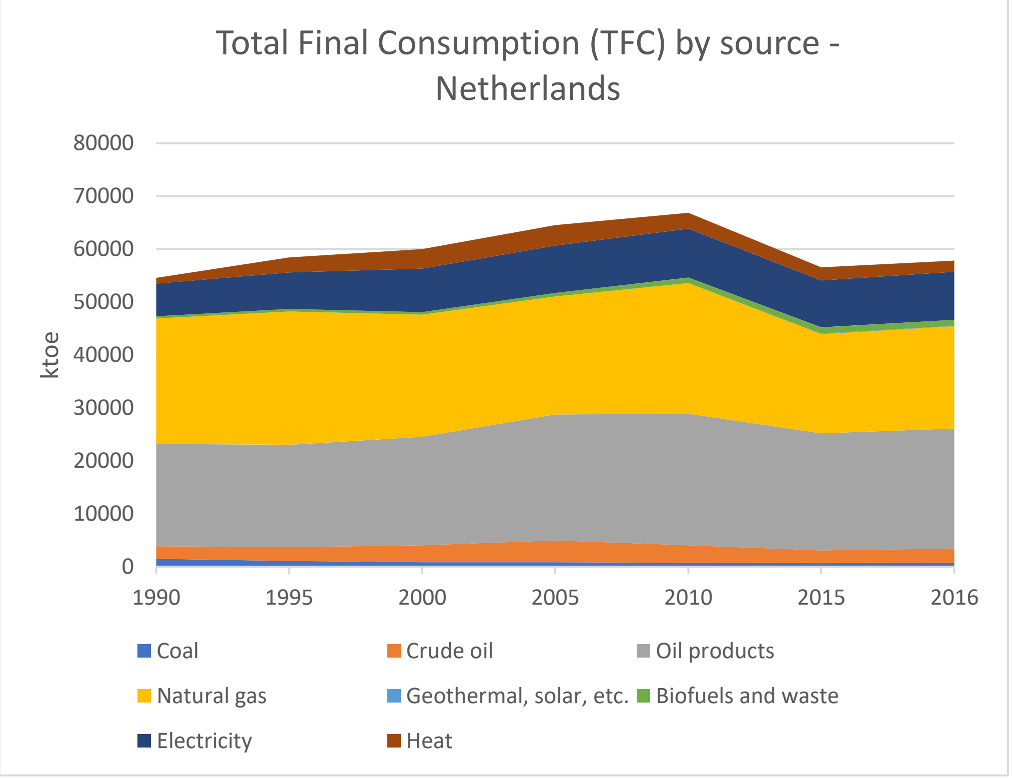


Figure 12 Dutch energy consumption by resource type (IEA, 2017).

The gas distribution network started to develop in various cities and regions long before gas was found in the North of the country. Since the beginning of the 19th century, several cities started using gas for public lighting and heating. By the 20th century, many urban areas had built their own networks while most rural areas were not connected to gas yet. After 1959, when gas was found in Slochteren (Groningen, north of the Netherlands), the distribution network was extended from city-based nets to a connected national grid. Due to the regional origin of the pipelines however, there still are differences in the design of networks in different locations (e.g. pressure levels) (Netbeheer Nederland, 2019).

The first electricity networks in the Netherlands were developed for industry and public lighting at the end of the 19th century. As a result of a large amount of simultaneously running privatized initiatives at the beginning of 20th century, also here large differences in prices and quality emerged. The national government intervened and created large municipal and provincial electricity companies. Later that century (in the 80's and 90's) the municipal and provincial distribution operators merged, but differences in terminology and voltage levels still exist. (Netbeheer Nederland, 2019)

3.6.3. The Energy Market

Currently 95% of the households in the Netherlands are connected to the gas network (Netbeheer Nederland, 2019) and virtually all households are connected to the electricity grid (ECN, Energie-Nederland and Netbeheer Nederland, 2016). The current energy use of a household exists for more than 80% of natural gas (Netbeheer Nederland, 2019).

The electricity law (1998) and gas law (2000) have regulated the distributive parts of the system (Netbeheer Nederland, 2019). As such, there is a free market for the production and retail of electricity and gas, but the national and regional distribution is regulated. The national electricity distribution is the responsibility of Tennet, while the Gasunie is responsible for the national gas networks. At the regional levels there are smaller distributors, each responsible for their own territories. Apart from distributing energy, they are also required by law to provide non-discriminatory access to the grid for everyone, and to balance supply and demand. (Netbeheer Nederland, 2019)

4. Understanding innovations

4.1. What is innovation?

Innovation has not always been as popular a term or research topic as it is today. The first research centres on the topic were established around the middle of the 1960s (Fosaas and Sapprasert, 2012). Since then, several scientific journals as well as professional societies related to innovation have emerged. A commonly accepted standard definition however, dates way back to the works of Joseph Schumpeter, one of the first scholars to devote explicit attention to the topic in modern science literature (Fosaas and Sapprasert, 2012). According to Schumpeter, innovation can be defined as "new combinations" of existing knowledge and resources. He clearly distinguished the concept from invention, which refers merely to the emergence of new ideas without the explicit need for those to be implemented in practice (which would make it an innovation) (Schumpeter, 1942; Fosaas and Sapprasert, 2012).

Currently, several general definitions of innovation have found ground in scientific literature (Gault, 2018). Gault combines many of these using a systems approach, in order to create a conceptual framework to statistically measure innovation, which he claims is essential for the evaluation of innovation policy. The *Oslo Manual*[3] has published a general definition for similar (measurement) purposes in each of its editions. The most recent one is:

> *"An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."* (OECD and Eurostat, 2018).

Earlier editions of the OSLO manual used the expression "introduced to the market" instead of "made available to potential users" (OECD and Eurostat, 2005). Critics such as Gault (2012, 2018) pointed out that this formulation made the definition distinctively applicable to measurement in the business sector, while there is no international standard for the equally relevant public and household sectors (Gault, 2012, 2018). Especially in relation to a transition to a low-carbon and resource efficient economy, this is an important point of criticism. After all, a sustainability transition that drastically alters the current system, requires innovation not only on the supply but also on the demand side (e.g. distributed vs. centralized power production, prosumers vs. consumers, sharing economy vs. ownership, redefining development in a broader sense than growth of GDP etc.)(Rifkin, 2013; Raworth, 2019). Also, the OECD definition left no room for innovations to be offered for free. Gault furthermore suggested to impose restrictions on the definition. Restrictions could state that innovations should address social challenges, support sustainable development or promote social inclusion. This does imply the need for an extra measurement later in time, for instance by means of a survey, because the outcomes of an innovation can be directly measured but the later impacts cannot (Gault, 2012, 2018).

[3] The Oslo Manual, published by the OECD, provides guidelines for collecting and interpreting data on innovation. It is intended to support national statistical offices and other producers of data on innovation by facilitating internationally comparable data, indicators and analysis. (OECD and Eurostat, 2018)

Across the definition provided by Schumpeter, the one in the *OSLO manual* and a myriad of other paraphrases, there seems to be a general form in which innovation is defined, consisting of some combination of a formulation of at least two particular clauses. Firstly, innovation is thought to require some "new" element in the form of new knowledge or an idea. Secondly, this new element is required to be "applied" in some way. Traditionally, "application" referred to the creation of new products or processes, but more recently the options for application have been stretched to organizational or even societal configurations, as it will be elaborated on in the following sections.

4.2. Categorization of innovation

As is the case with many multi-facetted and widely applicable concepts, innovation has been classified in many ways. The third edition of the *Oslo manual* (2005) proposed four categories for innovation in the business sector: product, business process, organizational and market innovations (OECD and Eurostat, 2005). The fourth edition of the same manual, published in 2018, reorganized the most important sub-categories in such a way that only the first two categories, product and process innovations, were kept but those cumulatively still contained similar sub-categories (OECD and Eurostat, 2018).

For the energy transition this categorization can be valuable. After all, product innovations such as electric cars, solar panels and bio-degradable plastics, are highly relevant for transitioning to a low-carbon economy. Likewise, process innovations, such as combined heat and power generation, make important contributions to highly required energy efficiency improvements. However, limiting innovation to these categories seems to imply a rather technocratic approach to sustainability, in which technological advancements will solve the issues we are facing today while continuing to aim for development as it is traditionally understood in economics: growth of Gross Domestic Product (GDP) (Fleurbaey, 2009; UNECE and OECD/Eurostat, 2013; Raworth, 2019). Neo-classical economists generally support this idea that new ways of producing Gross Domestic Product (GDP) would make it possible to "decouple" economic growth from environmental impacts (Ward *et al.*, 2016). As such, they reason that growth in GDP could continue to be a goal to strive for, because once decoupled from environmental impacts, growth in GDP would be sustainable. Within the sustainable development discourse however, technocratic viewpoints are highly criticized (Baker, 2005). Transitioning to a low-carbon economy is thought to require more than rethinking the things we produce and the way in which we do so. There are at least three arguments against "decoupling" as a sustainable solution that are commonly given by ecological economists and other critics of the concept. Firstly, "decoupling" growth in GDP from environmental impacts is not believed to be possible, because GDP has always been closely linked to material and energy use, which are in turn closely linked to environmental impacts, as is demonstrated by the model of Ward et al. (2016). Secondly, because of this link between GDP and material and energy use, there appears to be an inevitable incompatibility between infinite growth and finite resources in itself. Thirdly and more fundamentally: GDP in itself is not accepted as a worthy goal because it would not adequately reflect human well-being (Ward *et al.*, 2016). Such fundamental reconsiderations require openness to a variety of pathways. Classifying based on the outcomes, improved products or processes, might turn out to be incomplete as for example new forms of ownership, participation and understanding of well-being arise. Although many other categorizations have been proposed on top of the product/process one, most of these also classify based on the outcomes of innovations. For example, other commonly found categories are: sustaining versus disruptive innovations (Christensen, 1997), incremental versus radical innovations (Dewar and Dutton, 1986), evolutionary versus revolutionary innovations (Tushman, M.L. and O'Reilly, 1996; Twomey and Gaziulusoy, 2011). A classification that is based on the source of innovation rather than the outcome seems more appropriate for a transition to a society of which the exact appearance is still highly uncertain. Innovations are investigated in this thesis organized in four categories: technical, social, policy/governance and business innovations. This categorization leaves the development paths and final outcomes free of preconceptions, while still significantly reducing the breadth of innovation as a term. Because innovation as a concept is regularly linked or conceived to be linked to product or process types of innovation, this study will not use "innovation" as the umbrella concept. Instead of "innovation", "sustainable innovation" is understood to be the umbrella concept that encompasses the four categories: technical, social, policy/governance and business.

Important to note is that "social innovation", under the scope of this thesis, is considered to be the type of innovation that arises out of the reconfiguration or reorganization of social actors or their attitudes or behaviours. It is not used here to describe innovations that contribute to social/societal problems. This is only partly in line with the definition that Polman et al. (2017) decide to adhere to in their review of definitions of social innovation: *"[Social innovation is] the reconfiguring of social practices, in response to societal challenges, which seeks to enhance outcomes on societal well-being and necessarily includes the engagement of civil society actors."* While this definition also refers to social reconfigurations, the desired outcomes should be social too. All innovations considered in this study will be seeking to alleviate societal problems. After all, this study investigates innovations that can accelerate the Dutch transition to a low-carbon economy. Therefore, the term "sustainable innovations" will be used to refer to the entirety of innovations that aim to contribute to the transition to a low-carbon economy, with social innovations being merely one of its flavours, alongside technical, policy/institutional and business innovations. The focus will be on the energy-related aspects of this transition to a low-carbon economy. Therefore, the terms "energy transition" and "low-carbon transition" are used interchangeably in this study. "Energy transition" is a term that is also commonly used at the European policy level. It is used to describe the progress towards the "Energy Union", a low-carbon, secure and competitive economy (European Commission, 2017). To avoid confusion, the categorization is summarized graphically in Figure 13 below.

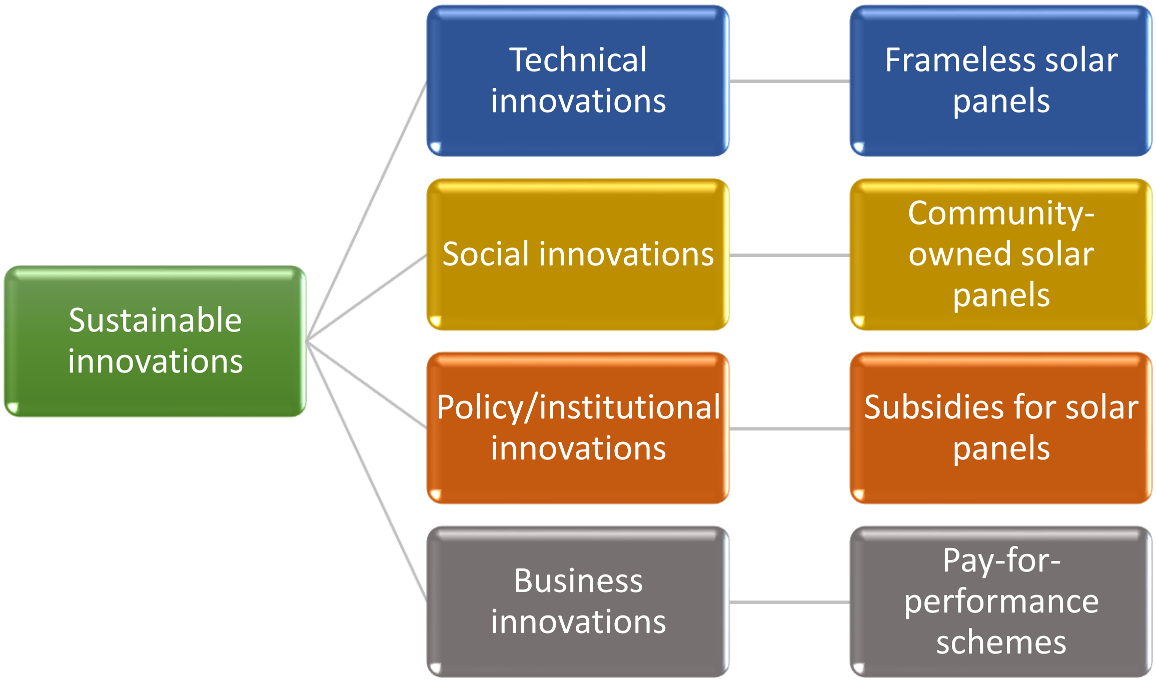


Figure 13 Categorization of innovations with "Sustainable innovations" as the umbrella concept and an example of each type.

Regardless of whether the categorization used is based on sources or outcomes of innovation, scholars have emphasized the importance of viewing innovation also as a process and a mind-set (Kahn, 2018). Although this is only partly related to categorization, Kahn (2018) claims that focusing too strongly on the outcome (as a category) will lead to inefficiencies due to double efforts and resource overconsumption. Innovation as a process, according to Kahn, consists of three phases that are all essential for the process: discovering, developing and delivering. Innovation should also be a mind-set within an organization, by making it part of the culture and way of thinking (Kahn, 2018).

At a closer look, the *Oslo manual* turns out to, at least to some extent, acknowledge the relevance of innovation as a process on top of an outcome, but does not include it as a sub-category of innovation. Rather it differentiates between innovation as an outcome (with the categories "product innovation" or "business process innovation"), and innovation as a process by referring to the latter as "innovation activities" (OECD and Eurostat, 2018). In this study too, innovation as a process is not considered a category of innovations like technical, social, policy/governance and business innovations. Alternatively, the "process" component is considered in each of the categories with the help of innovation and transition theories, of which the most important ones are discussed under 4.4.

4.3. The relation between innovation and the energy transition

Clearly, not every innovation contributes to reducing GHG emissions. Specifying that "sustainable innovations" are those that aim to contribute to the energy or low-carbon society transition is thus important in positioning this thesis. Before proceeding any further however, another important question deserves some attention. Are "sustainable innovations" indeed linked to progress in the energy or low-carbon transition? The common idea of progress being related to innovations that create change seems intuitive, but even if it is, the size of the impact of innovations greatly influences the extent to which it is worthwhile to investigate the emergence and development of sustainable innovations. As it is the foundation for the rest of this study, the following paragraphs briefly review some scientific literature on the relation between innovation and the energy transition.

Irandoust (2018) describes the direct causal relationship between technological innovation and renewables in Denmark and Norway and the same, but reverse, relationship in Sweden and Finland. The author concludes that to speed up the transition to renewables, investments for technological innovations must be made. Since the oil crisis of the seventies, the Nordic countries have heavily invested in alternative energy sources, mostly in nuclear, hydro, combined heat and power, and wind. The author suggests that the divergent results, regarding the direction of causality, could be due to differences in the energy mix, economic structure in terms of primary, secondary or residential sectors, the role of nuclear energy and the role of policies. In Norway, almost all electricity is produced from hydropower. Denmark produces about 30% of its electricity from renewables, of which approximately 2/3rd is wind power and the rest comes mostly from solid biomass and municipal waste. Sweden produces about 55% of its electricity renewably. Hydropower accounts for 84.6% and the furthermore mostly biomass. Finland generates about 35.5% of its electricity from renewables, 58% of which is hydropower and the rest mostly biomass (Irandoust, 2018). At policy level, the study concludes that investments should be made in technological innovations (Irandoust, 2018), since technological innovation effectively contributes to renewable energy deployment which in turn spurs innovations.

Similar conclusions are drawn by Lin and Zhu (2019), who investigate role of renewable energy technological innovation on climate change based on empirical evidence from China. Their linear regression model confirms a significant negative relationship between renewable energy technology innovations and CO_2 emissions (Lin and Zhu, 2019).

Hoppe & de Vries (2018) confirm the relation between social innovations and the energy transition in their editorial comment of 20 article contributions of the special issue “Social innovation and the Energy transition”. They conclude that social innovation is required for a transition to a low carbon energy system. For example, social innovations can be closely related to certain technological innovations, such as technologies that allow people to participate in peer to peer trading and local energy collectives. Also, new government arrangements are considered social innovations, such as regions serving as “living labs” to find out what works and what does not. “Green nudges” (changes in the design of technologies or surroundings that stimulate more sustainable behaviour) are also mentioned as social innovations that can contribute to the energy transition. An example of a “green nudge” would be a hotel room in which the lights can only be turned on once the key has been plugged into the master switch, thereby rendering it easier, or rather, almost impossible, to leave the lights on when leaving the room (Hoppe and de Vries, 2018).

Aldieri, Bruno and Vinci (2018) investigated the relationship between innovation and happiness. Considering that the transition to a low-carbon society arguably requires a reconsideration of growth in GDP as the main aim of development, this is an important research topic. In their study, the relationship between innovation and happiness is mediated by the environment, measured as eco-efficiency. They conclude that there is a positive relationship between eco-efficiency and happiness at the macro level, but unidirectional causality is not confirmed. It is furthermore hypothesized that at the micro-level, a negative relationship exists as a result of the well-known “Not In My Backyard” (NIMBY) syndrome (Aldieri, Bruno and Vinci, 2018).

4.4. Innovation theories

The findings of the previous paragraphs illustrate that innovation plays an important, if not crucial, role in the transition to a low-carbon economy. As such, it is important to investigate how innovations emerge and develop. The concept “innovation” moved from being a term that was initially mostly used in the Schumpeterian (economic) sense to one applied to a wide variety of change phenomena and which is often phrased as a panacea for resolving many problems (Godin, 2008). Consequently, it caught the attention of a wide range of scholars from different backgrounds. This has boosted the development of several innovation and transition theories over the years.

In the economic discourse, Schumpeter coined the term “creative destruction” in relation to innovation as a means to describe a “process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one” (Schumpeter, 1942). Later, Christensen used the notion of “disruptive innovation” to describe a specific type of innovation in which new products or processes create new markets that disrupt the existing market and eventually take in the place of existing market-leading firms and products (Christensen, 1997). At first glance, this popular term can be understood in a typological way with “disruptive” as an antonym to “sustaining” innovations, just like typologies exist that juxtapose “incremental” and “radical” innovations (Dewar and Dutton, 1986), put “evolutionary” on the other end of “revolutionary” innovations (Tushman, M.L. and O’Reilly, 1996); or, like discussed in the previous section, position “product” alongside “process” and “organizational” innovations (OECD and Eurostat, 2018). At a closer look however, “disruptive innovation” is more than just a category, but contains a theory of how the most impactful innovations develop and grow. Disruptive innovation as a framework describes the process by which innovations disrupt the economic system and overthrow the incumbent firms because they address over-served users instead of creating new markets for under-served users (McDowall, 2018). McDowall (2018) illustrates this theory with an example from the mobility sector. Although owning a car consumes a considerable portion of most household’s income, their vehicles stand still for 95% of the time. Owning a typical car provides the user with more mechanical power and technological features than an average driver uses. “Disruptive” innovations would therefore not be focused on providing newer, better vehicles. Rather, “disruptive” innovations are the ones that bring the user closer to what they actually need. In the mobility sector, car sharing services or electric bicycles make good examples (McDowall, 2018).

On top of the economic discourse, several other fields of study have made contributions to the base of literature on innovations and transitions. With regards to technical or knowledge innovation, the most important fields of study are Entrepreneurship studies (ENT), Innovation Studies (INN) and Science and Technology Studies (STS). Bhupatiraju, Nomaler, Triulzi & Verspagen (2012) conclude that over time these fields of study have become more compartmentalized and there is less interaction between them. In the 1960s and 70s, INN and STS still showed considerable overlap, illustrated by the relatively higher amount of between-field citations in core publications during that time (Bhupatiraju *et al.*, 2012). By 2000, however, the amount of between-field citations had gone down considerably, and ENT had emerged as a new separate field of study. Bhupatiraju et al. (2012) conclude that the decline in the amount of interaction between the fields was partly caused by specialization; and in part also, driven by the development of specific values and norms in particular subgroups of scholars (Bhupatiraju *et al.*, 2012). For example, in some fields, it may be common to have very extensive reference lists, while other fields use much shorter lists. Also, “strategic” motivations may influence citation patterns; for example, a particular author or paper may be cited or not cited to increase the probability of publication, and citations may be influenced by personal relations or dislikes (Bhupatiraju *et al.*, 2012).

Within Science and Technology studies (STS), Christensen’s disruptive innovation framework has regularly been contested. Firstly, it is claimed not to be broad enough to encompass all possible trajectories of the complex system change to a low-carbon society (McDowall, 2018). McDowall (2018) explains that the concept “disruptive innovation” is valuable in that it “highlights the tendency for analysts to overlook ‘overserved’ users or missing markets”. As the previously described example from the mobility sector illustrated, this depicts the tendency of analysts to focus predictions of the future on their knowledge of current users more than is appropriate and under-estimate the potential of new user-groups to emerge. However useful this insight may be, this is only one possible trajectory for innovations to cause change (McDowall, 2018). Apart from innovations that respond to the needs of over-served users, other types of innovations may also radically change the current system. Other critiques to Christensen’s disruptive innovation framework include the narrow consideration of products instead of the entire system, the limited multi-dimensionality and the simplistic (point source) interpretation of change (Geels, 2018; McDowall, 2018). Several scholars claim that for the transition to a low-carbon economy to be successful, energy services are what matters. In this context, such systems are required to be provided through large-scale infrastructures that co-evolve with related technologies, institutions, skills, knowledge and behaviour. This requires a perspective that considers the system as a whole (Geels *et al.*, 2018; McDowall, 2018). The consensus within STS is that a so-called socio-technical approach should be taken instead. This does not assume innovation to be a linear phenomenon in which a technology develops independently and then causes change in the system. Rather, socio-technical approaches assume interaction between technology and other actors within the system in the sense that they co-develop and co-construct each other (Geels *et al.*, 2018). Technological aspects are not more nor less important than for instance interpretations, fights for power, resource allocations, learning processes and decisions in determining the development path of a socio-technical system (Geels *et al.*, 2018).

Some socio-technical theories that incorporate some or all of the before-mentioned aspects are the Social Construction of Technology (SCOT) approach, the Large Technical System (LTS) approach and Actor Network Theory (ANT). The most commonly applied socio-technical theories in relation to low-carbon transitions however, are the Technological Innovation System (TIS) and the Multi-Level Perspective (MLP) frameworks (Markard and Truffer, 2008). Both of these combine ideas on the relevance of social networks, decisions and interpretations with, among other aspects, economic considerations about the pressures of existing systems on radical innovations. Also, both originate from evolutionary economics and hold onto ideas such as path-dependency, lock-in and non-linearity (Markard and Truffer, 2008). However, they have evolved to be rather different in some approaches too.

A technological system in the TIS approach has been defined as “a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology” (Carlsson and Stankiewicz, 1991). TIS is concerned with explaining the performance and growth or decline of specific technologies with institutions, actors and networks. The Multi-Level Perspective structures its understanding of a socio-technical system in another way. It divides the socio-technical system into three levels: the micro-level of niches, the meso-level of socio-technical regimes and the macro-level of landscape factors. It is through the interaction of these levels that change comes about (Geels, 2002; Walrave *et al.*, 2018). Figure 14 visualizes how the success of a new technology is not only governed by processes within its niche, but also by processes at the regime and sociotechnical landscape level. Developments at the landscape level, for example, may put pressure on the regime, that can create openings, or windows of opportunity for new technologies. At the level of the regime, several incremental processes take place: Industrial networks, strategic games, techno-scientific knowledge, culture and symbolic meaning, sectoral policy, infrastructure, markets and user practices, and technology. These regularly ongoing processes are depicted as relatively long arrows. The internal dynamics between the different dimensions may at times lead to uncertainty and differences of opinion, represented with shorter diverging arrows. The developments at the landscape level generally take place slowly. Examples are cultural changes, political trends and demographic changes. At the level of technological niches, the developments are fast and go in all sorts of directions, because no dominant design has been established yet. Some radical innovations may gradually stabilize into a dominant design, which is represented in Figure 14 by longer and fatter arrows. The MLP has been used as the theoretical base for policy recommendations such as Strategic Niche Management or Transition Management (Edsand, 2017; Geels, 2018).

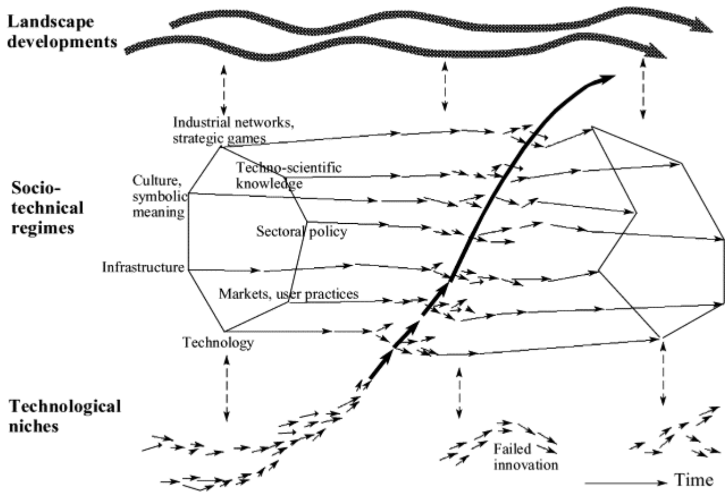


Figure 14 The dynamic Multi-Level Perspective on technological transitions (Geels, 2002)

Different variants of socio-technical theories have been applied in different cases. Some authors strictly stick to the frameworks as they were originally proposed, but others adapt them slightly or even combine them. For example, (Markard and Truffer, 2008) combine Innovation System approaches with the Multi-Level Perspective framework and propose their own integrated framework. Walrave et al. (2018) extend the application of socio-technical frameworks from mostly innovation-policy related research to innovation-strategy research (Walrave *et al.*, 2018). Another example is introduced by Planko et al. (2017), who suggest slight adaptations to TIS for use in the entrepreneurship sector (Planko *et al.*, 2017). Although one should be cautious not to complicate models and theories to the extent that they lose their value as a simplification of reality, it is interesting to see that the use and combination of the frameworks is to some extent taken flexibly. In part this could be due to the fact that the socio-technical theories, although having developed along largely separate paths, are thought to share some key concepts (Markard and Truffer, 2008). As was briefly highlighted before, most socio-technical theories acknowledge phenomena such as interdependence, non-linearity, path dependency, lock-in, and coupled dynamics (Markard and Truffer, 2008).

