Diagnosing Barriers and Enablers for the Flemish Energy Transition

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Abstract: Industrialised economies are currently confronted with the challenge of transitioning to a low-carbon energy system. Starting from the insight that ‘system innovation’ rather than incremental change is needed, we diagnose barriers and enablers for energy system transformation for the case of Flanders (Belgium). We thereby combine multiple perspectives: a techno-economic perspective to derive a technology-based vision on the energy transition, a technology innovation perspective to assess barriers and enablers regarding the upscaling of technological niche-innovations, and a system innovation perspective to address fundamental barriers and enablers associated with transformative system change. We highlight the complementary features of the three perspectives and describe how insights can feed into the development of energy transition pathways.

Keywords: energy transition; technological innovation systems; sustainability transitions

1. Introduction

Energy systems in industrialised economies are currently confronted with a number of persistent and urgent problems. According to the International Energy Agency (IEA), about three-quarters of the greenhouse gas (GHG) emissions of Annex I countries to the United Nations Framework Convention on Climate Change (UNFCCC) (Annex I Parties include the industrialised countries that were members of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT parties), including the Russian Federation, the Baltic States, and several Central and Eastern European States [https://unfccc.int/party-bodies/annex-i-parties]) are directly linked to the use or production of energy [1]. In addition to the emission of GHGs, the supply and use of energy is responsible for the majority of air pollutants such as NOₓ, SO₂, polycyclic aromatic hydrocarbons (PAHs), dioxins, particulate matter, and heavy metals. Finally, the reliance on nuclear power in some industrialised countries also leads to sustainability problems with respect to the production of radioactive wastes, the risk of a large-scale accident with catastrophic dimensions, and the low energy efficiency of the current generation of nuclear plants [2].

High-level political decision makers increasingly recognise that addressing these persistent problems requires long-term political goal setting and planning. This is most obvious for the problem of climate change. In line with the position endorsed by world leaders in the Copenhagen and Cancun agreements (in December 2009 and 2010), confirmed in December 2015 by the Paris Agreement (signed at the end of the 21st Conference of the Parties (COP21) to the UNFCCC), the European Council reconfirmed the European Union (EU) objective of reducing greenhouse gas emissions by 80–95% by 2050 compared with 1990, in order to keep global warming below 2 °C compared with pre-industrial levels. Following up on its early commitment, the European Commission published its “Roadmap for
moving to a competitive low carbon economy in 2050”, which sets a framework of milestones, policy challenges, investment needs, and opportunities for the EU member states [3].

Progress so far with regard to tackling the above-mentioned persistent problems is, however, rather incremental. At the global level, despite relevant progress on renewable energy technologies and energy efficiency [4], renewable energy sources are not yet replacing fossil fuels, but are rather expanding the overall amount of energy that is produced [5]. In Flanders, the share of renewable energy in final energy consumption in 2017 was a mere 6.7% [6]. This illustrates the systemic nature of the energy transition challenge resulting from the inherent inertia of the current energy system that is firmly anchored in (infra)structures, routines, organisations, power relations, and culturally-entrenched consumption patterns. Such systemic challenges are addressed by the still expanding research field of transitions to sustainability [7–9]. Starting from the insight that ‘system innovation’ rather than incremental change is required to make key economic sectors more sustainable, transition scholars have developed theoretical insights as well as practical guidance to steer socio-technical changes along the desired pathways [8,10,11]. Transitions approaches are, however, relatively weak in integrating insights about technical and economic features of the system. Therefore, a better integration of methods is still needed, for which different integration strategies are currently being debated [12–14].

This paper provides a concrete application of such an envisaged integration of methods. We show how the integration of transition research methods and concepts is instrumental to diagnose barriers and enablers for energy system transformation. We thereby combine multiple perspectives on transitions: a techno-economic perspective [15] to derive a technology-based vision on the energy transition, a technology innovation perspective [16,17] to assess barriers and enablers regarding the upscaling of technological niche-innovations, and a system innovation perspective [18,19] to address fundamental barriers and enablers associated with transformative system change. We use the region of Flanders in Belgium (see Supplementary Materials) as a case-study to demonstrate the practical application of the approach. Section 2 introduces the three transition perspectives, discusses their strengths and limitations, and shows how combining the three perspectives potentially yields supplementary insights in the interventions needed to ‘steer’ the energy transition. The methods for the application of the perspectives—supported by input from a range of stakeholders and experts—are briefly described under Section 3. Section 4 presents the results of the application of the three perspectives to the case of the Flemish energy transition. In Section 5, we highlight the complementary features of the three perspectives and describe how insights can feed into the development of energy transition pathways. Section 6 concludes the paper.

2. Literature Review on Perspectives on (Energy) Transitions

Our approach draws upon three different strands of research. Broadly, we distinguish first a techno-economic perspective, which—although traditionally not to the core of transitions research—is an essential aspect when reflecting on sustainable energy transitions. Second, we make a distinction between technological innovation systems (TIS) and, third, a system innovation perspective. Whereas the TIS perspective focuses on (clusters of) innovative technologies, the system innovation perspective focuses on the level of infrastructures, social structures, and institutions (http://www.transitsocialinnovation.eu/theme/system-innovation). This classification partly overlaps with previous classifications [4,11] that distinguish three strands of transitions research: the socio-ecological, socio-technical, and socio-institutional strands. The system innovation perspective adopted in this paper draws from both the socio-technical and socio-institutional strands, the TIS perspective can be positioned under the socio-technical strand, and the techno-economic perspective falls outside of these previous classifications.

In this section, we systematically introduce the three different perspectives, by showing how each of these conceptualises the energy system in a different way, and by drawing out the strengths and weaknesses of these different conceptualisations.
2.1. The Techno-Economic Perspective

The techno-economic perspective focuses on energy systems defined by energy flows, conversion processes, and uses coordinated through energy markets [15]. Theoretically speaking, the best articulated example of the techno-economic perspective is neo-classical general equilibrium price theory. In this perspective, the behavioural patterns of each individual consumer or producer of labour, goods, or services is in principle accounted for by the market clearing mechanism operating on the interactions with all other individuals on relevant markets (energy being just one of the goods being produced, traded, and consumed in the economy). In principle, the techno-economic perspective thus easily lends itself to quantitative mathematical modelling. Techno-economic models of energy systems, however, usually do not follow the general equilibrium approach (applied to the economy as a whole), but put a much stronger emphasis on the representation of different energy production or demand technologies (i.e., bottom-up, technology-rich modelling).

