Transitions Pathways and Risk Analysis for Climate Change Mitigation and Adaptation Strategies

D3.2 Context of 15 case studies:

Sweden: Road Freight Transport

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November 2016

TRANSrisk

Transitions pathways and risk analysis for climate change mitigation and adaptation strategies

GA#: 642260

Funding type: RIA

Deliverable number (relative in WP)	D3.2
Deliverable name:	D3.2 Context of 15 case studies
WP / WP number:	3
Delivery due date:	November 2016
Actual date of submission:	
Dissemination level:	
Lead beneficiary:	SPRU
Responsible scientist/administrator:	Jenny Lieu
Lead authors (equal contribution, in alphabetic order):	Björn Nykvist & Timothy Suljada (SEI)
Estimated effort (PM):	2.5
Contributor(s):	Contributing author: Henrik Carlsen
Estimated effort contributor(s) (PM):	1.0
Internal reviewer:	Wytze van der Gaast (JIN), Jenny Lieu (SPRU), Francis X Johnson (SEI)

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1 COUNTRY CASE STUDIES OF THE HUMAN INNOVATION SYSTEM (HIS): THE ENABLING ENVIRONMENT FOR SUSTAINABILITY

Globally, the transport sector emits an estimated 23% of energy-related greenhouse gases and is more than 95% dependent on fossil fuels (Sims et al., 2014). Sweden is no exception to the general trend but due to low emissions in many other sectors transport-related greenhouse gas emissions are 33% of the country's territorial emissions (see Figure 1 and Table 1) (Naturvårdsverket, 2016; Swedish Environmental Protection Agency, 2015). At the same time, the transport sector boasts a considerable share of biofuels, making it only 87% fossil fuel dependent. While incremental changes in technology and the rapid introduction of biofuels (see Figure 2) have slowed emissions growth somewhat, Sweden's size, low population density and its export-oriented industries all pose significant challenges to decarbonisation. This is the case for both passenger and freight transport where the largest share of transport mode is by road, as shown in Figure 3.

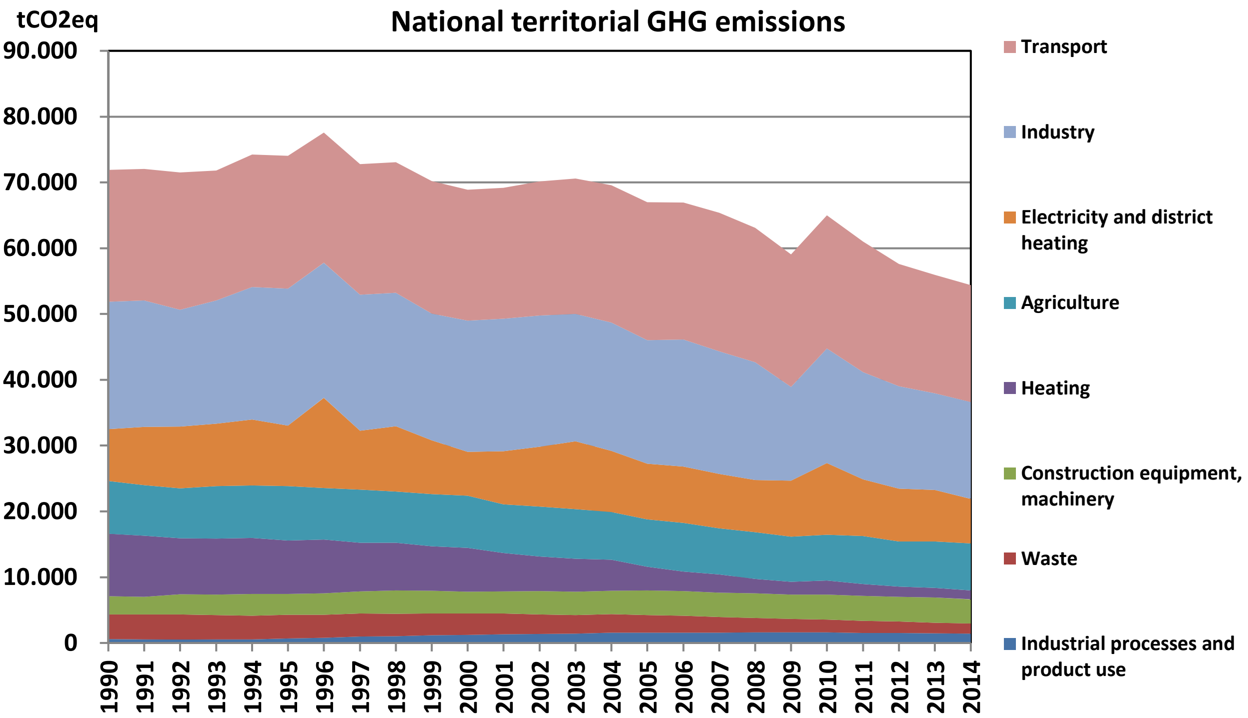


Figure 1: National territorial GHG emissions in Sweden, by sector and year (tonnes of CO_2 equivalent)