The development of socio-technical theories is still on-going. For example, in their discussion of several ongoing debates in the socio-technical transitions and low carbon innovation research discourse, Geels et al. (2018) point out that there is a strong focus on temporal aspects in literature, but less attention is paid to geographical questions. Given that transferability of (successful) innovations is at least as interesting as scalability, this is an especially interesting direction of research. Bridge et al. (2013), argue that transition should be viewed as a process that is geographically constituted rather than something that merely effects places (Bridge *et al.*, 2013). They therefore emphasize the practical value of considering the interactions between geographies and transitions for policy makers (Bridge *et al.*, 2013). Another example of ongoing debates is given by Tyfield (2018) who reasons that the MLP needs to be extended to assume a more complex power-knowledge perspective. According to the author, understanding transitions goes further than a socio-technical system or MLP, since they are highly dependent on sources of power and knowledge (Tyfield, 2018).

5. DPSIR framework in the context of the nexus

As it is the main aim of this thesis to identify innovations for the scarcity of land challenge in the light of a transition to a low-carbon economy in the Netherlands, it is important to understand the Climate Land Energy Water and Food nexus in which this transition is to take place. This chapter will systematically map the nexus challenge of land scarcity using the Driver Pressure State Impact Response (DPSIR) framework. The DPSIR framework is a theoretical tool to break down complex and interrelated (environmental) processes into more tangible and quantifiable units (Kristensen, 2004). In this chapter the framework will be used to better understand land scarcity as a challenge, later in this thesis the DPSIR framework will also be used to understand the transition paths of different countries. The value of the DPSIR framework for integrated approaches to environmental assessments has long been recognized. An example is its application by the European Environment Agency (EEA) in their State of the Environment Reports (Kristensen, 2004). This chapter will first introduce the theoretical framework in section 5.1. The framework will then be applied to the Dutch CLEWF nexus in section 7.2. taking the challenge of land scarcity as the starting point.

5.1. DPSIR framework theory

Within the DPSIR framework, environmental processes are understood to consist of a chain of causal links running from Driving forces, Pressures, States, Impacts, to Responses, see Figure 15 (Kristensen, 2004; Stanners *et al.*, 2007). Driving forces are the societal or economic aspects that are at the base of the framework and come with certain needs. These put Pressures on the environment through excessive use of resources, changing land use or emissions. Pressures then alter the State of the environment, being its physical, chemical and biological characteristics. A change in the state of the environment can have impacts, both on ecosystems and on human welfare. These impacts may trigger political or societal responses that aim to alter developments in any of the previously mentioned links or the strength of the relationship between them. (Smeets *et al.*, no date; Kristensen, 2004; Stanners *et al.*, 2007)

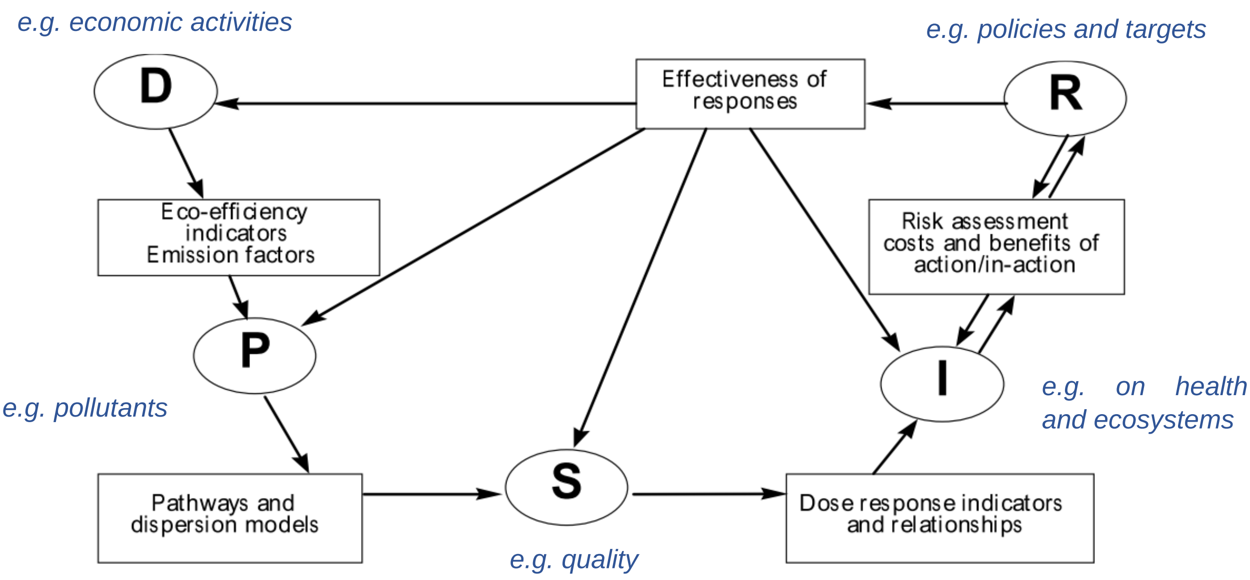


Figure 15 The links between the different elements and their possible indicators. Adapted from "Frameworks for Environmental Assessment and Indicators at the EEA" by David Stanners, et al., (2007)

For each element of the DSIPR framework, indicators can be used to quantify the issue. Also the relations between the DPSIR aspects can be quantified using indicators (Stanners *et al.*, 2007). Indictors mainly serve communication purposes. More specifically, they serve to communicate the size of environmental problems to support decision making on political prioritization, but can also help to monitor the effects of societal or political responses to these issues (Smeets *et al.*, no date).

In this thesis indicators will be used in the DPSIR characterization of land scarcity as a CLEWF nexus challenge in section 5.2., and in the analysis of the transition paths of the selected countries that is done in section 8.1.

Different types of indicators can be used depending on the purpose of quantification (Stanners *et al.*, 2007). Appendix A: DPSIR indicator categorization provides an overview of indicator types as well as some examples.

5.2. Applying the DPSIR framework to the Dutch nexus challenge “scarcity of land”

The DPSIR framework was combined with the nexus approach by creating a table that puts the five nexus domains vertically below each other and the five DPSIR elements horizontally next to each other. Hence, a five by five matrix was created in which for each nexus domain the Drivers, Pressures, States, Impacts and Responses could be described. Later a sixth row was added, labelled “Overarching aspects”, for the DPSIR aspects that recurred in all nexus domains. A summary of all six rows (overarching aspects, Climate, Land, Energy, Water and Food) is given in Table 1 below. The complete table can be found in Appendix B.

Table 1 Summary of the DPSIR-CLEWF table that was made about the scarcity of land challenge in the Dutch CLEWF nexus. For the complete table, see Appendix B.

The Netherlands’ nexus challenge of scarcity of land				
Driver	**Pressures**	**State**	**Impact**	**Responses**
RE and EE policy goals Compliance to CO2eq emission targets Land requirements for agricultural production Socioeconomic factors (lifestyle, western diet and consumption patterns)	Competition for land resource (energy, food, agriculture, biofuel production, settlements, other infrastructure) GHG emissions from the energy sector Nitrogen emissions from the agriculture sector	Low % RE in the primary energy supply Energy intensity of the economy Relatively high CO2eq emissions per capita Competition in the use of land (Political scarcity of land): infrastructure, agriculture)	Costs of adaptation and mitigation Costs of no-adaptation and mitigation Failing to meet national and international targets (%RE and GHG emission reduction) Trade-offs between economic sectors	Klimaatakkoord Investments in RE in the energy sector Reduction of GHG in the transport sector (e.g. mobility plans, congestion charge) Energy / electricity: Off-shore RE development, Waste-to-energy,

Circular economy vision and ambitions	Urbanization and population density Waste production Living standard Energy costs to consumers	Overexploitation of water for irrigation Country land area below sea level (vulnerability to sea level rise and energy pumping requirements) Biofuel production and biofuel blends	(in particular due to competition for land; e.g. impact in electricity costs, food prices, agricultural goods exports, etc) NIMBY cases (particularly due to RE expansion) Eutrophication (fertilizer use, N emissions)	roof-top solar systems) Integrated solutions for wastewater treatment Shift to the production of higher-value agricultural products Dietary change

Where possible indicators to quantify elements were found and compared to EU targets or averages. The cells containing elements for which the Netherlands is either not achieving its EU targets or in the lower half of the EU ranking, were coloured red. Alternatively, cells that contain indicators for which the Netherlands is performing well (achieving its targets or in the upper half of the EU ranking), were coloured green.

As the table was created taking land scarcity as a starting point, all elements in the table are somehow related to this initial challenge. Sometimes the relation between the element in the table and land scarcity as a challenge is obvious (e.g. competition for land by different sectors), in other cases less so (e.g. energy intensity of the economy). It is therefore important to note that the elements mentioned in the table are not exclusively the result or cause of land scarcity, but they are all (to a smaller or larger extent) related to it. The elements that were coloured red (in Appendix B) thus form challenges that are related to land scarcity. In a way these are more specific, but they are simultaneously broader, because they open up the possible solutions beyond those specifically aimed at land use.

Take for instance energy intensity of the economy as a state characterization that the Netherlands is performing poorly on. Innovations that contribute to reducing this level can be completely unrelated to land use at first sight. For example, the business model innovation commonly used by Energy Service Company's (Energy Performance Contracting) can lead to more efficiency retrofits being done in private households or company buildings, this reduces the energy intensity of the economy without altering land use in any way (Boza-Kiss, Bertoldi and Economidou, 2017). However, the DPSIR-CLEWF table helped to see that indeed energy intensity is related to land scarcity, for instance because of the amount of land required for energy production. Innovations addressing energy intensity are thus very much relevant to the challenge of land scarcity that was the starting point of the analysis. Therefore, the challenges contained in the red cells of the table were used to frame five related challenges. These five are listed below and an example of the reasoning behind their link to land scarcity is given in brackets for each of them.

- **Renewable energy deployment** (e.g. Renewable energy sources have larger spatial requirements than non-renewables).
- **Energy intensity of the economy/living** (e.g. Demand for energy drives demand for land to generate this energy on).
- **Resource use and disposal** (e.g. Waste recycling and circularity could not only reduce spatial requirements for landfills, but perhaps more importantly, reduce the demand for virgin resources and therefore mining).
- **Mobility** (e.g. Population density could form an opportunity rather than a challenge, but the Netherlands is not necessarily a frontrunner on green mobility in Europe).
- **Agricultural emissions** (e.g. Food choices greatly affect land requirements for agriculture).

The listed challenges will from now on be referred to as "DPSIR challenges" and were used as one of the categorizations of innovations that will be discussed further in chapter 7.

6. Best-practice countries selection

6.1. How are goals set?

As was explained briefly in the introductory chapter, climate goals and targets are voiced at many different political levels. Whether at the global, European or national levels, generally at least three types of goals are set: reducing GHG emissions, increasing the share of renewables in the energy mix and increasing energy efficiency. The latter two are clearly related to the first goal of reducing overall emissions, but the inclusion of targets specifically dedicated to renewables and efficiency give direction to the means by which this should be achieved. Also, they have their value in that they emphasize topics such as circularity and dependence on finite resources.

Globally, the Paris agreement of 2015 expresses the goal of the signatory parties to keep the global temperature rise "well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C". In contrast to their previous Kyoto protocol in 1997, the United Nations Framework Convention on Climate Change does not set legally binding national emission targets in the Paris agreement. Instead, the nation states face binding procedural rules. These include the obligation to "prepare, communicate and maintain" Nationally Determined Contributions (NDC's), at least once every 5 years. Successive NDC's are required to show progress beyond previous ones and "reflect its [the country's] highest possible ambition". Within their NDC's, developed countries are immediately required to adopt economy-wide absolute emission reduction targets, and developing countries should aim to do so over time. Achieving these self-determined targets is in no way legally binding for the nations, but complying with the guidelines on the creation and assessment of NDC's is. (Center for Climate and Energy Solutions, no date; ClimateFocus, 2015; UNFCCC, 2015a, 2018)

At the European level, the goals of the Paris agreement currently resonate in the form of the Clean Energy for All Europeans package. This legislative framework includes, among other things, the Renewable Energy Directive and the Energy Efficiency Directive (European Commission, 2016a). The European Council sets a legally binding target of 32% renewable energy consumption in 2030 for the European Union as a whole. The target for increased energy efficiency is 32.5% and with regards to the electricity market the target is an interconnection of 15% in 2030 (European Commission, 2016b). The only aspect for which the European Union also imposes binding targets on its individual member states is their total GHG emission reductions. Similarly to the previous 2020 targets, the targets for 2030 were established through the effort sharing legislation, which covers most sectors not included in the European Emissions Trading Scheme that focusses on industry. These national targets for 2030 for the Non-EU ETS sectors, range from 0 (Bulgaria) to 40% (Luxembourg) from 2005 levels (European commission, 2019). The Dutch target is set at 36% reductions (European Parliament and Council of the European Union, 2018). No nationally binding targets are set for renewable energy shares or energy efficiency improvements. Instead, similar to the approach taken in the Paris agreement, member states are required to pledge contributions through national energy and climate plans (NECP's). Regional consultations on the plans, the possibility for the Commission to make recommendations, and the overarching policy framework are supposed to create enough "peer pressure" for Member states to pledge high. (European Commission, 2016b, 2016a)

It is thus the national government that sets its own targets for renewable energy generation and energy efficiency. As optional as this may sound, the binding procedural obligations that the Dutch and other national governments committed to at the European and global level are elaborate. Not only are countries expected to critically consider their possibilities and ambitiously set their targets, they will also be held accountable for their progress (ClimateFocus, 2015; European Commission, 2016b). One advantage of self-setting targets is that countries are to a large extent free to choose their climate mitigation strategies. This means that NDC's and NCEP's should be customized better to both the different starting points as well as local conditions, working methods and ambitions.

6.2. Current goals

Currently only draft versions of the NECP's have been published. The final NECP's have to be submitted by the end of 2019 (European Commission, 2019b). For the purpose of evaluating and comparing the performance of different European countries therefore, old targets and current levels of renewable energy consumption, energy efficiency and GHG emissions will be considered in this study. More specifically, the European targets for 2020 will form the basis of the climate performance benchmarking of the next paragraphs. Whereas for 2030, only the national targets for GHG emission reductions in the ESD sectors were set at the European level, for 2020 binding national targets were set at the European level for both GHG emission reductions as well as renewable energy generation. Differences in starting points, potential and economic conditions were taken into account (European Commission, 2019c). For energy efficiency, no specifications for binding national targets were decided upon at the European level neither for 2020 nor 2030. Instead, individual member states set their own indicative national energy efficiency targets for 2020: similar to how the 2030 targets are decided by member states in their NECPs. Depending on the countries' preferences, the 2020 targets were based on primary or final energy consumption, primary or final energy savings or energy intensity. The Netherlands set its targets for Primary energy consumption or Final energy consumption at 60,7 or 52,2 respectively (European Commission, 2012) . An overview of the European and Dutch targets for 2020 and 2030 is provided in Appendix C.

6.3. Benchmarking European countries on climate and energy goals

In business, “benchmarking” generally refers to the measurement of the quality of an organization’s product or business practices and the comparison with standards or similar measurements of peers. The purpose of benchmarking is to identify where improvements can be made and to learn from how other organizations reach their performance levels (Merriam-Webster dictionary, 1952; Business Dictionary, 2019; Cambridge English Dictionary, 2019; Collins English Dictionary, 2019). Here, not the quality of a product or organization is measured, but the performance of a country, the Netherlands, on several climate and energy indicators. The performance is not only compared with its own targets, but also with the performance of other EU member states and their targets. The purpose is, similar to benchmarking in business, to identify where improvements are called for most, and on which aspects other countries could serve as examples.

The benchmarking in the following paragraphs is in no way exhaustive and could have been done in a myriad of other ways (e.g. based on different indicators), possibly leading to a different ranking of best-practice countries. It should therefore be noted that it was not the purpose of this study to thoroughly compare the performance of the European member states on all climate and energy goals and aspects. Rather, the selection of countries is supposed to simplify the progress to the overall aim of this study: to find innovations that can benefit the challenge of land scarcity in the Dutch energy transition. Two things were considered to be crucial for countries to be best-practice candidates: firstly their performance on climate and energy goals as such, and secondly their contextual similarities to the Netherlands. For that reason, not only the countries that show the best values in the graphs, but also those with similar targets are considered as candidates to be selected as best-practice examples. After all, the goals set at the European level reflect contextual considerations such as starting points, economic welfare and renewable energy generation potential. Furthermore, geographical proximity was considered a pre, not only because of climatic and cultural similarities, but also because the Netherlands, small as it is, has a relatively large share of border-regions where opportunities for exchange of information and possibly even collaboration are especially present. Also inclusion of a country as a case study within the SIM4NEXUS research project was considered a pre for a country to be selected. This is because of the expected benefits of SIM4NEXUS inclusion in relation to data gathering about similarities or differences in Climate, Land and Energy nexus trade-offs, policy contexts and innovations.

The most easily quantifiable comparisons are those for which national targets were set by the EU: GHG emission reductions and renewable energy generation. After all, these targets were set taking into consideration the contextual differences between countries in terms of wealth in the first case and additionally in terms of starting points and potential in the second. Countries with similar goals to the Netherlands can thus be expected to be somewhat similar in these respects. Regarding energy efficiency, comparisons are slightly less straight forward. Even when comparing energy consumption per capita, the influence of sector dependencies of the economy and the level of economic welfare dilute the value of the comparison. Therefore, the energy intensities of the economies were compared using the energy intensity of GDP as an indicator.

6.3.1. GHG emissions

The progress on the national GHG emission reduction targets for 2020, set at the European level under the so called “Effort Sharing Decision”, are shown in Figure 16 below. The target for the Netherlands was set at 16% by 2020, compared to the base year (2005). In 2017 already an 18% reduction was achieved. Although the Netherlands is on track for its ESD target, the Dutch state lost a now famous law-suit that was sued by the foundation “Urgenda” for not reaching its targets. The foundation claimed that the current reduction levels were not sufficient for the Netherlands to meet their IPCC commitments, for which they deemed necessary a 25% reduction compared to 1990 levels.

Regardless of whether the targets are sufficiently ambitious, for the sake of benchmarking it is useful to compare the performance of different European countries on their effort sharing decision targets. For the correct interpretation of Figure 16, it is important to note that “target” is a confusing word in the context of GHG emissions. “Limit” would arguably better describe the meaning of the number. All countries with emissions below their target after all, are on the right track. These were coloured green, while the countries that had not yet achieved their 2020 target in 2017 were coloured red. As can be seen from the presence of both positive and negative targets, some countries were allowed to increase their emissions compared to the base year while others were required to reduce them. The countries have been sorted from those with the largest relative reductions in 2017 on the far left to those with the largest increases to the right. The levels at which the targets were set, which are indicated by the black markers, give some indication of the context and economic comparability of countries.

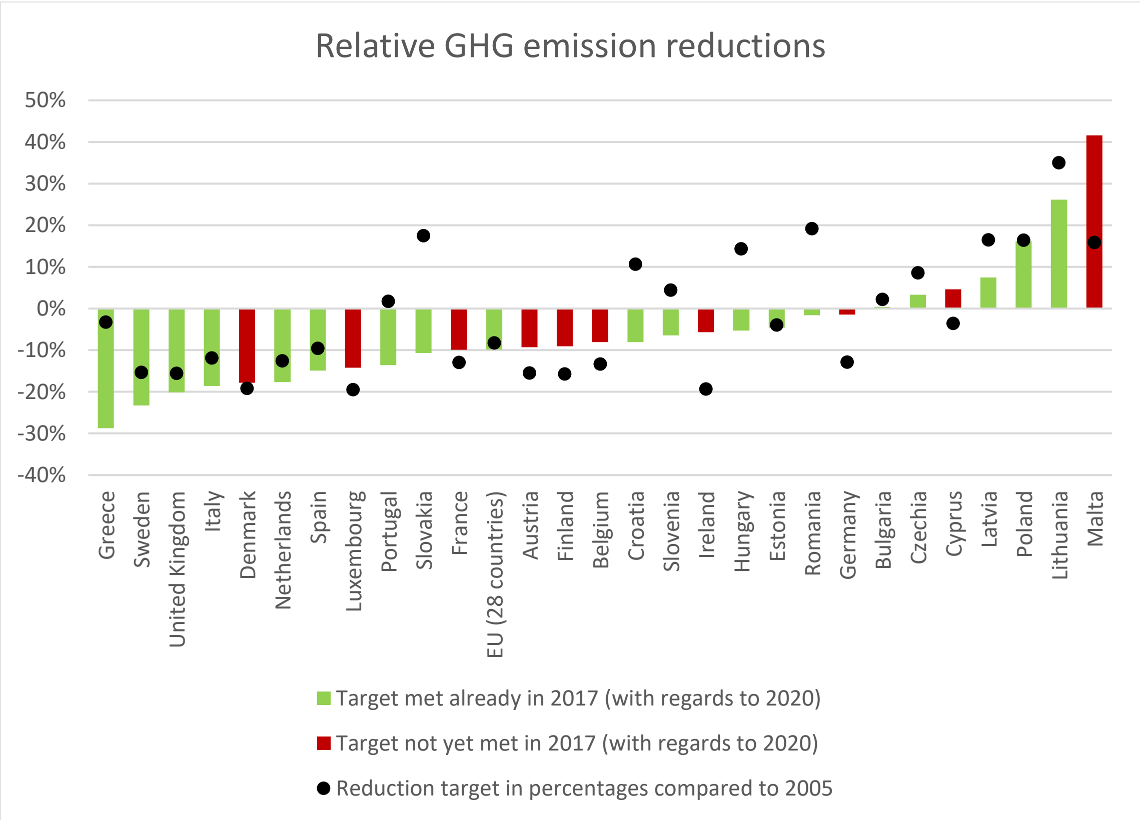


Figure 16 ESD GHG emission as a relative change to the ESD base year 2005 (Eurostat, 2019b)

To the left of the Netherlands are the potential best-practice examples based on the relative size of their GHG emission reductions. For example, although Denmark did not yet achieve its target in 2017, it still had a larger reduction in GHG emissions than the Netherlands.

Apart from progress in the sense of reducing GHG emissions, it is furthermore interesting to evaluate the current per capita GHG emissions of the European member states. After all, those countries that are already emitting less GHG emissions per person can be considered potential examples regardless of their recent reductions. In Figure 17 these levels are ordered from highest to lowest per capita emissions. Countries that had lower and higher per capita GHG emissions than the Netherlands in 2016 are coloured green and red respectively.

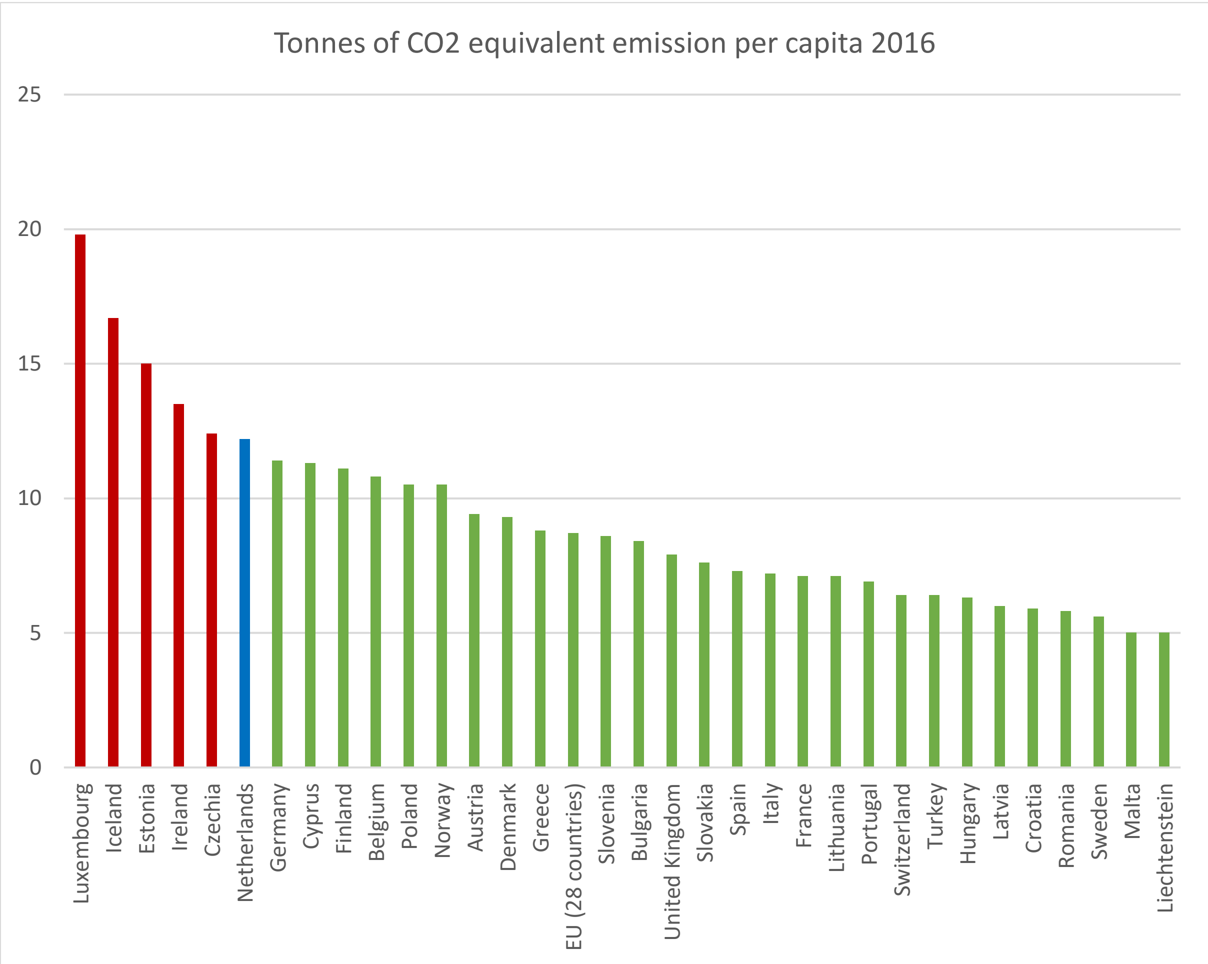


Figure 17 Tonnes of CO_2 equivalent emissions per capita 2016 (EEA, 2018)

Figure 17 shows that the Dutch are among the highest per capita emitters of GHG emissions, with 12.2 tonnes of CO_2 equivalent per capita in 2016.

6.3.2. Renewable energy

Similarly to the GHG targets, also the national renewable energy targets for 2020 were set at the European level; under an earlier version of the Renewable Energy Directive. The directive set a European wide target of 20% renewable energy consumption, but also specified national targets which ranged from 10% in Malta to 49% in Sweden. The Dutch target was set at 14%. To determine the national targets, differences in starting points, renewable energy potential and economic conditions were taken into account (European Commission, 2019c).

Figure 18 shows the progress of EU member states towards their targets. The countries are ordered based on the size of the share of renewable energy generation.

