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Path creation in Nordic energy and road transport systems – The role of technological characteristics

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ABSTRACT

This paper reviews path-creation processes in road transport systems in the Nordic countries: e-mobility in Denmark, hydrogen and fuel-cell electrical vehicles in Norway, and advanced biofuels in Finland and Sweden. The study builds on the path creation literature, which seeks to explain the emergence of new technological pathways. Drawing on recent insights concerning the differences between design- and manufacturing-intensive technologies, the paper analyses the influence of technological characteristics on path creation processes. The case comparison indicates that technological characteristics seem to have greater influence on the content of activities in the later phase rather than the early phase of path creation processes. The analysis also emphasises that barriers to path creation processes differ depending on technological characteristics. This highlights the importance of considering technological characteristics in energy and transport policies.

1. Introduction

The political debate and urgency of dealing with climate change have increased in recent years. While several spheres of our social and economic environment need to change in the effort to reduce carbon emissions, a large contribution to the emissions problem is generally perceived as lying in the ability to transform current dominant energy systems based on fossil fuels. However, despite significant recent developments, it has proved difficult to change rapidly from fossil-based energy systems to widespread use of renewable energy technologies.

One of the major current challenges is fossil energy-based road transport systems. The energy use for transport has increased significantly over the last decades and most of it is constituted by road transport using fossil fuels [1]. The CO_2 emissions from road transport have similarly increased and are now more than 50% higher than in 1990 [1]. In recent years, significant efforts have been made in a number of countries to move away from a fossil energy-based road transport system. Often, changes in the relationships between transport systems and other societal systems, not least energy systems, are of central importance here.

In this paper, we review work on such path-creation processes in Nordic transport systems. The theoretical point of departure of the paper is recent work on path creation processes [2,3], which is concerned with explaining the emergence of new technological pathways. This approach has been widely applied to studies of renewable energy technologies e.g. [4,5–7], however, these contributions focus on single technologies. Thus, little is known about differences in path creation processes for renewable energy technologies with different technological characteristics, even though recent conceptual contributions in the technology lifecycle literature points to the importance of this aspect [8,9]. Consequently, the aim of the current paper is to answer the following research questions:

- How do new paths creation processes develop in Nordic road transport systems?
- How do technological characteristics influence the path creation processes?

The paper compares path creation processes in four of the Nordic countries (Denmark, Finland, Norway and Sweden) for the following reasons. Firstly, the Nordic countries are frontrunners in the field of renewable energy [10] and their development paths may therefore hold important lessons for other countries. While complete changes in the road transport system on a larger scale have not appeared [11], this review also highlights that important cracks in the existing fossil fuel-

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based regime have been made. Secondly, the four countries are characterised by relatively similar socio-economic contexts. Thus, while the countries differ in some aspects (e.g. population density), they are nevertheless similar along many dimensions, which make comparisons feasible. Thirdly, as we aim to analyse path creation processes for different technology platforms, it is necessary to cover different countries, since none of the Nordic countries have significant path creation processes in all technologies platforms.

The article is structured as follows: in the next sections, the core aspects of path-creation theory are described and the research methodology introduced. The reviews of the four case studies are subsequently presented according to different stages in path-creation processes. The following section contains a comparison of the cases, focusing on the influence of technological characteristics. Finally, we conclude and highlight needs for future research.

2. Theory

Work on path-creation processes highlights that engaged and entrepreneurial actors are central to technological and societal change [12]. Typically, through long-lasting efforts and interaction between many actors, new paths of development are created which move beyond existing path dependencies. The concept of path creation has gained special relevance in analyses of sustainability transitions [13]. Here it has been used to examine how new niches (e.g. renewable energy technologies) may overcome incumbent regimes. In order to understand the various phases in path-creation processes, Simmie [3] has proposed a distinction between the initial conditions of path-dependency, path-creation processes by agents in niches, new path-establishment processes to achieve critical mass, key path creation barriers, and envisioned landscape change outcomes. Originally applied to wind energy, this theoretical approach has been applied in multiple studies of renewable energy technologies e.g [4,5–7].. Yet, these contributions all analyse path creation processes focusing on a specific technology. Consequently, the literature is still to analyse if and how differences in technological characteristics influence path creation processes.

The importance of technological characteristics for differences in innovation processes has been underlined by recent conceptual contributions in the technology lifecycle literature [8,9]. Huenteler et al. [8] present a stylised typology, which builds on two dimensions: the complexity of product architecture and the scale of production process. The first of these dimensions is given by the amount of sub-systems and components as well as their interaction in a given technology. The second dimension is given by the modularity of the system and the magnitude of demand. Most technologies will be either highly complex (design-intensive) or produced on a large scale (manufacturing-intensive), but some (such as trains) can be characterised as both design- and manufacturing-intensive [9]. A central proposition in this work is that innovation trajectories will differ considerably between technologies, depending on their characteristics. To exemplify, technologies with high design-intensity require continuous emphasis on developing and designing new solutions in specific components. For technologies with high manufacturing-intensity, innovation efforts are primarily aimed at improving the production process.

Given these differences following from varying technological characteristics, it seems likely that this will also influence the attributes of path creation processes. Thus, in the analysis we combine these theoretical perspectives to assess if and how technological characteristics influence path creation processes. This will also allow us to make a contribution to the literature on technological characteristics, where Schmidt and Huenteler [9] call for comparative research in order to improve policy decisions for different types of technologies.

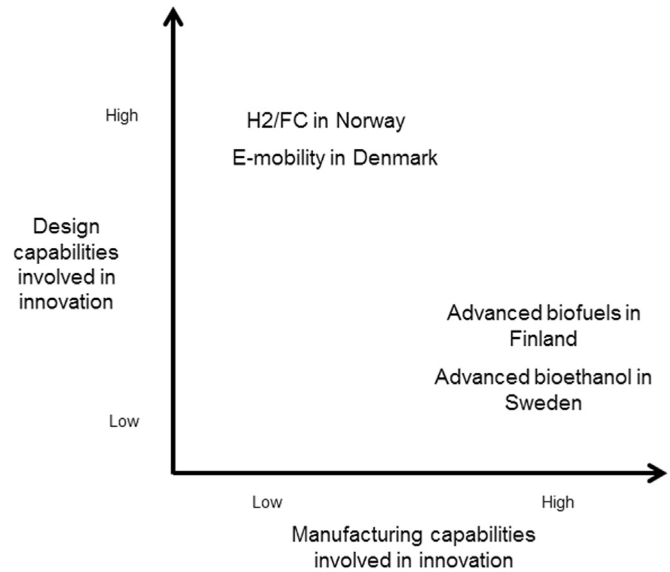

Fig. 1. Classification of technologies according to design- and manufacturing-intensity.

