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

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ABSTRACT

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

1. Introduction

Nowadays, sustainability is regarded as an important landmark for the future development of our planet (UNDP, 2015). Sustainable development can be considered as an approach "that meets the current needs without compromising the ability of future generations to meet their own needs" (UN, 1987). It influences society, economy and environment in every region of the world and raises the challenges that can be addressed only with collective action. Since the energy sector is a major contributor and a driver of the economy in most countries, sustainable development in this area becomes the core international goal. In this regard, significant changes are needed on the global, regional and national level in order to set up effective long-term strategies and development policies.

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

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reaching the national and regional targets in energy area.

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

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

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

Thus, different practical studies in relation to low-carbon energy scenarios have been conducted on the national and regional level, and some attempts were made in academic research to compare these approaches. Nevertheless, in the scientific literature there have been no works devoted to the systemic analysis of the differences in policy settings of the low-carbon energy scenarios in the European countries. Existing studies mainly deal with fragmented aspects and are not comparable. Therefore, the main goal of this paper is to propose such a structured approach, taking six north-west European countries (the Netherlands, Germany, France, Denmark, the UK, Belgium) as the examples.

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

Therefore, the research question is:

How can we compare and evaluate the policy settings

of the low-carbon energy scenarios 2050 in European countries,

which they have put in place to achieve the EU 2050 targets?

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

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

2. Methodology

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

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

The methodology of this study includes the stages of *preparing, analysis* and *integration of data* (radar diagrams). For this, *qualitative* (literature review, expert interviews) and *quantitative methods* (statistical analysis, trend monitoring) are used. The following *information sources* form the basis for research: scientific publications, international and national (governmental) reports and strategic programs (e.g. the Netherlands (CPB/PBL, 2015), Germany (Öko-Institut/Fraunhofer ISI, 2016), France (Criqui and Hourcade, 2015), Denmark (Danish Energy Agency, 2014), the UK (UKERC, 2013) Belgium (FPB, 2015)), international statistics (e.g. European Commission (2016); European Environment Agency (2018)), materials of energy conferences and workshops (e.g. PBL, 2016; Koelemeijer, 2016; Eichhammer, 2016; Mattes, 2016; Criqui, 2016; Pedersen, 2016; Watson, 2016; Devogelaer, 2016), consultations with the experts from energy area.

Based on the literature review and interviews with national experts, the ***conceptual framework*** of this research proposes ten characteristics for the assessment of policy settings in energy scenarios: *modelling* *framework (diversity)*, *ambitiousness of the targets 2050*, *relations with other (European) countries*, *stakeholder involvement*, *technology options*, *non-technological aspects*, *economic component*, *the usage of scenarios in policy design*, *intermediate indicators of targets' (2050) achievement* and *revision of scenarios*.

Table 1 presents a short description of these characteristics, possible policy settings within them (with the scale for assessment), as well as their advantages and disadvantages. The score ranges are as follows: 1 (low), 2 (medium) and 3 (high).

The scores for all characteristics are summed up and the final score for each country is calculated and presented in radar diagrams (see example in Fig. 1).

A more detailed description of how this methodology has been applied for the assessment of energy scenarios in six north-west European countries is presented in Section 3.

3. Assessment of energy scenarios

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

3.1. Modelling framework (diversity)

In this research modelling framework of energy scenarios is analysed in terms of *diversity* of the pathways developed. The assessment scale for this characteristic assumes that aiming at a single or two scenarios may not well present the diverse nature of trajectories to be considered (see Table 1).

In six countries analysed, there are differences in the ***variety and types of scenarios***. As a rule, due to the need to follow the long-term EU targets (80–95% GHG reduction by 2050), the countries deal with several *normative scenarios with additional measures* (the names of policy scenarios developed in each country are presented further in Table 3). Such policy measures may be related to: electrification of buildings, transport or industries; improving efficiency in supply sectors (f.e. in energy, telecom, water and waste); diversification of energy prices for local and international energy markets, etc. Most countries (five out of six) start from *a reference scenario* (there is no reference WLO[1] scenario in the Netherlands). At the same time, various approaches are applied for designing *alternative policy scenarios*. This differentiation may be based on predetermined shares or ranges for certain energy carriers, as well as on the main frame parameters: e.g. in France – demand reduction, share of renewables, share of nuclear (Criqui and Hourcade, 2015); in Denmark – the shares of different "known" technologies: wind, biomass, bio+,[2] hydrogen, fossil fuel (Danish Energy Agency, 2014); in the UK – emission reduction, technology development, fossil fuel prices, import dependency (UKERC, 2013).