Source: Naturvårdsverket, 2016

Table 1: National territorial GHG emissions in 2014, by sector (tonnes of CO_2 equivalent)

Economic sector	GHG emissions (tCO_2e, 2014)	Proportion of total (per cent)
Transport	17,769	33%
Industry	14,713	27%
Agriculture	7,143	13%
Electricity and district heating	6,773	12%
Construction equipment, machinery	3,687	7%
Waste	1,522	3%
Industrial processes and product use	1,433	3%
Heating	1,343	2%
Total territorial GHG emissions	**54,383**	**100%**

Source: Naturvårdsverket, 2016

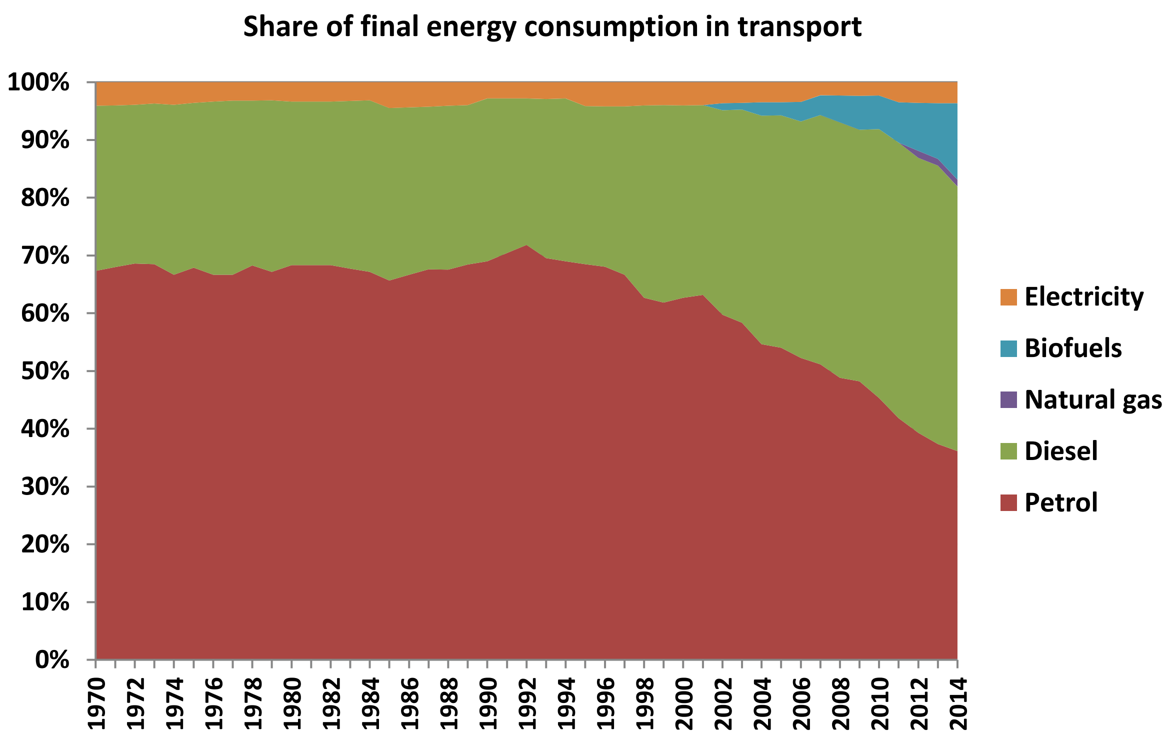
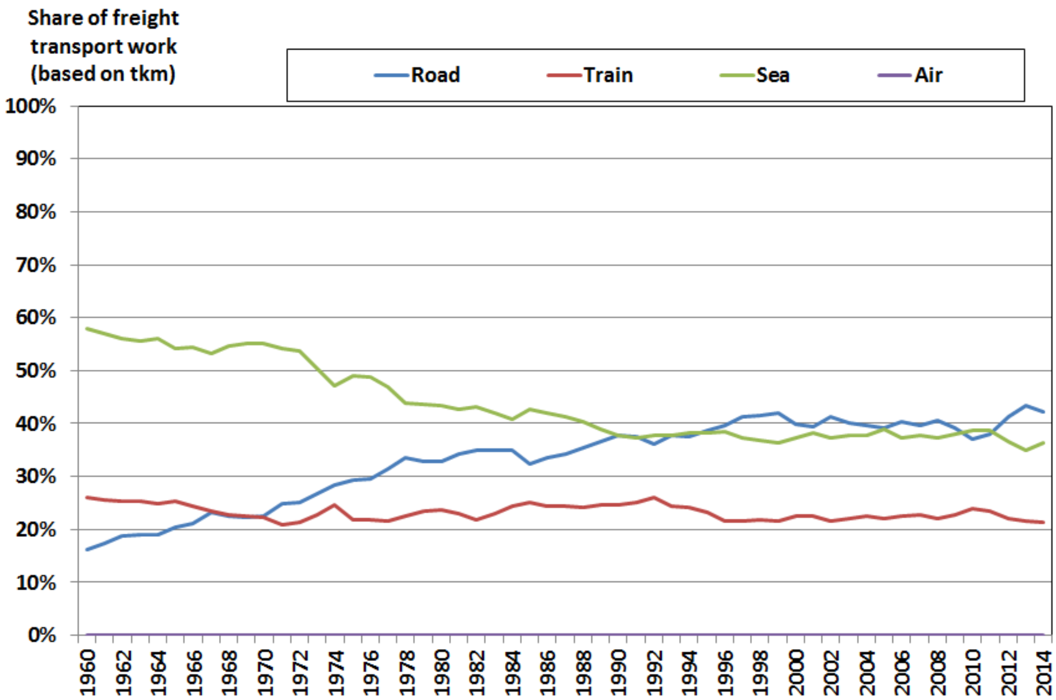