3. Methodology

The main empirical sources are four case studies: e-mobility in Denmark [14], advanced biofuels in Finland [15], hydrogen and fuel-cells in Norway [16], and advanced bioethanol in Sweden [17]. These four technologies were chosen in order to analyse path-creation processes in cases with different technological characteristics (see Fig. 1).

E-mobility (Denmark) and hydrogen and fuel-cells vehicles (Norway) are both classified as design-intensive, but not manufacturing-intensive. In both cases, design-intensive activities relating to vehicle availability and technology as well as the infrastructure of car use (including charging infrastructure for EVs, gas stations for hydrogen and fuel-cells vehicles, and hydrolysers for hydrogen production) are of central importance.

Advanced biofuels (Finland and Sweden) are classified as manufacturing-intensive, but not design-intensive. In both cases, manufacturing-intensive activities relating to establishing large-scale production of biofuels, in particular through changes in the pulp and paper industry, are of high importance. The design-intensity is low, because many of the core processes in biofuel production are well-known. Furthermore, biofuels can be used as drop-in fuels and flexi-fuel cars can use the existing fossil fuel based infrastructure.

The research process included mainly two steps: (1) case studies on value chains, path dependencies and institutional context, and (2) using path creation concepts for analysing the empirical material.

1. The cases were carried out over several years, using a similar methodological approach, which included (a) a review of existing literature and (b) interviews with key actors in industry and stakeholder organisations. Key focus was on the role of companies in the emerging pathways, their position in the value chains, and their interaction with the institutional context. The literature reviews covered corporate reports and presentations, industry analyses, media reports and academic papers. The interviews focused on understanding the barriers to and opportunities for wider diffusion of the technology platforms, giving specific attention to the role of technological characteristics, up- and downstream actors, and the institutional context. The case studies were guided by a template which is given in the annex and were published as project reports [14–17].
2. After the finalisation of the case studies started the comparative analysis of the case studies using path dependence and path creation

concepts [11]. The comparative analysis of path creation processes was further informed by workshops focusing on renewable energy and transport strategies, action plans developed by public authorities, companies and interest organisations in the different countries, and scenarios towards 2050 for the different countries [18]. The workshops functioned as method triangulation for the comparative case study analysis. Results from the literature review and the interviews were discussed in workshops with external experts and stakeholders in the respective countries to improve the reliability of the results, and in a joint workshop between the involved researchers.

In order to ensure triangulation of data sources, we involved many different types of experts through interviews and workshops, such as central employees in key firms, policy makers, researchers, NGOs, project managers, and branch organisations. The following numbers indicate the number of organisations these experts are affiliated with: in Denmark 11, in Norway 14, in Finland 20 and in Sweden 12 during 2013–2016. The interviews were conducted with experts from key firms in the respective value chains, as well as with experts and stakeholders, which had good knowledge of their development. The selection of interviewees included both 'insiders' and 'outsiders'.[1] Annex B gives an overview of the involved organisations for the expert interviews. There have been several cases where several experts came from one organisation.

Drawing on these empirical sources, the case studies are presented and summarised in narratives, following an adapted version of Simmie's model (see Fig. 2). Tables 1–5 summarise the findings. Under 'Initial conditions of path-dependency' we address the specialisation of the country regarding energy production and natural resources relevant for the cases, i.e. electricity production for e-mobility or pulp and paper industry and forest resources for advanced biofuels. Ongoing niche-creation processes are pointed under the heading 'Path-creation experiments'. Planned actions and processes for strengthening the started paths are highlighted under the heading 'New path-establishment processes'. These paths meet different types of barriers, which are summarised under the heading 'Barriers to new path creation'. And, finally, we have analysed existing visions for the selected technologies and whether they will have an impact. Some of the visions go as far as to 2050, while others reach just to 2020. These summaries are included under 'Envisioned landscape outcomes'.

4. E-mobility in Denmark

The area of electric vehicles (EVs) has received renewed attention in Denmark since the middle of the 2000s, partly due to increasing European policy attention to the transport sector as a major climate problem. Among the *initial conditions* for path-creation activities for the use of EVs are the generally well-developed road transport and electricity systems. More specifically, the activities depend on and continue the tradition of relatively large, 4–5 seater cars and mobility patterns established through the use of petrol and diesel cars over decades. Hereby, the activities deviate from a focus on micro cars, city cars, electro scooters, etc., seen in some cases, e.g., in earlier efforts in Denmark in the 1980s [19]. The small geographical size of the country means that most car trips are short. Even intercity and cross-country trips are less than a few hundred kilometres.

Electricity in Denmark is produced primarily from fossil fuels, however a considerable and growing share stems from renewable energy sources: 40–48% in the latest years [20]. Around two-thirds of this is from wind energy, but this fluctuates considerably from month to month and from hour to hour. Further development of wind

[1] To exemplify, the Norwegian Electric Vehicle Association is an outsider to the hydrogen and fuel-cells vehicle case.

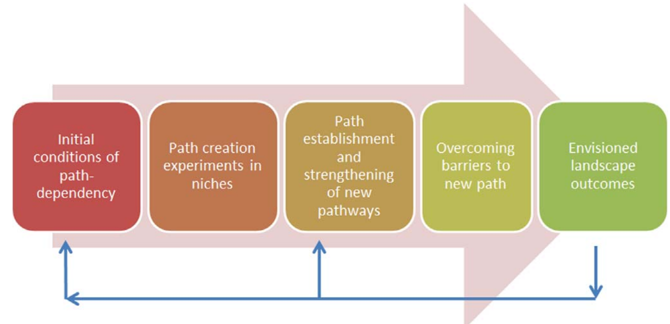

Fig. 2. New path-creation processes (adapted from Simmie, 2012:764). Note: Arrows indicate direction of trajectory of new path creation and feedback loops.

power is a central element in the Danish energy policy and the strategy plans of the energy sector. The fluctuation of wind energy constitutes a challenge for the systems, however. The vision of extending electricity consumption and establishing a big electricity-storage buffer in the electricity systems in the shape of thousands of batteries in EVs has therefore been able to mobilise leading electricity actors in Denmark, including policy makers, energy companies and grid-responsible organisations. While Denmark has no car manufacturing industry of significance and cars are imported goods, energy technology, not least wind technology, is an important industrial field.

With considerable policy support, *path-creation experiments* have been carried out since the second half of the 2000s. A test scheme on the practical use of EVs was established and public funding of R & D activities was made. Moreover, an impermanent tax exemption for EVs was introduced. Two main actor alliances for the development of operation and support systems for EVs appeared, both with energy companies in central roles: 1) Clever (formerly ChoosEV; a collaboration with five energy companies), and 2) Better Place (with the energy company Dong Energy; later taken over by E.ON).

