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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September 2019

Abstract: Land scarcity challenges the ambition of the Netherlands, a densely populated country, to transition to a low-carbon economy, particularly due to the large spatial requirements of renewable energy technologies. 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 nexus performance 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 land scarcity, a benchmarking analysis of European countries, and several classifications of innovations. An inventory of innovations was prepared collecting examples from the Netherlands, Belgium, Denmark, Germany, Latvia and Sweden. 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; DSPIR; systems thinking; the Netherlands

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1. Introduction

The Paris UNFCCC agreement, 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 [1]. 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 [2]. In the Netherlands, the "klimaatakkoord" is leading the way regarding environmental policy [3]. Achieving these goals and ambitions will, among other things, require a significant increase in renewable energy generation. At the European level, it has been agreed that by 2030 the share of renewable energy generation shall be 32% [4,5]. In 2017, the Netherlands reached 6.6% [6]. Considering that renewable energy sources have a significantly lower power density than fossil fuels, an increase in renewable energy generation will require more space [7]. Considering furthermore that 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, implies that dealing with land scarcity, albeit political or publicly perceived scarcity rather than absolute, is particularly challenging for the Netherlands [8].

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 [9]. After all, the urgency of transitioning to low-carbon economies is universal across Europe. However, the challenges that the energy transition evokes, 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. For land scarcity as a challenge in the Dutch context, especially the first three domains were focused on. The identification of relevant innovations that 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.

2. Research Questions and Objectives

The main aim of this study is (1) to identify innovations that can contribute to improving the performance of the nexus by addressing the land scarcity challenge while supporting the low carbon economy transition. Furthermore, the objectives are (2) to review the literature on innovation, (3) to develop a framework for the identification of potential innovations to apply in the context of the nexus, using the land scarcity example of the Netherlands. Application of the framework will result in an innovation inventory specific to the challenge under investigation and can be used by stakeholders and relevant actors in the case study to identify the most promising innovations to consider for future implementation. The exercise on the identification of relevant innovations performed in this study will exemplify the applicability and transferability of the framework. (4) to 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 and (5) to identify elements that unify successful transition paths across countries.

3. Literature Review: definitions, categorizations and relevance for sustainability

3.1. 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 [10]. Since then, several scientific journals as well as professional societies related to innovation have emerged. The most 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 [10]. 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 [10,11]. Currently, several general definitions of innovation have found ground in scientific literature [12]. The most recent definition used in the Oslo Manual, which provides guidelines for collecting and interpreting data on innovation to facilitate internationally comparable data, 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)."***[9]. Earlier editions of the OSLO manual used the expression of "introduced to the market" instead of "made available to potential users" [13]. Critics such as Gault [12,14] 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. 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.)[15,16]. Also, the OECD definition left no room for innovations to be offered for free [12,14]. 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.

3.2. 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 [13] proposed four categories for innovation in the business sector: product, business process, organizational and market innovations. 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 [9]. For the energy transition this categorization can be valuable. After all, product innovations such as electric cars, solar panels and biodegradable 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) [16–18]. 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 [19]. As such, it is reasoned 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 [20]. 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. Ward et al. argue that '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 and there appears to be an inevitable incompatibility between infinite growth and finite resources in itself [19]. On top of that, and more fundamentally: GDP in itself is not accepted as a worthy goal because it would not adequately reflect human well-being [19]. 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. Examples of other commonly found categories are: sustaining versus disruptive innovations [21], incremental versus radical innovations [22], evolutionary versus revolutionary [23,24] 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 investigated in this study are therefore organized in four categories: technical, social, policy/governance and business innovations, with "sustainable innovations" as the umbrella concept. This categorization leaves the development paths and final outcomes free of preconceptions, while still significantly reducing the breadth of innovation as a term. Important to note is that "social innovation", under the scope of this study, is considered to be the type of innovation that arises out of the reconfiguration or reorganization of social actors or their attitudes or behaviors. It is not used here to describe innovations that contribute to social/societal problems.

3.3. The relation between innovation and the energy transition

Before proceeding with the analysis, another important question deserves attention. Are 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. Irandoust [25] describes a direct causal relationship between technological innovation and renewables in Denmark and Norway and the same, but reverse, relationship in Sweden and Finland. The author suggests that the divergent results 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. At policy level, the study concludes that investments should be made in technological innovation, since technological innovation effectively contributes to renewable energy deployment, which in turn spurs innovations. Similar conclusions are drawn by Lin and Zhu [26], 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 CO2 emissions. Hoppe & de Vries [27] 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. Aldieri, Bruno and Vinci [28] investigate 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. In summary, innovation plays an important, if not crucial, role in the transition to a low-carbon economy.