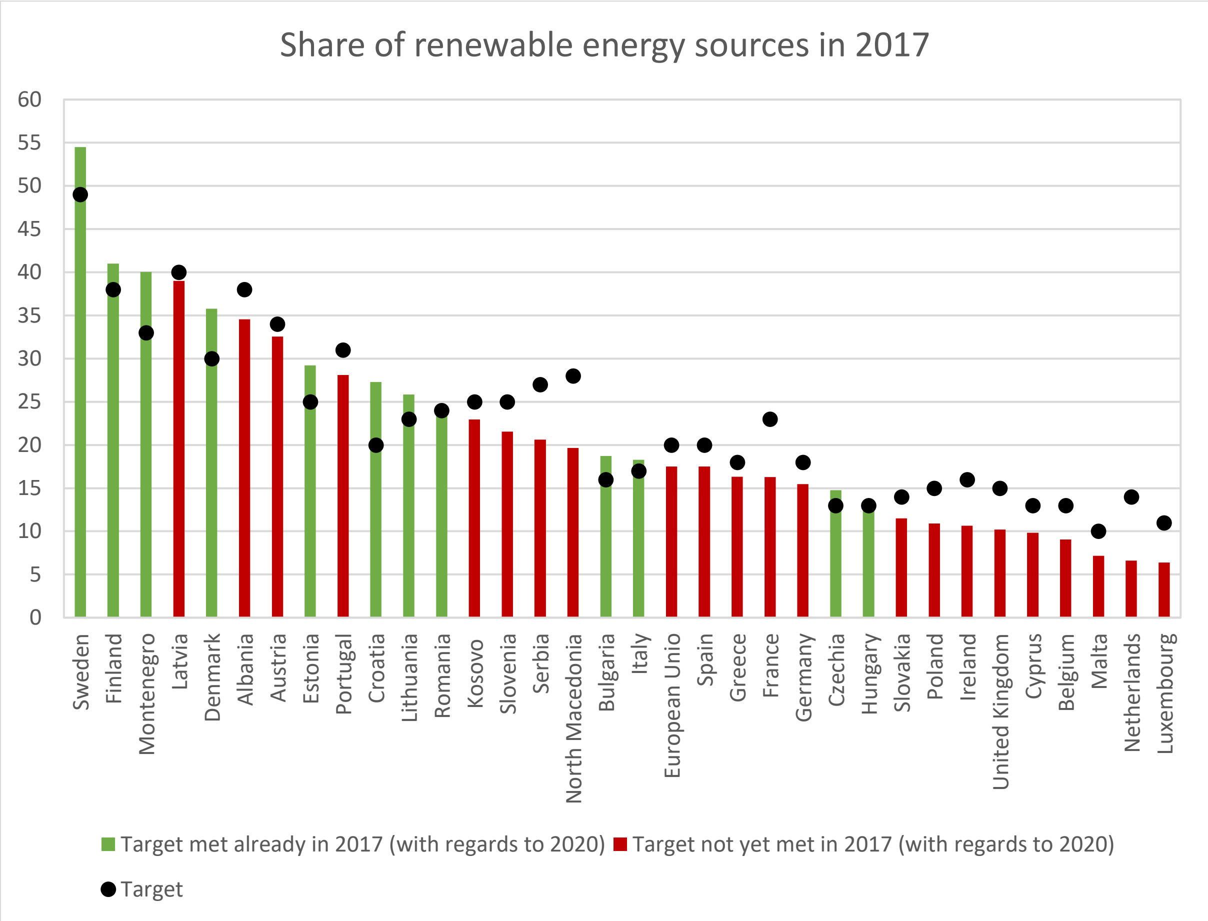


Figure 18 Renewable energy targets and current levels of the European member states (Eurostat, 2017)

The best performing country in this respect is Sweden, but also Finland, Montenegro, Latvia and Denmark have high shares of renewable energy generation in their energy mix. The Netherlands is performing extremely poorly on this parameter, not only with respect to its own target, but also relative to other countries. As an illustration: even if the Dutch Eastern neighbour Germany was still far removed from reaching its 2020 target in 2017, it had more than double the share of renewables in its energy mix (15.5% compared to 6.6% in the Netherlands).

6.3.3. Energy Efficiency

As was explained in the introduction of this chapter, energy efficiency will be evaluated here using energy intensity of GDP as an indicator, see Figure 19. This way, also the economic context of different European countries is, at least to some extent, taken into account.

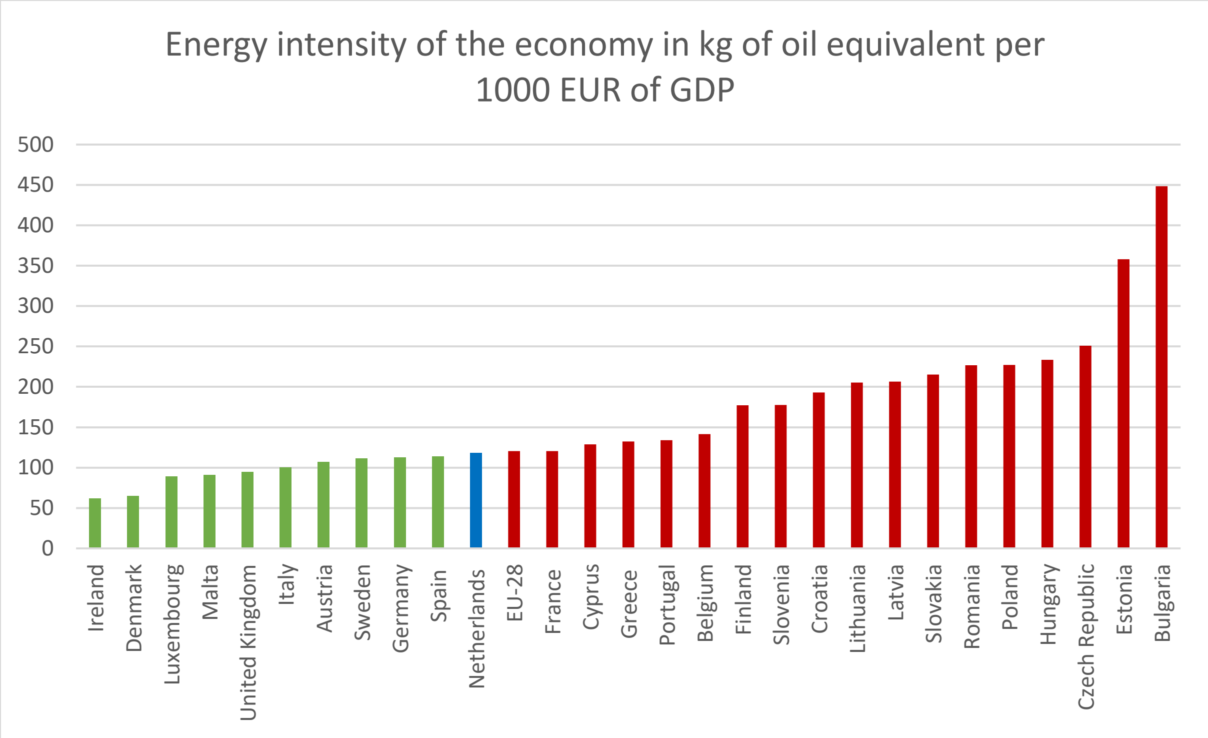


Figure 19 Energy intensity of the economies of the EU member states in kg of oil equivalent per 1000 Euros of GDP (Eurostat, 2017a).

The countries are ordered from left to right from those with the least to those with the most energy intense economies. The Dutch economy is slightly less energy intense than the EU average with 118.3 kg of oil equivalent per 1000 Euros of GDP (Eurostat, 2017a).

6.4. Best-practice countries selection

Depending on the indicator used, different countries could be chosen as best-practice examples for the Netherlands. Nevertheless, the overall insights in the performance and comparability of different EU member states of the previous paragraphs, supported the selection of five countries that will be used as a source of innovations to address the Dutch challenge of land-scarcity in the transition to a low carbon economy. As was mentioned before, the selection of countries was also based on the geographic proximity, similarities in opportunities for renewable energy generation and in- or exclusion of a country as a case-study within the SIM4NEXUS research project.

- **Sweden:** Sweden outperforms the Netherlands on all of the before mentioned aspects and as such was an obvious choice as a best performance example. Also, it makes extensive use of biomass, currently a popular topic for discussion in the Netherlands. Furthermore, Sweden is included as a case study in the SIM4NEXUS research project, facilitating data exchange with SIM4NEXUS researchers about Climate Land and Energy trade-offs as well as innovation data.
- **Denmark:** Also Denmark outperforms the Netherlands in all of the benchmarking comparisons of the previous paragraphs. Furthermore, Denmark is famous for its deployment of wind energy, which is one of the strategies the Dutch government is currently aiming for.

- **Latvia:** Latvia shows impressively low GHG emissions per capita and a high share of renewable energy generation. Also, its progress in recent years has been impressive and it is a SIM4NEXUS case study as well.
- **Germany:** Germany has similar levels of per capita GHG emissions as the Netherland and did not realize large emission reductions between 2005 and 2017 either. Its share of renewables is however notably larger than the Dutch one and also the energy intensity of its economy is much lower. As a neighbouring country included in the SIM4NEXUS case studies, it will therefore also be considered as a best-performance example.
- **Belgium:** Although Belgium does not perform exceptionally well on any of the considered parameters, it will be considered as a source of innovations because it is one of the two countries that the Netherlands shares it borders with. The geographical proximity does not only mean that contextual similarities can be expected, but also that regional actors might be interested in innovative developments close by.[4]

The performance of the selected countries on the benchmarking indicators, relative to each other, are shown in Figure 20 below.

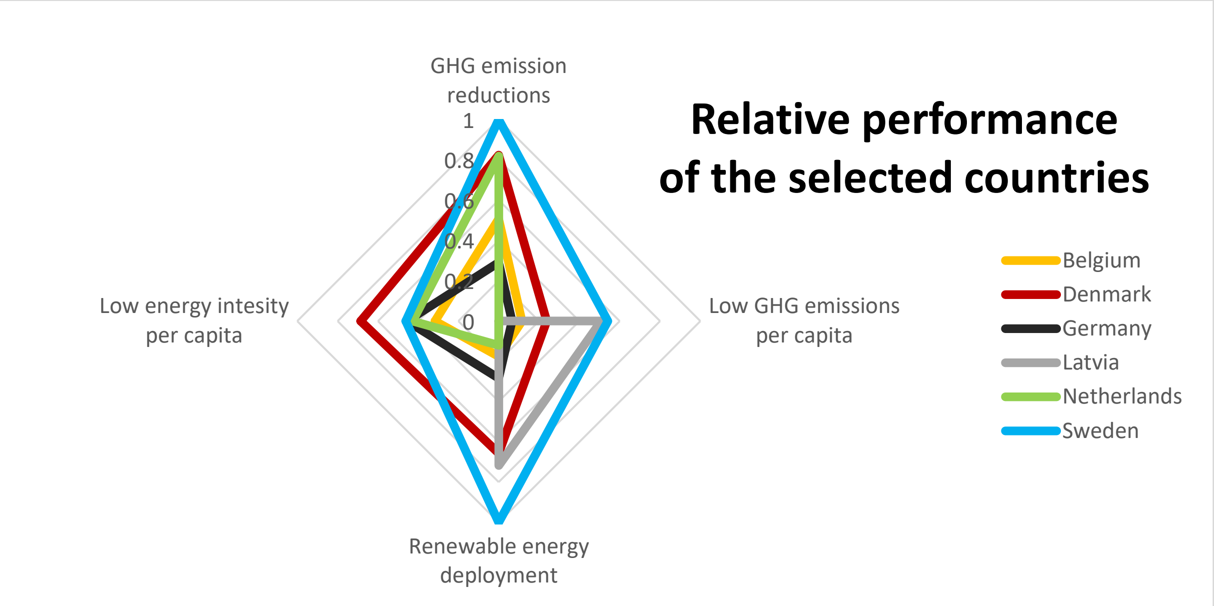


Figure 9 The performance of the selected countries on the aspects that were used in the benchmarking analysis are shown relative to each other. The scale goes from 0 (relatively bad performance) to 1 (relatively good performance). In the vertical direction the scores were calculated by setting the value of the best performing country equal to 1 and calculating the other scores as a proportion of that. In the horizontal direction the same approach was taken with the difference that the scales were reversed so that the best performing country has the score that is furthest away from zero.

[4] Dennis Fokkinga, a senior consultant at Driven by Values, confirmed this interest of regional actors by stating that he and his employees regularly receive questions about the developments in Belgium and Germany, especially in border regions (D Fokkinga 2019, personal communication, March).

7. Finding innovations

More than 70 innovations from within and outside the Netherlands were identified, listed and categorized in a table format. Innovations were named using either the English translation of a policy, the actual product name or a self-invented descriptive name. Separate columns facilitate the categorization on a range of aspects. These are summarized in Figure 21 and will be described further in the following paragraphs. These categories will be used later on to analyze the findings.

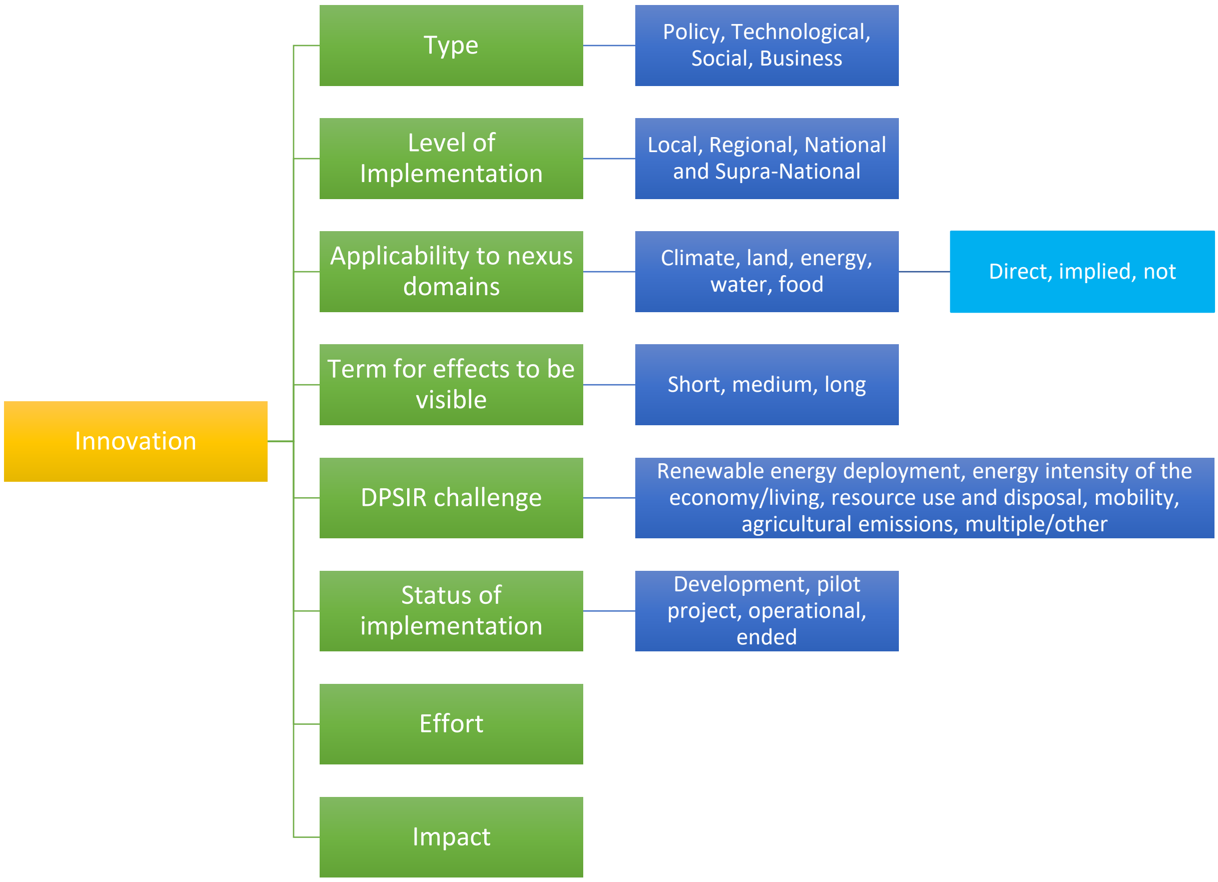


Figure 21 Categorizations used in the inventory.

7.1. Categorization: Innovation type

First of all, innovations were categorized according to their type. As was elaborated on in chapter 4.2., four categories are differentiated by: technical, social, policy/institutional and business innovations. It should be noted that the label “social innovations” will be assigned to those innovations that arise out of the reconfiguration or reorganization of social actors or their attitudes or behaviours. It is not used here to describe innovations that contribute to social/societal problems, as that is the implied purposes of all innovations identified in this thesis, regardless of their type.

Policy innovations were found in two ways. First, literature such as policy documents, policy reports (e.g. national energy outlooks) and academic papers were reviewed (Shipkovs, Kashkarova and Shipkovs, 1999; Nilsson *et al.*, 2004a; Wang, 2006; Borup *et al.*, 2008; Swedish Energy Authority, 2008; Sarasini, 2009; Uba, 2010; Federal Ministry for Economic Affairs (BMWi), 2010; IRENA, 2012; Rosenow, Hilda and Oxford, 2013; Rutten, 2014; Agora Energiewende, 2015; Nuclear Energy Agency [NEA] and OECD, 2015; Prodanuks *et al.*, 2016; Technopolis, 2016; Timma, Zoss and Blumberga, 2016; Danish Energy Agency, 2016; IEA, 2016; Kuzemko *et al.*, 2017; Locmelis, Bariss and Blumberga, 2017; Sturm, 2017; Jørgensen, Jørgensen and Jensen, 2017; Millsap, 2018; Clean Energy Wire, 2018; Kuittinen and Velte, 2018; Edquist, 2019). These texts did not only provide descriptions of implemented policies, but also helped in understanding which policies are most emphasized by the national governmental bodies themselves. Secondly, three databases kept by the international energy association were used to systematically include relevant policies introduced from 2009 onwards: the Climate Change Policies and Measures database, the Renewable Energy IEA/IRENA Joint Policies and Measures database and the Energy Efficiency Policies and Measures database (IEA, 2019a, 2019b; IEA and IRENA, 2019). Mainly database entries from 2009 onwards were included because these are expected to be most relevant for the current (2019) performance on 2020 goals, and the most determining policies of before this year are expected to also have been covered by literature (and thus already be included in the list). When presumably important and innovative, policy changes were made just before 2009 these were also included.

Some specific technological innovations were included in the list to provide illustrative examples of what kind of technologies the countries are developing. The most valuable for comparative ends however, is the couple of rows about patent families for each of the countries. These were taken from a website that was the product of the PhD work of François Perruchas (François Perruchas, Consoli and Barbieri, 2019): The website is mainly supported by data from PATSTAT 2016a.

Business innovations were found mainly in news articles and through web-searches.

Those innovations that are listed as "social innovations" were mostly taken from the same sources as the policy innovations were taken from. If the change in social structures, perceptions or behaviors was estimated more central to the deployment or success of the innovation than the legal or political change, the innovation was listed as "social" instead of "policy". An example would be the "Buy smart" awareness program of the German government that was intended to inform citizens of the benefits of buying energy efficient appliances (IEA, 2015).

7.2. Categorization: Level of implementation

The level at which an innovation is applicable is described using four geographical categories: local, regional, national and supra-national. Local innovations are those at the level of the city or part of a province. The regional level refers to slightly larger geographical area: on or multiple provinces or regions. Especially in Belgium this level of implementation is prevalent, given the political, linguistic and cultural division of the country into Wallonia, Flanders and Brussels. Innovations that are implemented in an entire country fall into the national category. Any cross-border innovations are referred to as supra-national. An example would be the Nord-pool energy market.

7.3. Categorization: Applicable nexus domains

The applicability of an innovation to each of the domains of the CLEWF nexus were included as indicators using three categories: “Yes”, “Implied” and “No”. For each of the Domains the prerequisites for an innovation to fall into each of these categories is described in the following paragraph. If the prerequisites for being rated as “Yes” nor for “Implied” are met, the domain is automatically rated “No”.

- **Climate**: If an innovation directly results in lower amounts of GHG emissions (e.g. fuels that release fewer GHG when combusted), lower amounts of disposed materials that are harmful to the environment (e.g. e-waste) or lower resource use (e.g. new technological methods to recycle previously not recycled materials), it is considered directly applicable to the Climate domain and thus rated “Yes”. If however an innovation results in less energy being used and as such results in lower emissions of GHG’s, it is rated “Yes” in the Energy domain, but the category “Implied” is used in the Climate domain.
- **Land**: If an innovation directly affects the purpose for which land is used (e.g. a policy innovation to promote biomass cultivation or the creation of new types of infrastructure) or directly alters the quality of the soil (e.g. innovations in fertilizers), it is considered directly applicable to the Land domain and thus rated “Yes”. If however an innovation increases the amount of renewable energy sources being deployed and as such might result in changes in land use, it is rated “Implied” in the Land domain.
- **Energy**: If an innovation directly affects the amount of energy used or the way in which it is produced, it is considered directly applicable to the Energy domain and thus rated “Yes”. If an innovation is mainly concerned with energy carriers or the climatic effects of using these for certain purposes (e.g. new fuels that emit less GHG’s when combusted) it is rated “Implied”. Such an innovation will fall in the “Yes” category in the Climate domain however.
- **Water**: If an innovation directly affects the amount of water used in a certain process, the amount of harmful substances being released into the water or the geographical shape of lakes, rivers, canals or seas (e.g. hydropower technologies), it is considered directly applicable to the Water domain and thus rated “Yes”. If however a larger change in land use purposes or process deployment causes alterations in the amount of water used (e.g. an innovation to promote biomass cultivation resulting in more agricultural lands requiring irrigation), this innovation is rated “Implied” in the Water domain.
- **Food**: If an innovation directly affects people’s food choices, the food production sector or the food supply chains, it is considered directly applicable to the Food domain and thus rated “Yes”. No innovation was found for which the category “Implied” seemed applicable in the Food domain.

7.4. Categorization: Short-, medium- or long- term

The time-span before the effects of an innovation can be expected is divided into three categories. Short-term innovations are those of which the effects are expected to be visible before 2023. This year was chosen because it is taken up in the Dutch Energy agreement “Energieakkoord voor duurzame groei" as the year in which 16% renewable energy has to be achieved (Sociaal-Economische Raad, 2013). The medium term category sets 2030 as the upper limit, the year for which bigger EU wide goals have been set. Long term innovations are all innovations which are estimated to only have effects after 2030.

7.5. Categorization: Main DPSIR challenge

Previously, the DPSIR framework was combined with the CLEWF nexus approach to better understand the challenge of land scarcity in the Netherlands (see Appendix B for the complete table). As was explained before, those aspects on which performance was well below the European average in the DPSIR-CLEWF table were grouped and taken as categories that indicate the main DPSIR challenge the innovation addresses. Additionally, the category "Multiple/other" was included for completeness. In other words, starting from "land scarcity" as a challenge, the following more specific challenges were identified:

- Renewable energy deployment
- Energy intensity of the economy/living
- Resource use and disposal
- Mobility
- Agricultural emissions
- Multiple/other

As was explained before, the link to the challenge that was the starting point of this table, "scarcity of land", is intuitive in some cases, but less so in others. For example, the limits to renewable energy technology deployment could easily, at least partly, be explained by competition for land with the agricultural sector. Also, the occurrence of NIMBY situations is clearly related to scarcity of (uninhabited) land. In some regards however, land scarcity even seems to form an untapped potential rather than the underlying issue. An example is that despite the population density and the existent biking culture, the Netherlands is hardly a frontrunner when it comes to green mobility. This aspect therefore provides considerable opportunities for improvement. It is important to note once that the DPSIR challenges narrow down the search for innovations as much as they broaden it. This is a result of the fact that DPSIR challenges themselves are related to many more things than land scarcity alone.

7.6. Categorization: Status of implementation

Innovations were also categorized based on the status of implementation. Four categories were adhered to: "development" (not implemented yet), "pilot project", "operational" and "ended". For policy innovations these categories are rather straightforward. For technological innovations it is important to note that the stages of diffusion were taken as a starting point: development, emergence, diffusion, maturity. The first two diffusion stages were considered equivalents of the previously mentioned "development" and "pilot project", but diffusion and maturity were both translated to "operational". In the consulted database of Perruchas, Consoli and Barbieri (2019) no unsuccessful patent applications or ended ones are included so this category was not used for any technical innovations. Similarly, for business and social innovations only operational or ended innovations were found.

7.7. Categorization: Effort versus impact

Scores for “effort” and “impact” were included as separate columns of the inventory because of the main aim of this thesis, which is twofold. Firstly, the objective is finding innovations that could make a contribution to the transition to a low-carbon economy in the Netherlands, hence the impact score. Secondly, the aim is to identify those innovations that could most easily be implemented, touched upon by the “effort” score.

Assessing the impact of an innovation requires time and is not a simple process. Causality can be hard to distill or the effect takes place at a later point in time or in a different location. Also the effort required to implement a certain innovation is hard to measure (Dziallas and Blind, 2019). It is related to various factors such as costs, time, but also inertia of the existing socio-technical system (a concept borrowed from MLP theories that were discussed in the literature review of chapter 4). As was explained in the literature review, this inertia is, among other things, constituted by existing policies, infrastructure, and stakeholder configurations.

Nevertheless, instead of measured, both impact and effort could be estimated in a consistent way by making use of multi-criteria decision analysis (MCDA). This approach to assigning one value to a phenomenon that consist of many different aspects makes the process and considerations transparent. On top of that, it allows for the inclusion of weighting factors that can be adjusted based on the stakeholder involved (Dodgson *et al.*, 2009).

In MCDA the overall score is broken up into several hierarchical levels. At the top one can find the overall score, while at the bottom there are several specific and measurable criteria. The intermediate level(s) contain the objectives that are thought to be relevant to the overall aim. Weighting factors can be added to the different components of each hierarchical level, which allow for adjusting the relative importance given to aspects. The size of weighting factors thus reflects how much a certain criterion matters, but it also reflects the range of options in the alternatives considered. For example, if all options for a criterion had approximately the same level, the weighting factor would be low even if the criterion was found “very important”. Ideally, the objectives, criteria and weighting factors would be the result of intensive stakeholder involvement so that coherent preferences can be established (e.g. through discussions with relevant actors and decision makers)(de Strasser *et al.*, 2016).The criteria to estimate an impact score could furthermore be expanded with or supported by outputs from the modelling tools developed under the SIM4NEXUS project. Also, a sensitivity analysis should be done to investigate potential disparities in stakeholder inputs (Dodgson *et al.*, 2009).

For the purpose of this thesis, an example of how effort and impact values could be estimated using MCDA is given below. Figure 22 and 23 show the decision trees with all objectives and criteria. Table 2 and 3 show example calculations based on the weighting factors that were obtained from the decision trees. The criteria and objectives focus on the challenge of land scarcity and the desire to find innovations that can be implemented in the Netherlands, preferably at the level of a regional

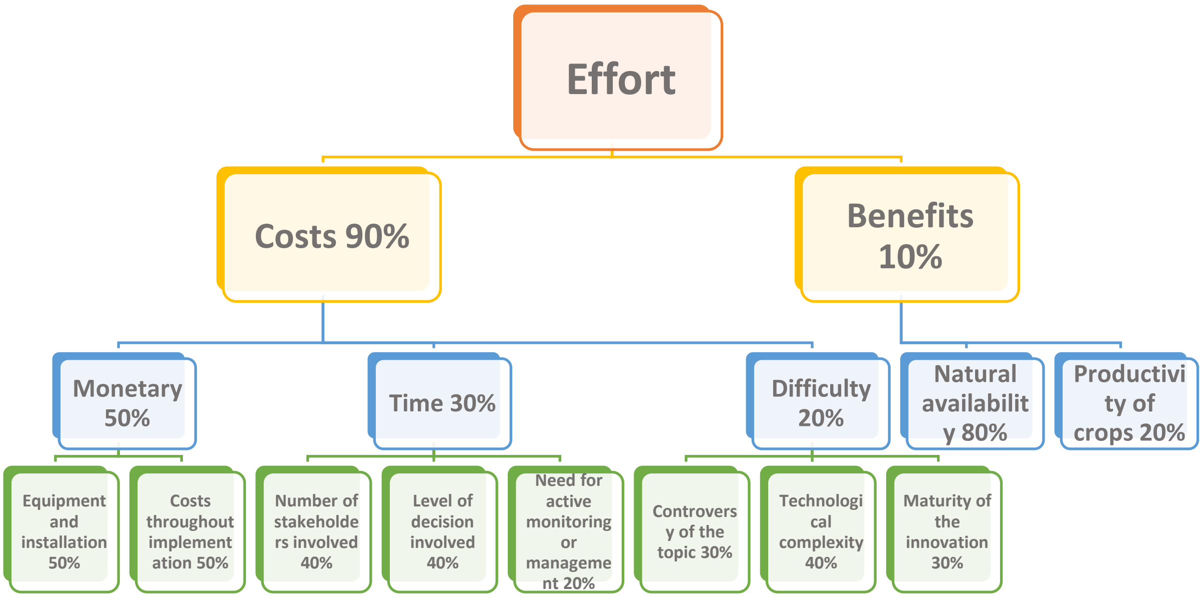


Figure 22 Decision tree for effort values with the overall score at the top, the criteria at the bottom and the (intermediate) objectives in between.

consultancy. All criteria scoring was done on a scale from 0 to 10, with 10 being most preferable. For criteria such as “number of stakeholders involved” the scoring does thus not represent the absolute number of stakeholders involved but rather whether they are few (closer to 0) or many (closer to 10). A high score always represents a preferable option over a low score. For effort the final values were reversed in the innovation inventory however, so that a low value for effort indeed indicates low effort required.