The experiments have consisted of a high number of activities of economic, technological, and organisational character, and considerable investments have been made by private and public actors. Among the technology activities are the development of charging technology, including fast charging, battery-swap technology, and technology for energy management and control on different levels (individual cars and consumers, the local grid and the electricity and charging systems in general). In many cases, the activities involved collaboration with international developers of, e.g., EVs, ICT and charging technology. The efforts for integrating the car use with flexible and 'smart' electricity systems also included new techno-economic models for the working and development of information exchange systems. Thus, not surprisingly, considering the high design-intensity of EVs, development activities in multiple areas were of central importance for path-creation experiments.

In the period 2010–2013 the two 'operators' established operation systems for EV use and built up networks for energy supply and charging of EVs. In addition to Clever and Better Place, a few other operators, e.g., a car-sharing organisation in Copenhagen and, more recently, the American e-car manufacturer Tesla, established charging networks on a smaller scale. Overlapping with the activities of the operators, the national test scheme gathered and analysed experiences of the use of EVs, including issues like utility, reliability, use and charging patterns.

By 2013, each of the two main operators had established several hundred charging points. This constitutes an important element of the *path-establishment processes*. The charging points are not only located in the capital, Copenhagen, but also in other towns and along intercity motorways. This makes Denmark one of the first countries where a countrywide infrastructure for EVs is starting to appear. Not only short trips, e.g. to and from work, but also longer trips have started to be

Table 1
Path-creation processes for e-mobility in Denmark.

Initial conditions	Path-creation experiments	New path-establishment processes	Barriers to new path creation	Landscape change outcome
Well-developed road transport systems.	Mobilisation of central energy sector actors and public authorities.	Several hundred charging points. Starting to become widespread.	Transport policy and energy policy are two independent areas.	Long term: fossil-free transport sector by 2050.
Small country; even cross-country trips are less than a few hundred kilometres.	Test scheme for EV use and R & D support.	Funding for establishment of charging points.	Flaws or breakdowns in the operation of charging networks; bankruptcy of Better Place.	Wind to constitute 50% of electricity production in 2020. EV charging to support this.
Well-developed electricity systems, primarily fossil fuels, but considerable and increasing amount of wind energy, fluctuating.	Tax exemption for EVs.	Public parking and charging spaces.	Limited support for battery-swap technology.	Promoters estimated 400,000–500,000 EVs in 2020. Authorities: 19,000–79,000.
Wind industry.	Two main developers of support and charging infrastructure.	Procurement of EVs by local and regional municipalities.	High prices of EVs.	4,000 EVs in 2015. EVs have become visible on roads and in mass media.
Cars are imported goods.	Private and public investments.	Increasing number of EVs.	Stop–go tendency of tax exemption.	Realistic alternative – not utopian.
Policy attention to transport as key sustainability challenge	Connecting to international developers of EVs, ICT and charging technology.	Public regulation; requirement of open access and roaming between systems.	CO_2 emissions; not sustainable so far.	Basic charging infrastructure established in cities and across the country.
	Normal/fast charging and battery-swap technology.	Efforts for standardisation of charging solutions. Test centre for interoperability.	Variations in wind energy and charging patterns do not match each other. Too little flexibility created.	
	Energy management and control technology.		Tariff schemes for electricity needs development.	
	Smart grid: Flexibility new asset in electricity grids and consumption.			

Table 2
Path-creation processes for advanced biofuels in Finland.

Initial conditions	Path-creation experiments	New path-establishment processes	Barriers to new path creation	Landscape change outcome
Forests are a big natural resource in Finland.	Well-planned and advanced fulfilment of EU directive for alternative fuels; Legislation for biofuel mixing with fossil fuel.	New, advanced biofuel production plant investments (St1 and UPM).	Scarce biomass resources are also wanted in the chemical industry.	Biofuels cover probably the largest part of the targeted 20% share of renewables in transport in 2020.
Wood industry in general developed in Finland producing wood-based side streams.	Tax favourable for biofuels.	R & D is finding new ways to produce biofuels and new resource options.	Lack of investment.	
Existing pulp mills in Finland are doing good business and producing tall oil as a by-product.	Companies (Neste Oil, St1 and UPM) are interested in creating a biofuel business.			
Existing petroleum infrastructure and internal combustion engine cars.	Existing liquid fuel station infrastructure and vehicles used in drop-in solution.			
Municipal and food industry and market-based bio-waste available, including forest waste.				

Table 3
Path-creation processes for H_2/FC in Norway.

Initial conditions	Path-creation experiments	New path-establishment processes	Barriers to new path creation	Landscape change outcome
Path-dependencies: hydropower and oil and gas sector – large energy companies are reluctant to engage in H_2 activities.	Subsidies for procurement of FCEVs: buses and passenger cars.	Connection of Norwegian H_2 infrastructure with other Nordic countries to allow travel throughout the Nordic region and to Germany.	Economic barriers:	Market penetration in 2025: 55,000 FCEVs and 30 H_2 refuelling stations in the greater Oslo area.
Many possibilities to produce H_2: electrolysis from renewable electricity and reforming of natural gas, and by-product hydrogen from industrial processes.	Local projects integrating different H_2 production methods.	Strengthening of niche markets:	Delivery costs of FCEVs remain high.	2025: H_2 may be cost-competitive and subsidies should not be required thereafter[34].
Lacking infrastructure for distribution of H_2.	Regional hydrogen strategy in Oslo-Akershus.	- Conversion of major city bus fleets.	- Less-developed H_2 refuelling infrastructure compared to charging points for BEVs.	2040: 1,760,000 FC vehicles[35].
Technology advantage in electrolysis from renewable electricity and reforming of natural gas, but also creating lock-in, especially regarding natural gas.	Establishment of H_2 refuelling infrastructure.	- Introduction of FC scooters.	- No strong investors for H_2 refuelling infrastructure – high first-mover risk	2050: nationwide H_2 infrastructure with 1,100 stations[34].
		- Deployment of light-duty FCEVs.	- Too high operation and maintenance costs for H_2 refuelling stations when low number of FCEVs.	
	Tax exemption for FCEVs in parallel with battery electrical vehicles (BEVs).	Public procurement of FC vehicles for car fleets in public services.	- H_2 costs vary substantially with demand, therefore cost-levelling measures will be required.	2050: total investment in a nationwide H_2 refuelling station infrastructure: €1.5 billion in 2005 up to 2050, the equivalent of €850 per car[34].
		Cost of H_2 is calculated to reach a competitive level of €15/kg by about 2019 and of €8–9/kg by 2024–25[35].	Institutional barriers:	
Limited connections to global automotive industry and too low a number of vehicles produced globally.	Engagement of environmental NGOs, firms and researchers in hydrogen society. Fulfilment of EU directive for alternative fuels is a target.	Total investment in H_2 infrastructure: €100 million–220 million in the greater Oslo area until 2025.	- Standards, codes and regulations on hydrogen quality, metering at refuelling stations and transport on roads are not harmonised and do not support the deployment of H_2/FC technology. - Lack of political leadership by the government. - Too low funding available for demonstration projects. Social/cultural barriers: - Competition between FCEVs and BEVs. - Lack of knowledge on FCEVs. - Fear of H_2 accidents.	McKinsey study: cost of €1000–2000 per car or approx. 5% of the overall cost of FCEVs[36]. Domestic renewable fuels (H_2, electricity, biofuels) cover all transportation fuel needs.