Figure 2: Share of final energy consumption in Swedish transport sector

Source: Energimyndigheten, 2016



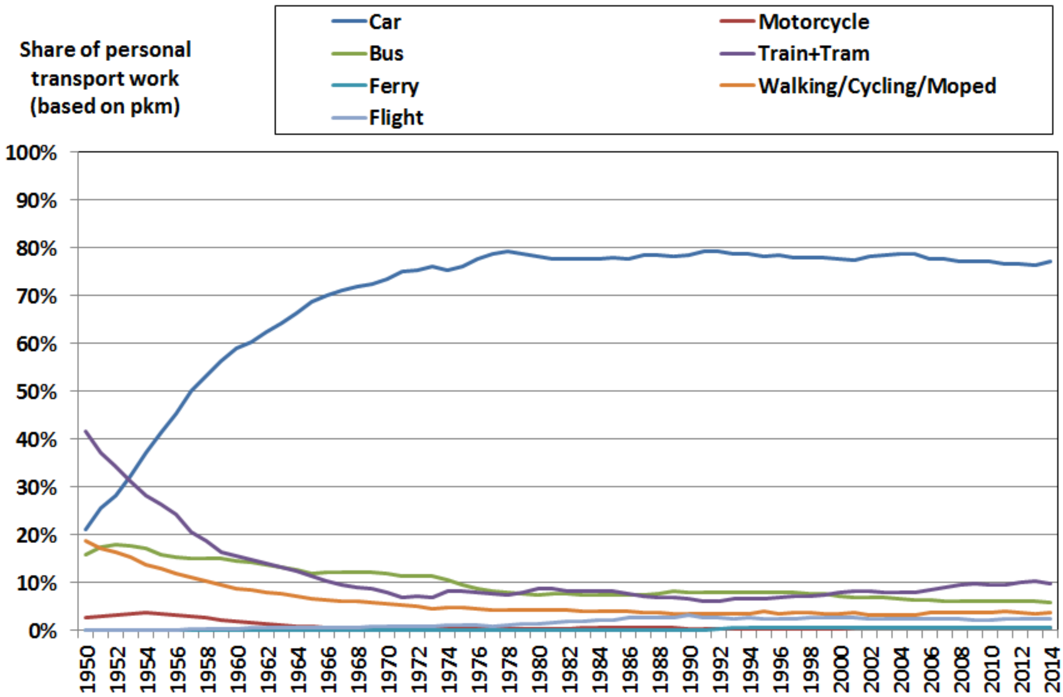


Figure 3: Share of transport work between modes of transport in Sweden. Top figure for freight transport is based share of total tonne kilometres (tkm) per year for each mode of transport and bottom figure for personal transport is based on share of person kilometres (pkm) per year.