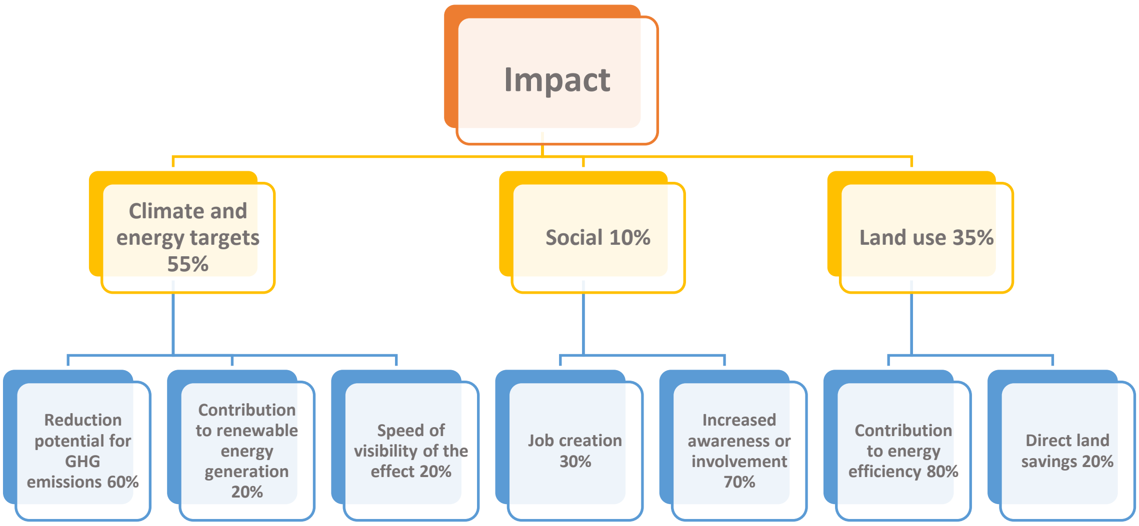


Figure 23 Decision tree for impact values with the overall score at the top, the criteria at the bottom and the objectives in between.

Table 2 Example calculations effort scores using MCDA.

Effort	Strong ESCO market	District heating and cooling	Green tax reform	Weight
Equipment and installation	10	4	5	0.225
Costs throughout implementation	10	10	5	0.225
Number of stakeholders involved	5	4	2	0.108
Level of decision involved	8	8	1	0.108
Need for active monitoring and management	8	4	3	0.054
Controversy of the topic	4	4	0	0.054
Technological complexity	5	3	3	0.072
Maturity of the innovation	9	10	3	0.054
Natural availability	7	8	0	0.08
Productivity of crops	0	0	0	0.02
Total	7.958	6.274	3.114	
Reversed score	**2.042**	**3.726**	**6.886**	

Table 3 Example calculations impact scores using MCDA.

Impact	Strong ESCO market	District heating and cooling	Green tax reform	Weights
Reduction potential for GHG emissions	9	10	10	0.33

Contribution to renewable energy generation	8	10	9	0.11
Speed of visibility of the effect	9	10	9	0.11
Job creation	9	7	10	0.03
Increased awareness or involvement	8	10	9	0.07
Contribution to energy efficiency	8	10	10	0.28
Direct land savings	5	5	7	0.07
Total	**8.26**	**9.56**	**9.5**	

8. Results

The publications and databases that were consulted provided a rich base of information on the transition paths of the selected countries. Not all of the developments that were encountered in this literature are innovative. However, understanding also the non-innovative developments that shape the transition paths of different countries is important for estimating the effectiveness and transferability of innovations. After all, innovations do not exist in vacuum, but are part of the larger socio-technical system. In other words, there are contextual factors that are important for successful implementation. If the context as a whole is understood, it becomes possible to identify components that could be transferable, albeit in a modified way: promising innovations. For example, if some country has a system of car sharing that works exceptionally well, perhaps a similar system for bike sharing would be fit for the situation in the Netherlands. In this example the Drivers (need for a more sustainable mobility system) are similar, but State-differences (popularity of cars or bikes) determine the extent to which the Responses (shared ownership business models) can be transferred.

Therefore, the general context of non-innovative as well as innovative approaches to the energy transition across the countries will first be described and analyzed in the paragraphs to come, making use of the DPSIR framework. At the end of the analysis an overview is provided in Table 4. Consequently the innovation inventory will be analyzed in section 8.2.1 and the most interesting innovations will be elaborated on further in section 8.2.2.

8.1. Results: transition paths of the countries

In terms of Drivers, the institutional context, targets and agreements of the selected countries are very similar at first sight. After all, the socio-economic context of the countries is strongly influenced by their communal membership of the EU. Yes, differentiated national targets have been set, but these were adjusted based on national differences such as the starting points and economic welfare of the member states (European Commission, 2019c). The burden imposed by differentiated targets on the respective member states is thus assumed to be of a comparable size. Without any intention to offend anyone, and merely to illustrate this point metaphorically: telling a five years old child to put their toys back in the box arguably puts a similar burden on the kid as telling their ten years old sibling to clean the entire room. To estimate whether the set targets are indeed the rightful result of differences in starting points and capacities, or rather the result of skillful lobbying of one or more of the metaphorical kids, goes beyond the scope of this thesis. In any case, the point is that the urgency to act is in all countries underlined by legal obligations and formal commitments. Failing to meet the targets, would in each case mean non-compliance with EU agreements and is thus interpreted here as a universal Driver.

Historically however, many more Drivers than the EU targets are at play. Some of these have been rather different across countries, or at least they have resulted in different Responses in different countries. For example, whereas the perceived risks of nuclear power resulted in early political consensus to ban nuclear power altogether in Denmark, even accidents like the one in Fukushima did not lead to consensus on the role of nuclear power in Belgium. Those drivers that were especially determining for the transition paths in each specific country are discussed in the chapters below.

In terms of Pressures, the countries show large similarities to some extent: the global concerns about for instance climate change, biodiversity loss and resource depletion are universal. However, the extent to which these can be felt and are perceived as important can differ per country, or even per region within countries. Furthermore, some pressures are not only perceived differently across countries, but are also truly different in size. For land scarcity, population density is one pressure that is particularly important to compare. This is done in Figure 24 below. Also, the living standard could be an important source of differences between countries, of which an indication can be given by the GDP/capita values. Across the selected countries the differences in GDP/capita are relatively small however. In 2018, the GDP per capita in constant local currency values were all between 35 and 36 thousand Euros in the Netherlands, Belgium and Germany. The Swedish and Danish values were a bit higher (353 thousand Danish Krones and 412 thousand Swedish Krones respectively). The only country in the selection with a remarkably low value in relative terms is Latvia, a bit more than 12 thousand euros per person.

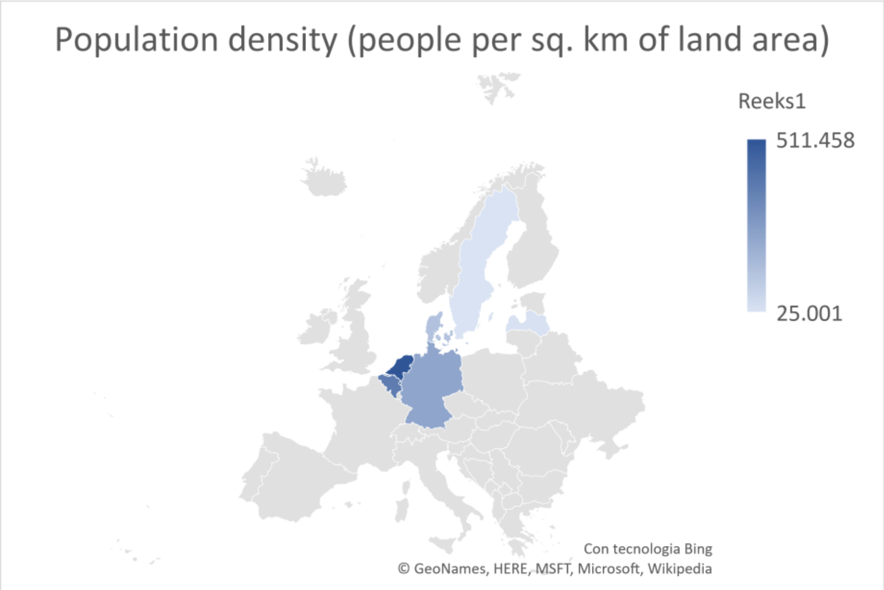


Figure 10 The population density of the selected countries in people per square kilometer of land area (The World Bank, no date).

In the State and Impact domains the six countries display larger differences. The starting points with regards to climatic performance as well as natural resources are two examples of State factors for which differences are significant. In 2017, the Swedish energy mix for instance already contained more than 50% renewable energy while the Dutch and Belgian shares of renewables were still hanging below 10%. Biomass resources are plentiful in countries like Latvia and Sweden that have large areas of forests, while Denmark or the Netherlands do not have these resources to the same extent, but are more fortunate in terms of wind availability. As a result, also the Impacts, for example the costs of climate change adaptation and mitigation, are different. The complete energy mix for each country is added in Appendix E. Here, in Figure 25, only the source that makes up the largest share of production and the share of renewable energy generation is listed.

	Largest share of electricity generation	Renewable electricity generation	Largest share of heat generation	Renewable heat generation
Belgium	Nuclear (51.2%)	19.5%	Gas (85.2%)	12.9%
Denmark	Wind (41.9%)	62.8%	Biofuels (38.7%)	61%
Germany	Coal (42.2%)	31%	Gas (45.8%)	22.6%
Latvia	Gas (45.8%)	54.2%	Gas (59.7%)	39.6%
The Netherlands	Gas (46.9%)	14.2%	Gas (66.7%)	19.3%
Sweden	Nuclear (40.4%)	58.1%	Biofuels (60.4%)	86.5%

Figure 25 The state of the current energy mix of the selected countries are very different (IEA, 2017).

Responses are simultaneously very similar and very different across the countries. For example, there are strong similarities in the procedural approaches, with the creation of energy agreements, visions and sectoral collaborations. However, the specific mitigation options that are focused on, show large differences. To point out just one example: nuclear power is strongly promoted in some countries, while others made an early decision to phase it out completely.

In the following paragraphs, the transition paths of each selected country will be described separately, highlighting the Drivers at the deep source of developments to the Responses that show at the surface. The developments will also be compared to the situation in the Netherlands. Some described Responses can reasonably be called innovative and might therefore also be discussed later, in section 8.2. In the next paragraphs however, the aim is to paint the general picture, regardless of whether the described responses are innovative or conventional. A summary table of the entire transition path analysis is provided at the end of this section, in Table 4.

8.1.1. Belgian drivers and responses: Division into regions and regional energy policy

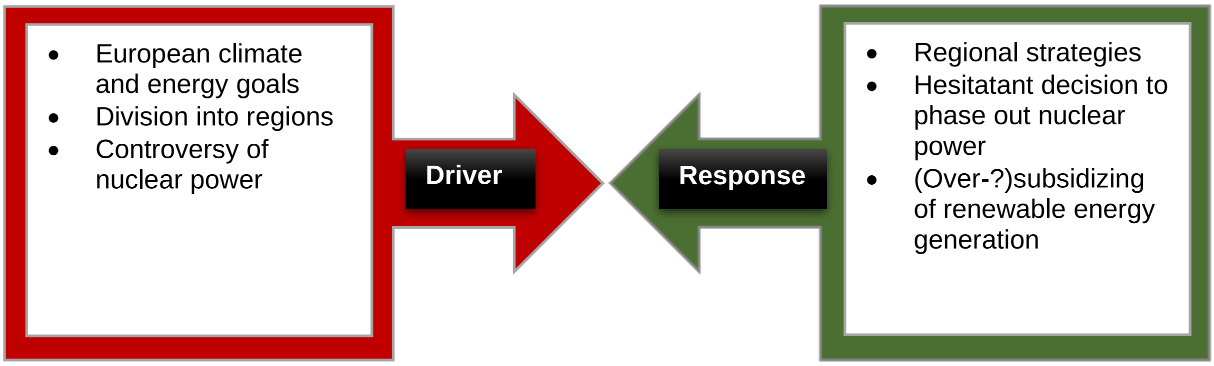
Important for understanding the Belgian energy policy context, is understanding that Belgium was officially divided into Flanders and the Walloon region in 1980 and later, in 1988, additionally the Brussels region was created. The regions became responsible for energy policy concerning the lower voltage transmission at the local level, public distribution of gas, district heating distribution networks, creation of all new energy sources except for nuclear power, energy recovery by industries and other users and rational use of energy. As such, large differences exist between the regions (Technopolis, 2016). The federal level only decides on those matters that require a national approach due to the technical or economic nature of the topic: the national equipment plan for the electricity and gas sectors, the nuclear fuel cycle, larger storage infrastructure (e.g. gas), transport and energy production regulation and the energy rates.

The division into regions has created several obstacles for the Belgian energy transition. Although it would perhaps better be called a barrier than a Driver, within the DPSIR framework it is understood as a Driver that underlies certain Responses (or the lack thereof). Not only do the regional energy responsibilities and budgets result in large differences between the strategies of the regions, they can also slow down decision making processes. For instance, offshore wind energy development required six years of quarrelling between the regions before settling who should pay for what (the federal or the Flemish government) and to whose targets the projects will contribute (Iago, 2018).

Important drivers in the Belgian energy transition have been the concern about climate change, the European targets and agreements and the controversy of nuclear power (Technopolis, 2016; Meinke-Hubeny, De Oliveira and Duerinck, 2017). In 2003, Belgium made an early decision to phase out nuclear power, but the final date has been changed many times (Heinrich-Böll-Stiftung European Union, 2017). Most recently, a law of the 23rd of January 2003 stipulated the phase out of nuclear energy by 2025 (Technopolis, 2016). Nevertheless, discussions in the public and political sphere have not curtailed yet (Iago, 2018). The hesitancy behind a complete phase out of nuclear energy and the lack of a national vision have certainly hindered progress towards a low-carbon economy in Belgium (Technopolis, 2016; Iago, 2018).

With regards to small scale decentralized production of renewable energy, Belgium and especially Flanders has enthusiastically promoted solar panels. Between 2009 and 2012 a large increase in installed capacity can be seen. In particular, the introduction of Tradeable Green Certificates has been important in the growth of the Flemish PV market (Huijben *et al.*, 2016). The first TGC scheme subsidized solar power by 450 euro for every 1000 kWh produced, for 20 years. Also net-metering and Feed in tariffs have been used to promote PV installation (Stam, 2018).

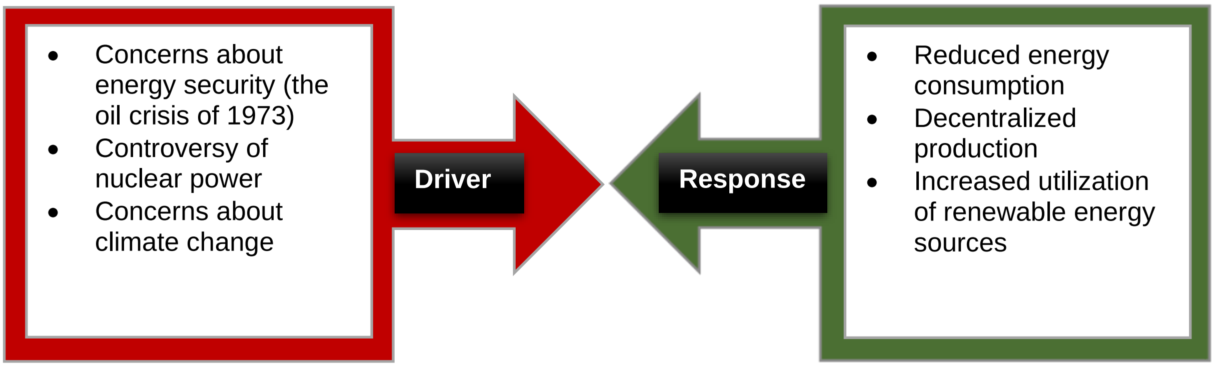
Although Belgium has one of the highest amounts of solar power generation per citizen in Europe, the support schemes used to achieve this have not gone without criticism. Excessively high subsidies for solar power are said to have given renewable financing a bad name (Iago, 2018).



8.1.2. Danish Drivers and Responses: the oil crisis and wind power

Denmark has a long tradition of clean energy policy, that started as a response to the first oil crisis of 1973. Since then, a broad political consensus has grown supporting the idea that the Danish energy system should transition to a model in which there is reduced energy consumption, decentralized production and increased utilization of renewable energy sources. (IRENA, 2017)

Already in 1985, well before the Fukushima accident and one year before the Chernobyl disaster, the Danish government passed a law that prohibits nuclear power generation (Nuclear Energy Agency [NEA] and OECD, 2015). As such, the only alternative to fossils from then on were renewables. Despite deploying almost no hydropower resources, Denmark has managed to become a global leader in renewable energy generation (Danish Energy Agency, 2016). The high share of renewable energy generation is predominantly because of large scale power generation from wind, a natural resource that is also widely available in the Netherlands.



In contrast to the Netherlands however, there is widespread public support for (both offshore and onshore) windmill deployment in Denmark. One of the reasons for this is thought to be the early appreciation by the government of the importance of giving the public a stake in the development of wind power (IRENA, 2017). Already in the 1980s the Danish government created a scheme to support local investments in windmills by providing grants that covered up to 30% of the initial installation costs. As such, community owned wind power became common practice. This scheme was progressively reduced to 20%, then 10% and finally repealed in 1988 with the growth in reliability and improved cost-effectiveness of turbines (IRENA, 2017).

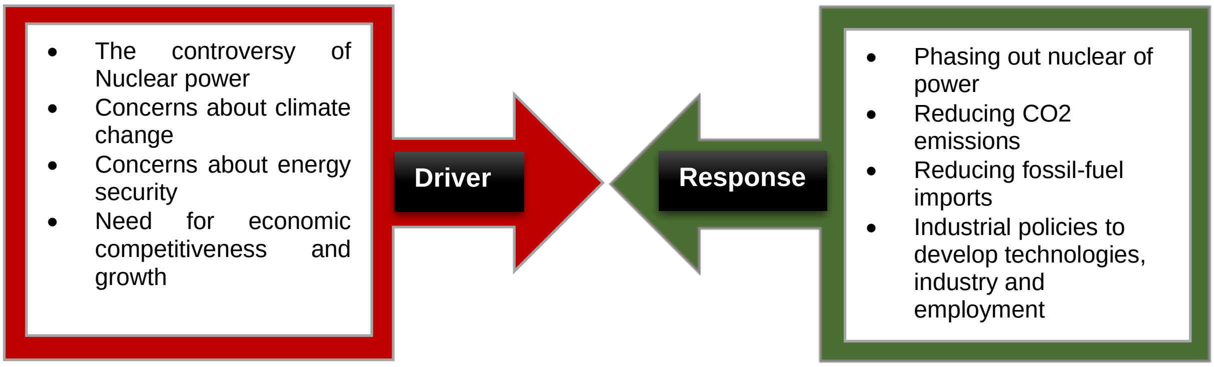
Public involvement has remained on center stage in Danish Energy policy throughout the years (IRENA, 2012). For example, the Renewable Energy Act of the 1st of January 2009 also exemplifies the conscious inclusion of policies to create public support for wind energy. The act introduced four policy measures with the specific aim of enhancing local acceptance of wind projects. The first, the compensation to neighbors' scheme, obliges wind power developers to compensate neighbors for any losses of property value of dwellings above 1%. The second, the co-ownership scheme, aims to increase the local interest in wind turbines financially and applies to both onshore as well as near-shore turbines. The third, the community benefit scheme (green scheme), is specifically aimed at enhancing local acceptance of onshore wind turbines. The scheme provides grants to support initiatives that improve the local landscape and recreational values in communities that establish onshore wind turbines. Finally, the guarantee fund for local ownership initiatives, was created to finance preliminary investigations by local wind turbine owners' associations, such as the investigation of locations, or technical and financial considerations (Anker and Jørgensen, 2015).

The large scale deployment of wind power (41.9% of the electricity generation) is furthermore facilitated by the well-established Nordpool Spot market on which energy is traded between the Nordic countries for the next day. It makes it possible for Denmark to export wind power during times of overproduction instead of pausing production (Houmøller, 2017). Alternatively, when winds are low and domestic renewable production falls, renewable energy can be imported, for example from Sweden's or Norway's hydropower and biomass plants. As such the overall production and demand for renewable energy can be balanced better and therefore renewable energy penetration higher.

Domestically, flexibility as well as efficiency is being enhanced by another important successful component of the Danish energy transition: the high penetration of district heating. More than 60% of Danish households are connected to the district heating grid (Ray and Jain, 2016). Most district heating systems are operated using Combined Heat and Power (CHP) plants. These plants have been designed such that the proportions of heat and electricity production can be adjusted in response to changing availabilities of for example, wind power (Danish Energy Agency, 2016).

8.1.3. German Drivers and Responses: Fukushima and the Energiewende

The German energy transition is more regularly referred to as “die Energiewende”, a term that was politically controversial when it was first used in the 1990s. Since the nuclear accident in Fukushima in 2011 however, it enjoys broad political support for four main reasons: avoiding nuclear risks, combatting climate change, improving energy security and realizing economic competitiveness and growth. Within the DPSIR framework, these could be considered Drivers of the Energiewende with the following responses: phasing out nuclear power, reducing CO2 emissions, reducing fossil-fuel imports and introducing industrial policies to develop technologies, industry and employment. Within the German political landscape and cultural context, especially the fear of nuclear accidents created widespread support for this response. (Agora Energiewende, 2015)



As was mentioned before, in the Netherlands, there has historically been less consensus in the public opinion on the (un-)acceptability of nuclear power. As such, the Response of a Dutch energy transition was more dependent on other drivers, such as the ones also mentioned for Germany: combatting climate change, improving energy security and realizing economic competitiveness.

Like in Denmark, the agreed phase out of nuclear power increased investment security in all alternative power options in Germany, including renewables (Jacobs, 2012). Specifically renewables also benefitted from the concern for domestic energy security because they require far lower amounts of raw materials to be imported. The aim of reducing CO2 emissions and fossil fuel imports furthermore created an urgency for increased energy efficiency. In fact, the German Energiewende contains a very strong focus on energy efficiency in the transition to a low carbon energy system (Federal Ministry for Economic Affairs (BMWi), 2010).

The strong focus on energy efficiency improvements of the German Energiewende is interesting with regards to the challenges of the Dutch CLEWF nexus. After all, saving energy saves space more directly than any other innovation could. Increased energy efficiency would clearly bring the Netherlands closer to its efficiency goals but also to its emission and even renewable generation targets. Indeed, the same absolute amount of renewable energy would amount to a higher relative share if the total energy demand is lower, without adding even one windmill or solar panel.

The efficiency related policies of Germany are manifold: from building requirements such as the energy conservation ordinance EnEV, to national campaigns to increase public awareness (e.g. "Deutschland machts effizient"), to cheaper mortages for energy efficient buildings and refurbishment loans by the KfW promotional bank and many others. With regards to the promotion of renewable energy, policies include feed-in tariffs, tax adjustments (e.g. storage facilities were exempted from certain levies and grid tarrifs), "E-energy" demonstration projects and regional guarantees of origin. The innovative ones among these were included in the innovation inventory (Appendix D). (Kuzemko *et al.*, 2017)

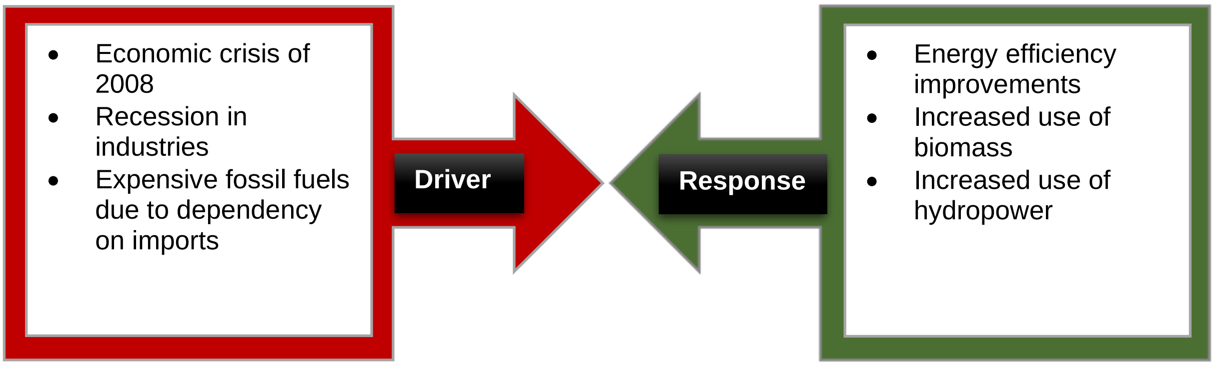
Furthermore, the emphasis on economic goals such as realizing growth and employment through the Energiewende drove a focus on green industries as an opportunity. Currently, Germany is among the market leaders in various green technology sectors.

8.1.4. Latvian drivers and responses: economic decline, recession in industry, increased energy prices, energy efficiency and biomass

In contrast to the other countries discussed, the Latvian performance on energy and climate goals cannot at all be attributed to the existence of large subsidy or support schemes. The most apparent Driver for reduced energy consumption and increased use of renewables are thought to be macro-economic (Shipkovs, Kashkarova and Shipkovs, 1999). The economic recession of 2008 hit Latvia especially hard, and the subsequent recession in industry also greatly reduced the final consumption of energy. This is not to say that the decline in energy intensity is only due to a decline in the Latvian economy as a whole. In fact, in a study by Timma Zoss and Blumberga (2016) it was concluded that the decline in energy intensity was mainly due to improvements in transportation and storage, manufacturing and other industrial consumers, instead of due to changes in the composition of the economy. The recession and increasing energy prices thus spurred improvements in energy efficiency (Timma, Zoss and Blumberga, 2016), or at least resulted in a "survival of the fittest" for energy efficient companies or technologies.

The increasingly expensive fossil fuels imports contributed also to the renewable energy performance of the country with widespread use of biomass as a cheap alternative to fossils. Furthermore, hydropower has emerged as an important source of renewable energy (Shipkovs, Kashkarova and Shipkovs, 1999).

Climate change as such does not seem a priority topic in Latvian policy-making. Security of energy supply is currently the main concern, especially because the country remains isolated from energy networks of the EU and is highly dependent on Russian gas (Smith *et al.*, 2014).



8.1.5. Swedish drivers and responses: oil dependency, climate change, nuclear power and renewables

The drivers that played an important role in shaping the energy policies of Germany and Denmark, namely the threats that came with oil dependency and the perceived risks of nuclear energy, also played their part in shaping Swedish energy policy. Initially, in the 1970s, nuclear energy was considered a logical alternative because the focus was mostly on reducing dependence on oil. In fact, 12 reactors were built between 1973 and 1985 (Wang, 2006). However, the controversy of nuclear power grew over time and the Three Mile Island accident triggered a referendum on nuclear power in 1980. Subsequently, the parliament decided that nuclear power should be phased out by 2010. This closing date was abandoned in the 1997 energy bill however, which means that so far only one reactor was phased out (Wang, 2006). Nevertheless, growing controversy of nuclear power made renewables a more appealing alternative. Also the more recent concern for reducing greenhouse gasses has contributed to an increasingly strong positive perception of renewables as a source of energy in Sweden (Nilsson *et al.*, 2004b).