Table 4
Path-creation processes for advanced bioethanol in Sweden.

Initial conditions	Path-creation experiments	New path-establishment processes	Barriers to new path creation	Landscape change outcome
Vast forest resources.	Fulfilment of EU directive for alternative fuels is a target.	Policies create fuelling infrastructure (on top of fossil fuel infrastructure) and secure availability of flexible fuel vehicles.	Initial reliance on first-generation bioethanol creates lock-in – renewable targets fulfilled.	Long term: fossil free transport sector by 2050.
Strong competencies within the pulp and paper sector.	Policy cooperates with Swedish OEMs to secure the availability of flexible fuel vehicles.	Policy incentives for owners of flexible-fuel vehicles to facilitate market growth.	Lack of long-term advanced bioethanol policies.	Short/medium term: status quo – continuing reliance on first-generation bioethanol.
Well-developed conventional fuelling infrastructure.	Public funding of R & D projects.	Public procurement of flexible-fuel vehicles.	Absence of new, ambitious renewable energy requirements for the transport sector that go beyond what is already achieved. Insufficient distinction between first-generation and advanced biofuels.	Increasing focus on products other than advanced bioethanol by key industrial actors.

realistic and EVs appear a direct alternative to petrol cars instead of an extra vehicle for short trips only. National funding support for the establishment of charging points contributed to this development.

Considerable dialogue with local municipalities has taken place in order to ensure public parking and charging spaces and encourage public procurement of EVs. A number of local and regional municipalities have decided to primarily buy EVs for their car fleets. There has been a considerable increase in the number of EVs since 2011, due amongst other things to procurement by these municipalities. Considerable media coverage, active media strategies and the use of EVs for publicity by private and public actors also contributed to this.

Public regulation and requirements of open access and roaming between different charging systems are part of the path establishment processes. Coordination between authorities, EV operators and electricity system operators on data-exchange formats and models for operation has taken place. In addition, work for the harmonisation and standardisation of charging systems has been made on national and international levels and a test centre for the interoperability of different charging systems has been established.

Despite considerable coordination efforts between several authorities, one of the *barriers to new path creation* is that transport policy and energy policy are two independent areas. It is difficult to ensure full coordination of efforts. The use of the charging networks is not unproblematic. The networks need further development, both in the extent and number of charging points and in the reliability and efficiency for consumers. Flaws and breakdowns in the operation have occurred, not least in 2013 when Better Place went bankrupt and the operation stopped for months until the international energy company E.ON took over the charging infrastructure. There has been limited support for the battery-swap technology among car manufacturers and the swap stations are closed.

Among the other barriers for further development of the e-mobility path are the relatively high prices of the EVs and the uncertainty created by stop–go tendencies in tax exemption. Concerning sustainability, the CO_2 emissions from electricity production are a barrier. The patterns of charging and the variations in wind energy do not fit each other. The ‘smart’ charging and the flexibility created for the electricity systems are too limited and require further development both technically and with respect to tariff schemes (economic incentives). Despite significant emphasis in the path creation process towards design activities, technical aspects continue to be an important barrier, however this is in line with expectations for technologies with design-intensive characteristics [8].

Concerning *landscape change outcome*, there is still a considerable way to go before the goal of 50% wind energy by 2020 in electricity production, supported by EVs, is ensured. This is similarly the case concerning the long-term goal of a fossil-free transport sector by 2050 [21]. Estimates made by promoters of EVs that 400,000–500,000 EVs will be on the roads in Denmark by 2020 differ from the estimates by authorities and energy sector actors of 19,000–79,000 [22]. The landscape change so far is more modest. The number of EVs is increasing and is now around 4,000. This corresponds to approximately 0.15% of the total Danish car fleet.[2] The outcome not least consists in that EVs have become visible on the roads and in the mass media. They now appear as a realistic alternative for many consumers instead of a utopian or exotic choice. A basic charging infrastructure is established in cities and intercity corridors, but it still needs to be developed further.

5. Advanced biofuels in Finland

Kivimaa and Mickwitz [23] analyse the political framing of bioe-

[2] Own account, building on 2015 figures from Statistic Denmark and Danish Electric Vehicle Alliance.

nergy in Finnish energy policy and divide the development of energy policy 'into four phases: the start of official energy policy in the 1970s, support for domestic energy sources in 1979–1991, support for wood- and industry-based bioenergy in 1992–1998, and diversified bioenergy in 1999–2010' (2011:1814). They conclude that forest-based options have dominated Finnish bioenergy policy, favouring large incumbent companies, and hence creating the dominant *initial conditions* for the Finnish transition process towards renewable energy. However, in the last decade, with the entrance of the Biofuel Directive in 2003, competing technologies have emerged and agricultural raw materials and waste have diversified the resource base [5].

The second dominant condition in Finland is that the Finnish transport system relies heavily on liquid fuels and the infrastructure related to it. In 2013 there were 4.95 million vehicles in Finland, including 2.58 million passenger cars of which the use of internal combustion engines in personal vehicles was 76.8% petrol cars and 23.1% diesel cars [24]. The numbers of EVs and biogas-using vehicles were estimated at respectively 170 and 1700 cars in 2013 [25]. Thus, vehicles without internal combustion engines are really a niche in Finland.

The petroleum infrastructure is also well-developed in Finland, with around 2000 service stations selling fossil fuels. An oil company, Neste, was founded in 1947 to produce and distribute domestic petrol and diesel for cars from imported oil. Gradually, other Finnish and foreign actors entered the petrol and diesel distribution markets in Finland, including the Finnish firm St1.

The route to the transformation of the transport system towards renewables in Finland is focused on drop-in option where liquid biofuels are added to fossil fuel. In 2011, only 0.4% of the energy consumed in the transport sector came from renewable sources [26], mainly from biofuels. However, Finland has stated the most ambitious target in the EU for renewable energy share in the transport system, with a goal of 20% by 2020 (Law for biofuel distribution 1420/2010). This policy choice creates an important *path-creation experiment*. The law states that the share of biofuel in the fuel mix should be at least 6% in the years 2011–2014, increasing gradually towards 2020. This target is supposed to be achieved through the domestic development of biofuels. This is supported by taxes (Law for liquid fuel tax 1399/2010) that are favourable for biofuels and by the National Climate and Energy Strategy [27].

The development and production of biofuels is already rather extensive in Finland, with several products on the market, constituting *new path-establishment processes*. Both Neste and St1 are increasingly distributing biofuels. Neste has invested over €1.5 billion in production plants in Finland and abroad. Their NExBTL biodiesel, made from vegetable oils and animal-based fatty waste by using hydrogen treatment technology, is already on the market. Current biodiesel production capacity is 2 million tonnes a year and profitable. Initially, NGOs (mainly Greenpeace) protested as Neste produced biodiesel from palm oil, a first-generation biofuel, which is in conflict with food production and rainforest protection areas. Neste has responded by searching for new resource options, for instance fatty acids from straw.