Source: Trafikanalys, 2016

This case study explores an ambitious decarbonisation transition for heavy duty vehicles in Sweden's freight sector. In Sweden and globally, there remain knowledge gaps on heavy transport that are important to assess mitigation potential and facilitate the transition. The IPCC's fifth assessment report highlighted both technological and behavioural knowledge gaps in transport that relate to freight and heavy duty vehicles, including transport innovation processes, infrastructure requirements for low-carbon transport fuels and social acceptance and behavioural insights for more reliable projections of mobility (Sims et al., 2014).

Sweden provides an interesting case study due to its high ambition in reducing GHG emissions as well as meeting the Sustainable Development Goals, its export-oriented economy together with its large domestic freight task and the significant role the heavy vehicles industry plays in truck technology development in Sweden and globally.

The freight transport task in Sweden is driven by the economy's dependence on trade-dependent industrial sectors such as vehicles and high-tech machinery, which are high up the value chain (i.e. higher margin product) and heavily dependent on supply chains (Statistiska Centralbyrån, 2015a). Domestic industries such as forestry also drive significant demand for freight transport. The large geographical size of Sweden and its low population density constrain the reach of the national freight rail network. At approximately 20% of total freight-kilometres travelled, the modal share of rail freight in Sweden is higher than the EU average of 11% (European Commission, 2013). However, the limited capacity for rail expansion to meet future freight needs means that rail does not offer a viable alternative to road freight. Partly owing to this, road transport accounts for a large and growing proportion of GHG emissions in Sweden. In 2013, 33% of total GHG emissions were from road transport compared to 28% in 1990. Heavy duty vehicles accounted for 21% of total domestic transport emissions in 2014 compared to 16% in 1990 (Naturvårdsverket, 2015).

Developments in truck technologies in Sweden will also have important implications worldwide. Sweden is home to Scania and Volvo Trucks, global companies with significant R&D programs and large market shares in trucks and engines in Europe and globally. While innovations are typically incremental, both companies are highly innovative as the capacity to reconfigure or substitute technology to adopt to changing market conditions is fundamental to their business strategy (Berggren et al., 2015). Volvo Trucks competes with Daimler as the world's largest truck manufacturer with an annual production of 220,000 trucks and Scania is in the top ten manufacturers with an annual production of between 59,000 and 66,000 trucks in addition to an extensive manufacturing program for truck components (Berggren et al., 2015). Their size and prominence in the market are central to the development of alternative fuel technologies to enable decarbonisation efforts in road freight, both in Sweden and abroad.

The Government of Sweden has committed to being one of the world's first fossil fuel-free welfare states. High political ambitions for a GHG-neutral transport sector in 2030 have been clearly stated in policy documents since 2008,[1] and the overarching goal of becoming a fossil fuel-free welfare state since 2015 (Regeringskansliet, 2015a). In the transport sector, Sweden has set a goal for a fossil-fuel-independent vehicle fleet by 2030[2] but the interpretation of this is a matter of much debate. The overarching ambition is certainly in line with the outcomes of the Paris climate agreement of December 2015, but to date there is no firm plan in place to guide the required shifts in the transport sector to meet this goal.

There are other jurisdictions confronting the same challenge of road freight decarbonisation in Europe and abroad. These efforts could both inform and be informed by the findings of the Sweden case study. Other jurisdictions could learn from the ambition of Sweden's policy goals and its efforts to implement its goals. The potentially pioneering role of the country's truck industry could have wide-ranging impacts, but it is also potentially fragile given its business relies on global markets which may not offer the same incentives as those in Sweden. At the same time, lessons from pilots of new road freight technologies in other jurisdictions, such as electrified road technologies that are being piloted in the United States, could benefit the case study's analysis of similar pilots being conducted in Sweden. To facilitate this transfer of knowledge between Sweden and other jurisdictions, our research will include an international outlook to identify policy and industry approaches that may align with or differ from those being pursued in Sweden. Our research will also draw from historical examples of industrial and technological shifts in Sweden, some of which have included successful cooperation between Government and business.