Such technology-rich, bottom-up models can be used for simulation and optimisation purposes [20–23]. Models can be represented by flowcharts, linking various processes by material and energy flows (e.g., an exogenously determined demand for steel is linked to different steel manufacturing processes, each with their own demand for specific energy vectors, resulting in specific emissions to the environment). Additional information relates to the price of purchased energies and materials, investment, and operational costs of different technologies. The total system cost is generally defined as the sum of all cost components in the system: cost of raw materials and primary energies, operational costs for the processes, investment cost for new capacities, and possibly environmental taxes. In principle, external costs of environmental pollution and social impacts can be added to the cost components, though in practice it is hard to provide a fully comprehensive account of these costs. In optimisation mode, the adopted technological solutions are determined by minimising the total system cost. This means that, from all possible solutions to fulfil the final demand requirements, the combination is chosen that minimises the system’s cost. In simulation models, technology uptake is determined from historical observations or based on ad hoc expert opinion [22].

Optimisation—in particular—is a normative approach, rather than an explorative one. The model results indicate what should rather than what will be done based on principles of economic optimisation (achieving (a) given objective(s) in an economically efficient way). In developing such normative long-term scenarios (i.e., horizon 2050–2100), a range of possible solutions exists to fulfil externally specified energy (service) demand and emission requirements. Optimisation will select only one by relying on a coherent, consistent, and transparent set of decision rules, which is a clear strength of the techno-economic approach. Because of the normative focus, the main drawback of this perspective is that it does not necessarily paint a realistic picture of technology diffusion, as it does not take into account technology dynamics such as bounded rationality in investment behaviour, path dependence, or the functioning of innovation systems [15]. Furthermore, modelling political interventions in the energy system is limited to regulations (e.g., prohibiting the use of certain technologies) or the use of price instruments (e.g., emission taxes, subsidies). Hence, the techno-economic perspective takes a view of the governance process as an ‘external steering mechanism’ to the energy system, which is clearly an over-simplified view of both the dynamics and outcomes of the policy-making process [12]. These drawbacks can be partly addressed by representing actor behaviour and strategies via, for example, equilibrium [24] or agent-based modelling [25,26]. Compared with optimisation modelling, however, these approaches require many (potentially debatable) assumptions and hypotheses (e.g., concerning models of human behaviour) going to the cost of transparency and technological detail.

2.2. The Technical Innovation Systems Perspective

Techno-economic modelling rests on the assumption that technological innovations and improvements will simply become available in the future. These assumptions (e.g., availability of new technologies, decreasing investment costs) are usually built into the models as externally imposed parameters (e.g., learning curves can be added for technologies for which a relevant market
exists that drives the learning). As such, the techno-economic perspective offers no explanation on how these innovations come about. The so-called ‘technological innovation system’ (TIS) approach brings in a complementary perspective that addresses this gap. The TIS approach is probably best described as a heuristic framework that starts from the basic insight that technological innovations should not be attributed to the actions of the research and development (R&D) departments of firms or research institutes alone, but rather are the result of the interactions occurring in the context of an entire innovation system made up of (possibly competing) technologies, markets, actors (including civil society organisations), and institutions. A TIS analysis is usually centred on one specific technology and seeks to understand its success or failure on the basis of the functional performance of the TIS. Functional performance is predicated on how well particular functions of the innovation systems are fulfilled and how functions interact. Seven functions of particular technological innovation systems were identified [16,17]: entrepreneurial activities, knowledge development, knowledge diffusion/exchange, guidance of the search, market formation, resource mobilisation, and support from advocacy coalitions (cf. Table 1).

Table 1. The technological innovation system (TIS) functions.

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<tr>
<th>Innovation System Function</th>
<th>Explanation</th>
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<tr>
<td><strong>F1—Entrepreneurial activities</strong></td>
<td>Entrepreneurs are key actors for transforming (technological) innovations into new business models. These entrepreneurs can be either new start-ups or incumbent firms. By testing innovations in new markets, social learning processes are instigated.</td>
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<td><strong>F2—Knowledge development</strong></td>
<td>Development of knowledge about functioning and performance of the innovation, not only in a purely technological sense, but also as related to functioning in new (niche) markets, user experiences, applicable regulations, and so on.</td>
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<td><strong>F3—Knowledge diffusion</strong></td>
<td>Processes of knowledge exchange such as networks, collaborations between different partners, conferences, workshops, and co-creation activities. Knowledge diffusion not only relates to the exchange of technology-specific information, but also exchanges between companies, government, academia, and civil society about broader aspects of the technological innovation (e.g., findings about user interactions, new business models).</td>
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<tr>
<td><strong>F4—Guidance of the search</strong></td>
<td>This key process summarizes all the activities and events that convince actors to enter the TIS or to further invest in it. A positive expectation about the development of the technology is the main aspect here.</td>
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<td><strong>F5—Market formation</strong></td>
<td>As (technological) innovations generally face difficult competitive conditions with incumbent technologies, the creation of temporary market protection is usually necessary for the technology to further develop and to gain market share. Favourable tax regimes, guaranteed consumption quotas, environmental standards, government procurement policies, and so on can all be used as protective instruments.</td>
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<tr>
<td><strong>F6—Resource mobilisation</strong></td>
<td>Financial and human resources need to be mobilised to enable the building of the innovation system; and complementary assets need to be developed, such as complementary products, services, and network infrastructure.</td>
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<tr>
<td><strong>F7—Support from advocacy coalitions</strong></td>
<td>(Technological) innovations often struggle with overcoming the reluctance of the incumbent regime to change. Therefore, advocacy coalitions need to be formed to enable the entry of the innovation on the political agenda and to lobby for resources.</td>
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While the TIS perspective has yielded important insights into the evolution of specific innovation systems, it has also been the subject of some criticisms [27,28]. Chief among those are the criticisms that little analytical attention is paid to the interaction between the TIS and wider dynamics of the system environment in which the innovations are destined to play a future role. That is why we propose to complement the TIS perspective by the system innovation perspective (next section).