Similarly to Neste, St1 has invested heavily in biofuels despite having their main business area in fossil oil. St1 primarily produces bioethanol from food industry waste and bio-waste. Their current bioethanol production concept is focused on small production plants near resources and a dehydration plant for concentrating the fuel into distribution concentration. St1 currently has four bioethanol units operating in Finland, producing and distributing totally about 15 million litres of bioethanol a year. Additionally, St1 invests in R & D, focusing on wood-based ethanol production, and runs a demonstration plant which currently produces about 1 million litres of bioethanol from bio-waste per year. In the future, St1 plans to widen its ethanol production in order to broaden the feedstock capacity into using straw, sawdust, wood chips, waste wood and other waste from the forest sector.

Finally, pulp and paper firm UPM has recently constructed a biodiesel production plant, which will produce up to 120 million litres per year from tall oil from a pulp mill located near the plant. The investment of €150 million is made without any public subsidy. UPM is also planning to build a demonstration plant producing biodiesel from wood by using Fischer-Tropsch technology. However, the demonstration plant will be located in Strasbourg, France, with the EU NER300 (New Entrants Reserve) programme subsidy (€170 million).

To some extent the development and production of advanced biofuels from forest resources and forest-industry side streams are creating competition between the chemical industry and the fuel industry. Wood- and forest-industry by-products, such as tall oil, are scarce resources, which create *barriers to new path creation* in biofuel businesses. There is an ongoing discussion as to whether it is wise to produce low-volume high-value products, e.g. cosmetics, or high-volume low-value products, e.g. biofuels. This competition especially touches the UPM tall oil biodiesel production, because other Finnish firms like Forchem also use tall oil. The production of pulp and tall oil as side streams in Finland is not enough for all these actors, hence, companies could be forced to import tall oil for their purposes. Other Finnish forest-industry companies producing pulp, e.g. Stora-Enso, are not interested in entering the biofuel business and prioritise the development of other bio-based products. In general, the lack of investment creates barriers to biofuel business development.

Accordingly, the Finnish biofuel story tells us that production capacity is growing and at least three companies, Neste, St1 and UPM, are developing their business towards advanced biofuels. The national vision and policy actions of Finnish renewable energy based transport in short, medium and long term are strongly linked to biofuels. The tax policy supports biofuels and policy support to other renewable energy options in transport are marginal and not focused on stimulating consumer demand. For instance recent effort to support investments in EVs was directed only to companies.

To sum up, the path creation process in the Finnish case utilises existing manufacturing capabilities in industry sectors such as food production and pulp and paper. Design capabilities from chemical engineering are important in e.g. optimising the fuel production process in St1's dehydration concept, but the path creation process is not concerned with introducing systemic changes related to the whole transport sector including vehicles and energy infrastructure, such as required in EVs and H2/FCs cases.

6. Hydrogen and fuel-cell electrical vehicles in Norway

The presence of vast and varied energy sources forms important *initial conditions* for the path creation activities related to the use of hydrogen and fuel-cells in transport systems in Norway. The large oil and gas resources combined with a long tradition for exploiting natural endowments of hydropower makes Norway an important supplier of energy and energy technology. Nearly all of the electricity generated in Norway comes from renewable sources and almost exclusively from hydropower [28] and about 65% of the gross final energy consumption stems from renewable energy sources (data for 2011 retrieved from [26]). So, while the electricity supply in Norway is already largely decarbonised, the challenge remains how to substantially reduce the emissions in the transportation sector. Together with electricity and biofuels, hydrogen is being considered as an alternative to reduce carbon emissions from the transportation sector [29].

Path-creation experiments for fuel-cell and hydrogen technology have existed in Norway since the middle of the 1990s [30,31]. The experiments are largely based on close collaboration between universities, research institutes and private companies [32]. The experiments targeted different components with a mix of technological characteristics ranging from manufacturing intensive production of hydrogen to the production of tanks for hydrogen storage, a typically design and manufacturing intensive activity. The focus of the largest energy companies was in the early development stages on the production of hydrogen based on solid oxide fuel-cell technology using natural gas as feedstock. As most of the natural gas produced on the Norwegian continental shelf was exported, it was envisioned that such a technology would make use of these resources for energy production [30]. Since the beginning of the 2000s there has been a growing interest in exploiting natural gas resources for hydrogen production, to act on environmental concerns and to see hydrogen as a market opportunity for the Norwegian industry [33]. An OECD report pointed out that Norway needed a hydrogen supply infrastructure and that collaboration with the global automotive industry was still too weak [33]. Increasingly, technology strategies have changed from exploitation of natural gas to produce hydrogen, to utilising renewable energy sources. Recent hydrogen projects, such as HyNor or NorWays, are examples of projects focussing on other technology options and in recent years, companies have emerged developing these pathways further. After the failure of big industrial projects supported by Statoil and Norsk Hydro in the early 2000s, and the withdrawal of bigger industrial players, there are currently only a few companies which are engaged in H_2/FC technology and which could support the R & D of public research organisations. The development of electrolysers for hydrogen filling stations used by automobiles continued in a European setting and research capabilities were further developed, both in national and European research projects.

Hydrogen production is decentralised, often related to local energy sources or as a by-product of industrial processes. There are some firms engaged in different solutions for on-site hydrogen production. Only a few Norwegian small- and medium-sized enterprises are engaged in the hydrogen production and storage field, such as the producers of small electrolysers for on-site production of hydrogen (Nel ASA) or hydrogen compression with metal hydrides technology, applied on the storage of hydrogen (Hystorsys AS). The transportation of hydrogen is mostly done with trucks, but short pipelines are also in use. Hydrogen is stored in compressed tanks at production sites and at refuelling stations. Equipment for the storage and transportation of hydrogen in compressed tanks is produced by Hexagon, a globally operating Norwegian firm. The lack of Norwegian companies providing integrated hydrogen fuel-cell solutions was seen as a barrier for the faster commercial deployment of this technology. However, recent developments (May 2015) indicate a shift in this regard, since the Norwegian producers of water electrolysers Nel ASA acquired the Danish H2Logic company, a specialist in hydrogen refuelling stations. The acquisition meant that Nel ASA could extend its activities to include integrated solutions for supply infrastructure for fuel-cell electrical vehicles (FCEVs) globally.