The scenarios discuss a need to account for uncertainties in the pathways to follow up and so called "wild cards"[3] on the way to achieving the EU 2050 targets. Nevertheless, the challenge of "wild cards" for modelling, mentioned in energy scenarios, is in fact not addressed in the countries investigated. At the same time, diverse ***restrictions and challenges*** are indicated in scenario pathways. One of the major challenges in different scenarios is *availability of natural resources* (e.g. for bioenergy production, as mentioned in the report of Danish Energy Agency (2014)). Some more specific challenges are considered as well. For example, *infrastructure changes* are needed in France: deep retrofitting, electrification, plants' renovation, etc. (Criqui and Hourcade, 2015). Another problem is ensuring *a reliable electricity supply*. In Denmark a wind power-based, fully electrified system assures good fuel supply security but requires a reliable electricity supply, while a bioenergy-based system has to ensure a reliable fuel supply. In Germany *a ban for a specific energy source* (e.g. for nuclear energy) may serve as a significant political barrier. The problems discussed in the UK scenarios are as follows: understanding of *potential winners and losers*, changing *human behaviour and values*, dealing with *inconsistencies with local decision-making* and *testing of policies against a range of futures* (e.g. if the oil, gas and electricity price fall, the government should be prepared) (UKERC, 2013). In Belgian report the importance of *quantitative evaluation in energy decisions* is emphasised, as well as *a complementarity of the scenarios* (they should be supplemented by other analyses to cover all relevant topics) and the role of *coherence and (inter)national communication* (Devogelaer, 2016).

3.2. Ambitiousness of the targets 2050

Achievement of the EU 2050 goal to reduce the GHG emissions to 80% below 1990 levels seems to be possible in case of a significant contribution made by each member state. In accordance with the European Commission's Roadmap (European Commission, 2011), 80% reduction target should be reached through domestic measures alone. Nevertheless, despite these overall requirements that the countries agreed upon in order to achieve the EU 2050 targets, there are observable differences in the ***modelled GHG emissions reduction compared to 1990*** on the national level. Table 2 illustrates emissions reduction levels (minimum and maximum) that have been considered in the scenarios under investigation and the countries' reduction ambitiousness compared to the EU 80% goal (2050).

As is seen from Table 2, there is an observable range in reduction ambitiousness within the selected group of countries, which may influence the achievement of the EU 2050 targets (80% reduction). Germany and Denmark determine the maximum EU reduction target of 95% (ratio = 119%). The Netherlands and the UK focus on the lower boundary of the international EU goal (80% GHG emissions reduction, ratio = 100%). At the same time, France and Belgium determine the maximum national targets only at 75% and 65% respectively (ratio = 94% and 81%).

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

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

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

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

Table 1
Conceptual framework.
Sources: based on PBL, 2016; Russel et al. (2010); and consultations with the experts.