4. Materials and Methods

The CLEWF nexus challenge of ‘scarcity of land’ in the Netherlands was analysed using the Driver Pressure State Impact Response (DPSIR) framework, a theoretical tool to break down complex and interrelated (environmental) processes into more tangible and quantifiable units [29]. Within the DPSIR framework, the environmental processes are understood to consist of a chain of causal links running from Driving forces, Pressures, States, Impacts, to Responses [29][30]. 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 [29][30]. 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 5 by 5 matrix was produced describing the DPSIR elements that characterize each nexus domain for the challenge of land scarcity. Later a 6th row was added, labelled “Overarching aspects”, for the DPSIR aspects that recurred in all nexus domains. Review of statistical information, SIM4NEXUS project outputs and of academic and grey literature 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 [30]. Indicators were also compared to European targets, or if targets were unavailable, average performances of European member states. Aspects identified as important “Drivers”, “Pressures”, “States”, “Impacts” and “Responses” were used to guide the search for innovations to be included in the innovations inventory. Furthermore, these identified aspects (renewable energy deployment, energy intensity of the economy, resource use and disposal, mobility, agricultural emissions and multiple/other) were included as a categorization of the innovations in the inventory in the column “Main DPSIR challenge addressed”.

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 indicators was an extensive review of the national, European and global targets which led to the conclusion that 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 benchmarking done in this study adhered to this three-fold categorization by comparing the performance of European Union member states to each other and in relation to their targets for 2020. National targets for GHG emission reductions and renewable energy generation in 2020 were set by the EU, taking differences in starting points, potential and economic conditions into account [31]. The progress on GHG emission reductions was compared using the relative change to the base year (2005) in 2017, and by comparing these to the targets set for 2020 under the Effort Sharing Decision [32][33]. Furthermore, the absolute levels of GHG emissions in tonnes of CO_2 equivalent emissions per capita 2016 were compared across member states, independent from the targets set [34]. After all, those countries that are already emitting less GHG emissions per person can be considered potential examples regardless of their recent reductions. Also renewable energy performance was benchmarked using 2017 values. The shares of renewable energy generation were compared to the national renewable energy targets for 2020 set at the European level under an earlier version of the Renewable Energy Directive [31,35]. Selecting an indicator for the benchmarking of energy efficiency is slightly less straight forward, because no binding national targets were set by the EU for 2020. Instead, an EU wide target of 20% improvements was set and individual member states set their own indicative national energy efficiency targets. In order to take into account, at least to some extent, the influence of sector dependencies of the economy and the level of economic welfare of different countries, the energy intensities of the economies were compared using the energy intensity of GDP as an indicator: in kg of oil equivalent per 1000 Euros of GDP [36]. Five European countries were selected based on their performance as well as their expected relevance as best-practice examples for the Netherlands: Belgium, Denmark, Germany, Latvia and Sweden. Also 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 in which there is a natural tendency for social, technical and intellectual interaction.

An inventory was created stating the innovation’s name, origin, type and most relevant DPSIR-CLEWF challenge. Also the relevance to each nexus domain was indicated on a three-step scale: “Yes” for innovations that are directly applicable to the domain, “Implied” for innovations that are indirectly applicable, and “No” for innovations that are not applicable. Several other categorizations were added to support the research questions. For example, the timespan for the expected effect to occur was divided into short (before 2023), medium (before 2030) or long- term (after 2030) effects. The level of implementation of innovations was indicated as “development”, “pilot project”, “operational” or “ended”. Furthermore, the estimated effort required for implementation as well as the estimated positive impact were indicated using a score between 0 and 10. For effort a low score is positive while for impact a high score is. In this study the impact and effort scores were estimated keeping in mind the interests of regional actors and practitioners in the Nehterlands, but an exercise on calculating scores using Multi-Criteria Decision Analysis (MCDA) was done to show the possibility for stakeholders to create their own scores based on their interests. 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. 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 [37–39]. 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). If changes in social structures, perceptions or behaviors were estimated more central to the deployment or success of the innovation than legal or political changes, 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 [40]. For technical innovations in particular, information about the amount of green patent families in different areas of research was included in the inventory. These were taken from a website that was the product of the PhD work of François Perruchas [41]. The website interface is mainly supported by data from PATSTAT 2016a.