Several publicly funded projects have contributed to the establishment of a limited hydrogen refuelling infrastructure in the greater Oslo area. These have been important to support this design intensive technology. However, a significant barrier was the limited connection to the global automobile industry. In addition, the acquisition of fuel-cell vehicles was hampered by the fact that they were not available or that the available cars were too expensive. This was the reason why commercial retailers of hydrogen could not maintain the established refuelling stations – the costs of operation and maintenance were too high compared to the income from a very low number of fuel-cell vehicles. The infrastructure was taken over by new entrepreneurial entrants, thus securing the future of the hydrogen projects in the Oslo region.

Norway is expected to develop into an early market for the commercial rollout of FCEVs in the coming years and a number of original equipment manufacturers of vehicles are currently involved in Norway's hydrogen activities. In 2012 this was addressed by a memorandum of understanding between important car manufacturers from Japan and South Korea, representatives from hydrogen infrastructure companies, and NGOs for hydrogen and fuel-cells in Norway as well as in Denmark.

Several demand oriented policies facilitated *new path establishment processes*: public procurement of fuel-cell vehicles for car fleets (postal delivery, road authorities, renovation service, etc.) in public services, public procurement of hydrogen filling stations and strengthening of niche markets, such as fuel-cell scooters, bus fleets and light-duty FCEVs. The transformation of the public transport system of Oslo and Akershus, for example, includes the public procurement of fuel-cell buses and a hydrogen filling station for those buses.

Political framework conditions have contributed to more-favourable market conditions for fuel-cell vehicles compared to other countries. Fuel-cell cars and battery electrical cars are treated equally in Norway regarding taxes, parking, road tolls, free ferry use, use of bus lanes, etc., which means rather favourable conditions compared to internal combustion vehicles. Regional authorities in Oslo and Akershus are drivers for the deployment of H_2/FC technologies. However, a visionary political focus at the national level on replacing oil and gas with hydrogen, which also includes the sufficient funding of the development of a national infrastructure for hydrogen as an important energy carrier, is lacking.

The major *barriers to new path creation* are the market conditions for new entrants (such as high delivery costs of FCEVs and high investment/maintenance costs for refuelling stations), a lack of strong industrial actors engaged in fuel-cell and hydrogen technology and complementing public R & D on this technology, and the competition between fuel-cell vehicles and battery electrical vehicles. Further barriers relate to the lack of political leadership at the highest political level that may ensure the necessary infrastructure for the deployment of hydrogen as an important energy carrier and to overcome the existing lock-in on oil and gas.

In terms of envisioned *landscape outcomes,* existing visions and road maps planed a stepwise increase for the deployment of hydrogen and FCEVs in Norway. The plans envisioned that hydrogen would become cost-competitive in 2025 and that it would not require further subsidies by that time. Plans also estimated a market penetration of about 55,000 FCEVs and 30 hydrogen filling stations by the same year in the greater Oslo area. However, it was estimated that large investments were needed for the establishment of a refuelling infrastructure corresponding to about €100–220 million. In the longer term, these visions projected that the development would go further to 1.76 million FCEVs in 2040 and that a nationwide hydrogen infrastructure would be in place by 2050 [34,35].

7. Advanced bioethanol in Sweden

The transition process towards sustainable transport forms in Sweden is significantly influenced by *initial conditions*. Firstly, the existing infrastructure favours – as in most other developed economies – a focus on biofuels rather than electrical mobility, as the compatibility between, e.g., diesel and biodiesel is high in terms of storage facilities and fuelling infrastructure. Secondly, the production of biofuels is not a new phenomenon in Sweden. The pulp and paper industry, which has been of significant economic importance throughout Swedish history, has over time established considerable competencies within this area. Ethanol production was, for example, widespread as a substitution for import fuels during World War II. In the middle of the 20th century, 32 Swedish pulp and paper mills had a yearly combined production of approximately 60,000 t ethanol [36]. In the late 1970s, bioethanol was primarily promoted by farmers and their interest groups, while R & D and testing programmes on vehicles to run on bioethanol followed in the 1980s. In the early 1990s, the development of the distribution infrastructure came onto the agenda and the public procurement of flex-fuel vehicles by municipalities contributed to a high share of registered vehicles meeting environmental standards [37].

The long-term interest in bioethanol is important to take into consideration in order to understand the background for the significant policy efforts, which have supported the use of bioethanol in transportation over the last decade. Policies focused on facilitating *path-creation experiments* were in particular targeting technological development. Of particular importance were public procurement activities that ensured the supply of flexible fuel vehicles, initially produced by Ford. With the increasing access to E85 across Sweden (see below), the two large Swedish car producers Volvo and SAAB introduced flexible fuel models in 2005 [38]. Thus, despite the technological characteristics of biofuels (high manufacturing-intensity, low design-intensity), path-creation experiments in fact gave significant attention to design-activities.

In the *new path-establishment* stage, the most important driver was the so-called Swedish Pump Act of 2005, which made it mandatory for larger fuel stations to sell renewable fuels by April 2006, thereby ensuring access to biofuels for consumers. This law was instrumental in establishing a well-developed E85 pump infrastructure. Integrated with normal fossil fuel stations, E85 pumps are now available at approximately 2,000 locations across Sweden. Additional important policy initiatives include encouraging sales of flexible fuel vehicles through incentives such as tax exemptions, bonuses to buyers and exemptions from congestion fees. As a result of these efforts, the bioethanol consumption for transportation in Sweden is one of the largest in Europe in absolute figures (more than 207,000 toe in 2012), and the share of biofuels in transport increased from 6.3% in 2011 to 7.8% in 2012. Consequently, biofuels have played a major role in ensuring that Sweden already now meets the 2020 EU-RED requirement of 10% renewable energy in transport. see also [5].

Notably, the potential for production of bioethanol from cellulose and the specific characteristics of Sweden with a very large domestic supply of wood were emphasised in the ethanol debate in the time around the introduction of the Swedish Pump Act e.g. [39,40]. Thus, the connection between these policy efforts and the diffusion of advanced bioethanol was clear. However, Sweden continues to rely on first-generation bioethanol in its transportation sector. This is partly produced in a domestic large-scale facility and partly imported from, in particular, South America. Thus, approximately 20% of all ethanol imported to the EU is shipped to Sweden [41]. By way of example, a producer of bioethanol fuel, which has played a central role in the market development of bioethanol fuel in Sweden, relies on 90% imported first-generation bioethanol, while only 10% is based on Swedish wood. Reflecting this reliance on first generation bioethanol, the Swedish government has worked actively in the EU to ensure that bioethanol imported to the EU is exempted from tax [42,43]. This has resulted in some debate concerning the sustainability of different types (first- and second-generation) of biofuels [44].

Thus, to summarise, the success of biofuel in Sweden is partly due to a stable policy framework see also [5], which in the new path-establishment stage was particularly focused on stimulating the demand-side. However, these demand-side policies have to a limited extent been connected to manufacturing activities in Sweden, and the path creation process is therefore relying on fuel production abroad.

In order to comprehend the limited diffusion of advanced bioethanol in the Swedish transportation system, two interrelated *key barriers* have been identified.