2.3. The System Innovation Perspective

The system innovation perspective focuses on the co-evolution of technologies, institutions, and wider social and cultural developments in society [18,19,29,30]. The multi-level perspective (MLP) forms one of the theoretical cores of this particular strand of transition theory. It mainly draws upon insights from historical studies of system changes, evolutionary economics and science and technology studies (STS). The MLP proposes that transitions occur through interactions among three levels: landscape, regime, and niche. The landscape level refers to external developments, shocks, or crises
(e.g., climate change, ideological changes such as the liberalisation of the energy sector), which put the regime under pressure while being beyond the control of the regime actors. The socio-technical regime refers to the practices, rules, and institutions of the incumbent socio-technical actors, which generally work towards reproducing this system and thus create barriers to the introduction of (radical) system innovations [9,19]. On the niche level, space is created for experimentation and (radical) innovation. On this niche level ‘protected spaces’ are often created by targeted interventions aiming to shield the innovations from market and regulatory conditions favouring the regime. In time, innovations grow mature and start competing with the dominant regime.

The concept of a ‘socio-technical regime’ helps us to understand that the further course of technological development and the behaviour of the regime actors will be to a large extent ‘programmed’ by a desire to maintain the regime power base (and the associated advantages in terms of financial gains and/or political influence) for as long as possible. These dynamics are illustrated by the so-called X-curve, which indicates that a rise of niche innovation needs to be accompanied by a decline of a regime to allow for system transformation [11]. Looking in more detail, different transition patterns occur depending on the timing and nature of the interactions between developments on the three levels of the MLP [23,31]. Ultimately, these dynamics can lead to a fundamental change in the structures, cultures, and practices (SCPs) of a societal system (see Table 2 for definitions), profoundly altering the way it functions [32]. Such an analytical perspective allows for an interpretation of transition dynamics as the building up and breaking down of SCPs, for example, as implemented in the transition scenario methodology of Sondeijker et al. [33]. Limited work has been done on the mechanisms that allow such a build-up and break-down of SCPs, although the theory of institutional work does provide insights on this topic [34]. Therefore, in the context of this paper, we will use the system innovation perspective mainly as a tool to explore the resistance of the Flemish energy regime to innovative changes by addressing barriers and enablers related to structures, cultures, and practices.

Table 2. Definitions of structures, cultures, and practices [32].

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<tr>
<th>Structures</th>
<th>The formal, physical, legal, and economic aspects of functioning restricting and enabling practices.</th>
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<tr>
<td>Cultures</td>
<td>The cognitive, discursive, normative, and ideological aspects of functioning involved in the sense-making of practices.</td>
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<tr>
<td>Practices</td>
<td>The routines, habits, formalisms, procedures, and protocols by which actors, who can be individuals, organisations, companies, and so on, maintain the functioning of the societal system.</td>
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3. Methods

From the previous discussion, it will be clear that the three perspectives not so much contradict each other, but rather represent complementary analytical ‘lenses’, enabling a rich conceptualisation of a complex and multi-dimensional reality such as the ongoing energy transition. Drawing upon this inherent complementarity, we have combined insights from the three perspectives into a three-layered diagnostic applied to the case of the Flemish energy transition as a first practical ‘test’ (cf. Section 4). The three layers are as follows:

- In a first layer, techno-economic modelling is used to derive a comprehensive vision on the energy transition specified for different subdomains (cf. Figure 1) of the energy system. The potential contributions of these different domains to the goal of realising a low-carbon economy by 2050 are calculated by the models in light of externally imposed political long-term transition objectives; first and foremost, the ambition to transform the Flemish economy into a low-carbon economy by the year 2050 (i.e., GHG emissions should be reduced by at least 80% compared with 1990 levels).
- In a second layer, the TIS framework is used as a guiding framework for a series of specialised stakeholder workshops. The aim of the workshops was to elicit, for a selection of so-called ‘solution categories’ (provision of low-temperature heat for the built environment, energy supply, provision of high-temperature heat for industry, and matching supply and demand), the main
barriers, opportunities, and actions needed for each of the seven innovation system functions in order to accelerate the energy transition along desired transition pathways.

- In a third layer, insights from the system innovation perspective are used to describe fundamental barriers pertaining to the different solution categories related to an inherently resistant energy regime characterised by rigid structures, cultures, and practices.

Figure 1. Comprehensive overview of the potential contributions in terms of required reductions of greenhouse gas (GHG) emissions in different subdomains of the energy system (CAPEX=Capital Expenditures; OPEX=Operational Expenditures; CCU=Carbon Capture and Utilisation; CCS=Carbon Capture and Storage).
Compiling the results of these different lines of investigation provided a rich description of energy transition challenges for the Flemish region. In Section 5, we reflect on the added value of the combined findings in light of both diagnosing the current status quo, as well as developing future energy transition pathways.

Application of the three different transition perspective layers to the ongoing Flemish energy transition involved the following methods.

For the first layer, we provided an estimate of the possible and needed application level of different solution categories until 2050. This estimate is mainly based on the study “Roadmap towards a low-carbon Belgium by 2050” and the extensive sectoral analyses that were carried out as part of this study [32]. The estimate of the application potential is based on the ‘core’ scenario from the Roadmap Study, which relies on a balanced mix of behavioural and technological solutions to achieve an 80% reduction in greenhouse gas emissions in Belgium by 2050 (compared with 1990). The energy model used in the Roadmap study (OPE2RA) is a bottom-up simulation model. Because this study dated from 2013, more recent model-based results, specifically for the electricity production sector, were drawn from a study used to support the negotiation of the ‘Energy Pact’ on the long-term objectives for the Belgian energy system [33]. The TIMES-model used for this study is a bottom-up, technology rich, techno-economic optimisation model. The model outcomes clearly indicated specific end points or pathway objectives for different subdomains of the Flemish energy system. Additional qualitative information on overall environmental performance (besides GHG emissions) and socio-economic feasibility of the different technologies needed to realise the 2050 vision was compiled in ‘fact sheets’ and submitted for an ‘extended peer review’ in a half-day workshop involving academic and stakeholder experts on energy transition. Table 3 gives an overview of the validated results of this workshop.