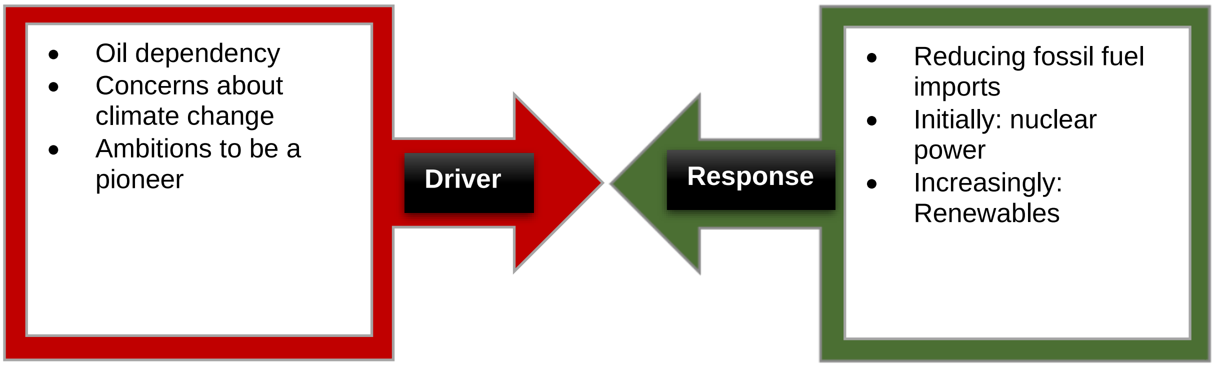
Some of the political measures taken to promote renewable energy have been investment subsidies, research and technology demonstration strategies, tax policies such as emission taxes or tax reliefs for renewables and a green quota obligations scheme. Investment subsidies were politically favored over long term subsidy schemes because they allowed the government to keep more control over the total expenses within the program. If the budget had been surpassed, there would simply be no more subsidized activity. These investment subsidies were mainly used to support wind power, biomass fueled CHP and later also small scale hydropower.

Sweden has long profiled itself as a pioneer with regards to the energy and climate transition, voicing high ambitions and claiming to want to lead by example (Swedish Energy Authority, 2008). The early liberalization of the energy market as well as the introduction of a carbon tax exemplify this attitude. Also with regards to research and technology, Sweden is regarded to be at the forefront in for instance research on biofuels, heat pumps and solar cells. The commitment to taking the lead in the energy transition can partly be explained by how this transition has been framed. In Sweden, energy and climate commitments have commonly been presented in relation to broader policy objectives such as economic growth, industrial competitiveness, job creation, energy security and sustainable development (Sarasini, 2009).

In 2003, Sweden adopted quota systems for electricity certificates (Wang, 2006). The system obliges the consumer or distributor of electricity to buy certificates for a certain fraction of their consumption. Between 2003 and 2010 the quotas were such that renewable energy production would increase by 10 TWh. Exceptional in the Swedish quota system compared to other systems, is that until 2008 it did not simply set obligations, but also guarantees a price for the certificates. This was done to protect generators against excessively low certificate prices. Energy intense industries were exempted from the quota obligations to protect their international competitiveness (Wang, 2006).

At present, the major sources of renewable energy are hydropower and bioenergy (Swedish Energy Authority, 2008; Uba, 2010). As was explained in the paragraph about Denmark, the Nordpool spot market facilitates the inclusion of a high amount of renewable energy since wind power can be imported from Denmark in times of high wind and hydropower or biomass plants can be used to export electricity in times of low wind.

Also, in Sweden district heating and CHP plants are common and have made major contributions to the energy and climate goals of the country, which will be elaborated on in section 8.2.2.1.



8.1.6. Overview of the most important DPSIR elements of the selected countries

On the next page, in Table 4, an overview is given of the analysis done in the previous sections of this chapter. Note that YES or NO are used to indicate which elements were found to be most important in shaping the energy transitions of the countries. If a cell indicates NO for a certain Driver or Response, this does not mean that this element has not played any role, but solely that it was not found to be the most important according to the analyses in the previous sections. It should be noted also that the table is not exhaustive, but builds only from the analysis done in the sections before. There will undoubtedly have been more developments that have shaped the transition paths of the countries, but the analysis attempted to describe only the most important ones. The values listed are taken from earlier sections of this chapter or from the benchmarking done in chapter 6.

Table 4 Overview of the DPSIR analysis of the transition paths of the selected countries.

	Belgium	Denmark	Germany	Latvia	Sweden
Drivers					
EU targets	YES	YES	YES	YES	YES
Concerns about climate change	YES	YES	YES	NO	YES
Controversy of nuclear power	YES	YES	YES	NO	NO
Concerns about energy security	NO	YES	YES	YES	YES
Need for economic competitiveness and growth	NO	NO	YES	NO	YES
Economic crisis 2008	NO	NO	NO	YES	NO
Division into regions	YES	NO	NO	NO	NO
Pressures					
Global climate change	YES	YES	YES	YES	YES
Global biodiversity loss	YES	YES	YES	YES	YES
Global resource depletion	YES	YES	YES	YES	YES
Living standard (GDP/capita in 2018 in constant local currency)	35.248	353.691	35.866	12.387	412.502
Population density (people per sq. km of land area)	377.215	138.067	237.37	30.982	25.001
States					
Energy intensity of the economy (kg of oil equivalent of primary energy per 1000 EUR of GDP in 2015)	141.3	65.1	112.6	206.7	111.3
GHG emissions in tonnes of CO_2 equivalent per capita	10.8	9.3	11.4	6	5.6
Share of renewable energy (electricity and heat)	10%	36%	16%	39%	55%
Impacts					
2020 EU target already reached in 2017	NO	NO	NO	YES	YES
Responses					
Reducing fossil-fuel imports	NO	YES	YES	YES	YES
Increased utilization of renewable energy sources	NO	YES	YES	YES	YES
Reducing energy consumption or CO_2 emissions	NO	YES	YES	YES	NO
Clear decision to phase out nuclear power	NO	YES	YES	NO	NO
Policies to develop green technologies, industry and employment	NO	NO	YES	NO	YES
Decentralized production	NO	YES	NO	NO	NO
Regional strategies	YES	NO	NO	NO	NO
(Over-?) subsidizing of renewable energy generation	YES	NO	NO	NO	NO

8.2. Results: promising innovations for the Netherlands

Now that the transition paths of the different countries have been analyzed using the DPSIR framework, it is time to move on to those Responses that are innovative, or at least, contain innovative aspects. As was explained in the beginning of this chapter, an inventory was created that lists more than 74 innovations from Belgium, Germany, Denmark, the Netherlands, Latvia and Sweden. Important for the usefulness of the inventory is to assess if a certain innovation is transferable to, or can be scaled-up within the case of The Netherlands. In other words, is the successfulness of an innovation not clearly linked to factors that are beyond influence? For example, it is obvious that large scale hydropower is close to impossible in a country as flat as the Netherlands. Therefore, it was attempted to only include innovations that could be transferrable to the Netherlands, taking into consideration the context that was described in chapter 3, the analysis in section 8.1. and the findings from the DPSIR-CLEWF table (Appendix B). As was explained in chapter 7, all innovations were assigned to categories on various of their characteristics such as the nexus domains that they apply to and the type of innovation that they are best described as. These categories will be used to analyze the content of the innovation inventory in section 8.2.1. The aim of this analysis is twofold. Firstly, the graphs serve to give an overview of the content of the inventory and describe general trends. Secondly, the aim is to identify those innovations that are most promising. For the ones identified as most interesting, the working principle, relevance, potential impact and transferability will be more elaborately described and recommendations will be given in section 8.2.2.

8.2.1. General analysis of the inventory

8.2.1.1. Effort and impact

All Innovations in the innovation inventory were plotted based on their performance on two dimensions: effort and impact. These values should be understood as a first heuristic to get closer to identifying innovations that could have a large impact while simultaneously being easily implementable.

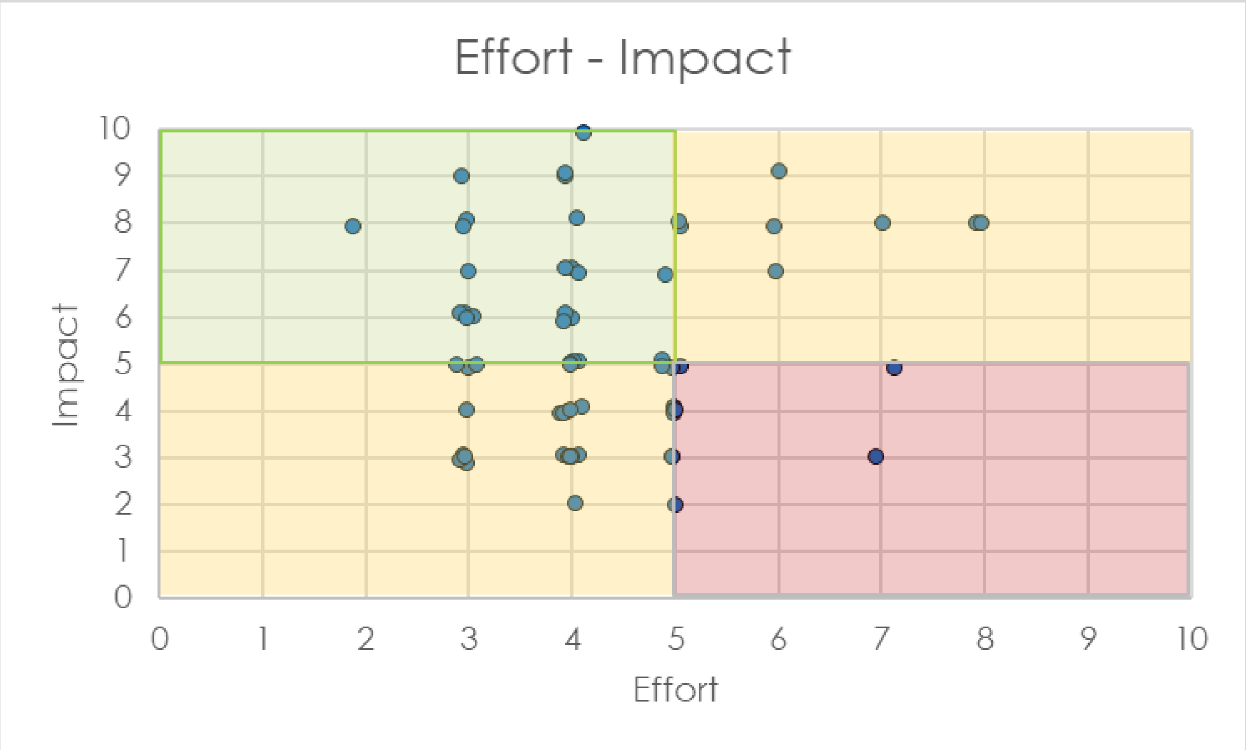


Figure 11 All entries of the innovation inventory were plotted in this Effort-Impact matrix. Some random noise was added to the scores in order to prevent the dots from completely overlapping each other.

The plot in Figure 26 shows that a great deal of entries fall into the upper-left quadrant, signifying their effort required for implementation is estimated to be relatively low and their impact high. The inventory thus contains a considerable amount if innovations that are potentially valuable for the Dutch transition to a low-carbon economy.

To narrow down the selection, the innovations within the green quadrant of the graph in Figure 26 were analyzed further. For each innovation, the ratio between the impact and effort was reduced to one value by dividing the first by the latter (impact over effort). Each type of innovation was then ranked from high to low based on this ratio. The top three for each type (policy, business, social and technical) is visualized in Figure 27 below. For technical innovations the top five instead of three is shown, because district heating and cooling (DHC) made it to the top of the list multiple times, as DHC in Denmark was considered separately from DHC in Sweden or Latvia.

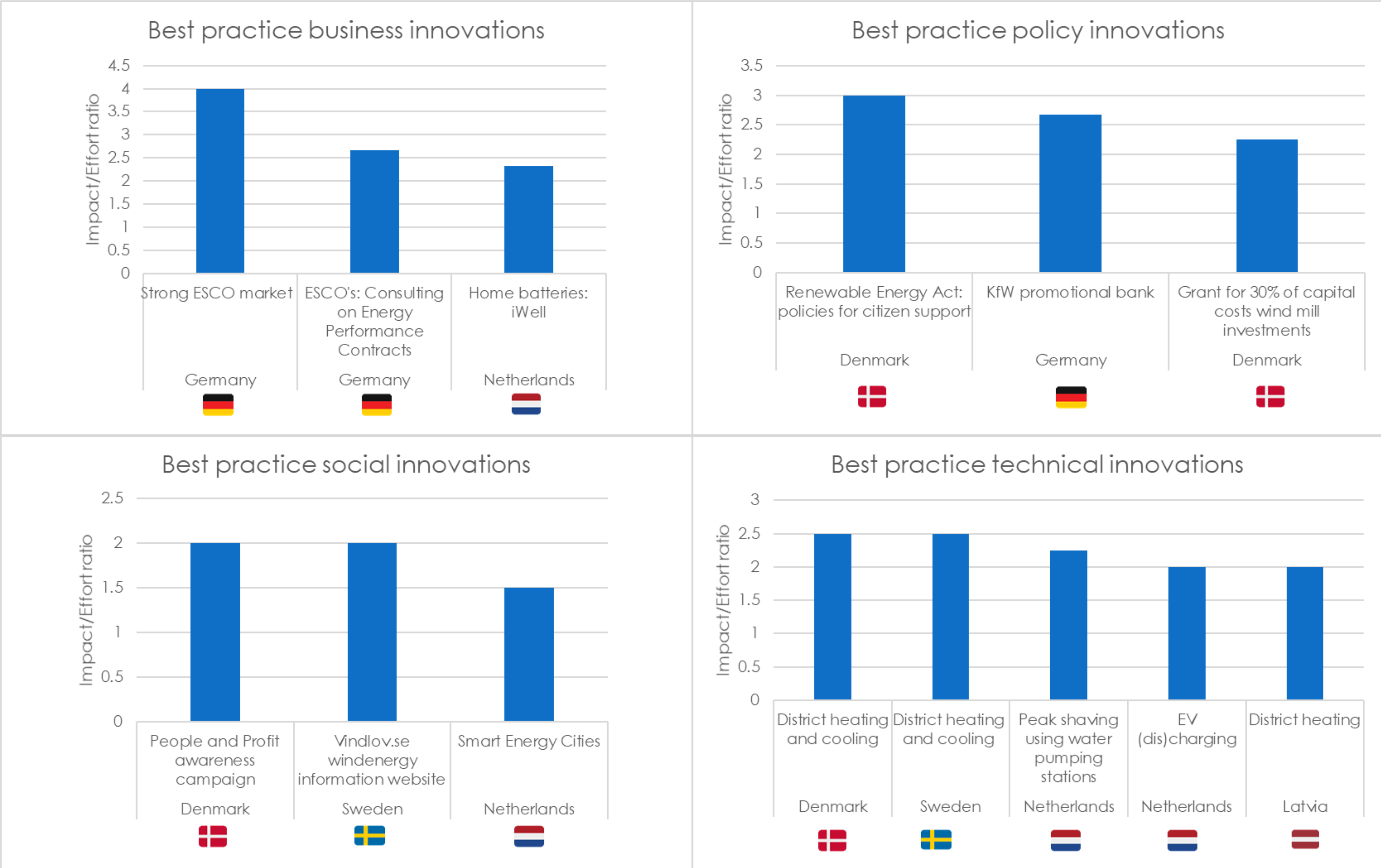


Figure 12 The four innovation types (business, policy, social and technical) were ranked from high to low based on their Impact/Effort scores. The top three or five is shown for each type.

From Figure 27, three promising innovations were selected: district heating and cooling, Energy Service Companies (ESCO's) and peak shaving in combination with water management. These will be described in more detail in section 8.2.2. The reasons for selecting these innovations over the other ones in Figure 27 are specific to each choice. Firstly, district heating and cooling was encountered in three of the investigated countries. That, in combination with its high potential impact on the Dutch energy transition evoked interest in investigating why the Netherlands is not implementing it at the same scale and whether this would be possible and desirable. Regarding ESCO's, the low effort for a consultancy at the regional level to promote or implement it, was an important consideration. Finally, peak shaving using water management was mainly chosen as an illustration for several wider recommendations. These are related to the increasingly large opportunity of value creation by predicting energy demand, the advantages of being at the forefront of developments and of using national strengths and expertise areas (see section 8.1. and 8.2.2.3.).

8.2.1.2. DPSIR challenges per country

The specific strengths of countries can be estimated from the sample of innovations that is included in the inventory. To this end, the amount of entries per DPSIR challenge category were plotted in a radar graph in Figure 28.

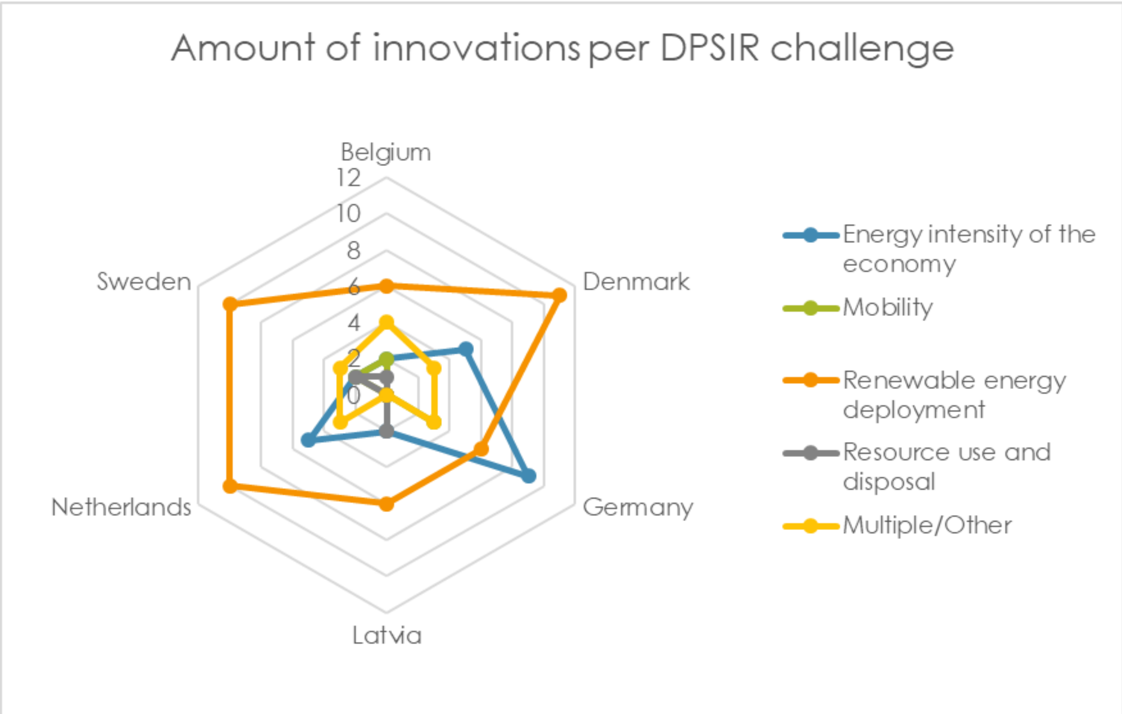


Figure 28 The amount of innovations per DPSIR challenge for each considered country.

It can be seen that most innovations in the inventory address "Renewable energy deployment" and that especially Denmark, Sweden and the Netherlands provided many innovations in that category. Regarding "Energy intensity of the economy", Germany provided most entries. Given that the inventory is just a sample of all existing innovations, this graph provides some hints with regards to where to look for what. If, for example, energy efficiency is one's main concern, perhaps Germany would be the most promising place to start searching for more innovations.

8.2.1.3. Technical innovation: fields of expertise

For technical innovations in particular, information about the amount of green patent families in different areas of research was included in the inventory. The absolute amount of green patent families per country is shown in Figure 29.

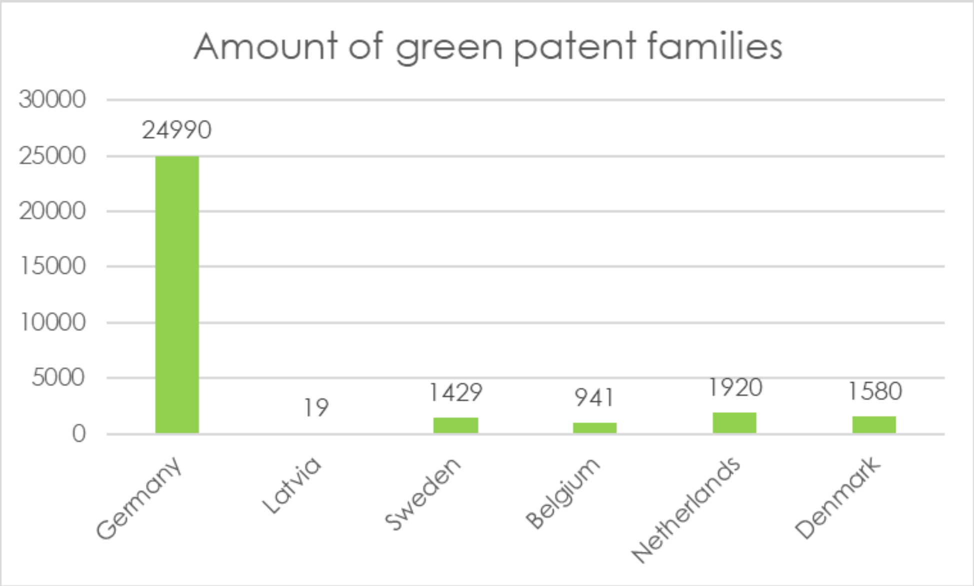


Figure 29 Amount of green patent families in the different countries (F. Perruchas, Consoli and Barbieri, 2019).

Figure 29 shows that especially Germany has a large amount of green patent families. This does not necessarily mean that Germany has the largest green economy, because the amount of granted patents differs across patent offices of different countries. After all, national patent offices assess applications against nationally defined legal standards of novelty, non-obviousness and industrial applicability, which as such may differ across countries. These and other differences in the examination processes make cross-country comparisons difficult (World Intellectual Property Organization, 2018). Nevertheless, the extremely large difference with the other countries is an interesting observation as such. To control for the other factors that determine the absolute number of patents per nation, the relative shares of green patents per topic were visualized for each country individually in Figure 30. In this way, the technical fields of relative expertise can be observed per country. Similar to the values of Figure 28 in section

8.2.1.2., these charts give direction to anyone interested in expanding the innovation inventory with a specific interest in certain technologies.

Figure 13 The relative shares of green patent families per topic per country.

The figures show that the largest share of Germany's patents is related to air pollution abatement or road transport. These are the same sectors that make up more than half of the green patents of Sweden. For Denmark, 53% of the green patent families falls into the renewable energy generation category. Both the Netherlands and Belgium have a relatively large number of patents related to enabling technologies in buildings, 30 and 35% respectively. Latvia's modest amount of 19 patent families in total (compared to the second lowest amount of 941 in Belgium and the astonishing 24990 in Germany), are mostly related to renewable energy generation and enabling technologies in buildings.

8.2.1.4. Applicability to nexus domains

The complete list of innovations was also analyzed based on the applicability to the different nexus domains. Although all five nexus domains were listed in the inventory, by far the largest part of innovations did not apply to neither the Water nor the Food domain. The analysis will therefore focus on the other three domains: Climate, Land and Energy. From Figure 31 it can be concluded that it is rather challenging to find innovations that are directly applicable to all three domains simultaneously (only five of the 78 innovations, see Table 5). If also Implied relations are counted however, this number grows to 37. To consider also implied relations seems appropriate considering that the appreciation for the interrelated nature of different domains is exactly what makes the nexus approach so valuable. Because the main objective of this thesis is to identify innovations for land scarcity in the Netherlands, especially the land domain is of interest. The third and fourth bar from the top in Figure 31 therefore show the amount of innovations that have some (direct or implied) applicability to the land domain and one of the other two domains. The sixth bar from the top furthermore shows that in total, 44 of the innovations are applicable to the land domain, directly or implied. For the sake of completeness as well as comparability, Figure 31 also shows the sums of combined applicability to climate and energy and to climate or energy separately.

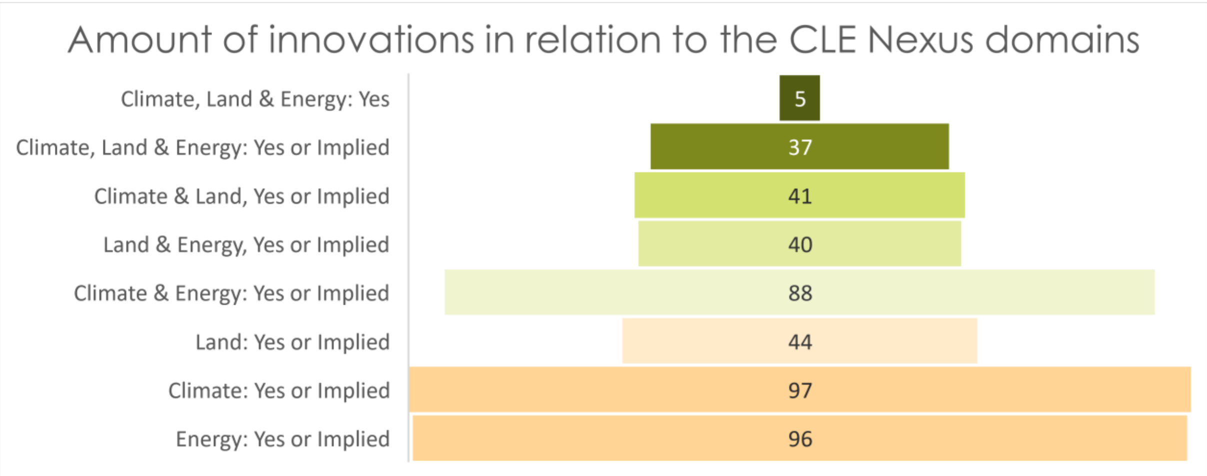


Figure 31 The amount of innovations in relation to the CLE nexus domains. The categories on the left describe whether only direct ("Yes") or also indirect ("Implied") applicability was counted.

The five innovations that address all three domains directly are listed in Table 5 below.

Table 5 Innovations that directly influence simultaneously the Climate, Land and Energy domains, with some of their categorizations.

#	Country of origin	Innovation Name	Type	Level	Short, medium or long term	Main DPSIR challenge	Status of implementation	Effort	Impact	Impact /Effort ratio
12	Germany	kfW promotional bank	Policy	National	Short	Multiple/Other	Operational	3	8	2.67
13	Netherlands	Invest-NL (investment fund but not a bank)	Policy	National	Medium	Multiple/Other	Development	3	5	1
29	Sweden	Biomass from agricultural residues	Technical	Regional	Short	Renewable energy deployment	Operational	3	5	1.67
50	Netherlands	NREAP > Green Deals	Policy	National	Medium	Renewable energy deployment	Operational	4	6	1.5
67	Sweden	International Development collaborations	Policy	Supranational	Long	Renewable energy deployment	Operational	5	2	0.4

Of these, the kfW investment bank has the highest impact/effort score and it is operational. At a closer look, this innovation is in fact similar to the Invest-NL innovation, but the latter is still being developed and will not be an actual bank but rather an investment fund (as such a different impact score has been assigned). For stakeholders at the national policy making level this might be an interesting innovation to consider further. Here, innovations that are most promising for actors and practitioners at the regional level will be elaborated on.

8.2.2. Examples of promising innovations

Based on the analyses done in this chapter and in previous chapters, three interesting innovations were selected that could contribute to the transition to a low carbon economy of the Netherlands. Table 6 provides an overview of these innovations. The subsequent paragraphs discuss them more elaborately.

Table 6 Overview of the promising innovations that will be elaborated on further.