Firstly, Sweden has already achieved the EU target of 10% renewable energy in the transport sector by 2020, thus, the direct financial incentive for the Swedish state to invest in the further commercialisation of advanced bioethanol is low. In contrast to Finland, which has increased its target to 20%, Sweden has not set a new target beyond the vision of a fossil-free transport sector in 2050, which is too long-term and vague to stimulate investments in facilities. Thus, informants point to the need for intermediate goals, which may act as steps towards the 2050 target. Further, no distinction is made between first-generation and advanced biofuels in the plans, which is also a barrier to the commercialisation of advanced biofuels technology. Interviewees highlighted that targeted support for the first advanced bioethanol plants is necessary to compensate the significantly higher investments associated with the construction of the first full-scale plants. Further, it was also pointed out that specified quotas for first-generation and advanced ethanol are necessary to make sure that high-volume advanced bioethanol production can be established.

Secondly, the lack of long-term policies is a central barrier. The current biofuels tax deduction is decided on by the Swedish Ministry of Finance from year to year. Thus, there is a very large political risk associated with investments in full-scale commercialisation advanced biofuel technologies, which has so far prevented these from taking place. Thus, in the biorefinery in the city of Örnsköldsvik, €55 million had been secured from the EU for an industrial-scale 200 MWth biofuels plant intended to produce biomethanol and BioDME using forest harvest residues as feedstock. However, the owners found the additional investment of €275 million too risky due to the lack of long-term policies, which eventually created a substantial liability for the project.

Consequently, in terms of *envisioned landscape change*, the vision of the Swedish government is a fossil-free transport sector by 2050 where biofuels play a key role. However, due to the lack of policy support for advanced biofuels, Swedish firms involved in biorefining activities are increasingly focusing their attention towards higher-value-added products such as speciality cellulosic products and green chemicals. As a consequence of the decreasing attention of firms towards advanced biofuels, the attention of intermediaries and research institutes within the field is also increasingly directed towards other fields such as green chemicals and green materials. Combined, these factors slow down the progress towards the national goal of a fossil-free transport by 2050.

To conclude, having been a frontrunner in the use of biofuels for transportation, the current situation in Sweden is characterised by stagnation. The consequence is that actors move their focus to other products and use resources there, which also implies that there is less pressure on the politicians to create favourable framework conditions. Thus, this highlights that the early adoption of first-generation biofuels does not ensure an early adoption of advanced biofuels and it may in fact create a new lock-in situation where the transition to more sustainable technologies loses momentum.

8. Case comparison – the influence of technological characteristics

This section compares the four cases, discussing the influence of technological characteristics on path creation processes. We focus on the three central elements in path creation processes: path creation experiments, new path establishment and path creation barriers.

Comparing the *path creation experiments*, an interesting observation is that their content seems to be quite unrelated to the technological characteristics. While the focus of the path creation experiments in Denmark and Finland corresponds to the technological characteristics in the two cases, this is not the case for the Swedish and Norwegian cases. In Sweden, path creation experiments were initially focused on design-intensive activities in relation to the development of flexible fuel vehicles, and the emphasis in Norway was on different types of hydrogen technologies, ranging from hydrogen storage (high manufacturing- and high design-intensity), hydrogen production (high manufacturing- and low design-intensity) and refuelling station solutions (high design- and low manufacturing-intensity). Firstly, this highlights that even though technologies can be more or less manufacturing- and design-intensive, path creation experiments may entail activities related to both aspects. Secondly, it indicates that path creation experiments will focus on targeting the most important bottlenecks. To exemplify, developing flexible fuel vehicles was a greater bottleneck in the Swedish case than the large-scale production of fuels, where Sweden had significant competencies from existing economic activity. Thus, even for a technology characterised by low design-intensity, path creation experiments may be focused on design

Table 5
Case comparison.

	Focus of path creation experiments	New path establishment process	Key path creation barriers
Denmark (design-intensive)	Design-intensive development activities	Continuous focus on design activities	Technical barriers
Finland (manufacturing-intensive)	Changes in manufacturing processes	Establishing new production facilities	Scarcity of raw material inputs
Norway (design-intensive)	Mixed, covering both design- and manufacturing-intensive activities	Stimulating initial demand; interactive learning	High FCEV costs; limited commitment of large manufacturing firms
Sweden (manufacturing-intensive)	Design-intensive development activities	Stimulating large scale demand	Decreasing interest of domestic industry

activities in order to overcome a certain barrier.

Examining the *new path establishment* processes in the four cases, we find that the activities are more in line with what we would expect, considering the technological characteristics, than for path creation experiments. In the Danish case, there is a continuous focus on design activities (particularly at the infrastructure level). Conversely, in the Finnish case, focus is on establishing new biofuel production facilities, while only minor efforts go into infrastructure design. Demand stimulation activities are central in both the Norwegian and Swedish cases, however, in very different ways. Efforts are in the Swedish case focused on stimulating large-scale demand, which fits with the high manufacturing-intensity of the case. In the Norwegian case, activities focus on stimulating initial demand, but also on learning from early adopters and gaining experience with installing and operating the technology. Thus, learning following from close interaction between users, manufacturers and infrastructure suppliers was important to continuously improve the design of the hydrogen and fuel-cell technology platform. Thus, in summary, it seems that technological characteristics have greater influence on the nature of activities in the new path establishment phase, compared to the proceeding path creation experiments.

Finally, concerning key *path creation barriers*, we see that their character seems to be considerably influenced by technological characteristics. In the Danish case, as expected for technologies with design-intensive characteristics, technical aspects continue to be an important barrier despite significant attention towards design activities in the path creation process. Similarly, need for further technical developments which can lead to decreasing FCEV prices, constitute an important challenge in the Norwegian case. Furthermore, the Norwegian case also illustrates that while demand policies that stimulate learning between different types of actors are needed for the development of design-intensive technologies, a lack of inclusion of large manufacturing companies, which can contribute significant resources to design activities, may delay or hinder path creation.

Turning to the manufacturing-intensive technologies, a key barrier in the Finnish case is the scarcity of raw material inputs, in particular tall oil, which is also an important input into biochemicals production. Lack of feedstock is likely to be a more important barrier in relation to manufacturing-intensive technologies, where production is likely to take place at a larger scale. In the Swedish case, the decreasing interest of domestic industry in biofuels results from the lack of connection between the demand creating activities in the new path establishment process and domestic manufacturing. This has resulted in a significant import of biofuels and a subsequent lack of interest in and legitimacy for the new path among domestic actors. This highlights that for manufacturing-intensive technologies, path creation activities should not only be focused on supporting the demand-side, but also on relating this to domestic manufacturing activities to avoid the stagnation that characterises the Swedish case.