Characteristics	Description	Possible policy settings (with the scale for assessment)	Advantages (reasons for scale selection)	Disadvantages (possible scale limitations)
1. Modelling framework (diversity)	The diversity of policy scenarios	1 One single policy scenario 2 Two policy scenarios 3 Multiple policy scenarios (range of pathways)	Aiming on a single trajectory might not be desirable (PBL, 2016, p. 15). A multiplicity of scenarios may provide more flexible approach and opportunity to choose the appropriate way to achieve the targets, taking into account various conditions or pathways.	More resources (time, money, people, etc.) are needed to develop multiple policy scenarios. This may be difficult to organise for the countries with a short history of energy scenario development. Too many scenarios may cause confusion and blur the appropriate pathway towards the ultimate target.
2. Ambitiousness of the targets 2050	Maximum modelled GHG emissions reduction compared to 1990[a]	1 Low ambitiousness (0–49%) 2 Medium ambitiousness (50–79%) 3 High ambitiousness (80–95%)	Ambitious targets are necessary for reaching collective EU 2050 targets.	Overambitious scenarios may have a limited impact on actual policy making (implementation gaps might increase).
3. Relations with other (European) countries	Inclusion of trans-border regional developments (TRD)	1 Low TRD inclusion (isolated scenarios) 2 Medium TRD inclusion (integrated scenarios) 3 High TRD inclusion (fully-fledged integrated scenarios)	Fully-fledged scenarios are necessary especially in the power sector, since the market interdependencies are already strong and expected to increase. Ignoring these interdependencies misses both challenges and opportunities.	In integrated scenarios, dependency of one country on another country is possible (e.g. import dependency caused by importing sun and wind energy from Morocco to Germany).
4. Stakeholder involvement	The degree of stakeholder involvement (particularly, public engagement)	1 Governmental bodies and municipalities 2 Governmental bodies and municipalities, business, academic community 3 Governmental bodies and municipalities, business, academic community, the general public	In case of active stakeholder involvement more informed decisions can be made (scientific advice given, society needs translated, etc.), which in turn may increase social acceptance of technological and non-technological changes ("Our opinion was heard"). Moreover, modelling efforts could also include "opportunity costs" into the scenario, which reflect the costs needed to overcome (public) resistance (PBL, 2016, p. 17).	Active stakeholder involvement requires more resources (time, money, people, etc.) to coordinate. The responses may include extremely different opinions, which are difficult to be collated. Impossibility to balance all opinions might lead to dissatisfaction of ignored opinions. Lack of knowledge/background/experience by the citizens may lead to superficial understanding of social effects and non-democratic input into decision making (Russel et al., 2010, p. 109). By involving stakeholders into the process of shaping long-term energy and climate visions, this also inherently makes the quantification of its implications more complex (PBL, 2016, p. 15).
5. Technology options	Transparency of technology selection[b]	1 Low transparency (0–3 technology options out of 6 are justified) 2 Medium transparency (4 technology options out of 6 are justified) 3 High transparency (5–6 technology options out of 6 are justified)	Clear technology selection is needed to reach the EU 2050 targets, since the 80–95% reduction can be achieved only under full exploitation of available technologies. Transparent technology selection (justification) is needed to chose the best basic technology for a scenario in a specific country and understand why other technologies are not possible to use.	More resources (time, money, people, etc.) are needed to describe all technological options in detail.
6. Non-technological aspects	Inclusion of non-technological aspects (social acceptance, etc.)	1 Low inclusion (without social acceptance) 2 Medium (implicit) inclusion (only social acceptance) 3 High (explicit) inclusion (social acceptance and other aspects)	Non-technological aspects such as social acceptance should be at least taken into account in scenarios, since technological changes sometimes are not possible without the acceptance of an appropriate infrastructure and stimuli for usage by citizens.	Non-technological aspects are difficult to measure, especially in terms of social acceptance of the novel technologies (f.e. CCS), which are not yet massively used in the market.
7. Economic component	Description of economic component (cost-benefit analysis, etc.)	1 Low description 2 Medium description (without details) 3 High description (with details)	Economic analysis is needed to assess what scenario is more feasible, in terms of costs and benefits.	Comparison of the results of economic analysis can be too complicated, since diverse approaches and models are used in different country scenarios. It requires using the harmonised parameters (discount rate, etc.) for analysis.
8. The usage of scenarios in policy design	The degree of scenarios' usage in policy development	1 Low usage (not at all) 2 Medium usage (only for strategic thinking) 3 High usage (for strategic thinking and making tactical decisions)	It is important to use scenarios not only for general strategy development, but also for setting short- and medium-term measures that should be taken in order to achieve both final and intermediate targets.	The effective integration of scenarios into the policy design requires clear understanding of how the scenario targets should be converted into policy indicators and what institutions should be responsible for their implementation.
9. Intermediate indicators of targets' (2050) achievement[c]	Current consistency of scenarios with the EU 2050 targets[d]	1 Low consistency (0–15% of the EU 80% (2050) achieved)		Achievement of intermediate indicators may be difficult, since the countries have different target ambitions, economic

(*continued on next page*)

Table 1 (*continued*)

Characteristics	Description	Possible policy settings (with the scale for assessment)	Advantages (reasons for scale selection)	Disadvantages (possible scale limitations)
		2 Medium consistency (16–35% of the EU 80% (2050) achieved) 3 High consistency (36–100% of the EU 80% (2050) achieved)	Following the average intermediate indicators may be the evidence that a country can effectively contribute to the EU 2050 targets' achievement.	potential (population, territory, GDP, etc.) and local context (not easy to compare). All this leads to the variance in their possible speed to achieve the national 2050 and the EU 2050 targets.
10. Revision of scenarios	Frequency of scenario revising	1 Low frequency (every 4–5 years or more rarely) 2 Medium frequency (every 3 years) 3 High frequency (annually)	In order to be able to adapt to the possible changes, it is important to revise the scenarios as frequently as possible.	Regular revising requires additional resources (time, money, people, etc.).

[a] The maximum ambitiousness of the most ambitious scenario developed in a specific country.
[b] Technology options: see details in Table 3.
[c] In terms of total GHG emissions reduction.
[d] A ratio of the targets achieved in 2015 (%) to the EU 80% target (2050).

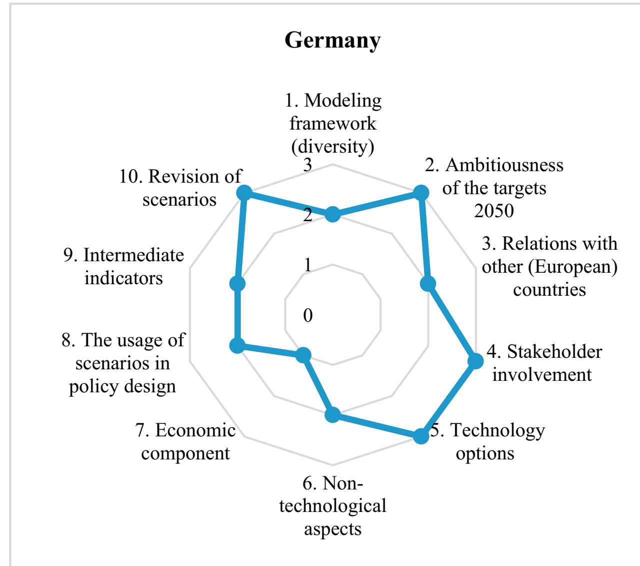

Fig. 1. An example of a radar diagram (Germany).