Innovation Name	Countries to learn from	Short description
District heating and Cooling	Denmark Sweden Latvia Germany	Utilization of waste heat streams for the aggregated heat demand of multiple households or buildings
Energy Service Companies (ESCO's)	Germany Denmark	Business models based on energy savings
Peak shaving in combination with water management	Netherlands	Shifting inevitable energy demands for energy to low-demand timeslots

8.2.2.1. District heating and Combined Heat and Power

District heating (DH) is commonly used in Sweden, Denmark, Latvia and Germany (Woods and Overgaard, 2016). Also in the Netherlands, the sector is developing (Planbureau voor de Leefomgeving, 2018). It was selected as a promising innovation because of its high potential impact on the Dutch energy transition. Given the maturity of the foreign DH markets, the concept can hardly be called innovative as such. Nevertheless, there are many aspects of the foreign systems that are innovative to the Dutch system and could considerably diminish the effort required for implementation and the risk of failure. This was also recognized by the Dutch house of representatives (de Tweede Kamer der Staten Generaal) when on the 20th of June of this year, 2019, a motion was submitted stating:

"Considering that in the coming years more and more households will be connected to district heating, considering that the market for heat functions better abroad, with many more suppliers, a transparent supply and low prices" [the house of representatives] *"requests the government to investigate what the Netherlands can learn from the approach in other European countries for the organization of the market in our country"* (Sienot, 2019).

Before highlighting ways in which the Netherlands could learn from other countries, the following two paragraphs will first introduce the concept of district heating in general and explain the potential benefits of this innovation in relation to land scarcity in the Netherlands.

8.2.2.1.1. A general introduction

District heating networks, heat networks, district heating and cooling networks, or district energy networks all refer to the same basic concept. As opposed to generating heat (or cold) at the level of the individual household or building, the demand of many households is aggregated and is, through a network of water pipelines, connected to larger sources of waste heat that are locally available. A traditional, decentralized system uses (thermodynamically) high quality fossil energy carriers for the production of the extremely low-quality form of energy that low temperature heat is thermodynamically. Within a district heating system instead, the sources of heat are waste heat streams that can come from for example surplus industry heat, waste to energy plants, biomass plants, solar fields, geothermal facilities, heat pumps, or fossil fuel power plants. When renewable energy sources, such as biomass, solar or geothermal energy are directly used to supply heat to the system, it is disputable whether these should be labelled “waste” heat sources. It is important to note therefore that in most cases where renewables are used as a heat source, these are actually utilized to produce a combination of electricity and heat. Ideally, heat would then merely be the byproduct, or waste-flow, of the anyhow required electricity production process. Realistically, some concessions are made on the efficiency of electricity production to adequately produce the required amount of heat. However, the efficiency of combined heat and electricity production, as is done in so-called Combined Heat and Power (CHP) or co-generation plants, lies considerably higher than if this combination had not been realized. In summary, the benefits to energy and climate goals of district heating go beyond the increased efficiency realized at the source of heat generation. Also, the fact that the demand is aggregated and that a network is put in place opens up possibilities for increased deployment of renewable sources. Especially biomass is commonly used in CHP applications, but also geothermal energy is an increasingly popular source of heat in district heating. (Lund *et al.*, 2010; Rezaie and Rosen, 2012; Galindo Fernández *et al.*, 2016; Werner, 2017; Euroheat & Power, 2019)

8.2.2.1.2. Relevance to the Dutch CLEWF challenges

Heating and cooling together comprise 50% of the Dutch final energy demand (Paardekooper *et al.*, 2018). Of that, almost half is used for space heating, followed by process heating as the second largest demand. Cooling, of processes or spaces, accounts for less than 5% of the heating and cooling energy demand in the Netherlands. Especially the heating sector thus plays a crucial role in the transition to a low carbon economy.

The Heat Roadmap2050 report describes a scenario for decarbonization of the Dutch heating and cooling sector at a higher efficiency and reduced cost compared to the “conventionally decarbonized scenario” in which the energy system is developed by encouraging renewables but not radically changing the heating and cooling sector. The report was written as part of the European Union's Horizon 2020 research and innovation program and addresses the topic “Removing market barriers to the uptake of efficient heating and cooling solutions”. The described scenario includes significant investments in district heating networks (as well as several other measures such as refurbishments and installation of heat pumps in areas that are not suitable for DH). Interestingly, the annual costs of the scenario (including but not exclusively using DH as a solution) are approximately 7% lower than a conventionally decarbonized energy system, which equals cost savings of around €3,9 billion annually. The initial investments were found to increase slightly, but the shift away from using fuels results in a large reduction in fuel costs that significantly outweighs the increased investment costs. (Paardekooper *et al.*, 2018)

The increased efficiency of the overall energy system that can be achieved through district heating implies that land scarcity as a challenge in the Netherlands would directly benefit from its increased deployment. After all, higher efficiencies mean lower total demand for energy and thus reduced land requirements for energy.

Land scarcity, or rather population density and urbanization, could even form a specific opportunity rather than a challenge for the case of district heating. For example, the distribution costs of realizing a DH or cooling system are generally lower in densely populated areas compared to when less people lived more distributed over a larger surface area (Werner, 2017).

8.2.2.1.3. Barriers and recommendations

While district heating has been common practice for years in Sweden, Denmark and Germany, it still makes up a small part of the heating sector of the Netherlands (CBS, 2017). One of the most obvious reasons for this difference is historical.

Until the middle of the 20th century space heat was predominantly done inside houses by burning various fuels in open fires and enclosed stoves. From 1900 onwards, it became more and more common to use the fuel to heat water or produce steam, which could then be circulated through radiators around the building: central heating. In some countries however, the open fires were instead gradually replaced by district heating systems using steam or hot water. In Europe it did not take long for hot water systems to become the most preferred option for DH systems. It was recognized at an early stage that power plants as well as municipal solid waste incinerators were valuable sources of waste heat. For example, in the Frederiksberg area of Copenhagen, the local hospital was already supplied by heat from a waste incinerator in 1903. The most rapid growth of DH penetration in Europe began around the first oil crisis when oil rapidly became more expensive. Both Denmark and Sweden then still had limited access to natural gas. The alternative to oil was mostly coal in the case of power generation. For heating, DH systems were an attractive option. These countries thus mainly developed DH to increase energy efficiency as a Response to a financial and political Driver, dependency on imports of fossil fuels. Furthermore, waste was increasingly becoming an issue in European cities. DH was seen as the best way of using energy from municipal waste and as such also aided the development of DH systems, especially in Germany. Lastly, in some cities, such as Stockholm and Copenhagen, the contribution of DH systems to cleaner air policies was also a Driver for implementation. More recently, the wider advantages of DH to the energy system have been recognized, especially in Denmark. There, the flexibility to operate with various heat sources and thermal storage is used to manage intermittent wind energy in the grid. (Woods and Overgaard, 2016)

The fact that the most important barrier to implementation in the Netherlands has been the historical availability of cheap natural gas does not mean that we cannot learn from other countries. After all, now, finally, there are Drivers to move to DH systems. The Netherlands needs to move to a low-carbon economy, and district heating can play an important role in realizing this in a cheaper way (Paardekooper *et al.*, 2018).

The selected countries provide many examples of successful district heating and cooling implementations. Galindo Fernández et al. (2016) describe several European case studies and identify key success factors for the development of high quality, efficient and low-carbon DH systems, and discuss how these factors can be replicated in other EU countries, see Table 7 and 8. Also, several recommendations made by Woods and Overgaard (2016) based on their review of the historical development of DH, were added to the table. The paragraph following the tables will briefly highlight some examples of successful inclusion of these best-practices from the cases of Denmark (Copenhagen), Germany (Hafencity) and Sweden (Stockholm).

Table 7 Key success factors for the development of district heating and cooling.

		Key success factors	**Description and/or examples from Denmark, Germany and Sweden**	**Additional recommendations for the Netherlands**
External	1	Adequate national policy and regulatory environment	• Ambitious CO2 targets • Specific fiscal measures promoting the use of renewable energy. (e.g. the Danish heat supply act, taxes on electricity and fossil fuels in Denmark and Sweden and feed-in tariffs in Germany)	
	2	Direct/indirect financial support through subsidies and other instruments	• Investment grants, • Support schemes for CHP and RE • Fossil fuel taxes • Dedicated financial instruments (e.g. those offered by the “Kommunebank” in Denmark or KfW in Germany).	Collaborations could be created between DH projects and regional investment funds, or in the future: NL-invest.
	3	Focused local policy and	Local authorities promote DHC as part of their energy supply and climate strategy and integrate heat	Local authorities should use heat mapping to identify what is the most

		coherence with urban planning	planning in their urban development project, for example by • Undertaking a long-term cost-benefit analysis for heat planning, • Establishing DH zones or specific environmental requirements for buildings, • Promoting compact and mixed-use new districts (e.g. the Hafencity project was embraced as a flagship project by the municipality of Hamburg and the option for mandatory connections was included. Also in Copenhagen the local policy allowed for mandatory connections.)	economic heating option for each area. This is the core of Danish heat planning legislation which requires all local authorities to Define DH and natural gas zones. This also demonstrates to customers that the cheapest option has been selected (Woods and Overgaard, 2016).
	4	Alignment of interests / cooperation maturity	Public authorities at national and local level, regulating bodies, end users, the DHC company and other local actors cooperate in an efficient manner to achieve a good quality service and a sustainable and cost-efficient heat and cold supply. (e.g. the non-for-profit principle in Denmark)	Regional actors could take inspiration from Prisdialogen and the non-for-profit principle in Denmark.
Internal	5	Availability and relevance of local resources	The DHC system relies to a large extent on available local resources such as renewable energy sources (e.g. biomass, solar, geothermal), waste-to-energy or surplus heat/cold.	
	6	Comprehensive project development	The DHC system was conceived, developed and implemented following a comprehensive, seamless approach aimed at achieving a heat/cold supply that is: • High quality • Cost-efficient • Sustainable	Local authorities should use heat mapping as was explained under key success factor 3.

	7	Price competitiveness against alternative energy solutions	This price competitiveness can be enhanced through an • Optimized system design • Competitive procedures for the market • By allowing competition between different heat/cold supply solutions.	Project developers should emphasize that despite being more expensive than the current heating system, DH will be less expensive than the conventional decarbonization scenario (Paardekooper *et al.*, 2018).
	8	Flexible heat and cold production	A flexible production allows better cost-efficiencies, mainly through a dynamic optimization of the supply. This can be achieved through • A diversified and complementary energy mix • The use of CHP and enhanced ramp-up/cycling practices • Connecting the electricity and heating markets, etc. (e.g. grid balancing using district heating systems in Denmark)	Project developers should use district heating for its benefits beyond increased efficiency, e.g. balancing the grid when increased intermittent renewable sources will be included.
	9	Combining technical and non-technical innovation	The DHC system embraces and cross-fertilizes innovation at all levels: from the use of state-of-the-art technologies to new governance modes, keeping a long-term approach when making strategic decisions.	

Note. Adapted from "Efficient district heating and cooling systems in the EU - Case studies analysis replicable key success factors and potential policy implications" *by Marina Galindo Fernández et al. (2016).*

Table 8 Secondary success factors for the development of district heating and cooling.

	Secondary (non-critical) success factors	**Description and/or examples from Denmark, Germany and Sweden**
1	Size	The large size of the grid provides scope for economies of scale.

		In several countries this has been achieved by making connection to the grid mandatory. In other places taxes on alternative heating fuels were used (Woods and Overgaard, 2016).
2	Customer empowerment	Customers are at the core of the DHC business and its main stakeholders.
3	Long-term secured prices (visibility)	Investors have a clear long-term visibility on DH prices. (e.g. the price dialogue or "Prisdialogen" approach in Stockholm)
4	Climate conditions	Cold climate conditions improve the business case for DH

Note. Adapted from "Efficient district heating and cooling systems in the EU - Case studies analysis replicable key success factors and potential policy implications" *by Marina Galindo Fernández et al. (2016).*

The case studies from Denmark (Copenhagen), Germany (Hamburg) and Sweden (Stockholm) provide many examples of how these key success factors can be realized. Some of these will be mentioned here. For instance with regards to the policy frameworks, the Danish Heat Supply Act clearly defines the roles for key actors and the procedures for municipalities regarding choices on heat supply and as such supports the development of DH projects. Also, taxes on electricity and fossil fuels have facilitated the development of district heating and cooling in Denmark, but also in Sweden. In Germany, feed-in tariffs for renewable energies and CHP plants have played a positive role in the deployment. Furthermore, the German KfW investment bank, that was introduced in section 8.2.1.4. has fostered DH investments through affordable loans and investment subsidies. At the local level, the municipality of Hamburg approached Hafencity DH as a flagship project and as such it enjoys high political support. Also, the district is owned by the municipality which makes it possible to set high environmental standards for tenders and impose mandatory connections to the DH networks. Mandatory connections also eased project developments in Copenhagen. Coherent urban planning proved worthwhile in all three examples. Alignment of interests between municipalities, DHC companies and final users, has been facilitated by the non-for profit principle in Denmark, while in Hamburg this was facilitated by choosing a district that was owned by the municipality (Hafencity) and was to be renewed entirely. Regarding secondary success factors, the Copenhagen case (as well as other Danish cases) form a highly illustrative example of successful customer empowerment. Denmark has a long tradition of cooperatives and active participation of citizens in managing these. Local acceptance of projects benefits from this. A unique way of achieving transparency and predictability regarding DH pricing can be found in Stockholm, where a major voluntary market initiative called The Price Dialogue ("Prisdialogen") is in place. This initiative makes it possible for customers to participate in the price setting process and as such fosters transparency as well as public involvement. (Galindo Fernández *et al.*, 2016)

Although 70 per cent of the demand for heat is covered by DH systems in Latvia too, no specific examples from the country were listed here. This is because in this thesis DH is understood as a system that primarily uses waste heat streams. In Latvia, currently still 63% of the heating is produced in fossil fuel heat plants that do not co-generate electricity and could benefit from more modern and efficient installations. The large scale deployment of DH means that Latvia has high potential for replacing heat plants with cogeneration units and being at the forefront of sustainable heating systems, but should at present not be the first example to look at for the Netherlands (Rasmussen, 2003). The systems in Latvia did not enjoy the same technical progress as in Sweden, Denmark or Germany, where significant amounts of time and money were spent on research and development (Woods and Overgaard, 2016).

8.2.2.2. ESCO's

Energy Service Companies (ESCO's) could alleviate barriers to the installation of retrofits that increase the energy efficiency of households, companies and public buildings. The low estimated effort required for expanding this concept in the Netherlands was the main reason for choosing it as an innovation to elaborate on here. After all, ESCO's function within the regular capitalist market system, do not require (but could benefit from) specific policies, and can be implemented on a small scale.

The market for Energy Service Companies, or ESCO's, is relatively undeveloped in the Netherlands, especially when compared to the one of its Eastern neighbor, Germany, which is by far the most mature one in Europe (Boza-Kiss, Bertoldi and Economidou, 2017). Regarding the other case studies of this thesis, also the Danish and Belgian market are larger than the Dutch one (Bertoldi, Boza-Kiss and Rezessy, 2007).

The basic components of ESCO business models will be introduced in the subsequent paragraph. After that, their relevance to the Dutch CLEWF nexus challenges will be explained in section 8.2.2.2.2. and some recommendations for implementation will be made in section 8.2.2.2.3.

8.2.2.2.1. ESCO's: a general introduction

The business model of an ESCO is based on the possibility to make a profit off reduced energy costs as a result of energy efficiency investments. A wide variety of ESCO types as well as several definitions exist, ranging from very narrow to extremely broad, in which case any company that delivers a service related to energy is included. Here, the focus lies on companies that deliver energy services or efficiency improvements using either a contracting type that is known as Energy Performance Contracting, or Energy Service Contracts. (Boza-Kiss, Bertoldi and Economidou, 2017)

Although nuances exist in the exact form of contracts, the basic premise of an Energy Performance Contract is that the investment costs of the improvement are paid for by the efficiency gains that have been realized, using part of the energy bill savings. The customer is therefore not confronted with large upfront investment costs and does not bear the risk of not saving money if the performance turns out lower than expected. Instead, the customer for example shares the savings with the ESCO or pays a fixed performance rate for a set amount of time based on a performance guarantee. The ESCO makes a profit because of the margins they apply to the pay-back of the investments and because of the benefits acquired through the aggregation of many comparable projects. These include better insight in investment risks and economies of scale through specialization and standardization of procedures and retrofits (United States Department of Energy, 2019). Energy Service Contracts work differently. In

Energy Service Contracts, customers pay for a certain service (e.g. heating of their house) and the ESCO generally takes care of the installation, maintenance and operation of the entire system (e.g. heat pumps). The premise of the contract again lies in energy efficiency gains, but this time on the side of the supply instead of demand. (Boza-Kiss, Bertoldi and Economidou, 2017)

8.2.2.2.2. Relevance to the Dutch CLEWF challenges

Increased energy efficiency is directly related to land scarcity as a challenge, as reduced demand for energy implies reduced area required for energy production. In as far as any innovation increases the total amount of efficiency improvements made, it thus contributes to alleviation of the land scarcity challenge. Energy Service Companies definitely have the potential to do this at the market level, because they take away barriers related to finance, risks and know-how. The importance of ESCO's was recognized by various EU directives and initiatives, perhaps most noteworthy in the Energy Efficiency Directive (European Commission, 2012), which describes explicit requirements to promote the market of energy services in Article 18. The Energy Research Centre of the Netherlands estimated the potential of the Dutch ESCO market to be in the range of 35 to 165 million euros (Boza-Kiss, Bertoldi and Economidou, 2017).

The main benefits of ESCO's as an innovative business model are that they form a new source of financing for energy efficiency projects, come with high levels of expertise and take away the need for private households or companies to pay large upfront investment costs or worry about installation and maintenance. Additionally, there is no need for the customer to be convinced of the environmental urgency of energy savings, even plain financial motivations suffice for making the business model work. The important role of Energy Performance Contracting (one type of ESCO contracting that is focused on in this chapter), is also emphasized in the "Clean Energy for All Europeans" communication (European Commission, 2016a). It states that the role of EPC must increase, particularly in the public sector, because it offers a holistic approach to renovations from financing to carrying out the works and the energy management. (Boza-Kiss, Bertoldi and Economidou, 2017)

8.2.2.2.3 Barriers, Drivers and recommendations

The political context of the Netherlands does not form major barriers to the ESCO market (Boza-Kiss, Panev and Bertoldi, 2015). It does however not constitute any noteworthy support either. Boza-Kiss, Bertoldi and Economidou (2017) concluded that most importantly, the relevant frameworks lack ambition and are not all properly implemented yet.

The market evaluation of Boza-Kiss, Panev and Bertoldi (2015), that was done as part of a European survey for the European Commission Joint Research center, identifies several drivers that have proven important for the successful establishment of energy service markets throughout Europe. One example is long-term, manifested and credible commitment to sustainable energy efficiency or the ESCO concept by governmental institutions. In Denmark, the National Energy Efficiency Action Plan and Sustainable Energy Action Plan are examples of long term energy strategies that are independent of election cycles and therefore provide security for the sector (Boza-Kiss, Panev and Bertoldi, 2015). In Germany the strong commitment to the Energiewende and energy taxes has certainly also aided in creating a favorable ecosystem for ESCO's.

At the level of customers, Boza-Kiss, Panev and Bertoldi (2015) mention split incentives as a key barrier. An example of these are residential buildings where lower energy bills would benefit tenants while apartment owners would be the ones responsible for investing in efficiency retrofits. This leaves apartment owners unincentivized to improve the energy performance of their buildings. Furthermore, a lack of officially standardized contracts were found to increase risks and transaction costs and hinder trust.

These findings are supported by the outcomes of a large-scale survey among ESCO agents by the EU's Horizon 2020 QualitEE project . It mapped the most important barriers and drivers in different European countries, as experienced by the ESCO's themselves (IEA, 2019e). The results indicate that in the Netherlands, indeed, lack of policy support and split incentives were seen as important barriers. Although, the most commonly mentioned barriers in 2017 were:

- High costs of project development and procurement
- Lack of trust in the ESCO industry, and
- Complexity of the concept / lack of information

To some extent, these overlap with the barriers experienced by ESCO's in Germany. There too, high costs and complexity are frequently mentioned. Complexity was perceived as a barrier to a lesser extent than a few years earlier however. Interestingly, lack of trust is not among the most important barriers in Germany.

One best-practice example with regard to building trust and providing information comes from the local Berlin Energy Agency that organizes seminars, training programs and workshops to promote energy services. The International Energy Agency concludes that these type of organizations help to overcome non-technological barriers such as lack of trust, by providing systematic information, procurement procedures and know how (IEA, 2019c).

Apart from designated information dissemination, the Energy Saving Partnership (ESP) in Berlin has been identified as an important visible starting signal for the ESCO industry that created demand for energy performance contracting forms from the public sector (Vreeken, 2012). Leading by example could thus be an approach to promote in municipalities or other public authorities.

Public trust in the Dutch sector would furthermore benefit from standardized contracts (Boza-Kiss, Bertoldi and Economidou, 2017). Inspiration could be taken from the standardized German contracts that have been in effect for years. A promising development for trust enhancement from within the Netherlands is the publication of guidelines for procurement of EPC (Boza-Kiss, Bertoldi and Economidou, 2017).

Considering successful ESCO projects from within the Netherlands can also help to create trust. For example the national government has made use of EPC contracting for the renovation of the Van Gogh

Museum. Furthermore, elementary schools were renovated in Veldhoven. The municipality of Rotterdam is a front runner, with three EPC projects performed (the Kunsthal, municipal buildings and swimming pools). Although the energy savings were the primary goal of these projects, also improved indoor climate conditions has proven an important selling point.

High costs of project development and procurement are expected to be less of a barrier when the ESCO market and companies grow. For short term alleviation of this barrier it is worth noting that sometimes ESCO projects could make use of Energy Savings Funds, although this has relatively rarely been done in the Netherlands (Boza-Kiss, Bertoldi and Economidou, 2017). For example the Fûns Skjinne Fryske Enerzjy (FSFE) facilitated a project on an ice rink and the provincial Energiefonds Overijssel has officially included ESCO projects in their portfolio of purposes that loans can be requested for (Roskam, Piessens and Thijssen, 2016; *Energiefonds Overijssel*, 2019).

Actors and practitioners at the regional level could promote and disseminate information about the ESCO market at the local level, in order to build trust and increase visibility. This could for example be done when performing housing checks for energy improvements in private households or by suggesting to municipalities to lead by example.

8.2.2.3. Waterpumping to do peak shaving

The last innovation that will be elaborated on here, was not only selected because of its high estimated effort-impact ratio. It also serves as an illustration for one of the overall conclusions of this work: that effective innovations build from aspects that are already present in countries. This is true for the availability of natural resources such as forests in Sweden or wind in Denmark, but arguably also for less quantifiable societal structures such as a long tradition of citizen cooperatives in Denmark, or a natural cultural tendency to aim for efficiency in Germany.

Pumping water is an inevitable part of maintaining dry land in large parts of the Netherlands that are below sea level. This task is one of the responsibilities of regional water authorities (waterschappen), alongside the management of overall water levels, water barriers, waterways, water quality and sewage treatment. Pumping, but also processes like feeding and aerating sewage water in the waste water treatment facilities are rather energy-intense. Although the margins are limited, some freedom to shift execution times exists. This provides an opportunity for the Netherlands in relation to peak shaving. The next paragraph will explain the importance of these concepts in relation to increased shares of renwables in the energy mix in the future as well as the overall efficiency of energy production. (Kuipers *et al.*, 2016; Chang *et al.*, 2018)

8.2.2.3.1. A general introduction to peak shaving

Demand for electricity is not evenly distributed over the day. Human behavior, industrial operation times and many other aspects of daily life aggregately determine the demand curve for a given day. In general, the daily demand curve is not flat but contains one or more “peaks”, times at which much more electricity is demanded than the average. In part, these peaks are predictable, for instance based on the biological and professional rhythms of people. The exact height of peaks is however different per day.

The existence of peaks in energy demand results in efficiency and costs concerns for energy producers (Kutkut, 2006). Also, it can hinder large scale penetration of renewables in the energy mix. This is related to the intermittent nature of renewable resources, reflected by supply curves that contain peaks too. The peaks of renewable energy generation (e.g. during maximum solar irradiation) do not necessarily, or in fact rarely, overlap with the peaks in demand. During times of peak demand, producers are therefore often required to start operating more expensive and less clean energy generation units such as gas-fired power plants. After all, fossil fuel burners that are used for base-load production are generally more efficient than the ones used during peak hours and therefore cheaper. The marginal costs of renewable energy are even close to zero. On top of that, peak demands also largely determine the grid and capacity sizing. Lowering peak demands, or "peak shaving", can thus reduce costs for energy utilities, while facilitating penetration of renewables.

If the share of renewables in the energy mix is so large that there are times at which not all of the produced energy can be used, it can occur that the production is deliberately constrained, a phenomenon that is called curtailment. At present, this is not a major concern in the Netherlands, but in the future it could add extra weight to the urgency of shaving peaks.

8.2.2.3.2. Relevance to the Dutch CLEWF challenges

For the transition to a low-carbon economy, efficiency and renewable energy penetration are important challenges. For the Netherlands to reach its climate goals, the share of renewables in the energy mix is required to grow strongly in the years to come. The previous paragraph explained that larger shares of renewables in the energy mix augment the desirability of having more control on demand for electricity producers. This implies that predictability of demand will increasingly hold economic value for the (public, private or industrial) consumer. This was also appreciated by the Dutch foundation of applied research for water management (STOWA), that decided to investigate the possibilities for flexible energy management at waste water treatment facilities, or "smart pumping" (STOWA, 2018). Although the exact value of demand side management will depend on various factors such as electricity prices or the development of the markets and connections that facilitate cross-country energy trading, the report recommends the water utilities to invest in increasing the predictability of their system (Chang *et al.*, 2018).

The report investigated the effects of adjustments in the water supply to treatment facilities, for instance by means of buffering for a day, reversing day and night, flexibly changing the oxidation set points or intermittently feeding and aerating. They concluded that these adjustments do not result in considerable energy savings in absolute terms, but, depending on the future climate policy of the Netherlands, can certainly lead to increased sustainability of the system. For this increased sustainability, the predictability of water supply to treatment plants is found to be crucial (Chang *et al.*, 2018).

8.2.2.3.3. Recommendations

In line with the recommendation made by STOWA, investments in increased predictability of energy usage at wastewater treatment plants is recommended. The broader point to be taken from this chapter however is that any sector, company, or other large energy consumer should beware of the future opportunity to contribute to national climate goals by participating in demand side management.

Warren (2015) conducted a global systematic review of demand-side management policies and identified the key factors that cause demand-side policies to succeed or fail. The most important ones for European states were found to be regulatory frameworks, appropriate incentives, comprehensive evaluation, legislative support, industry engagement and innovation.

The amount of emissions that can be avoided through peak shaving is highly dependent on the future development of the Dutch energy system. Slingerland, Rothengatter, Van der Veen, Bolscher and Rademaekers (2015) conclude that until 2023, increased flexibility is most probably not required, but that it will be at some time in the future. They expect this moment to arrive around 2030. Timely anticipation of future flexibility needs (in any sector) are however expected to reduce costs because of long lead times of certain cheaper flexibility options (Slingerland *et al.*, 2015).

8.2.2.3.4. Promising innovations

An interesting observation across the three innovations described above, is the co-existence of policy, social, technical and business innovations for successful implementation. Although district heating had been classified as a technical innovation in the inventory, the recommendations show that also the policy and business aspects are crucial in successful implementation. Some innovative components of the development of DH abroad are more social or business related than technical (e.g. the “Prisdialogen” initiative, long term political commitments etc.). Similarly, ESCO’s were classified as business innovations, but also alleviate technical barriers because they can develop technology specific expertise that individual customers lack. Also peak shaving was classified as a technical innovation, but the economic value that it could hold in the future (and therefore potential for new business models) is another example of the co-existence of several innovation types. This implies that categorization is useful for analysis, but the system should always be viewed as a whole when innovations are implemented.