In the succeeding sections of this report, we will outline the case study's research questions (Section 1.1), introduce the general context relevant to the case study, building on the overview provided above (Section 1.2) and finally explain the specific innovation issues relevant to the case study (Section 1.3).

[1] Klimat Prop. 2008/09:162: "En sammanhållen svensk klimat- och energipolitik" (A coherent climate and energy policy).
[2] SOU 2013:84: "Fossilfrihet på väg" (Swedish Government Official Report: Fossil fuel independent vehicle fleet)

1.1 Research questions for the Sweden case study

Through this case study, we aim to explore transition pathways to decarbonisation of road freight by heavy duty vehicles to meet the Government of Sweden's goal of a fossil fuel-independent vehicle fleet by 2030. The case study will include a time horizon of 2050, based on the TRANSrisk case study framework, which captures the period of the 2030 goal and its continued implementation in subsequent years. Questions that arise when considering how this transition could occur in a sustainable way relate to the patterns of future freight demand, innovation processes related to technology changes and the economic and system-wide impacts of policy and industry efforts to pursue the transition.

The initial research questions for our case study on road freight in Sweden are presented below.

1. What are the social, environmental and economic drivers and barriers in Sweden, Europe and globally that shape future freight requirements for heavy duty vehicles in Sweden in 2050?
2. To meet the identified freight requirements, how would road transport related to heavy duty vehicles change in order to meet the national goal of a fossil fuel-independent vehicle fleet by 2030?
    a. Which non-fossil fuel and truck drivetrain technologies could be used?
    b. What are the system-wide costs, benefits and risks of the associated changes in the transition(s)?
    c. What are the interests and capabilities of actors in the value chain and how do they influence the transition(s)?
3. To pursue the transition(s) in road freight transport related to heavy duty vehicles in a sustainable way, what governance approach needs to be developed?
    a. What governance interventions such as policy options and industry initiatives (within Sweden and Europe) could support implementation of the identified transition(s)?
    b. What are the key uncertainties of the transition(s) and what are they dependent on (e.g. technology, actors' priorities and perceptions, external factors, etc.)?
    c. What are the risks and opportunities of the policy options and industry initiatives associated with the transition(s)?

These initial research questions and the scope of the case study will be refined in consultation with stakeholders and project partners. Our approach to stakeholder engagement, including a participatory process with policy and industry stakeholders to explore the transitions from a system-wide perspective, is outlined in Section 1.5.

1.2 Introduction to the general context

1.2.1 Policy overview

As an EU Member State, Sweden jointly formulates EU policy and is required to implement legislation fulfilling EU directives on climate change, energy and transport and is legally bound by EU regulations that take direct effect. Mobility in general is included in EU sustainability policy through strategic visions such as the "Roadmap to a Single European Transport Area" White Paper,[3] which identifies the challenges to sustainability of the sector, the GHG emission reductions needed to reach overall targets (60% reduction by 2050 with respect to 1990 levels for the transport sector at large), technological options such as energy efficiency and alternative vehicle technologies and possible regulatory mechanisms to achieve these goals. However, for heavy road freight transport, EU regulations and targets geared toward reducing GHG are currently scarce, and primarily include or relate to:

- The Renewable Energy Directive (EU-RED) mandatory minimum target of 10% for the share of renewable energy in the transport sector by 2020[4] (Sweden has already met this target).
- Rules on technical requirements for the type-approval of heavy duty vehicles and their engines with respect to emissions.[5]

Since the road-based transport sector is not included in the EU Emissions Trading System (ETS), and specific regulation on CO_2 emission standards is only in place for personal vehicles, greenhouse gases from heavy vehicles remains largely unregulated. As a result, CO_2 emissions from heavy road-based transport in the EU rose by 36% between 1990 and 2010. The EU has recognised that the current policy framework is not sufficient to reach its climate goals (European Commission, 2016a). There are initial developments toward fuel efficiency standards for heavy duty vehicles in Europe with a consultation ongoing in 2016 (European Commission, 2016b). It is noteworthy that regulations for fuel efficiency standards for heavy vehicles have recently been finalized in the United States and a precedent on how to develop such regulation jointly with industry now exists (EPA, 2016). Until progress is made in this direction or road-based transport is included in the ETS, regulation on CO_2 emissions will remain largely up to each member state through local taxation and other policy measures.