Some examples of specific technological innovations were also included in the inventory. Business innovations were found mainly in news articles and through web-searches. The innovations in the inventory were analysed by producing graphical visualizations of the analysis of the outputs per category. This allowed the identification of three promising innovations to address the land scarcity issue in the Netherlands. The publications and databases that were consulted to populate the innovation inventory provided a rich base of information on the transition paths of the selected countries. Not all of the developments encountered in this literature are innovative. However, understanding also the non-innovative developments across the countries, is important to explain differences in performance that cannot be assigned to innovations and to identify contextual factors that are important for emergence and successful implementation of innovations. 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. The general transition paths of the selected countries were therefore described using the DPSIR framework and compared to the transition path of the Netherlands. For several elements, qualitative indicators were used to support the analysis.

5. Results

5.1. Contents of the innovation inventory for the land scarcity challenge

More than 70 innovations from within and outside the Netherlands were identified, listed and categorized in a table format. Figure 1 shows a plot of all innovations in the inventory 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.

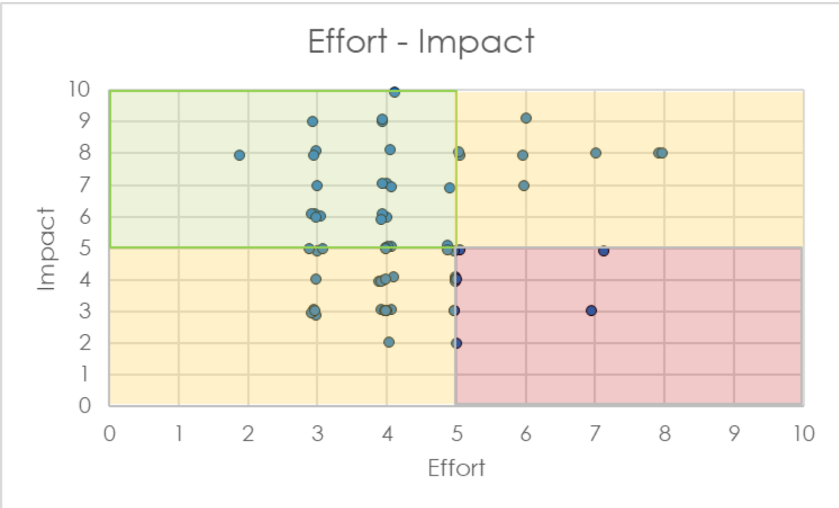

Figure 1. All entries of the innovation inventory were plotted in this Effort-Impact matrix. Some random noise was added to the scores in order to prevent the dots from completely overlapping each other.

A great deal of entries fall into the upper-left quadrant of the plot in Figure 1, signifying that the effort required for their implementation is estimated to be relatively low and their impact high. The innovations within the green quadrant of the graph 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. From these Effort/Impact rankings, three promising innovations were selected: district heating and cooling, Energy Service Companies (ESCO's) and Peak shaving in combination with water management. Using the categorization on "main DPSIR challenge adressed", it was found that most innovations in the inventory address "Renewable energy deployment" and that especially Denmark, Sweden and the Netherlands provided many innovations in that category. The most apparent difference between the amount of entries per country could be seen for innovations adressing "Energy intensity of the economy", where Germany provided by far most entries. National differences in technical expertise were analyzed through the information included in the inventory about patent families. Firstly, the absolute amount of green patent families per country shows that especially Germany has a large amount of green patent families (24990 compared to 1920 in the Netherlands, 1580 in Denmark, 1429 in Sweden, 941 in Belgium and only 19 in Latvia). This does not necessarily mean that Germany has the largest green economy however, because the amount of granted patents differs across patent offices of different countries. 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 amount of patents per nation, the relative shares of green patents per topic were also analysed. For Germany, the largest share of green 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 amount of patents related to enabling technologies in buildings, 30 and 35% respectively. Latvia's modest amount of patent families are mostly related to renewable energy generation and enabling technologies in buildings. The complete list of innovations was also analyzed based on the applicability to the different nexus domains. It was found that only five innovations are directly applicable to all three domains simultaneously. If also Implied relations are counted however, this number grows to 37. This underlines the value of a nexus approach in characterizing challenges and identifying innovations.