Table 2
Emissions reduction levels (2050) in the low-carbon energy scenarios of six north-west European countries.
Sources: CPB/PBL (2015); Öko-Institut/Fraunhofer ISI (2016); Criqui and Hourcade (2015); Danish Energy Agency (2014); UKERC (2013); FPB (2015).

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

3.3. Relations with other (European) countries

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

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

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

3.4. Stakeholder involvement

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

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

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

3.5. Technology options

The need for more intensive electrification of industry and other sectors (such as transport, residential and services sectors (heating of buildings), etc.) is a common feature of all country scenarios. That is why in this research the expected contribution of various technologies to the electricity generation is analysed. Table 3 contains the available information about such contribution retrieved from scenarios and expert consultations. ***Transparency of technology selection*** is crucial for understanding the role of specific technologies in the scenario settings. Scenarios may include a diverse (the Netherlands, Germany, France, the UK, Belgium) or a limited set of technologies (Denmark). Technology options may have a local character and be based on *availability of natural resources* (e.g. comparably more wind potential in the Netherlands and Denmark, less biomass potential in Denmark, etc.), *social acceptance* of a technology (nuclear technologies are not considered in Germany, but actively discussed in France) and other factors.

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

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

3.6. Non-technological aspects

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

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

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

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

Table 3
Technology options in the scenarios, based on the contribution of a specific technology to the electricity mix.[a]
Sources: CPB / PBL, 2015; Öko-Institut / Fraunhofer ISI, 2016; Criqui and Hourcade (2015); Danish Energy Agency (2014); Watson (2016); FPB (2014).

Scenarios	*Renewables*					*Nuclear*	*Hydrogen/ Power-to-X*	*CCS*	*Negative emissions (Bioenergy + CCS)*	*Fossil fuels*
	Solar	Wind	Biomass & Waste	Hydro (large/small)	Geothermal					
NETHERLANDS 1 (WLO_L)	Low- Medium (10%)	Medium- High (52%)	Low- Medium (6%)	None	None	Low-Medium (4%)	Low-Medium	None	None	Low-Medium (28%)
NETHERLANDS 2 (WLO_H)	Low- Medium (12%)	Medium- High (63%)	Low- Medium (2%)	None	None	Low- Medium (2%)	Low- Medium	Low- Medium (2%)	Low- Medium (10%)	Low- Medium (10%)
NETHERLANDS 3 (WLO_H80c)	Low- Medium (7%)	Medium- High (66%)	Low- Medium (2%)	None	None	Low- Medium (2%)	Low-Medium	Low- Medium (5%)	Low- Medium (11%)	Low- Medium (7%)
NETHERLANDS 4 (WLO_H80d)	Low- Medium (15%)	Medium- High (57%)	Low- Medium (6%)	None	None	Low- Medium (2%)	Low- Medium	Low- Medium (3%)	Low- Medium (8%)	Low- Medium (8%)
GERMANY 1 (CS 80)	Low- Medium	Low- Medium	Low- Medium	Low- Medium	Low- Medium	None	Low-Medium	Low- Medium	No info	Low- Medium
GERMANY 2 (CS 95)	Low- Medium	Low- Medium	Low- Medium	Low- Medium	Low- Medium	None	Low-Medium	Low- Medium	No info	Low- Medium
FRANCE 1 (EFF)	Medium- High					Low-Medium	Low- Medium	No info	No info	No info
FRANCE 2 (DIV)	Low- Medium					Medium- High	Low- Medium	Low- Medium	No info	No info
FRANCE 3 (DEC)	Low- Medium					Medium- High	Low-Medium	No info	No info	No info
FRANCE 4 (SOB)	Medium- High					None	Low-Medium	No info	No info	No info
DENMARK 1 (Wind scenario)	Low- Medium	Medium- High	Low- Medium	No info	No info	None	Low-Medium	No info	No info	None
DENMARK 2 (Biomass scenario)	Low- Medium	No info	Medium- High	No info	No info	None	None	No info	No info	None
DENMARK 3 (Bio+[a] scenario)	Low- Medium	No info	Medium- High	No info	No info	None	None	No info	No info	None
DENMARK 4 (Hydrogen scenario)	No info	Medium- High	Low- Medium	No info	No info	None	Medium-High	No info	No info	None
DENMARK 5 (Fossil-fuel scenario)	No info	No info	No info	No info	No info	None	None	No info	No info	Low-Medium
UK – UKERC 1 (Affordable)	Low- Medium	Low- Medium	Low- Medium	Low- Medium	No info	Low- Medium	Low-Medium	Low- Medium	No info	Low- Medium
UK – UKERC 2 (Late catch-up)	Low- Medium	Medium- High	Low- Medium	Low- Medium	No info	Low- Medium	Low-Medium	Low- Medium	No info	Low- Medium
UK – UKERC 3 (Maintain)	Low- Medium	Low- Medium	Low- Medium	Low- Medium	No info	Medium- High	Low-Medium	Low- Medium	No info	Low- Medium
UK – UKERC 4 (Maintain (tech failure + no CCS))	Low- Medium	Medium- High	Low- Medium	Low- Medium	No info	Low- Medium	Low-Medium	None	No info	Low- Medium
BELGIUM 1 (GHG40)	Low- Medium (10%)	Low- Medium	Low- Medium (8%)	Low- Medium	Low- Medium (1%)	None	Low-Medium	Low- Medium (19%)	None	Low- Medium (47%)
BELGIUM 2 (GHG40EE)	Low- Medium (9%)	Low- Medium (37%)	Low- Medium (10%)	Low- Medium	Low- Medium (1%)	None	Low-Medium	None	None	Low- Medium (42%)
BELGIUM 3 (GHG40EERES30)	Low- Medium (8%)	Low- Medium (44%)	Low- Medium (12%)	Low- Medium	Low- Medium (1%)	None	Low-Medium	None	None	Low- Medium (35%)