Conclusions

This study investigated land scarcity as an important challenge for the Netherlands in its transition to a low-carbon economy. The challenge and its context were analysed using nexus science, which appreciates the importance of several interconnected domains for the functioning of the larger nexus. Particular attention was paid to the Climate, Energy and Land domains, which together make up the CLE nexus, were considered. The extensive analysis of land scarcity as a challenge within the CLE nexus context was done making use of the DPSIR framework. Subsequently, innovations were identified that can contribute to addressing this challenge whilst supporting the transition to a low carbon economy. An inventory of innovations was created using examples from the Netherlands, Belgium, Germany, Denmark, Latvia and Sweden. These countries were selected based on their geographical proximity and a benchmarking analysis on performance with regards to European energy and emission targets. The study resulted in the creation of a generic framework for the identification of innovations with the potential to contribute to a specific nexus challenge, using land scarcity in the Netherlands as an example. This framework derived from a literature review on innovation, the beforementioned application of the DPSIR framework to land scarcity, the benchmarking analysis of European countries and several classifications of innovations. The innovation inventory that follows from application of the framework is specific to the challenge investigated. The applicability and transferability of the framework was demonstrated by the identification of innovations with the highest impact and highest potential for success to address the challenge considered in this study, land scarcity in the context of the CLE nexus of The Netherlands. The outcomes of this study imply that the combination of nexus science and the innovation space as a novel approach to investigating challenges of the energy transition is relevant and effective. The key findings and main contributions of the work are summarized in separate paragraphs below.

Key findings

Innovations were found to both follow from, and lie at the heart of, differences in the energy transition paths of Belgium, Denmark, Germany, Latvia and Sweden. The Netherlands can take learning from these by adapting the innovative aspects to the Dutch CLE context.

Through application of the DPSIR framework it was found that innovations related to renewable energy deployment, energy intensity of the economy, resource use and disposal, mobility and agricultural emissions are particularly relevant to the challenge of land scarcity. Considering that the aim of this study was to identify innovations with a high potential impact to address land scarcity as a challenge while simultaneously having a high potential to be easily implemented (low effort required) by regional actors, three innovations in the innovation inventory were identified as particularly promising for the Netherlands. These are: district heating, energy service companies, and peak shaving using Dutch areas of expertise such as, for example, water pumping.

Upon further investigation, it was found that district heating has the potential to drastically increase the efficiency and deployment of renewable energy in the Dutch heating system by aggregating demand and supplying for it using waste heat streams or renewables. Given that heating is one of the largest energy sectors of the Netherlands, improved efficiency in this sector can make considerable contributions to alleviating land scarcity as a challenge in the transition to a low carbon economy. Apart from its high potential impact, it also is a mature technology that has been widely adopted in various cities across Europe and beyond. Innovative approaches to its implementation, such as for example the inclusion of “Prisdialogen” as a participative and transparent approach to price setting, can thus be transferred to the Netherlands, albeit in an adapted form.

Energy service companies, a business-type innovation, address land scarcity as a challenge in one of the most direct ways possible: they can decrease the demand for energy and consequently potentially decrease the demand for land for infrastructure development. The innovative business models of ESCO’s furthermore come with the benefit that they use market forces to their benefit, take away financial and risk-related barriers and perform retrofits with high levels of expertise.

Peak shaving in innovative ways, such as by shifting pumping times in water management systems, can put the Netherlands at the forefront of innovation in the future. The benefits of peak shaving for energy generation efficiency and renewable energy deployment in the future, as well as the fact that these benefits are expected to increasingly hold economic value, should motivate regional actors to develop this opportunity in for example, water management. This technological innovation can also function as a product that could be exported to other countries, turning the Netherlands into a pioneer or even market leader. Especially in the water pumping sector this would be interesting to explore, for instance as an adaptation measure to sea-level rise.

From the DPSIR analysis of the transition paths of Belgium, Denmark, Germany, Latvia and Sweden, it was concluded that being a pioneer can be beneficial to the climate and energy performance of a country. This analysis of both innovative and non-innovative responses to larger societal driving forces showed that especially Denmark, Germany and Sweden benefitted from early commitment to climate and energy goals. Sweden explicitly profiled itself as a pioneer. Through leading by example, Sweden put itself in the position to create the dominant design for various aspects of the energy transition, export knowledge and create jobs. Also in Germany and Denmark, green developments were voiced as opportunities for economic growth and employment. Important in this respect is that countries generally pioneer in activities that they are naturally good at. In Germany this can be seen from the large emphasis on energy efficiency. In Sweden there is a strong focus on efficient heating, and Denmark excels in wind energy and citizen participation.

Decisions such as phasing out nuclear power entirely or setting up tax schemes that span over several government terms provide direction and security for the industry sector and citizens. It conveys the message that there is no need to wait and see if change is really going to be worthwhile or necessary - it will be. This point is also underlined by the fact that the opposite phenomenon, hesitant and slow decision making, was indeed found to be an important barrier in general and specifically in Belgium, where this was mainly the result of the division into regions.

Lastly, drivers for change were found to be economic and geopolitical at least as much, if not more, as they were related to concerns about climate change and sustainability. Concerns about energy security and rising import prices were by far the most important Drivers towards increased efficiency and large-scale biomass deployment in Latvia. In fact, concerns about energy security and rising import prices were also among the most important Drivers in Denmark Germany and Sweden. The historically cheap availability of natural gas as an alternative to imported oil meant that these Drivers were largely missing in the Netherlands however, which surely hampered the speed of progress towards a low-carbon economy. On a positive note, the fact that non-idealistic drivers can move a country in a specific direction, e.g. carbon neutrality, also means that challenges, such as land scarcity, could work in this way, especially if the responses chosen are innovative and build from the natural strengths of the Dutch CLE nexus.

Collectively the findings of this study suggest that in order to deal with land scarcity as a challenge for decarbonization, the Netherlands can take inspiration from other countries and their innovative approaches to related challenges. In other words: it is time for the actors involved in the Dutch energy transition to make space for innovation.

Contributions

In this thesis, a systematic approach to identifying cross-sectoral innovations was developed. The method for creating an innovation inventory is transferable to other countries and applicable to other nexus challenges. As such it can support a wide range of decision and policy making processes.

The specific inventory created for this work contains a rich base of knowledge that contributes to the SIM4NEXUS research project. Also regional actors and practitioners in the Netherlands could take their advantage of the list and the categorizations used, to identify other or more innovations and analyze these further. The complete inventory can be found in Appendix D. Also, the complete list of innovations, with part of its categorizations, is visualized on a map and hosted online on https://story.mapme.com/3221f134-add7-4b91-8b32-893dd84123f4.

Furthermore the combination of the DPSIR framework with the CLEWF nexus approach as a starting point for the identification of nexus-relevant innovations is new and proved to be useful in understanding and breaking down challenges of the nexus. As such the developed methodology is an acedemic contribution in itself.

Limitations and suggestions for future work

Due to the organizational nature of this research, namely the collaborations with the SIM4NEXUS research project and the regional consultancy Driven by Values, the country selection was not solely based on benchmarking. Also, the interests of the Netherlands case study stakeholders and the ease of access to data were considered. Furthermore, the limited scope of a master thesis resulted in the fact that only innovations from five countries were included in the inventory. More or different countries could be considered to expand the inventory and findings. However, the countries selected served the purpose of this study by enabling the development of a method that can support the identification of innovations to improve the nexus in the SIM4NEXUS case studies, and in other case studies in general.

The inventory for innovations included in this thesis, which is closely related to the country selection, should not be interpreted as an exhaustive list but rather as a finite sample of innovations that were mined in relation to the CLE nexus context. The list could be expanded to contain more possibly relevant innovations. The categorizations and analysis, however, provide valuable insights about the relative strengths of countries as well as which innovations can have a potentially large impact while being relatively easy to implement.

Despite deliberate inclusion of social and business innovations as innovation types, these are most probably under-represented in the inventory. This is probably due to policy and technical innovations being more commonly documented and easy to find in literature and databases.

Furthermore, the methodology for the estimation of effort and impact values could benefit from Multi-Criteria Decision Analysis with extensive stakeholder involvement, as explained in section 7.7. Also, modelling outputs from the Netherlands case study analysis of SIM4NEXUS could be used to support the MCDA for impact values by testing some of the innovations suggested. Possibly also model outputs structures and/or scenario analysis could be developed to account for the suggested innovations of this work.

Lastly, for the sake of faster analysis, the innovation inventory would benefit from the automated production of output graphs like the ones shown in section 8.2.1.

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Appendix A: DPSIR indicator categorization

Table 9 Summary of Indicator categorization (Smeets *et al.*, no date)

Indicator type	Aim to provide an answer to the question:	Explanation	Examples
Descriptive (type A)	“What is happening?”	Provide the current levels of certain variables.	Population sizes (driving force indicator), emission levels (pressure indicator) or the relative amount of electric cars (response indicator).
Performance indicators (Type B)	“Does it matter?”	Compare the descriptive variables to targets or agreements.	Heavy metal concentrations in surface water compared to the maximal allowable level (state indicator), or distance to renewable energy generation targets (response indicator).
Efficiency indicators (Type C)	“Are we improving?”	Relate environmental pressures to human activities.	Waste generated per GDP produced. Material Impact Per Service indicators: such as fuel per passenger mile.
Policy effectiveness indicators (type D)	“Are the measures working?”	Aim to evaluate if we are indeed pursuing sustainable development (these are also known as “total welfare” indicators).	Index of Sustainable Economic Welfare,

Appendix B: DPSIR – CLEWF table for the Dutch land scarcity challenge

It is important to mention that aspects that are mentioned in the same row but different columns are not necessarily related. Rather, the sum of Drivers is related to the collection of pressures, which are in turn cumulatively related to the States, Impacts and Responses. Reading the table is therefore probably easiest if done per domain but vertically, going from Climate-drivers to climate-pressures to climate-states etc.

	Challenge: Scarcity of land									
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**	
	Societal forcing powers that have an influence on the system (economic growth, demand for recreational space, etc.).		*Applied on the natural environment. Pressures can be excessive use of resources, emissions, pollution, change in land use, etc. The pressures in turn affect the state.*		*Initial conditions that characterize the system(s) under analysis.*		*Once the state of the environment has changed, the generated impacts are identified and assessed. These could be environmental, economic and social.*		*Impacts – either fully understood in their causal chain or not – lead to responses, such as management or policy actions.*	
↓Nexus Domain	**Description**	**Indicator**	**Description**	**Indicator**	**Description**	**Indicator**	**Description**	**Indicator**	**Description**	**Indicator**
Overarching aspects	High population density	510 inhabitants/km^2 (CBS, 2019c)			Resource productivity (Smits *et al.*, 2018)	€4,20 BNP/kg resources used *Position in the EU: 1st* (Smits *et al.*, 2018)			Klimaatakkoord: sets ambitious targets (GHG emission reduction of 49% compared to 1990 (Sociaal-Economische Raad, 2018) and requires regional energy strategies from provinces,	

	Challenge: Scarcity of land								
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**
									municipalities and water authorities.
	Population growth	0.44% on average between 2010 and 2017 (CBS, 2019a)			Resource footprint (Smits *et al.*, 2018)	8100 kg/inhabitant *Position in the EU: 18th* (Smits *et al.*, 2018)			
	Urbanization	Urbanization rate: grew from 16.2% in 1996 to 18.8% in 2015 (Planbureau voor de Leefomgeving, 2018) 0.53% increase in built up area *Position in the EU:*			Circular production (Smits *et al.*, 2018)	Environmentally-Sustainable national income (mDNI): 65.4% (Smits *et al.*, 2018)[5]			

[5] The Environmentally Sustainable national income (milieu-duurzaam nationaal inkomen, mDNI) is the maximal obtainable production level at which the environmental functions stay available for future generations using the currently available technologies. If production rises above this level, damage is done to the environmental functions, at the cost of future generations. De Boer and Hueting (2018) estimated the mDNI for 2000, 2005 and 2015 (Boer and Hueting, 2018).

	Challenge: Scarcity of land								
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**
		16^{th} (Smits *et al.*, 2018)							
					Percentage recycled municipal waste (Smits *et al.*, 2018)	53.1% of collected municipal waste *Position in the EU: 4^{th}* (Smits *et al.*, 2018)			
CLIMATE	Policy goals for GHG emission reductions at the EU level	Dutch ESD target: 16% by 2020 and 36% by 2030 compared to 2005 (European Parliament and Council of the European Union, 2018)	Land as a resource is being competed for by energy, food, urbanization etc.	Current land area occupied by forests and nature: 16% *Position in the EU: 26^{th}* (Smits *et al.*, 2018)	Resource footprint (Smits *et al.*, 2018)	8100 kg/inhabitant *Position in the EU: 18^{th}* (Smits *et al.*, 2018)	Costs of climate adaptation and mitigation		Klimaatakkoord: sets ambitious targets (GHG emission reduction of 49% compared to 1990 (Sociaal-Economische Raad, 2018) and requires regional energy strategies from provinces, municipalities and water authorities.

	Challenge: Scarcity of land									
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**	
	Policy goal for renewable energy consumption for the EU as a whole: 32% by 2030 compared to 2005 (European Commission, 2016b)	Percentage renewable electricity consumption in 2017: 6.6% (Dutch target for 2020: 14%)	GHG emissions from the energy sector	159.1 Tera-grams CO_2 equivalent (2016), 81.5% of total (National Institute for Public Health and the Environment, 2018)			Failing to meet international targets: Renewable energy has to be bought from other countries (nu.nl, 2019)		Environmental taxes	8.7 % of the national tax and social charges incomes *Position in the EU: 9th* (Smits *et al.*, 2018)
	Policy goal for energy efficiency for the EU as a whole: Increase of 32.5% by 2030 compared to 2005 (European Commission, 2016b)		Nitrogen emissions in the agricultural sector (Smits *et al.*, 2018)	191 kg N_2 / ha agricultural land *Position in the EU: 27th* (Smits *et al.*, 2018)	Energy intensity of the economy GHG emissions per capita	118.3 kg of oil equivalent per 1000 Euros of GDP. 12.2 tonnes of CO_2 equivalent per capita in 2016	Costs related to extreme events damages		Environmental investments (Smits *et al.*, 2018)[6]	3.7% of the national tax and social charges incomes *Position in the EU: 7th* (Smits *et al.*, 2018)

[6] These investments are not solely investments made to support climate goals, but also include investments to improve air quality, protect natural reservoirs etc. (CBS, 1998).

Challenge: Scarcity of land

DPSIR element→	DRIVER		PRESSURE		STATE		IMPACT		RESPONSE	
	High population density	510 inhabitants/km^2 (CBS, 2019c)	High amounts of waste	Municipal waste per person: 560 kg/inhabitant *Position in the EU: 20th* (Smits *et al.*, 2018)					Incentives for/deployment of CCS technologies	3.6 billion euro subsidies for coal fired powerplants to co-fire wood (ZEMBLA, 2017a) (ZEMBLA, 2017b)
			The socioeconomic system and lifestyle (consumption of energy and products)	11,3 ton Co2-equivalents per inhabitant *Position in the EU: 24th* (Smits *et al.*, 2018)					Biomass imports are considered to meet the demand (Strengers *et al.*, 2018)	Only a maximum of 230 PJ sustainable biomass is available domestically and the potential for usage is much higher (technically 2250 PJ in 2050, and realistically 410 PJ) (Strengers *et al.*, 2018)
									Promotion of biomass use	Subsidies (Rijkdienst voor Ondernemend

	Challenge: Scarcity of land									
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**	
										Nederland [RVO], 2019)
	Population growth	0.44% on average between 2010 and 2017 (CBS, 2019a) SSP2 projection: 10% increase by 2050	Competition for land: renewables compete for urban or agricultural land (wind/solar parks)		Limited availability of land	See Figure 9	Economic trade-offs between sectors		Increase / invest in domestic biofuel production	
LAND USE	High population density	510 inhabitants/km^2 (CBS, 2019c)			Relatively large coastline with low depth				Biomass imports are considered to meet the demand (Strengers *et al.*, 2018)	Only a maximum of 230 PJ sustainable biomass is available domestically and the potential for usage is much higher (technically 2250 PJ in 2050, and realistically 410 PJ) (Strengers *et al.*, 2018)

	Challenge: Scarcity of land									
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**		**IMPACT**		**RESPONSE**	
	Land requirements for Renewable Energy infrastructure to fulfil the RE goal	See Figure 7	Competition for land: biomass for energy has several implications on agriculture as it can compete with food and fodder crops				(reduction of) Agricultural production (output) if decrease in agricultural area and no further agricultural intensification		To save land, roof areas can first be used for solar panels	
	Land requirements for biofuel cultivation (Strengers *et al.*, 2018)		Urbanization	Urbanization rate: grew from 16.2% in 1996 to 18.8% in 2015 (Planbureau voor de Leefomgeving, 2018)	Biodiversity	Red List Indicator: 60.8 index (1950=100)A [7] Living Planet Index: 107,0 index (1990=100) (Smits *et al.*, 2018) A [8]	NIMBY situations with regards to renewables.	%%		

[7] The Red list indicator is a measure of the risk of extinction of sets of species as an indicator of biodiversity, for which the methodology was developed by the International Union for Conservation of Nature and Natural Resources (IUCN, 2009). A score below 100 indicates more threats to biodiversity, while a score above 100 indicates reduced threats (Butchart *et al.*, 2005).

[8] The Living Planet Index is an internationally used measure of biodiversity, for which the calculation methodology was developed by World Wide Fund for Nature (WWF) and the Zoological Society of London (ZSL) (World Wildlife Fund [WWF] and Zoological Society of London (ZSL), 2014). The abundance of species is compared to the level in 1990 which was set at 100, therefore any score above 100 indicates increased abundance while a score below 100 indicated decreased abundance (McRae, Deinet and Freeman, 2017).

DPSIR element→	DRIVER		PRESSURE		STATE		IMPACT		RESPONSE
Challenge: Scarcity of land									
				0.53% increase in built up area *Position in the EU: 16th*(Smits *et al.*, 2018)					
	Land requirements for agriculture and food production								To save land and prevent resistance (NIMBY-situations) investments are made in wind at sea.
ENERGY	Policy goal for renewable energy consumption for the EU as a whole: 32% by 2030 compared to 2005 (European Commission, 2016b)		Competition for land: renewable energy requires more land.		Current percentage renewables	Percentage renewable electricity consumption in 2017: 6.6% (Dutch target for 2020: 14%)	Increase in prices of electricity and gas	An average increase of 4.2% per year since 2000 (with an inflation of 2.0%) (Compendium voor de Leefomgeving, 2016)	Klimaatakkoord: sets ambitious targets (GHG emission reduction of 49% compared to 1990 (Sociaal-Economische Raad, 2018) and requires regional energy strategies from provinces, municipalities and water authorities.

DPSIR element→	Challenge: Scarcity of land DRIVER		PRESSURE		STATE		IMPACT		RESPONSE	
	Policy goal for energy efficiency for the EU as a whole: Increase of 32.5% by 2030 compared to 2005 (European Commission, 2016b)		High energy intensity affects climate through GHG emissions from energy production from fossil fuels, agriculture and (supply of energy).	4425 kg Oil equivalents/inhabitant *Position in the EU: 23th* (Smits *et al.*, 2018)	Energy intensity of the economy GHG emissions per capita	118.3 kg of oil equivalent per 1000 Euros of GDP. 12.2 tonnes of CO_2 equivalent per capita in 2016	Import of electricity	45.8% in 2016. *Position in the EU: 17th* (Eurostat, 2019a)	Investments (Smits *et al.*, 2018)[A]	
	The socioeconomic system and lifestyle (consumption of energy and products)	11,3 ton Co2-equivalents per inhabitant *Position in the EU: 24th* (Smits *et al.*, 2018)	High energy expenses for households (Smits *et al.*, 2018)		Land requirements for Renewable Energy infrastructure	See Figure 9	Fossil fuel imports dependency	13.7 tonnes of fossils energy carrier imports per inhabitant *Position in the EU: 28th* (Smits *et al.*, 2018)	Mobility plans for the reduction of fossil fuel use in the transport sector (Rijksoverheid, 2019b)	

	Challenge: Scarcity of land				
DPSIR element→	**DRIVER**	**PRESSURE**	**STATE**	**IMPACT**	**RESPONSE**
			High (historical) dependency on natural gas	NIMBY situations with regards to renewables.	
			Biofuel blends	Awareness of the need for sustainability is high	Congestion charge / other measures to reduce the use of cars in cities, for example
			Share of biofuels in the transport sector		Development of Wind at sea
					Consideration of waste-to-energy solutions (including trough waste-water treatment)
					Solar roof systems are gaining popularity

	Challenge: Scarcity of land				
DPSIR element→	**DRIVER**	**PRESSURE**	**STATE**	**IMPACT**	**RESPONSE**
WATER		The water subsystem affects fossil energy production (cooling water), agricultural production (irrigation) and energy from biomass production (biogas from sewage sludge).	Overexploitation of water by the food production sector that uses water for irrigation	Reduction of agricultural output if less water is available for irrigation or increased costs due to investment in more advanced irrigation technology	Use of sludge from waste water treatment to produce energy (waste-to-energy solutions)
	Klimaatakkoord voices ambitions for a circular economy (Sociaal-Economische Raad, 2018)	It is affected by climate (water availability), agriculture (overexploitation of freshwater resources) and land (nutrient emissions from runoff).	The country is partially under sea-level so water management is a serious task (including energy requirements for pumping). Approximately one quarter of the country lies below sea level (EURAXESS Netherlands, 2019).	Eutrophication from agricultural practices	

Challenge: Scarcity of land							
DPSIR element→	**DRIVER**		**PRESSURE**		**STATE**	**IMPACT**	**RESPONSE**
			Accelerated hydrological cycle comes with more frequent extreme weather events			Reduction / curtailment of thermal power generation, ultimately resulting in import of electricity (more expensive)	
FOOD	High population density	510 inhabitants/km^2 (CBS, 2019c)	Relatively large amount of cattle per hectare agricultural land (Smits *et al.*, 2018)	3.7 cattle-units /ha agricultural land *Position in the EU: 28th* (Smits *et al.*, 2018)		Reduction / increase of food and agriculture production	Invest in the production of more valuable crops? (Reduce the area of less profit / unit cultivated area?)
	Western diet and consumption, (estimated) requirements for the average annual consumption in the Netherlands	Current: 0.6 hectare/per person of which 0.4 hectare is required for food (rest for resources such as timber and cotton). a vegetarian diet: 0.26 hectares/per person,	Low share of biological /organic agriculture (Smits *et al.*, 2018)	2.9% biological agriculture *Position in the EU: 24th*	Agro-sector exports represent 4.4 percent of GDP (CBS, 2016b)	Reduction / increase of food and agriculture production	

Challenge: Scarcity of land							
DPSIR element→	DRIVER		PRESSURE		STATE	IMPACT	RESPONSE
		the recommended diet: 0.33 hectare/ person (Laspidou, 2017)					
			Nitrogen intense agricultural sector	191 kg N_2 surplus/ha agricultural land *Position in the EU: 27th* (Smits *et al.*, 2018)	Intensive agriculture and developed food production systems (profile of food production systems)	Reduction of food exports	More vegetarians, vegans or flexitarians (Het Voedingscentrum, 2019)
			High amount of food waste	Approximated by organic waste: 873 kg/inhabitant *Position in the EU: 28th* (Smits *et al.*, 2018)	Argo-sector exports represent 4.4 percent of GDP (CBS, 2016b)	Increase of imports (probably applies more to land use system, related to agriculture)	

Appendix C: Overview of the European energy and climate goals

Blue cells were used to mark the targets for the EU as a whole. Red cells indicate the aspects where national binding targets were set at the European level. Green cells mark the aspects of which the EU required its member states to set their own targets.

	2020 June 2009: The climate and energy package				**2030** The Energy and Climate Framework (October 2014) Clean energy for all Europeans framework			
Topic	**EU wide goals**	**Policy framework**	**Description**	**Country specific targets or requirements compared to 2005 levels**	**EU wide goals compared to 1990 levels**	**Policy framework**	**Description**	**Country specific targets or requirements compared to 2005 levels**
GHG emissions reductions	20% (compared to 1990 levels)	Emission Trading Scheme	Cap-and trade certificate scheme covering the power sector, major industry and aviation emissions (45% of total GHG emissions).	EU total: 21%	55%	Revised ETS		EU total: 43%
		Effort Sharing Decision	Binding annual targets for each EU Member State for GHG emissions	Range: -20 to +20% NL: 16%		Effort Sharing Regulation (May 2018)	Binding annual GHG emissions reductions for each member	Range: 0% to 40% NL: 36%

			reduction in non-ETS sectors (including agriculture, smaller industry, waste sector and transport except aviation). The targets (annual emission allocations AEAs) vary based mainly on the differences in wealth between countries (GDP/capita)	EU total: 10%			state for the period 2021-2030 (differentiated primarily based on per capita GDP)	EU total: 30 %
Increasing renewables	20%,	Renewable energy Directive	binding targets per member state for 2020: based on starting point and potential.	Range: 10% to 49% NL: 14% EU total: 20%	32%	Regulation on the governance of the Energy Union (June 2018)	Procedural requirements for all member states	Bi-annual national energy and climate plans (NECPs)
Improving energy efficiency compared to	20%	Energy Efficiency Directive	Member states set their own indicative national energy efficiency targets. Depending on country preferences,	NL: Primary energy consumption: 60.7 Mtoe	32.5%	Regulation on the governance of the Energy Union (June 2018)	Procedural requirements for all member states	Bi-annual national energy and climate plans (NECPs)

forecast levels			these were based on primary or final energy consumption, primary or final energy savings, or energy intensity.	Final energy consumption: 52.2 Mtoe				
Other						EU Framework Strategy for the Energy Union, 25 February 2015.	long term goals: security of supply, sustainability and competitiveness	