5.2. Transition paths of Belgium, Denmark, Germany, Latvia and Sweden

Below, in Table 1, an overview is given of the DPSIR analysis of the transition paths of the countries that served as sources of innovations for the inventory. 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, Impact, or Response, this does not mean that this element has not played any role, but merely that it was not describes as the most important or determining in the analyzed literature and policy documents. The quantitative values listed are taken from the benchmarking analysis and extended with statistics about the living standards, energy mixes and population densities [34,36,42].

Table 1. 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 level of primary energy in kg of oil equivalent per 1000 EUR of GDP (2015)	141.3	65.1	112.6	206.7	111.3
GHG emission 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%
Impact					
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

6. Discussion

The large amount of innovations that fall into the green quadrant of Figure 1 indicate that the inventory contains a considerable amount of innovations with a high potential to positively impact the land scarcity challenge within the Dutch CLE nexus, while being relatively easy to implement. As it was one of the main aims of this study to identify such innovations, this is a positive observation. To illustrate the applicability and transferability of the model, the scores for effort and impact were furthermore used as heuristics for identifying three innovations as examples. These will be elaborated on in the subsequent section.The categorization on “main DPSIR challenge addressed” not only provides a quick overview of the current contents of the inventory but it was also found to be an important tool in the expansion of the inventory through a comparison of national fields of expertise. The characterization of the case study using the DPSIR could further benefit from stakeholder engagement and participation by providing opportunities for validation and verification of the analysis performed; and, secondly, by establishing a communication bridge between analysts and the relevant actors in the case. Such environment could contribute to speed up the identification of relevant innovations for specific stakeholders as the sample of innovations can be used to give direction with regards to which country provides most innovations in which field. In this case for example, the sample suggests that Germany might be a good place to look for more innovations supporting energy efficiency. Similarly, the insights from the analysis of the amount of green patent families in different categories across countries could be used as a heuristic for identifying technical fields of expertise of the countries.

The applicability of innovations to the different domains, as was shown in Figure 2, indicate that only 5 of the more than 70 innovation in the inventory directly apply to all three CLE domains at once. This is an important observation it itself as it suggests that innovation at present does not regularly take on a cross-domain approach to (land scarcity as a challenge of) the transition to a low-carbon economy. However, if implied relations are considered too, which seems reasonable given the interrelated nature of the nexus, the amount of innovations that address all three domains grows considerably, to 37.

6.1. District heating

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, Combined Heat and Power (CHP) and/or renewables [43–47]. 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. Paardekooper et al. [48], conclude that decarbonization of the Dutch heating and cooling sector with significant investments in district heating systems will have a higher efficiency and reduced costs 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 [48]. District heating is commonly used in Sweden, Denmark, Latvia and Germany [49]. One of the most important reasons for the low permeation of district heating in the dutch energy system is related to the historically cheap availability of natural gas. In Sweden, Denmark, and Latvia, district heating was an economically attractive alternative to oil when import dependencies and rising prices became issues [49,51]. In contrast to the lack of an economic or geo-political drivers in the past, now, finally, there are Drivers to move to DH systems in the Netherlands: the ambition to move to a low-carbon economy while dealing with land scarcity. In fact, 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 [46].

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 [52]. At the national level, the Netherlands could for example learn from Denmark with regards to policy frameworks: The Danish Heat Supply Act clearly defines the roles for key actors and the procedures for municipalities regarding choices on heat supply. Also, the wider advantages of DH to the energy system are recognized and exploited in Denmark. There, the flexibility to operate with various heat sources and thermal storage is used to manage intermittent wind energy in the grid. [49] Furthermore, 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 has fostered DH investments through affordable loans and investment subsidies. At the local level, succesful projects from for example Copenhagen, Stockholm and Hamburg exemplify the importance of flagship projects, mandatory connections to DH networks, coherent urban planning, alignment of interests between municipalities, DHC companies and final users (for example by the non-for-profit principle in Copenhagen) and customer empowerment. Innovative aspects of these could be used in the Netherlands. For example the inclusion of 'Prisdialogen' as a participative and transparent approach to price setting, can be transferred to the Netherlands, albeit in an adapted form.[47][49]