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

in France the appropriate institutions should be developed in order "to maximize the learning and allow for stakeholders' participation in the dynamic management of the different goals, targets and instruments (Criqui, 2016, p.20)".

3.7. Economic component

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

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

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

3.8. The usage of scenarios in policy design

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

3.9. Intermediate indicators of targets' 2050 achievement

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

Table 4 illustrates the EU target 2050, the targets achieved in six countries by 2015 (%), as well as the ratio of the targets achieved in 2015 (%) to the EU 80% target 2050.

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

3.10. Revision of scenarios

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

Table 5 presents the results of an integrated assessment of the scenario policy settings in six north-west European countries. The final scores are calculated and then used for creating the radar diagrams (Fig. 2). The maximum final score is 30. The higher the final score is, the more potential a country has to develop policies contributing to the EU 2050 targets' achievement. This potential can be considered as a possible input, since it is important to take into account that scenarios may help to formulate policies, but only putting into place strong policies may lead to achieving the EU long-term objectives. The results show that Germany has the highest final score (23 points) among six north-west European countries. This country is followed by the UK and Belgium (21 points each), and then by France and Denmark (20 points each). The lowest score goes to the Netherlands (19 points). Therefore, the scores for all countries lie in the range of 19–23 points out of 30 points possible.

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

4. Results and discussion

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

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

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

Third, *new renewable technologies* play an important role in emissions reduction, however, technology favouring is different. In all scenarios

Table 4
The percentage of achievement of the EU 80% target 2050 by 2015 in six countries.
Source: European Commission (2016); European Environment Agency (2018).

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

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

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

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

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

First, *the limitations of the methodological scale* should be taken into account. The list of ten characteristics has been created based on literature review and consultations with national experts and should be considered as a starting point for further scenario comparison. The possible limitations of each characteristic are presented in Table 1. In general, those ten characteristics were selected for this research after literature review and consultations with the experts, because from the authors' point of view, their importance for scenario design (advantages) prevail over their limitations (disadvantages) (see Table 1). More sophisticated analysis and revision of the scales can be needed on the next stages of research, through additional literature review and expert discussions.

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

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

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

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

5. Conclusions and policy implications

The main purpose of this paper was to propose a transparent approach allowing to compare and evaluate the policy settings of low-carbon energy scenarios 2050 in six north-west European countries (the Netherland, Germany, France, Denmark, the UK, Belgium) aiming to achieve the EU 2050 targets. In this study a methodological framework including ten characteristics was proposed for their comparison and then applied to assess the policy settings of energy scenarios under research.

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

The analysis of the scenarios' ***modelling framework*** shows that almost all countries start from a reference scenario and have several normative scenarios with additional measures (from 2 to 5 policy scenarios) in order to satisfy the long-term EU targets (80–95%). However, on the national level there are significant differences in the modelled GHG emissions reduction compared to 1990 and therefore in ***the targets' 2050 ambitiousness***. Most countries set up highly ambitious targets of 80–95% reduction (the Netherlands, Germany, Denmark, the

Table 5
Integrated assessment of scenario policy settings in six countries.