For the second layer, three workshops were organised to first discuss the feasibility and desirability of end points or pathway objectives with experts from different stakeholder organisations (cf. Figure 2). Each workshop discussed particular thematic groupings (‘solution categories’) of the subdomains indicated in Table 2:

- “Sustainable low-temperature heat and cooling for the built environment”: this solution category groups all technological options regarding heat and cold supply that are discussed for the built environment and heat networks;
- “Sustainable energy supply”: this solution category groups all wind energy solutions, photovoltaic energy, nuclear phase-out, and sustainable biomass (The solution category ‘making the supply of energy sustainable’ originally also included the provision of high temperature heat in industry. However, owing to the major uncertainties involved in the nature and scale of future industrial activities and the lack of specific roadmaps for Flemish industry, and also because a TIS analysis would require specific in-depth knowledge on these industries, the stakeholders/experts felt unable to go into any more depth on barriers and opportunities for the Flemish industry. In the remainder of this paper, we thus consider energy efficiency in industry to be ‘out of scope’);
- “Aligning energy demand and supply”: this solution category groups all demand response options discussed for the built environment and with regard to the central alignment of demand with supply.
Figure 2. Sequencing and interaction between the three workshops.

Together, these solution categories constitute a major portion of carbon reductions needed, acknowledging that other main sectors (i.e., mobility, heavy industry) are omitted. The mobility transition was discussed in a separate parallel project. However, the impact of the mobility transition on the energy transition (in terms of additional electricity demand) was included in the model calculations. Also, industrial demand for high temperature heat was considered as an aggregate based on total demand.

The TIS framework was used as a systematic guiding framework to elicit opinions on which barriers will have to be overcome, which leverage options are required, and which actors play a role in them in order to reach the end points or objectives. The relations between the subdomains were taken into account while planning the workshops (see Figure 2); as electrification of low-temperature heat supply is relevant for making the energy supply sustainable, insights from workshop 1 were used as input for workshop 2. Similarly, as the estimates regarding the use of fluctuating renewable energy sources is relevant for the need to adjust energy demand, the output of workshop 2 was used as input for workshop 3.

For the third layer, a desk-top analysis was performed to elicit structural system barriers related to dominant SCPs, considering infrastructures, regulatory structures, energy cultures, and practices. Findings were complemented with the results from an envisioning study on multi-energy innovation in Flanders [34]. This study included interviews with main actors in the Flemish energy innovation system (practitioners, governments, distribution system operator) eliciting opportunities and barriers for the upscaling of multi-energy innovation in the context of the Flanders energy transition. Consequently, the findings were validated through phone interviews and via written comments from four expert stakeholders [27].

4. Results

4.1. Envisioning the Transition End-Points

The results of the techno-economic modelling and ‘extended peer review’ show, in order of magnitude, which structural changes in the Flemish energy system are needed to transition towards a low-carbon society in 2050.

Zooming in on the solution category low-temperature heating and cooling for the built environment, the following concrete energy-saving objectives emerged from the model-based analyses:

- For existing private sector residential buildings: achieve an average energy performance factor of a maximum of 100 kWh/m² (including a deduction for onsite RES generation) by 2050 for the whole of the building park, compared with 139 kWh/m² today. Regarding the renovation speed, the models indicate that roughly 2% of existing buildings should be renovated per year to an energy performance level of 60 kWh/m². These performance criteria broadly correspond to the criteria embedded in the Flemish ‘Renovation Pact’ (https://www.energiesparen.be/renovatiepact) that envisions renovation of the current building stock leading, both on the level of the building envelope and on the level of the heating installation;

- For collective social housing: already reach the performance level of 100 kWh/m² by 2040;
• For the trade and services sector: a fully energy-neutral (i.e., zero net energy consumption on a yearly basis considering heating, domestic hot water production, cooling, and lighting) building park by 2050;

• For public buildings: be energy neutral by 2040.

New buildings will be built according to the energy-neutral standard starting from 2020.

In terms of making the supply of energy more sustainable, the techno-economic analysis reveals that—taking into account the EU scenarios [3] and assuming that 80% to 97% of electricity production in Flanders will be based on renewable energy sources, with Flanders not being a structural net importer of electricity—62 to a maximum of 85 TWh of renewable electricity would have to be produced in 2050 (taking into account the increased electricity demand for low-temperature (LT) heating solutions and electric transport). Onshore wind capacity in Belgium increases up to ~8 GW in 2050. This would require installing on average 300 MW, or ~120 new turbines per year. Offshore wind capacity increases up to ~5.5 GW in 2050, which requires installing on average 200 MW, or ~40 new turbines per year. Replacement rates of 25 years are assumed for both types of wind electricity generation. Regarding solar PV, annual growth is ~200 MW/year up to 2025 and then slowly increases to ~1100 MW/year in 2050 (average of 500 MW/year over the 40 years). Solar PV capacity reaches ~14 GW in 2050. There is a gradual implementation of enhanced geothermal for electricity production, with 200 MW in 2025, rapidly ramping up to reach 3 GW of installed capacity in 2050. The level of bioenergy imports is consistent with the estimated maximum sustainable amount of biomass production worldwide when this potential is distributed equally per person at the world level, leading to ~80 TWh of potential for Belgium (including ~34 TWh of indigenous production). The estimated amount of sustainable biomass imports available for the purpose of energy production is highly uncertain. Especially if a decarbonisation of the chemical industry via the biocarbon pathway is anticipated, much less biomass would be available for energy purposes. A ‘safe’ assumption would be to only count on the ~34 TWh of indigenous production available for energy production. The OPE²RA model does not attempt to define the optimal allocation of biomass across sectors, which would require more extensive analysis. The model assumes a reduction of the combined demand for fossil fuels from the different sectors based on the overall biomass potential that can be used for energy purposes by type (solid, gaseous, or liquid).

Aligning energy demand and supply can be achieved, in principle, through energy storage, demand response, curtailment of renewable electricity production, or increased interconnectivity in the energy system. The model-based analysis, however, did not provide quantitative estimates of the most cost-effective options under a low-carbon future scenario. Nonetheless, some indicative numbers on flexibility can be given. A major smart grid pilot in Flanders [35] estimates the current potential of energy use flexibility—based on current availability of white goods, electric vehicles, and electrically heated hot water buffers—at some 268 MW of power that could be delayed for at least four hours, with higher levels of flexibility to be expected when the electric vehicle fleet and the number of electric hot water buffers would expand.