9. Conclusions and policy implications

In this paper we have reviewed path-creation processes in Nordic transport systems. The four cases highlight that initial conditions such as energy-production systems (e.g. the rather stable provision of hydropower in Norway for production of hydrogen and fluctuating electricity from wind power in Denmark) and other infrastructures (e.g. existing fuelling infrastructure) significantly influence path-creation processes. Thus, while the transition to a sustainable road transport system requires significant changes in the transport and energy systems, national contextual factors may favour certain emerging technologies. However, the degree of public support to path-creation experiments and path-establishment processes are also of crucial importance for the transition to sustainable transportation technologies. This is exemplified by recent differences between Finland and Sweden regarding the deployment of advanced bioethanol. While Sweden over the last decade was a forerunner for biofuels, the current situation in Sweden is characterised by stagnation. The Finnish government, however, has stated the most ambitious target in the EU for renewable energy share in the transport system, with a goal of 20% by 2020, and industrial actors are consequently entering the advanced biofuels market.

Drawing on recent insights from the technology lifecycle literature concerning the differences between design- and manufacturing-intensive technologies [9], the paper has analysed the influence of technological characteristics on path creation processes. The case comparison indicates that technological characteristics have less influence on the content of path creation experiments, compared to the subsequent path establishment phase. In other words, path creation experiments may entail design-intensive activities even for manufacturing-intensive technologies (as in the Swedish case) and vice versa (as in the Norwegian case). Conversely, in the path establishment phase, activities are more in line with what we would expect, considering the technological characteristics: technical development activities are of high importance for the design-intensive technologies, while establishing new production facilities and supporting the development of mass-markets are highly important for the manufacturing-intensive technologies. Similarly, the key path creation barriers in the four cases also appear closely related to the technological characteristics.

In terms of theoretical implications, our analysis highlights that the literature on path creation could benefit from a more in-depth understanding of the implications of different technological characteristics. Our paper has provided a first contribution here in pointing out that path creation processes seem to differ in the later parts of path creation processes. I.e. once the seed of a new path has been sown, differences in technological characteristics start to influence path creation activities. Future comparative studies should aim at scrutinising this insight and also expand the analysis to cover technologies which are both manufacturing- and design-intensive.

Regarding implications for policymaking in the fields of climate change and renewable energy, our analysis highlights that policies need to acknowledge differences stemming from technological characteristics, in particular once the initial technological experimentation phase is concluded. For design-intensive technologies, this includes continuous support for technical development activities and focus on stimulating feedback between technology users and producers. For manufacturing-intensive technologies, this requires emphasis on stable market support policies coupled to development of manufacturing capabilities.

Finally, we would like to highlight that path creation towards sustainable transport should be considered a continuous, iterative process. Kemp et al. [45] argue that there is a 'danger of getting locked into sub-optimal solutions from a sustainability perspective'. Indeed, this seems to be what has happened in the case of first-generation biofuels in Sweden. This danger of early inflexibility can be avoided by developing and applying a portfolio of solutions rather than selecting just one option, and ensuring that these technological solutions are reviewed regularly to avoid sub-optimal that suboptimal alternatives are created.

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Annex A. Template for analysis of value chains and path dependencies

1. **Basic input/output structure of value chain**
   a. Describe the main activities/segments through which the product flows – typically feedstock production, primary processing, secondary processing, integration, distribution and marketing, and sales. Show the segments and how they are connected and a brief description of the activities involved each segment.
   b. Describe also the main supporting activities for each segment (e.g. R & D, inputs, transport and processing equipment etc).
   c. Identify the type of companies involved in each segment and their key characteristics (global or domestic; state-owned or private; size; core business etc).
   d. Identify, if possible, 'lead' firms – i.e. powerful firms that influence/determine the conditions under which firms participate in the value chain (e.g. by setting quality standards) including the functional division of labour along the chain (who does what). Where in the value chain – upstream or downstream – are these firms typically located?
   e. Identify the dominant governance structure(s) of the value chain, according to the typology (market, modular, relational, captive and hierarchy).
2. **Key technologies**
   a. Identify the main technologies needed to carry out the primary activities / processes in the value chain as well as the secondary supporting activities.
   b. Assess the development stage of these technologies: embryonic (experimental; low performance), emergent (initial application; medium performance), mature (widespread application; high performance).
   c. Identify, if possible, whether this technology is disruptive or path-following/incremental
   d. Identify the market characteristics of these technologies: nursing markets, bridging markets, mass markets.
   e. Describe the energy and environmental performance of this technology.
3. **Geographic scope**
   a. Map the main activities according to country or region. Map also key supporting activities.
   b. Try to quantify the trade/import of the product.
   c. Identify the location (country of company headquarters) of the 'lead' firms identified above; the presence of lead firms in a country is an indication of the country's position in the chain.
4. **Path dependencies**
   a. Describe the main initial conditions (path-dependencies) and barriers for path creation.
5. **Institutional context**
   a. List the major policies (subsidies, taxes, regulations, R%D activities etc), standards and other national government or NGO initiatives deemed important.
   b. Describe path creation experiments and processes.
   c. Describe relevant strategies for future deployment of the technology.

Annex B. Involved experts

Denmark:

- Better Place
- Clever
- Copenhagen Electric, The Capital Region of Denmark (Region Hovedstaden)
- Danish Electric Vehicle Alliance (Dansk Elbil Alliance)
- Danish Energy Agency (Energistyrelsen)
- Danish Energy Association (Dansk Energi)
- Danish Transport Authority (Trafikstyrelsen)
- E.ON
- LeasePlan
- Roskilde Municipality (Roskilde Kommune)
- The City of Copenhagen (Københavns Kommune)

Finland:

- Aalto university
- Bioenergy association
- Energy industry association
- Finnsh Gas association
- Forest industry association
- Fortum Ltd
- Gasum Ltd
- Ministry of Agriculture
- Ministry of Transport
- NEOT Ltd
- Neste Ltd
- North European Oil Trade Ltd
- Petroleum & biofuels association
- SKAL (transport and logistics association)
- St1 Ltd
- TEKES (Finnish Funding Agency for Innovation)
- Trafi (Finnish transport safety agency)
- UPM Ltd
- VATT Institute of Economic Research
- VTT Technical Research Centre of Finland Ltd

Norway:

- Akershus County Council
- Det Norske Veritas
- Energy Norway (Energi Norge)
- HyNor Lillestrøm
- Hyop AS
- NEL ASA Hydrogen
- Norsk Hydrogenforum
- Norsk Industri, Elektro og energi
- Norwegian Electric Vehicle Association (Norsk elbilforening)
- Norwegian Hydrogen Council

- Ruter (Public transport in Oslo)
- Transnova (Agency under the Norwegian Ministry of Transport, now part of Enova SF)
- ZEG Power AS
- Zero – the Zero Emissions Resource Organisation

Sweden:

- Domsjö Fabriker
- Innventia
- KTH - Royal Institute of Technology
- Luleå University of Technology
- More Research
- Processum
- SCA
- SEKAB
- SP
- Södra
- Umeå University
- ÅF Industry

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