Characteristics	The Netherlands	Germany	France	Denmark	The UK	Belgium	Possible policy settings with the scale for assessment
1. Modelling framework (diversity)	4 policy scenarios **3 – Multiple policy scenarios**	2 policy scenarios **2 – Two policy scenarios**	4 policy scenarios **3 – Multiple policy scenarios**	5 policy scenarios **3 – Multiple policy scenarios**	4 policy scenarios (for 2050) **3 – Multiple policy scenarios**	3 policy scenarios **3 – Multiple policy scenarios**	1 – One single policy scenario 2 – Two policy scenarios 3 – Multiple policy scenarios (range of pathways)
2. Ambitiousness of the targets 2050	−80% **3 – High ambitiousness (80–95%)**	−95% **3 – High ambitiousness (80–95%)**	−75% **2 – Medium ambitiousness (50–79%)**	−95% **3 – High ambitiousness (80–95%)**	−80% **3 – High ambitiousness (80–95%)**	−65% **2 – Medium ambitiousness (50–79%)**	1 – Low ambitiousness (0–49%) 2 – Medium ambitiousness (50–79%) 3 – High ambitiousness (80–95%)
3. Relations with other (European) countries	Focus on international and inter-regional approaches **2 – Medium TRD inclusion (integrated scenario)**	The electricity exchange with European countries **2 – Medium TRD inclusion (integrated scenario)**	TRD are not mentioned **1 – Low TRD inclusion (isolated scenario)**	The regional differences in electricity prices and biomass prices **2 – Medium TRD inclusion (integrated scenario)**	TRD are not mentioned **1 – Low TRD inclusion (isolated scenario)**	Focus on international and inter-regional approaches **2 – Medium TRD inclusion (integrated scenario)**	1 – Low TRD inclusion (isolated scenarios) 2 – Medium TRD inclusion (integrated scenarios) 3 – High TRD inclusion (fully-fledged integrated scenarios)
4. Stakeholder involvement	Government, external experts, ministry representatives **2 – Governmental bodies and municipalities, business, academic community**	Federal states, municipalities, associations, research institutes, citizens **3 – Governmental bodies and municipalities, business, academic community, the general public**	1. Environmental NGOs 2. Consumer associations 3. Trade-unions 4. Industry 5. Local authorities 6. Parliament 7. Administration + Expert group + Citizen group **3 – Governmental bodies and municipalities, business, academic community, the general public**	Governmental bodies and municipalities, business representatives **2 – Governmental bodies and municipalities, business, academic community**	Governmental bodies and municipalities, business representatives **2 – Governmental bodies and municipalities, business, academic community**	Governmental bodies and municipalities **1 – Governmental bodies and municipalities**	1 – Governmental bodies and municipalities 2 – Governmental bodies and municipalities, business, academic community 3 – Governmental bodies and municipalities, business, academic community, the general public
5. Technology options	Scenario 1: 6/6 Scenario 2: 6/6 Scenario 3: 6/6 Scenario 4: 6/6 → Average: 6/6 **3 – High transparency (5–6 technology options out of 6 are justified)**	Scenario 1: 5/6 Scenario 2: 5/6 → Average: 5/6 **3 – High transparency (5–6 technology options out of 6 are justified)**	Scenario 1: 3/6 Scenario 2: 4/6 Scenario 3: 3/6 Scenario 4: 3/6 → Average: 3/6 **1 – Low transparency (0–3 technology options out of 6 are justified)**	Scenario 1: 4/6 Scenario 2: 3/6 Scenario 3: 3/6 Scenario 4: 3/6 Scenario 5: 3/6 → Average: 3/6 **1 – Low transparency (0–3 technology options out of 6 are justified)**	Scenario 1: 5/6 Scenario 2: 5/6 Scenario 3: 5/6 Scenario 4: 5/6 → Average: 5/6 **3 – High transparency (5–6 technology options out of 6 are justified)**	Scenario 1: 6/6 Scenario 2: 6/6 Scenario 3: 6/6 → Average: 6/6 **3 – High transparency (6 technology options out of 6 are justified)**	1 – Low transparency (0–3 technology options out of 6 are justified) 2 – Medium transparency (4 technology options out of 6 are justified) 3 – High transparency (5–6 technology options out of 6 are justified)
6. Non-technological aspects	Non-technological aspects are not mentioned **1 – Low inclusion (without social acceptance)**	Social acceptance **2 – Medium (implicit) inclusion (only social acceptance)**	Social acceptance, carbon pricing, lifestyle/consumption patterns, urban planning policies, institutional changes **3 – High (explicit) inclusion (social acceptance and other aspects)**	Non-technological aspects are not mentioned **1 – Low inclusion (without social acceptance)**	Without social acceptance **1 – Low inclusion (without social acceptance)**	Social acceptance, taxes, subsidies, tradable permits or certificates **2 – Medium (implicit) inclusion (only social acceptance)**	1 – Low inclusion (without social acceptance) 2 – Medium (implicit) inclusion (only social acceptance) 3 – High (explicit) inclusion (social acceptance and other aspects)

(*continued on next page*)

Table 5 (*continued*)