4.2. Barriers and Opportunities from a TIS Perspective

Owing to space limitations, we can only give a high-level summary of the TIS framework analysis for each of the energy subsectors. For a more comprehensive perspective, we refer the reader to the work of [36] (in Dutch).

With regard to the provision of low-temperature heat for the built environment, the consulted experts mostly pointed out the huge challenge of tackling the renovation rate of existing buildings, which in recent years has varied between 0.5% and 1%. In order to take on this transition challenge, the consulted stakeholder experts believe that this rate should at least be doubled (as indicated also by the model outcomes). Various ideas to improve ways to ‘take matters out of the hands’ of house owners were suggested, for example, making use of the ‘housing pass’—a concept currently being
developed as part of the ‘Renovation Pact’—to define a suitable energy renovation process for every house (F5—guidance of the search; F6—resource mobilisation). When selling the house, an obligation to perform certain steps of this renovation process within a suitable period of time (e.g., five years) could be imposed on the new owners. To help householders to meet the specified renovation target, the concept of ‘taking matters out of people’s hands’ could be applied, for example, by the actions of a ‘third party’ that coordinates and implements the entire renovation process on behalf of the house owner via an Energy Service Company (ESCO) (F1—entrepreneurial experimentation). A more radical idea would be to reduce the cadastral income (the cadastral income is a term used in Belgian tax legislation. The cadastral income is the estimated average normal net income of a cadastral parcel located in Belgium. This can be a piece of land or a building. For each building, an estimate is made of how much this would yield if rented out (Source: Wikipedia)) for improvements of the energy performance of the house, also taking into consideration the location of the house (in order to account for likely energy use as a result of transportation from and to the house). This could create a major incentive for households to invest in energy savings (F4—market formation).

There was particular emphasis placed on the importance of initiating the required modifications to the institutional environment, mainly in the field of policy vision forming (with a key role for local authorities, cf. infra), coordination between various policy levels (F5—guidance of the search), and ensuring that the required data become available (F2—knowledge development; F3—knowledge diffusion). After all, the long investment cycles for energy infrastructure require far-reaching policy measures and policy planning for the period until 2030 and 2050. Vision forming and strategic policy implementation (with a key role for local authorities) should answer the question of which sustainable energy networks are desirable and feasible specifically for various Flemish neighbourhood types (F5—guidance of the search). Besides energy efficiency improvements, there are three options: heat networks (fed by residual heat or sustainable sources, such as biomass or geothermal energy), the ‘all-electric’ solution (heat pumps), or individual heating based on biomass or green gas. According to the stakeholders, it is difficult to project a target for each of these technologies individually, as the choice in favour of a particular technology will be determined to a large extent by local circumstances (e.g., possibility to use waste heat from nearby industry, possibility to use geothermal heat). Such a vision cannot simply be imposed from the top down. According to the consulted experts, a key role is to be played by local authorities. Local authorities are in the best position to judge the local social, environmental, and economic aspects. On the basis of this consideration, the subsidiarity principle appears to be beneficial to local authorities, which may, for example, be given responsibility for working out local heat zoning plans (based on a local consideration framework in line with the overarching long-term vision). Major cities should take on a pioneering role when working out these local zoning plans; smaller municipalities and cities may require support owing to their limited administrative capacity (F7—creating advocacy coalitions).

With regard to making the supply of energy more sustainable, the suggested vision for 2050 was generally accepted as a feasible, but still ambitious target. Supporting of renewable energy production was considered to be a reasonably mature policy domain, where the necessary policy instruments have already been shaped, especially during the past decade. The majority also share the view that most technologies are already available and only few radical new breakthroughs are to be expected; it is thus mainly important to create a large market for the existing renewable solutions (F4—market creation). The workshop participants view a binding target imposed at EU level (currently for 2030, but to be maintained until 2050) as a strong legitimisation and incentive for the Flemish policy to be implemented (F5—guidance of the search). According to the consulted experts, the policy to phase out nuclear energy will play a key role in the medium term: choosing to phase out nuclear energy during the period 2022–2025 sends a clear signal to the market about the necessity for sustainable alternatives; postponing the phasing-out of nuclear energy creates uncertainty and delays (F4—market formation; F7—creating advocacy coalitions).
Regarding the application of specific technologies, a great deal is expected of the development of offshore wind farms in the Belgian part of the North Sea and beyond. In the long term, much is expected of the development of a modular grid or ‘power socket at sea’ (F2—knowledge development; F3—knowledge diffusion). This means that wind farms in the North Sea will be connected to a high-voltage station that can be built on a platform at sea. In the long term, this modular grid will then be connected to an international platform using direct-current connections, allowing a cost-efficient transport of electrical power over long distances. In the long term, an ‘energy hub’ could even be constructed in the North Sea, which would offer space not only for offshore farms, but also for cultivation of algae, wave energy plants, floating photovoltaic (PV) platforms, and so on (F5—guidance of the search; F7—creating advocacy coalitions). As far as onshore wind energy is concerned, in policy terms, the biggest gains were expected from the Flemish government’s ‘fast-lane’ initiative, which determines for various ambition levels the best locations for the installation of wind turbines in order to limit nuisance. Furthermore, the workshop participants believed that local policies could play a key role in actively supporting local wind energy projects (F7—creating advocacy coalitions). So far, however, local authorities appear to make up the largest group of opponents against onshore wind turbines. Mayors and aldermen sometimes take up an extremely unfavourable position regarding local wind farms, even if they signed the Covenant of Mayors during their period in office, committing themselves to a climate-neutral municipality. In the field of photovoltaics (PVs), a lot is also expected from ongoing policy initiatives that aim to improve the use of its considerable technical potential. New policy initiatives, such as remote net metering (in the case of remote net metering, solar panels are installed on someone else’s property (e.g., schools, car park buildings, churches) and the power generated is set off on the investor’s electricity bill. This means that the production of the PV installation (in kWh) is proportionally divided among the investors and subtracted from the amount of electricity consumed by the investor) or replacing roofs containing asbestos with PV roofs are considered to be necessary to make investments in PV systems accessible to a larger target audience (F4—market formation). One topic that plays a role in the short term is the lack of clarity regarding the revision of the regulations for prosumers (moving from net metering to an as yet undetermined compensation), which might have a negative effect on the profitability of PV installations (in order to achieve the goal of rational network usage) (F5—guidance of the search). On the horizon is the application of ‘building-integrated PV’, a technology that can significantly increase the surface area available for PV applications (integration in windows, walls, roof tiles, and so on) (F2—knowledge development).