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[3] COM/2011/0144: European Commission White Paper "Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system")

[4] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources

[5] Regulation (EC) No 595/2009 of the European Parliament and of the Council on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information

Sweden was a member of the EU delegation that adopted the Paris Agreement under the UNFCCC in December 2015. In April 2016, Sweden signed the Agreement and on 4 October 2016, the European Parliament approved its ratification, paving the way for EU Member States to ratify the agreement in their national parliaments (European Commission, 2016c).

The two national goals most relevant to this case study are to be one of the world's first fossil fuel-free welfare states and the goal of a fossil fuel-independent vehicle fleet by 2030, outlined in the introduction to Section 1. This should be viewed as a continuation of historical commitments to develop alternative transport fuels and technologies with a long precedence of taxation of CO_2 emissions in all sectors (Riksdagsförvaltningen, 1994),[6] and a strong focus on government supported innovation and technology development (Hillman and Sandén, 2008a; Nilsson et al., 2012a; Nykvist and Whitmarsh, 2008). Today these efforts continue, for example through a large joint government and industry funded research program on climate, environment and safety aspects of vehicles, named FFI - Strategic Vehicle Research and Innovation (Vinnova, 2016).

1.2.1.1 Natural resources and environmental priorities

Before turning to more detailed descriptions of the energy use in the transport sector, we first give a brief overview of the Swedish energy system. Final energy use by energy carrier is shown in

Figure 4 and electricity production by source is shown in igure 5 and Table 2. Sources of greenhouse gas emissions by sector were presented in Figure 1 as part of the introduction to Section 1.

[6] SFSD 1994:1776 "Lag om skatt på energi" (Law on energy tax)