Characteristics	The Netherlands	Germany	France	Denmark	The UK	Belgium	Possible policy settings with the scale for assessment
7. Economic component	Only economic impact is analysed (no cost-benefit analysis) **1 – Low description**	Only economic impact is analysed (no cost-benefit analysis) **1 – Low description**	Only economic impact is analysed (no cost-benefit analysis) **1 – Low description**	Calculations of the total costs for scenarios **2 – Medium description (without details)**	Calculations of the total costs for scenarios **2 – Medium description (without details)**	Cost-benefit analysis without details, calculations based on PRIMES model, etc. **2 – Medium description (without details)**	1 – Low description 2 – Medium description (without details) 3 – High description (with details)
8. The usage of scenarios in policy design	Strategic thinking **2 – Medium usage (only for strategic thinking)**	Strategic thinking **2 – Medium usage (only for strategic thinking)**	Actively used in policy (*e.g.* in Energy Transition for Green Growth Act) **3 – High usage (for strategic thinking and making tactical decisions)**	Strategic thinking **2 – Medium usage (only for strategic thinking)**	Strategic thinking **2 – Medium usage (only for strategic thinking)**	Strategic thinking **2 – Medium usage (only for strategic thinking)**	1 – Low usage (not at all) 2 – Medium usage (only for strategic thinking) 3 – High usage (for strategic thinking and making tactical decisions)
9. Intermediate indicators of targets' (2050) achievement[b]	* Target achieved (2015): −7% * The EU target (2050): −80% → 9% of the EU 80% target (2050) achieved **1 – Low consistency ((0–15% of the EU 80% (2050) achieved)**	* Target achieved (2015): −25% * The EU target (2050): −80% → 31% of the EU 80% target (2050) achieved **2 – Medium consistency (16–35% of the EU 80% (2050) achieved)**	* Target achieved (2015): −14% * The EU target (2050): −80% → 18% of the EU 80% target (2050) achieved **2 – Medium consistency (16–35% of the EU 80% (2050) achieved)**	* Target achieved (2015): −30% * The EU target (2050): −80% → 38% of the EU 80% target (2050) achieved **3 – High consistency (36–100% of the EU 80% (2050) achieved)**	* Target achieved (2015): −29% * The EU target (2050): −80% → 36% of the EU 80% target (2050) achieved **3 – High consistency (36–100% of the EU 80% (2050) achieved)**	* Target achieved (2015): −15% * The EU target (2050): −80% → 19% of the EU 80% target (2050) achieved **2 – Medium consistency (16–35% of the EU 80% (2050) achieved)**	1 – Low consistency (0–15% of the EU 80% (2050) achieved) 2 – Medium consistency (16–35% of the EU 80% (2050) achieved) 3 – High consistency (36–100% of the EU 80% (2050) achieved)
10. Revision of scenarios	The most recent WLO scenarios were published in 2006 **1 – Low frequency (every 4–5 years or more rarely)**	Annually **3 – High frequency (annually)**	The most recent scenarios were published in 2015 **1 – Low frequency (every 4–5 years or more rarely)**	The most recent scenarios were published in 2014 **1 – Low frequency (every 4–5 years or more rarely)**	The most recent UKERC scenarios were published in 2013 **1 – Low frequency (every 4–5 years or more rarely)**	Every 3 years **2 – Medium frequency (every 3 years)**	1 – Low frequency (every 4–5 years or more rarely) 2 – Medium frequency (every 3 years) 3 – High frequency (annually)
Final score (max = 30 points):	**19 points**	**23 points**	**20 points**	**20 points**	**21 points**	**21 points**	**30 points**

[a] Bio+ scenario entails a current fuel-based system, but with coal/oil/natural gas replaced by bio-energy (Pedersen, 2016, p. 12).
[b] In terms of total GHG emissions reduction.