6.2. ESCO's

The innovative business models of ESCO's that are meant here, are specifically Energy Performance Contracting and Energy Service contracts [53]. Although nuances exist in the exact form of contracts, the basic premise of a performance contract is that the investment costs of the improvement are paid for by after the efficiency gains have been realized, using part of the energy bill savings. In ESC's, 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. [53] 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 and 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. [54] In as far as any innovation increases the total amount of efficiency improvements made, it can contributee to alleviation of the land scarcity challenge within the Netherlands. After all, reduced demand for energy implies potentially reduced area required for energy production. Energy Service Companies definitely have the potential to increase the amount of efficiency improvements made, because they take away financial and risk-related barriers, perform retrofits with high levels of expertise 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 [53]. Regarding the other case studies of this thesis, the Danish and Belgian market are larger than the Dutch one too and could as such also function as role models [55]. For example, one important Driver for the successful establishment of energy service market throughout Europe has been found to be long-term, manifested and credible commitment to sustainable energy efficiency or the ESCO concept by governmental institutions. In Denmark, National Energy Efficiency Action Plan and Sustainable Energy Action Plan are examples of long term energy strategies that are not dependent on election cycles that provide security for the sector [56]. In Germany the strong commitment to the Energiewende and energy taxes has certainly also aided in creating a favorable ecosystem for ESCO's. With regards to barriers, especially lack of trust in the ESCO industry, high costs of project development and procurement and complexity of the concept (or lack of information) are important [56][57]. In Germany, one best-practice example with regard to building trust and providing information comes from the local Berlin Energy Agency (BEA) that organizes seminars, training programmes and workshops to promote energy services [58]. Furthermore, standardized contracts that have been in effect for years in Germany [53]. These are thought to be very important for trust enhancement. A promising development in this direction, from within the Netherlands, is the publication of guidelines for procurement of EPC. Also the Energy Saving Partnership (ESP) in by the municipality of 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 by leading by example. [59] In the Netherlands, successful ESCO projects could be used in a similar way, as examples that help to create trust. High costs of project development and procurement are expected to be less of a barrier when the ESCO market and companies grow [60]. 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 [53]. In some cases however, funds have made EPC projects possible, for example the Fûns Skjinne Fryske Enerzjy (FSFE) facilitated a project on an ice rink. Also, in the provincial Energiefonds Overijssel has officially included ESCO projects in their portfolio of purposes that loans can be requested for [60,61].

6.3. Using waterpumping to do peak shaving

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. Not only the benefits of peak shaving for energy generation efficiency and renewable energy deployment in the future, but also 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.

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 of 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, a concept that is gaining importance in relation to increasing the proportion renewables in the energy mix in the future as well as the overall efficiency of energy production. [62,63] . The Dutch foundation of applied research for water management (STOWA), investigated the possibilities for flexible energy management at waste water treatment facilities, or "smart pumping", for instance by means of buffering for a day, reversing day and night, flexibly changing the oxidation set points or intermittently feeding and aerating [64]. 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. [62]. 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 expected to reduce costs because of long lead times of certain cheaper flexibility options [65].

6.4. Transition paths

The DPSIR analysis of both innovative and non-innovative responses to larger societal driving forces in Belgium, Denmark, Germany, Latvia and Sweden, of which an overview was provided in Table 1, helped to better understand the historical transition paths of these countries. For example, it was found that especially Denmark, Germany and Sweden benefitted from early commitment to climate and energy goals. 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. Furthermore, pioneering, or in other words, leading by example, showed to come with advantages rather than risks (as is commonly feared in the Netherlands). This is illustrated by the transition path of Sweden in particular, but also by those of Germany and Denmark. Sweden namely explicitly profiled itself as a pioneer and as such put itself in the position to create the dominant design for various aspects of the energy transition, export knowledge and create jobs in the process. Also in Germany and Denmark, green developments were voiced as great 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. For the Netherlands to learn from this it would thus be worthwhile to draw from existing strengths, such as for example sustainability related applications of water management techniques. Lastly, Drivers for change were found to be economic and geopolitical at least as much, if not more, as they were driven by 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.

7. Conclusions and contributions

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 to the Dutch CLE nexus 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. Furthermore, the DPSIR framework helped 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. 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. Furthermore the combination of the DPSIR framework with the CLEWF nexus approach as a starting point for the identification of nexus-relevant innovations is an addition to science and proved to be useful in understanding and breaking down challenges of the nexus.

8. Limitations and suggestions for future work

Despite deliberate inclusion of social and business innovations as innovation types, these are most probably under-represented in the inventory. This is 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 was suggested in the materials and methods section. Also, modelling outputs from the Netherlands case study analysis of SIM4NEXUS could be used to support the MCDA for impact values and also test 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.

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