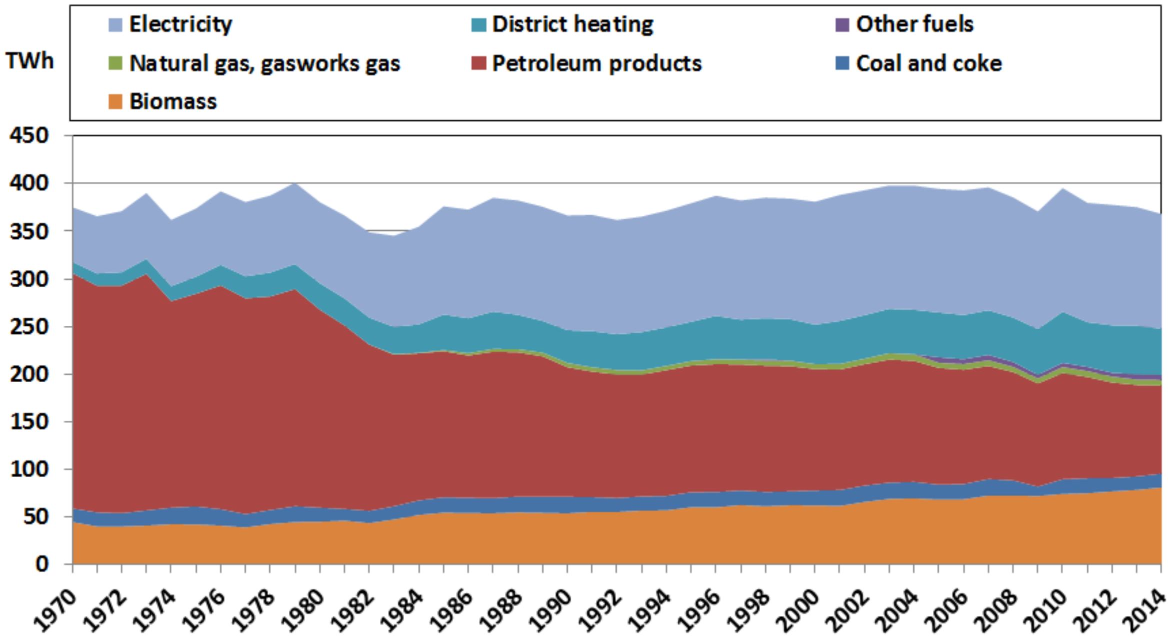

Figure 4: Total Final energy use by energy carrier

Source: Energimyndigheten, 2016b

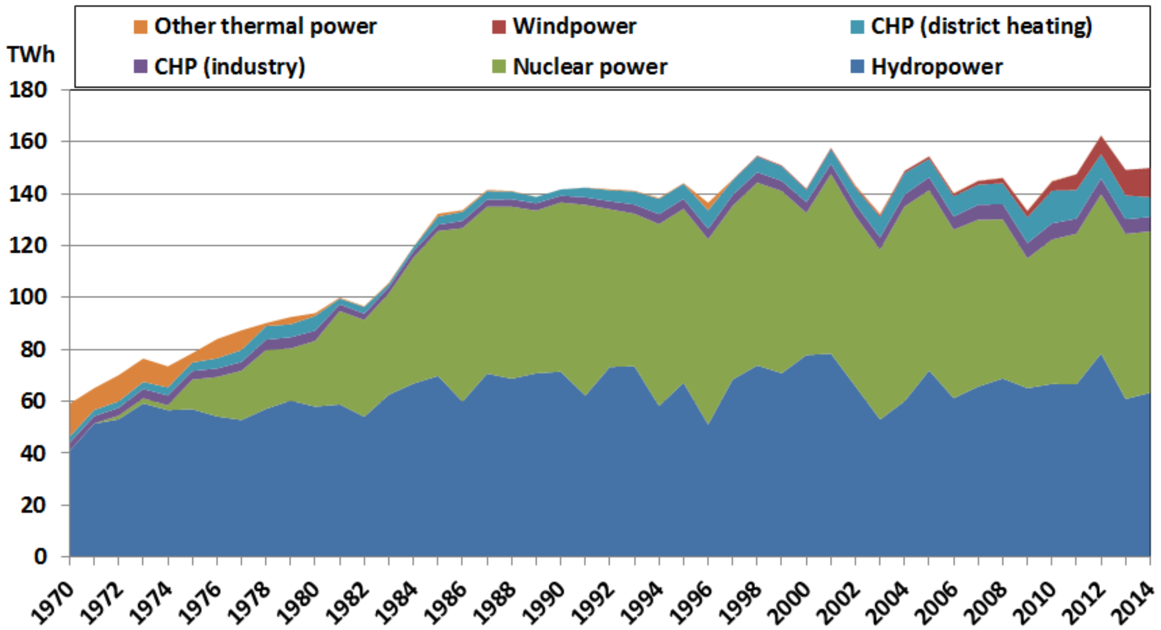

Figure 5: Electricity production (without thermal losses in nuclear power)

Note: CHP is combined heat and power *Source: Energimyndigheten, 2016b*

Table 2: Electricity production (without thermal losses in nuclear power) in 2014

Electricity source	Energy production (TWh, 2014)	Proportion of total (per cent)
Hydropower	63.3	42%
Nuclear power	62.2	41%
Windpower	11.2	7%
CHP (district heating)	7.6	5%
CHP (industry)	5.6	4%
Total electricity production	**150.0**	**100%**

Note: CHP is combined heat and power *Source: Energimyndigheten, 2016b*

Fossil fuels dominate road transport fuels in Sweden with conventional petrol and diesel accounting for 35% and 45% in 2014 respectively (Energimyndigheten, 2016a, 2016c). As shown in Figure 2, biofuel consumption has increased in Sweden due to concerted policy efforts to prioritise both biofuel production and consumption. In 2013, biofuels accounted for 13% of total transport fuel consumption in Sweden, thereby making it the only EU country to have already met the EU-RED target of 10% renewable energy in transport by 2020 (Energimyndigheten, 2016a; European Commission, 2015).

Biofuel has a long history of development in Sweden (Hillman and Sandén, 2008a; Johnson and Silveira, 2014). According to Hillman and Sandén (2008) the development can be divided into three periods in which different external forces influenced the course of events. First, there was a large-scale oil substitution with methanol, gasified coal and wood, triggered by oil crises and the associated increase in oil price during the period 1974 until 1985. A desire for energy security and a degree of independence from oil imports resulted in national competences being developed in gasification, which survive to this day. Then, a focus on reducing air pollution in cities from 1986 until 1997 led to a focus on ethanol, natural gas and biogas with some attention to electric vehicles before the third period from 1997 until 2004 in which climate change increasingly gained attention and oil prices rose, leading to a renewed interest in gasified biomass and ethanol, while biogas moved towards large scale diffusion. In more recent years, ethanol, while still blended at typically 5% in all petrol (the Government allows up to 10%), has declined in importance as fuel for flexi fuel cars in the form of E85 (85% ethanol) primarily due to changing legislation on biofuel subsidies and taxes (Nykvist and Nilsson, 2015; Sanches-Pereira and Gómez, 2015). Hybrid and battery electric vehicles have instead started to gain prominence (International Energy Agency, 2016), driven largely by the same factors in the third period suggested by Hillman and Sandén (2008). Over this final period biodiesel has also increased, driven partly by the same global factors but also due to the availability of black liquor residues from the Swedish pulp industry that is being successfully transformed into biodiesel at a high volume at a 3MW pilot plant in Sweden (Andersson et al., 2016).