Appendix D: Innovation inventory

Innovation Inventory

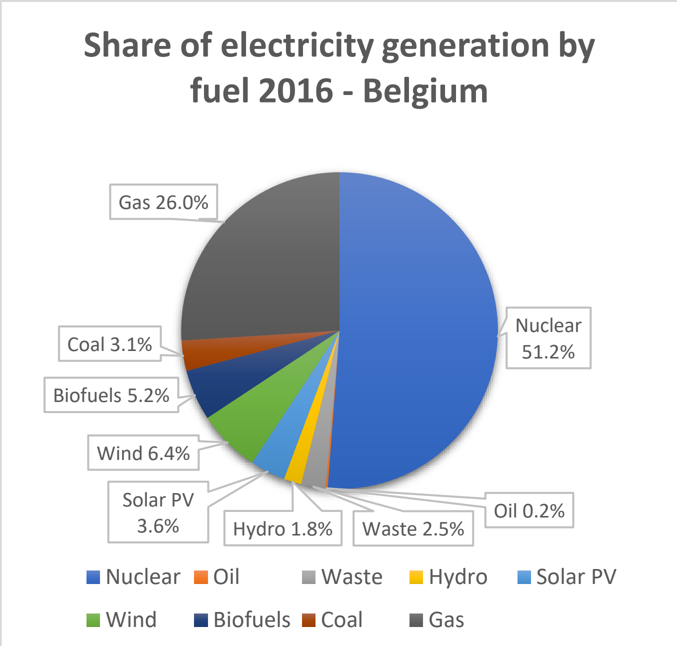
Flag	Country	Innovation name	Company involved	Type	Level	Applicable nexus domains: Climate	Land	Energy	Water	Food	Short-, medium- or long-term	Main DPSIR challenge	Status of implementation	Effort	Impact	Impact/ Effort
4	Netherlar	**EV (dis)charging**	LomboXnet	Technical	Local	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	4	8	2
5	Belgium	**Home batteries purchase premium**		Policy/Institution	National	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	4	4	1
6	Germany	**Home batteries**	Lichtblick, Tesla	Technical	Local	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	3	3	1
7	Germany	**Home batteries: Sonne**	Sonnen	Business	Local	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	3	6	2
8	Netherlar	**Home batteries: iWell**	iWell	Business	Local	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	3	7	2.333333
9	Germany	**Subsidy for solar PV with storage installations (I**		Policy/Institution	National	Implied	Implied	Yes	No	No	Medium	Renewable en	Operatioi	5	4	0.8
10	Belgium	**Optimosystem**		Policy/Institution	Local	Yes	Yes	No	No	No	Short	Resource use c	Pilot proje	5	5	1
11	Sweden	**ICA nudging**	Beteendelabbet	Business	Regional	Yes	No	No	No	Yes	Short	Resource use c	Operatioi	4	3	0.75
12	Germany	**KfW promotional bank**		Policy/Institution	National	Yes	Yes	Yes	No	No	Short	Multiple/Other	Operatioi	3	8	2.666667
13	Netherlar	**Invest-NL (investment fund but not a bank)**		Policy/Institution	National	Yes	Yes	Yes	No	No	Medium	Multiple/Other	Developr	3	5	1.666667
14	Denmark	**Grant for 30% of capital costs wind mill investn**		Policy/Institution	Local	Implied	No	Yes	No	No		Renewable en	Ended	4	9	2.25
15	Netherlar	**Peak shaving using wa**	Waterschappen	Technical	Regional	Implied	No	Yes	Yes	No	Short	Renewable en	Developr	4	9	2.25
16	Denmark	**Green tax reform: labour/capital**		Policy/Institution	National	Yes	No	Yes	No	No	Short	Energy intensity	Operatioi	7	10	1.428571
17	Denmark	**District heating and cooling**		Technical	National	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	4	10	2.5
18	Denmark	**District cooling Copenhagen**		Technical	Local	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	4	10	2.5
19	Latvia	**District heating**		Technical	Local	Implied	No	Yes	No	No	Short	Energy intensity	Pilot proje	3	6	2
20	Sweden	**Biofuels play an important role in District heatii**		Technical	Local	Implied	Implied	Yes	No	No	Medium	Renewable en	Operatioi	4	7	1.75
21	Sweden	**District heating and cooling**		Technical	Regional	No	No	Yes	No	No	Long	Renewable en	Operatioi	4	10	2.5
22	Latvia	**Biomass cogeneration**	In Jelgava	Technical	Regional	No	No	Yes	No	No	Short	Renewable en	Operatioi	5	8	1.6
23	Sweden	**Small scale heating using biomass**		Technical	Regional	No	No	Yes	No	No	Short	Renewable en	Operatioi	3	5	1.666667
24	Denmark	**Local co-generation**		Business	Local	Implied	Yes	Yes	No	No	Short	Renewable en	Operatioi	4	3	0.75
25	Latvia	**Rape oil instead of diesel fuel**		Technical	Regional	No	Yes	Yes	No	No	Short	Renewable en	Operatioi	3	3	1
26	Latvia	**Bioethanol (spirit) production**		Technical	Regional	No	No	Yes	No	No	Short	Renewable en	Operatioi	7	3	0.428571
27	Latvia	**Biogas**	Bolderaja	Technical	National	No	No	Yes	No	No	Long	Renewable en	Operatioi	4	4	1
28	Denmark	**Straw for biofuel**		Technical	Local	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	5	5	1
29	Sweden	**Biomass from agricultural residues**		Technical	Regional	Yes	Yes	Yes	No	No	Short	Renewable en	Operatioi	3	5	1.666667
30	Belgium	**Biomass from grass: graskracht**		Technical	Regional	Implied	Yes	Yes	No	No	Short	Renewable en	Ended	5	4	0.8
31	Belgium	**Biogas from dairy: pocketpower**		Technical	Local	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	7	5	0.714286
32	Belgium	**Decree on wood pellets for non-industrial hea**		Policy/Institution	National	Yes	Implied	Implied	No	No	Short	Renewable en	Operatioi	3	3	1
33	Belgium	**BRUSSELS - blending mandate for biofuels**		Policy/Institution	Regional	Yes	No	Yes	No	No	Short	Renewable en	Operatioi	4	5	1.25
34	Germany	**GASnzv**		Policy/Institution	National	Yes	Implied	Yes	No	Implied	Short	Renewable en	Operatioi	4	4	1
35	Netherlar	**Biokerozine**	KLM	Technical	Regional	Yes	No	Yes	No	No	Short	Renewable en	Pilot proje	5	5	1
36	Germany	**Alternative jet fuels**	Aireg	Technical	National	Yes	No	Yes	No	No	Medium	Mobility	Developr	4	4	1
37	Sweden	**Vehicle conversion to alternate fuels**		Policy/Institution	National	Yes	No	Yes	No	No	Short	Mobility	Operatioi	5	4	0.8
38	Germany	**Strong ESCO market**		Business	Regional	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	2	8	4
39	Germany	**ESCO's regulatory support**		Policy/Institution	National	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	4	7	1.75
40	Germany	**ESCO's: Consulting on Energy Performance Cc**		Business	Local	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	3	8	2.666667
41	Germany	**E-energy projects**		Technical	Regional	Implied	No	Yes	No	No	Short	Renewable en	Pilot proje	4	6	1.5
42	Germany	**The energy concept: Energy and Climate Fun**		Policy/Institution	National	Yes	No	Yes	No	No	Long	Energy intensity	Operatioi	4	5	1.25
43	Germany	**DHL electric vehivles**	Deutsche post DHL, str	Business	National	Yes	No	Yes	No	No	Short	Mobility	Operatioi	3	3	1
44	Nethelan	**More with less "Meer met minder", currently nc**		Social	Local	Implied	No	Yes	No	No	Short	Energy intensity	Operatioi	6	8	1.333333
45	Nethelan	**Stimulering Duurzame Energie SDE**		Policy/Institution	National	Implied	Implied	Yes	No	No	Short	Renewable en	Operatioi	4	7	1.75
46	Nethelan	**National Renewable Energy Action Plan (NREA**		Policy/Institution	National	Implied	Implied	Yes	No	No	Long	Renewable en	Operatioi	8	8	1
47	Netherlar	NREAP > Feed-in premium: SDE and SDE+		Policy/Institution	National	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	4	4	1
48	Netherlar	NREAP > Biofuels obligation		Policy/Institution	National	Implied	Implied	Yes	No	No	Short	Renewable en	Operatioi	5	7	1.4
49	Netherlar	NREAP > Research support		Policy/Institution	National	Yes	Implied	Yes	No	No	Long	Renewable en	Operatioi	4	3	0.75
50	Netherlar	NREAP > Green Deals		Policy/Institution	National	Yes	Yes	Yes	No	No	Medium	Renewable en	Operatioi	4	6	1.5
51	Netherlar	**Hier opgewekt**	HIER, alliander, enpuls,	Policy/Institution	Regional	Implied	No	Yes	No	No	Short	Renewable en	Operatioi	4	3	0.75

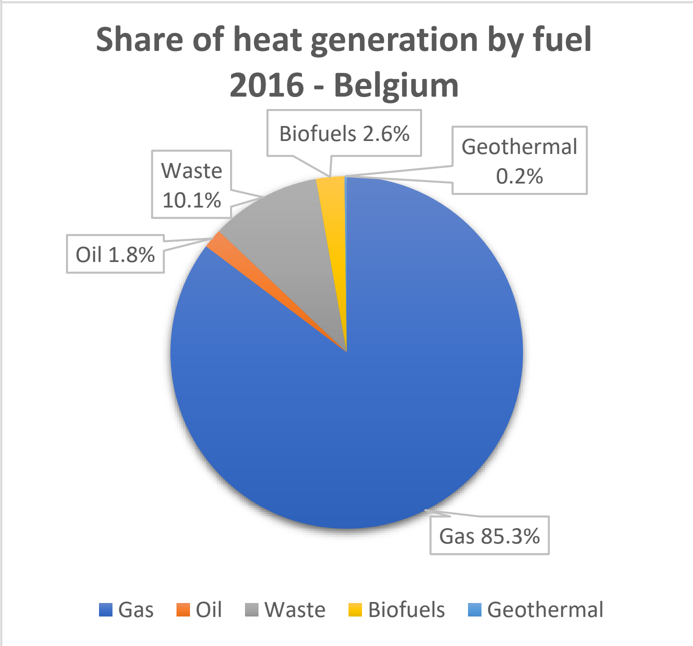
52	Netherlar	**Postcoderoos**	Policy/Institution	Local	Implied	Yes	Yes	No	No	Short	Renewable en	Operatio	4	3	0.75
53	Netherlar	**Smart Energy Cities**	Social	Regional	Yes	Implied	Yes	No	No	Medium	Energy intensity	Operatio	6	9	1.5
54	Denmark	**People and Profit awareness campaign**	Social	National	Yes	No	Yes	No	No	Short	Multiple/Other	Ended	3	6	2
55	Netherlar	**Energy performance compensation for "Nul o**	Policy/Institution	National	Implied	No	Yes	No	No	Short	Energy intensity	Operatio	5	8	1.6
56	Germany	**Agro-photovoltaics**	Technical	Local	Implied	Yes	Yes	No	No	Short	Energy intensity	Operatio	3	5	1.666667
57	Sweden	**Farmers business model innovations**	Business	Local	Implied	Yes	Implied	No	Implied	Short	Multiple/Other	Operatio	4	2	0.5
58	Denmark	**Integrating heat supply with electricity balanc**	Technical	Regional	Implied	No	Yes	No	No	Short	Energy intensity	Operatio	4	10	2.5
59	Denmark	**Wind forecasting**	Technical	National	Yes	No	Yes	No	No	Short	Renewable en	Pilot proje	4	6	1.5
60	Denmark	**Renewable Energy Act: policies for citizen sup**	Policy/Institution	Local	Implied	Yes	Yes	No	No	Medium	Renewable en	Operatio	3	9	3
61	Denmark	*REA > The value loss compensation scheme t*	Policy/Institution	Local	Implied	Yes	Yes	No	No	Medium	Renewable en	Operational			#DIV/0!
62	Denmark	*REA > The co-ownership scheme for citizens*	Policy/Institution	Local	Implied	Yes	Yes	No	No	Medium	Renewable en	Operational			#DIV/0!
63	Denmark	*REA > The comunity benefit scheme to enhar*	Policy/Institution	Local	Implied	Yes	Yes	No	No	Medium	Renewable en	Operational			#DIV/0!
64	Denmark	*REA > The guarantuee fund for local ownersh*	Policy/Institution	Local	Implied	Implied	Yes	No	No	Medium	Renewable en	Operational			#DIV/0!
65	Belgium	**Mileage charge for tru** VIAPASS	Policy/Institution	National	Yes	No	Implied	No	No	Short	Mobility	Operatio	3	4	1.333333
66	Sweden	**Carbon sequestration** Vattenfal	Technical	Local	Yes	Yes	No	No	No	Short	Resource use c	Operatio	5	3	0.6
67	Sweden	**International Developn** CENTEC	Policy/Institution	Supra-National	Yes	Yes	Yes	No	No	Long	Renewable energy depl		5	2	0.4
68	Sweden	**National Renewable Energy Action Plan**	Policy/Institution	National	Yes	Implied	Yes	No	No	Short	Multiple/Other	Operatio	8	8	1
69	*Sweden*	*NREAP > Exemption from energy and carbon*	Policy/Institution	National	Yes	Implied	Yes	No	No	Short	Renewable en	Operational			#DIV/0!
70	*Sweden*	*NREAP > Support for demonstration wind proj*	Policy/Institution	National	No	Implied	Yes	No	No	Short	Renewable en	Operational			#DIV/0!
71	*Sweden*	*NREAP > Biofuels obligations*	Policy/Institution	National	Implied	Implied	Yes	No	No	Long	Renewable en	Operational			#DIV/0!
72	Sweden	**Vindlov.se windenergy information website**	Social	National	No	*Implied*	*Yes*	*No*	No	*Short*	*Renewable en*	*Operatio*	3	6	2
73	Belgium	**BRUSSELS - Climate fund**	Policy/Institution	Regional	Yes	No	Yes	No	No	Short	Multiple/Other	Operatio	4	5	1.25
74	Belgium	**FLANDERS - Climate fund**	Policy/Institution	Regional	Yes	No	Yes	No	No	Short	Multiple/Other	Operatio	4	5	1.25
75	Belgium	**BRUSSELS - changing behaviour energy anima**	Social	Regional	Implied	No	Yes	No	No	Short	Energy intensity	Ended	7	8	1.142857
76	Germany	**Buy smart project**	Social	National	Implied	No	Yes	No	No	Short	Energy intensity	Operatio	5	4	0.8
77	Germany	**Mod.EEM – "Modular Energy Efficiency Model"**	Policy/Institution	Regional	Implied	No	Yes	No	No	Short	Energy intensity	Pilot proje	5	3	0.6
78	Germany	**Funding the refurbishment of facilities for sport**	Social	Local	Implied	Yes	Implied	No	No	Short	Multiple/Other	Operatio	6	7	1.166667
79	Germany	**Patent families**													
80	Germany	> Air pollution abatement	Technical	Local	Yes	No	Implied	No	No		Multiple/Other				
81	Germany	> Road transport	Technical	National	Implied	Implied	Implied	No	No		Mobility				
82	Germany	> Renewable Energy Generation	Technical	Regional	Implied	Implied	Yes	No	No		Renewable energy deployment				
83	Germany	> Enabling technologies in buildings	Technical	Local	Implied	No	Yes	No	No		Energy intensity of the economy/living				
84	Germany	> Enabling technologies in energy sector	Technical	National	Implied	No	Yes	No	No		Energy intensity of the economy/living				
85	Latvia	**Patent families**													
86	Latvia	> Renewable energy generation	Technical	National	Implied	Implied	Yes	No	No		Renewable energy deployment				
87	Latvia	> Enabling technologies in buildings	Technical	National	Yes	No	Yes	No	No		Energy intensity of the economy/living				
88	Latvia	> Energy generation from fuels of non-fossil ori	Technical	National	Yes	No	Yes	No	No		Renewable energy deployment				
89	Latvia	> Solid waste management	Technical	Regional	Yes	Yes	No	No	No		Resource use and disposal				
90	Latvia	> Water pollution abatement	Technical	Regional	Yes	Implied	No	Yes	No		Resource use and disposal				
91	Sweden	**Patent families**	Technical												
92	Sweden	> Road transport	Technical	National	Implied	Implied	Implied	No	No		Mobility				
93	Sweden	> Air pollution abatement	Technical	Local	Yes	No	Implied	No	No		Multiple/Other				
94	Sweden	> Energy efficiency in buildings	Technical	Local	Implied	No	Yes	No	No		Energy intensity of the economy/living				
95	Sweden	> Energy technologies in buildings	Technical	Local	Implied	No	Yes	No	No		Energy intensity of the economy/living				
96	Sweden	> Renewable Energy Generation	Technical	Regional	Implied	Implied	Yes	No	No		Renewable energy deployment				
97	Belgium	**Patent families**	Technical												
98	Belgium	> Enabling technologies in buildings	Technical	Local	Yes	No	Yes	No	No		Energy intensity of the economy/living				
99	Belgium	> Air pollution abatement	Technical	Local	Yes	No	Implied	No	No		Multiple/Other				
100	Belgium	> Renewable Energy Generation	Technical	Regional	Implied	Implied	Yes	No	No		Renewable energy deployment				
101	Belgium	> Technologies relating to chemical industry	Technical	Local	Implied	No	No	No	No		Multiple/Other				
102	Belgium	> Road transport	Technical	National	Implied	Implied	Implied	No	No		Mobility				
103	Netherlar	**Patent families**	Technical												
104	Netherlar	> Enabling technologies in buildings	Technical	Local	Yes	No	Yes	No	No		Energy intensity of the economy/living				
105	Netherlar	> Renewable energy generation	Technical	Regional	Implied	Implied	Yes	No	No		Renewable energy deployment				

106	Netherlar	> Energy efficiency in buildings	Technical	Local	Implied	No	Yes	No	No		Energy intensity of the economy/living
107	Netherlar	> Technologies relating to chemical industry	Technical	Local	Implied	No	No	No	No		Multiple/Other
108	Netherlar	> Water pollution abatement	Technical	Regional	Yes	No	No	Yes	No		Multiple/Other
109	Denmark	**Patent families**	Technical								
110	Denmark	> Renewable energy generation	Technical	Regional	Implied	Implied	Yes	No	No		Renewable energy deployment
111	Denmark	> Enabling technologies in buildings	Technical	Local	Yes	No	Yes	No	No		Energy intensity of the economy/living
112	Denmark	> Technologies in the production process for f	Technical	Local	Implied	No	Implied	No	No		Multiple/Other
113	Denmark	> Energy generation from fuels of non-fossil ori	Technical	National	Yes	No	Yes	No	No		Renewable energy deployment
114	Denmark	> Technologies relating to chemical industry	Technical	Local	Implied	No	No	No	No		Multiple/Other

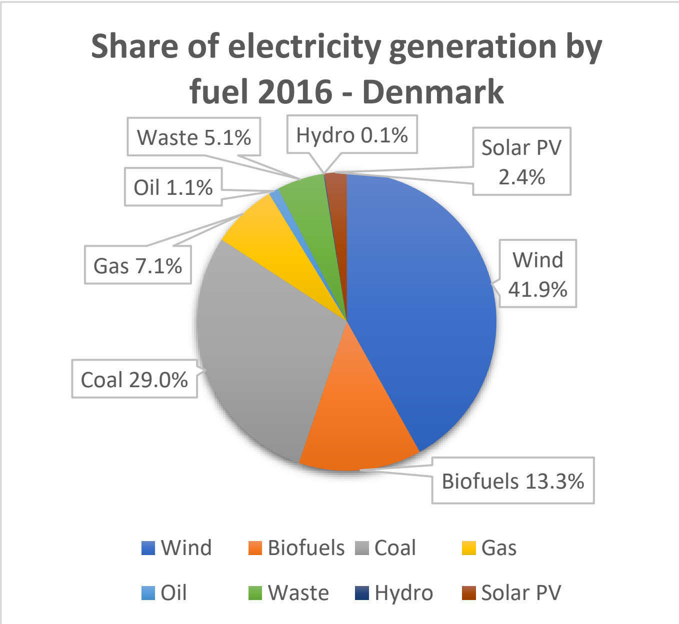
Appendix E: Electricity and heat generation by source per country

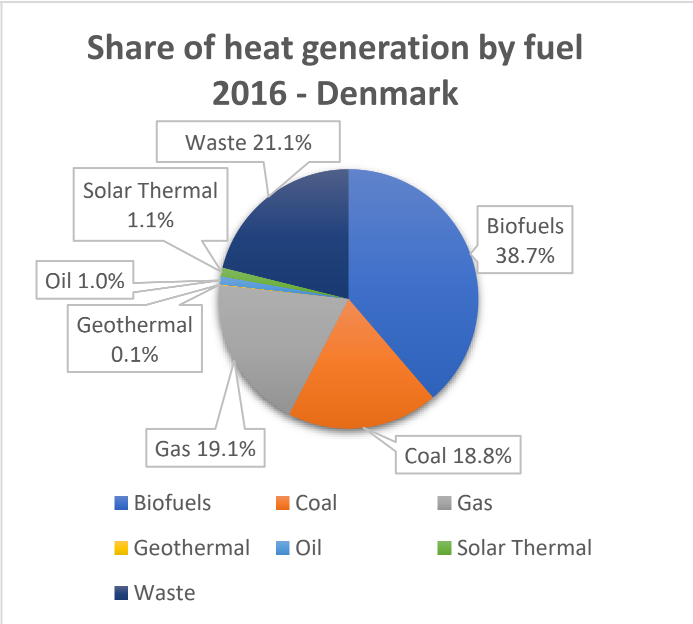
Belgium



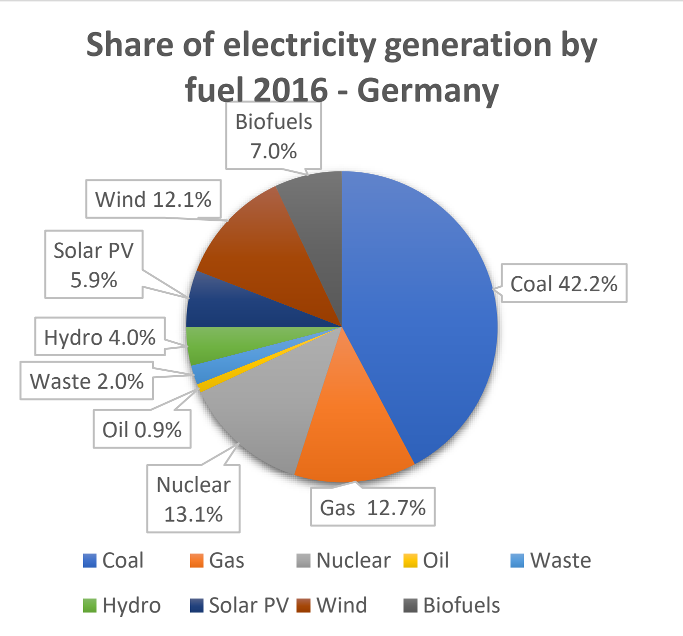


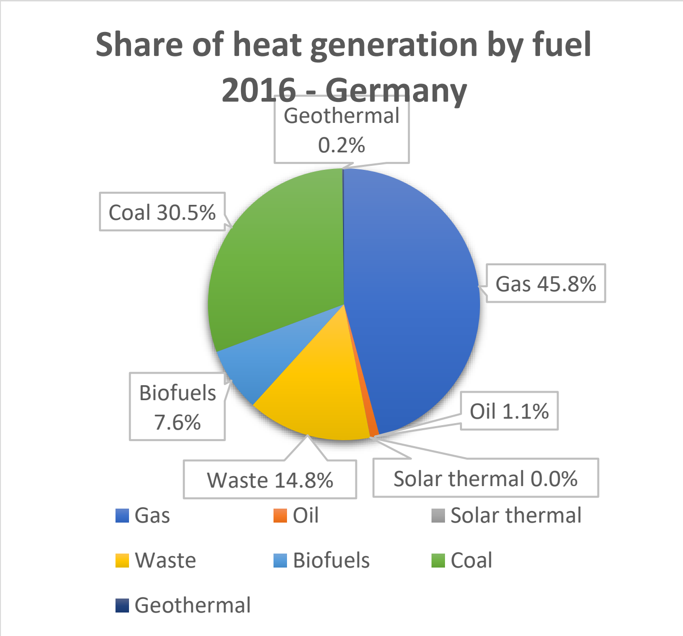
Denmark



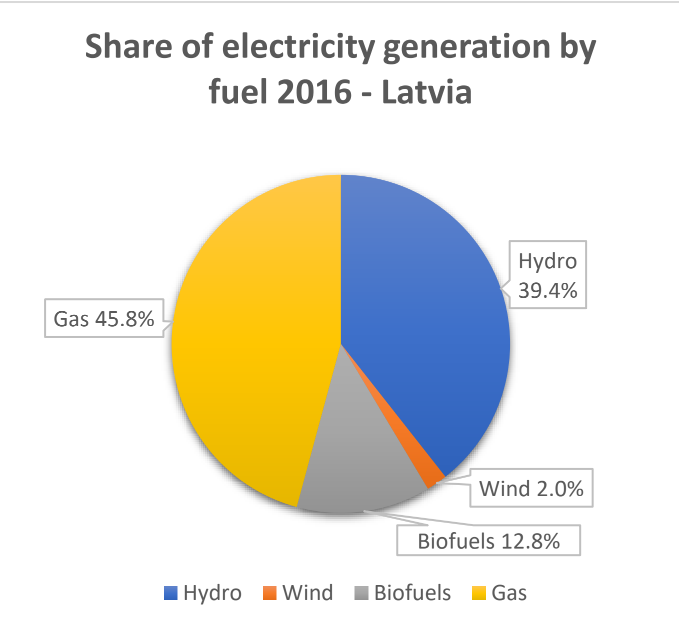


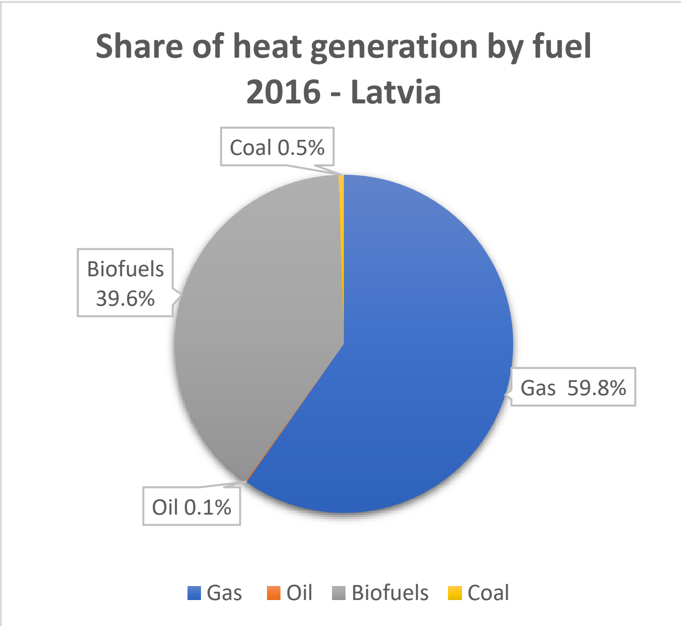
Germany



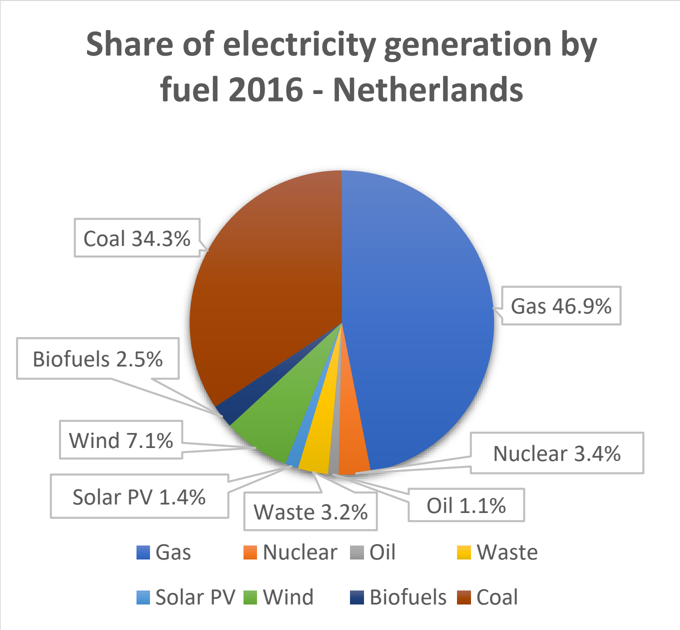


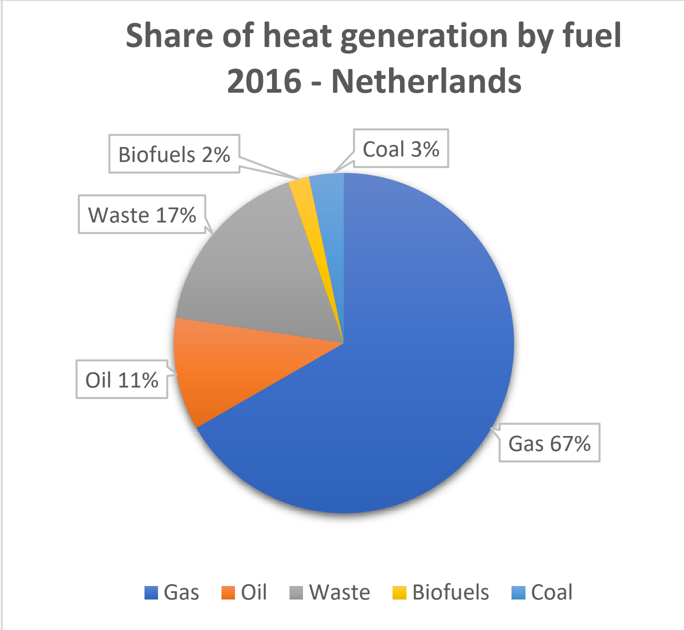
Latvia





Netherlands





Sweden