In terms of adjusting the energy demand to suit the supply, the consulted stakeholders/experts mainly pointed out that the possible solutions should be considered ‘enablers’ of a sustainable energy system, because they do not have a positive environmental impact as such, only indirectly by promoting the integration of renewable energy. Batteries were viewed as a good enabler, while their environmental impact during production and extraction of raw materials remains a focal point (F2—knowledge development). Next to demand response strategies, ‘curtailment’ or smart controlling of local production is an option to make more local production feasible without the major investments associated with network expansions. In the long term, when renewable energy sources are expected to represent a considerable percentage of the energy supply, ‘power-to-gas’ applications could become more important. Because of efficiency losses incurred by power-to-gas technologies compared with direct electrification solutions, these technologies are thus only useful if the gas produced is used for REPLACING Fossil energy carriers now used in processes that cannot be easily electrified—for example, provision of high-temperature heat for industry and use of hydrogen in industrial processes. According to the consulted stakeholders/experts, most technological solutions are already known and can be applied on a commercial scale (the first niche markets already exist), but getting the entire subdomain into an acceleration phase requires further boosting of the ‘business engine’ (F4—market formation). As the domain is in full development and is thus confronted by many uncertainties, it would be impossible to predict in advance exactly which business activities will or would have to develop.
4.3. System Level Barriers from a System Innovation Perspective

As explained in Section 2.3, the sustainability transition analysis focuses on the energy regime, which has an inherent resistance to change. We provide here a summary of the main resistive components in terms of two main structures (both infrastructures and legal structures), cultures, and practices; for a more extensive discussion, we refer the reader to the work of [37] (in Dutch).

4.3.1. Infrastructures

Current energy infrastructures generally cause resistance to system change typically owing to the high investment cost and long lifespan of assets. With regard to the provision of low-temperature heat for the built environment, we observe the following:

- A large part of the current gas infrastructure has a long life span (up to 100 years), is adapted to the supply of regular natural gas, and is difficult to adapt to renewable alternatives. This partly explains why the business case for power-to-gas applications in Flanders (syngas, H2) is currently not viable [38]. This also provides a competitive advantage of gas over renewable heat alternatives and resistance to change in the form of sunk costs.
- The current building stock—owing to the relatively low degree of insulation and dominant types of heating systems—is badly adapted to the envisioned low-temperature heat supply [39].
- The fragmentation of spatial planning (the so-called ‘ribbon development’) does not optimally match with a low temperature heat supply that is better suited for dense urban areas [40].

Moreover, the electricity grid—although a significant asset for the development of renewable energy—is currently adapted to a central delivery model and will have difficulties to accommodate a decentralised renewable electricity supply model in its present state and form. Besides the rollout of smart meters—which, for Flanders, is scheduled to start in 2019—this concerns low voltage grid capacity, which may hamper the further uptake of decentralised PVs and may provide limitations to the electrification of heat. The current network is currently being upgraded at specific locations with a high concentration of decentralised energy production and grid injection and/or large peaks in demand owing to extensive electrification, but this is a costly solution.

4.3.2. Regulatory Structures

The current regulatory structures have been developed to facilitate the present regime based on fossil fuels and nuclear power. Even though regulatory reforms are underway (c.f. the EU clean energy package and the Flemish Energy Plan [41]), the main regulatory barriers still remain.

Concerning the low temperature renewable heat supply, for example, landlords of social housing may only partly compensate for the costs of housing renovation with a higher rent proportional to the reduction of the energy bill. The recently approved energy correction (https://www.wonenvlaanderen.be/nieuws/sociale-huurwoningen-huurprijsberekening-en-diverse) for social housing led to significant political resistance for reasons of protecting socially vulnerable groups (https://www.vrt.be/vrtnews/nl/2019/04/17/hogere-huurprijs-voor-huurders-sociale-woning/). More generally, split incentives (between landlords and tenants) for the rental market are difficult to address. Also, the taxation of electricity—originally reflecting a tax on fossil fuel and nuclear based production and currently being used to cover the costs of the energy transition—hampers the electrification of heating and favours fossil heat sources such as oil and gas with a consequent ‘green tax shift’ being proposed in the Flemish 2020–2030 Energy Plan [41]. Even for new built areas that need to comply with relatively strict environmental norms, the phase out of gas is a slow process. Within the current regulations, condensing gas boilers are still the most applied heating sources in new buildings, often in combination with PV in order to meet the EPB requirements for renewable energy production.

A low temperature renewable heat supply and renewable electricity production would benefit from a high price on CO2, either via a CO2 tax (which is currently being discussed at Belgian federal level) or mechanisms to ensure cost reflective CO2 prices under the Emission Trading System (ETS)
system [34]. The resistance to such measures generally relates to considerations of distributional effects and competitiveness [42], the complex nature of tax regulations [43], and significant political economy constraints because the tax is imposed disproportionately on a limited group of articulate and politically influential emitters [44]. Also ‘carbon leakage’, mainly seen as an economic-financial question and less as an environmental issue, is of high concern in EU climate policy [45,46].

Regulatory barriers are probably most apparent for matching electricity demand and supply. Considering the temporal dimension, the current static electricity tariffs of residential end-users and small and medium-sized enterprises (single or day/night tariffs based on net metering) do not sufficiently reflect the temporal nature of the electricity production based on variable renewable sources. As such, there is no incentive for the end user to use the energy at the time of production. Interestingly, the roll-out of smart metering has been hampered by concerns from solar panel owners about the profitability of installed PV systems, leading to a compensation arrangement guarantees net metering for a period of 15 years for solar panel owners (https://www.vlaanderen.be/bouwen-wonen-en-energie/zelf-energie-produceren/zonnepanelen-en-zonneboilers/de-digitale-energiemeter).