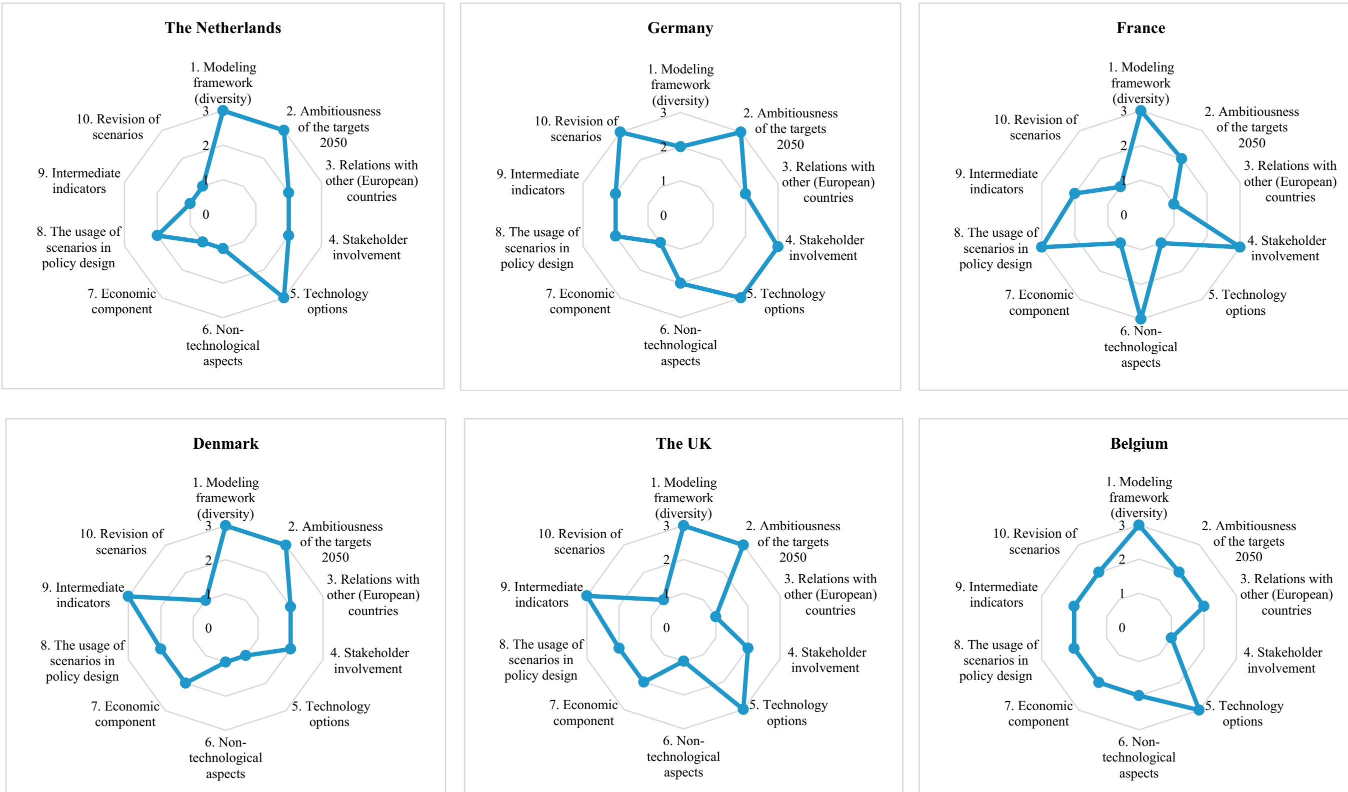

Fig. 2. Radar diagrams for six countries.

UK), while the targets ambitiousness of others (France and Belgium) is medium (75% and 65% respectively). Taking into account the ***relations with other (European) countries***, four out of six countries under research (the Netherlands, Germany, Denmark and Belgium) have integrated scenarios, while two countries (France and the UK) have isolated ones (in them trans-border developments are mentioned but not addressed in practice). Discussing ***stakeholder involvement***, most countries (apart from Belgium) engage not only governmental, but also non-governmental stakeholders in scenario development (the Netherlands, Germany, France, Denmark, the UK). For example, they may include the environmental NGOs, consumer associations, trade unions, businesses, research institutes, as well as the general public. The scenarios may focus on diverse (the Netherlands, Germany, France, the UK, Belgium) or a limited set of technologies (Denmark). Selection of ***technology options*** may have a national character and be determined by the availability of natural resources, social acceptance issues and other factors. The analysis shows, that technology transparency also differs in scenarios: with high justification of technology options (5–6 out of 6) in the Netherlands, Germany, the UK and Belgium and low transparency (0–3 out of 6) in France and Denmark. The possible ***non-technological aspects*** are weakly addressed in a half of scenarios under investigation (the Netherlands, Denmark, the UK), while included in the others – implicitly (Germany, Belgium) or explicitly (France). The examples are: social acceptance (Germany, France, the UK, Belgium), carbon pricing (France), taxes/subsidies/tradable permits or certificates (Belgium), lifestyle/consumption patterns (France), urban planning policies (France), appropriate institutions to be developed (France). Although these aspects are mentioned in energy scenarios, they are not investigated in detail. ***Economic component*** is missing in a half of scenarios (the Netherlands, Germany, France) and bound by high uncertainties (such as changes in fuel prices, electricity prices and technology costs, including costs of energy savings, etc.). There have been the attempts to perform a cost-benefit analysis (Denmark, the UK, Belgium), but the detailed analysis can be considered more as an exception. ***The usage of scenarios in policy design*** is still limited in all six countries. In most cases scenarios have been used for developing a long-term strategy (the Netherlands, Germany, Denmark, the UK, Belgium), and only in France their integration into the short-term measures (tactical decisions) is discussed. In addition, the north-west European countries under research differ in ***intermediate targets achieved by 2015*** in comparison to the maximum national targets set by 2050. All countries have made a progress in reducing GHG emissions by 2015, and a half of them have achieved more than 30% of the EU 80% reduction targets 2050 in this year, with the most significant progress made by Denmark (38% achievement), the UK (36% achievement) and Germany (31% achievement). ***The revision of scenarios*** is still spontaneous. In most countries (the Netherlands, France, Denmark, the UK) they are updated every 4–5 years or rarely, in Belgium – every 3 years, and only in Germany the energy scenarios have been revised on a regular basis (annually).

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

2050 targets, opening the possibilities for constant monitoring of the progress on the European level.

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