Other regulatory structures hamper the ability to match supply and demand on the local level. The rationale (and billing) of distribution network management, for example, is focused on the central delivery model. Following this rationale, residential end users are located at the end of the distribution chain with corresponding high distribution rates [34]. Large-scale users are closer to production, and thus pay less. In a decentralised model, this rationale would need to be reversed—with low distribution rates for users near decentralised production sites—which, however, could create problems for the traditional revenue model of the distribution system operators (DSOs). Furthermore, under current regulations, it is not possible to set up local energy communities (LECs), even though this could be beneficial for local harmonisation of electricity consumption and local variable renewable energy production and to avoid social costs for strengthening the distribution network that supplies the local energy community [34]. Finally, permit procedures are often based on known technologies; for innovative technologies (such as micro-grids), obtaining permits is always more difficult [37].

4.3.3. Energy Culture

Dominant energy cultures are strongly rooted in society and are usually resistant to change. In Flanders, the main examples that are relevant across the solution categories considered are as follows:

- Lack of urgency and attitude–behaviour gap: On the one hand, surveys (http://www.energiesparen.be/sites/default/files/atoms/files/grafisch%20rapport%202017.pdf) reveal that 9 out of 10 Flemish people consider energy saving to be important. On the other hand, the urgency seems to be lacking. On the basis of surveys, the Flemish government (https://www.vlaanderen.be/nl/publicaties/detail/beleidsnota-2014-2019-energie) states that there is a large gap between energy awareness and behaviour among households, for example, in the field of housing renovation. Also, the awareness-raising and policy incentives towards SMEs have been unsuccessful, illustrating that the average SME is “not always concerned with energy” [37]. Research in the Netherlands [47] shows that the lack of urgency about renewable energy may be partly fuelled by the misperception of current shares of renewable energy (33% as perceived versus 5.6% in reality in the Netherlands).

- The acceptance of relatively large-scale sustainable energy technologies: People oppose the installation of, for example, wind farms or geothermal plants in their neighbourhood, because of hinderance [48]. Procedural issues like the lack of (or late) participation of inhabitants and the lack of perceived local benefits may fuel the perception of an unfair distribution of project costs and benefits [49]. According to the authors of [47], resistance arises especially when core values—concerns about safety, ecological consequences, costs and effectiveness, restriction of freedom of choice, and reduction of comfort—are at stake.

- The dominant economic rationale for investment decisions: People tend to prefer short-term gains over long-term benefits. This works against sustainable energy solutions that often have a
relatively high investment cost ’upfront’, with main benefits like low operational costs emerging over the long term [50].

4.3.4. Energy Practices

The cultural aspects described above are equally reflected in current dominant social practices that contribute to maintaining the regime. On the general level, evolving norms on comfort, convenience, and cleanliness have contributed to continuously higher levels of energy consumption over the past decades [51]. In Flanders, energy efficiency improvements have led to decreasing energy demands across sectors, with energy consumption peaking between 2000 and 2010, although for transport, an increase in the number of vehicle kilometres travelled continues to further increase energy consumption [52].

Notably, for moving towards a low temperature supply, the tendency to stick to the use of the known energy technologies can be a barrier [53]. For example, users in households that need to replace an existing boiler that has broken down often opt for a conventional fossil fuel boiler comparable to the system they currently operate. One of the reasons is the short period of time within which the choice for a new boiler has to be made, making people inclined to opt for the known solution instead of the lesser known alternatives such as a (hybrid) heat pump. Installers of heating technologies have an important role to play here.

Concerning matching demand and supply, the concept of flexible energy use can be difficult to match with daily routines, which may hamper the roll-out of demand response. Even though people may be willing to adopt automated flexibility solutions, for example, for heating and white good appliances, solutions that compromise convenience are generally not well accepted [35].

5. Discussion

To combine the techno-economic, TIS, and system innovation analysis, Table 3 provides an overview of the main results for each perspective and solution category considered. Each perspective provides relevant features in a complementary way. The techno-economic perspective delivers main targets that portray in order of magnitude the ambition level for each solution category. Although actual target setting is subject to political and societal dialogue, the targets in the table were acknowledged by the consulted stakeholders and experts as necessary and plausible and, as such, give a sense of direction towards which the energy system should progress. The TIS perspective provides enablers for facilitating this change in terms of concrete recommendations for fulfilling the functions of the TIS. This perspective highlights what is needed to implement the solutions towards a low carbon energy system setting short-term priority actions.

Table 3. Summary of findings for different solution categories. LECs, local energy communities; SCP, structures, cultures, and practices.

<table>
<thead>
<tr>
<th>Low temperature heat supply</th>
<th>Targets</th>
<th>TIS Enablers</th>
<th>SCP Enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renovation: 100 kWh/m² residential</td>
<td>Housing pass (F5—Guidance of the search/Resource mobilisation)</td>
<td>Create urgency, for example, by focusing on the property value (risk of non-action) (Culture)</td>
<td></td>
</tr>
<tr>
<td>Base cadastral income on energy performance and location (F4—Market formation)</td>
<td>ESCO (F1—Entrepreneurial experimentation)</td>
<td>Split incentive policy (Regulatory structure)</td>
<td></td>
</tr>
<tr>
<td>Ensure data availability (F2—Knowledge development; F3—Knowledge diffusion)</td>
<td>Vision forming and strategic policy implementation at the local level (F5—Guidance of the search)</td>
<td>Relieve initial investment barriers (ESCO, low interest loans) (Structure/Culture)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Renewable Heating and cooling; 3 GW geothermal</th>
<th>Local heat zoning plans (F7—Creating advocacy coalitions)</th>
<th>Urban densification policy (Infrastructure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity taxation reform (Regulatory structure)</td>
<td>CO₂ pricing (Regulatory structure)</td>
<td>Educate installers (Culture)</td>
</tr>
</tbody>
</table>
| Educate installers (Culture) | Better anticipate on windows of opportunity (Practices) | }
### Table 3. Cont.

<table>
<thead>
<tr>
<th>Targets</th>
<th>TIS Enablers</th>
<th>SCP Enablers</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>Create a large market for the existing renewable solutions (F4—Market formation) Binding target at EU level (F5—Guidance of the search) Phasing out of nuclear energy (F4—Market formation; F7—Creating advocacy coalitions) Development of a modular grid or ‘power socket at sea’ (F2—Knowledge development; F3—Knowledge diffusion).</td>
<td>Dominant focus on cheap electricity and security of supply Dominant focus on short-term profits (e.g., relying on existing production assets).</td>
</tr>
<tr>
<td>Renewable electricity production</td>
<td>Offshore wind: 5.5 GW capacity Constructing an ‘energy hub’ in the North Sea (F5—Guidance of the search; F7—Creating advocacy coalitions).</td>
<td>Electricity grid investment (Infrastructure)</td>
</tr>
<tr>
<td>Onshore wind: 8 GW capacity ‘Fast-lane’ government initiative to find low nuisance locations (F1—Entrepreneurial activities) Local policies to support local wind energy projects (F7—Creating advocacy coalitions).</td>
<td>Create shared ownership of local renewable energy (Culture), for example, by supporting cooperative structures (Regulatory structure) Create a sense of fairness (Culture) Provide regulations for solar sharing (Regulatory structure) No possibility to sell surplus electricity to the grid (regulatory structure) Relieve initial investment barriers (ESCO, low interest loans) (Practices)</td>
<td></td>
</tr>
<tr>
<td>Photovoltaics (PV) 14 GW capacity Policy initiatives, such as remote net metering, solar sharing, or replacing roofs containing asbestos with PV roofs (F4—Market formation). Provide clarity on the revision of the regulations for prosumers (F5—Guidance of the search) Further develop ‘building-integrated PV’ (F2—Knowledge development).</td>
<td>Roll-out of smart meters (Infrastructure) Enable dynamic pricing (Regulatory structure) Distribution rate reform (Regulatory structure) Regulation on collective use of local renewable energy (e.g., LECs) Stimulate mind shift from yearly energy bills to self-consumption and billing on a daily basis (Culture)</td>
<td></td>
</tr>
<tr>
<td>Matching demand and supply</td>
<td>Reduce battery environmental impact (F2—Knowledge development) Develop solutions based on ‘curtailment’ or smart control of local production (F2—Knowledge development) Boosting of the ‘business engine’ of storage technologies (F4—Market formation)</td>
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</table>

The SCP analysis—on the contrary—focusses on structural barriers that have to be ‘broken’ down in order to accelerate the transition to a sustainable energy system. The changes in structures, cultures, and practices that have to occur are formulated as ‘enablers’ in the table. The structures, cultures, and practices are the main components of a ‘socio-technical’ regime that, much like a political regime, displays shared norms, decision rules, and procedures that facilitate a convergence of expectations and a fluent division of work among the many social actors involved in the regime. The concept of a ‘socio-technical regime’ also helps us to understand that the further course of technological development and the behaviour of the regime actors will be to a large extent ‘programmed’ by a desire to maintain the regime power base (and the associated advantages in terms of financial gains and/or political influence) for as long as possible. Therefore, ‘breaking down’ regime structures, cultures, and practices (called ‘exnovation’ in contrast to ‘innovation’ by Davidson [54]) will be a long-term strategic effort and is to the core of the current research agenda on sustainability transitions [30].

Table 3 shows that the TIS and SCP analysis generally reveal different types of enablers. For onshore wind, for example, the TIS perspective highlights the need for concrete local initiatives to create favouring conditions for developing local wind projects. Whereas these may support growth in the early stages of the energy transition, these may be insufficient to facilitate upscaling towards the targets set. Then, the more fundamental barriers regarding social acceptance of a large-scale roll-out of onshore wind will need to be addressed, for which the SCP analysis gives suggestions.
6. Conclusions

Our paper can best be conceived as a ‘proof-of-concept’ in bringing together a forward-looking and diagnostic application of transition perspectives. The forward-looking aspect was based on the results of techno-economic energy system modelling tools. Even though the technical end visions for the different energy sub-systems were acknowledged by the consulted stakeholders and experts as necessary and plausible, further applications of the techno-economic perspective could explore the feasibility and desirability of a number of different future visions on the energy system, based on an iteration between the different perspectives considered. The diagnostic aspect was represented by the application of the technological innovation system perspective and the system innovation perspective. It was remarkable that the TIS analysis provided a wealth of information and insights on how the needed energy system innovations could or should be scaled up, but that the majority of these insights pertained to actions that should be taken now or in the immediate future. In our view, this finding demonstrates the high sense of urgency expressed by the consulted stakeholders and experts, but also the difficulty in imagining transformative change. To this end, the system innovation perspective allowed us to map the most important components of the regime that stand in the way of a fuller system innovation. We have shown that in order to break up the system, lock-in phenomena must be strategically tackled in different domains: infrastructure, regulations, cultures, and practices. Here, further research could link up with analyses of institutional entrepreneurship (see, for example, the works of [55,56]) to inform policy strategic thinking on ways in which (regulatory) structures, cultures, and practices can be created, maintained, or broken down.

The proof-of-concept can be extended into a comprehensive transition pathway analysis framework. Such an analysis would entail iterations across the different perspectives considered to draw up full socio-technical transition pathways towards the visions set out above (for an example, see the work of [57]). This would constitute one operational approach for the integration of quantitative and qualitative insights, as proposed in the literature [9–11], where technological implementation targets are better informed by anticipated innovation barriers, and vice versa. A main extension to the current approach would be an elaboration of transition dynamics in terms of niche–regime interactions, covering the different pathways described in the literature [58]. The transition pathway analysis would, in turn, provide opportunities for policy monitoring. Where current monitoring schemes often focus on the environmental and technical aspects (like the implementation level of renewable energy technologies), these could be complemented with a state of play of barriers and enablers as an input for target setting and further policy action.

A main virtue of such a transition analysis framework is the reflection on the level of transformative change implied by the techno-economic targets and ways to achieve such transformative change. Two ways of thinking are possible. A first line of thought is to ensure that renewable energy can ‘beat’ the current regime according to the current rules (weak transformative change). In essence, this means becoming cheaper, more reliable, and available. This implies a focus on financial incentives, facilitating technological development and cost reductions, creating long-term investment certainty, adapting regulation where necessary, and creating a market environment and stimulating entrepreneurship. A second (complementary) way of thinking focuses on the rules of the game itself (strong transformative change). From this perspective, more attention will be paid to the dominant cultures and practices, such as the way in which investment decisions are taken, the extent to which climate and other environmental problems are discounted, and the energy and climate awareness among citizens.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/20/5558/s1, Background information on Flanders/Belgium.

Author Contributions: Conceptualization and methodology, E.L., P.V. and Y.D.W.; writing—first draft, E.L. and P.V.; writing—review, E.L., P.V. and Y.D.W.

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