The chart in Figure 6 shows the change in all transport fuel consumption by type, which demonstrates the substitution of petrol for ethanol-blended petrol and biodiesel-blended diesel.

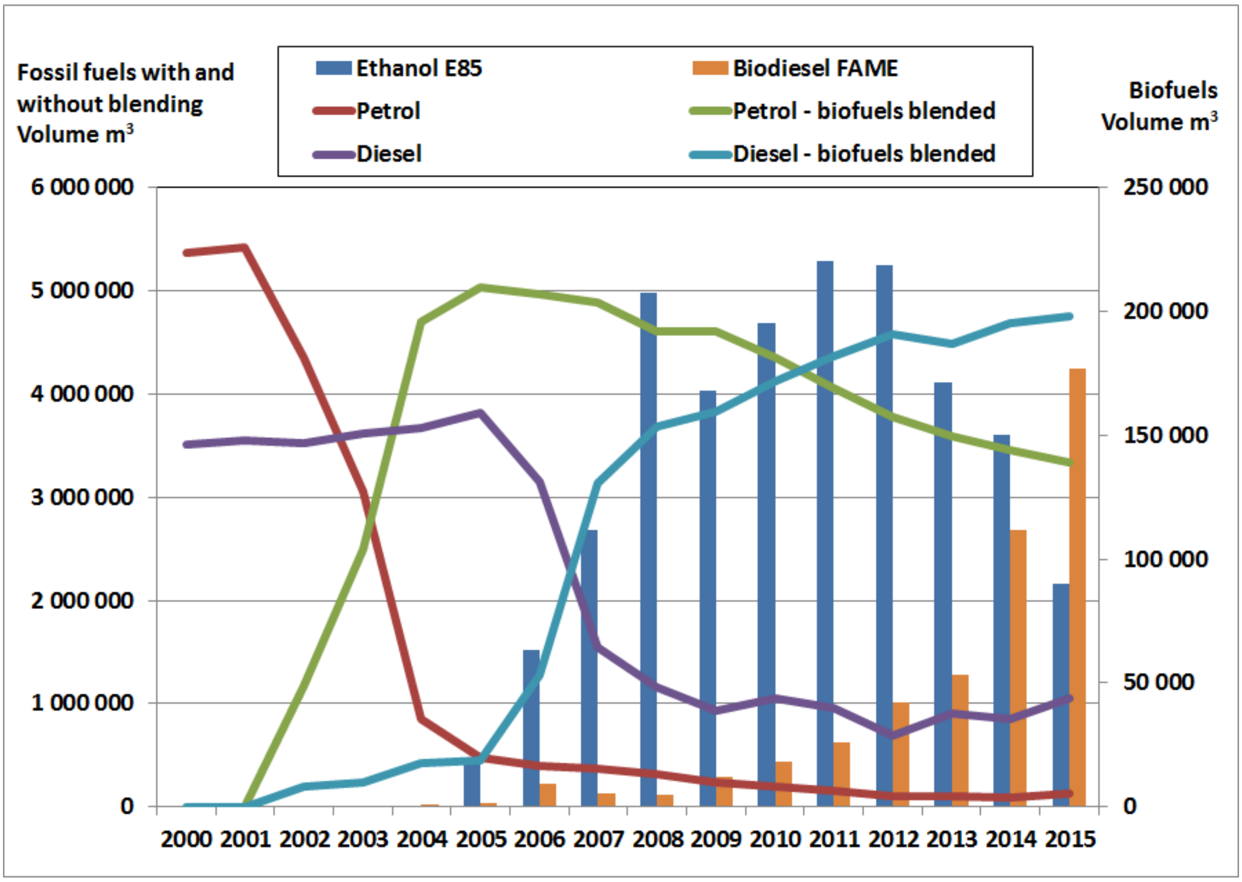

Figure 6: Development of biofuels in road based transport from 2000 until 2015. FAME stands for Fatty acid methyl ester

Source: SPBI, 2016

Sweden has a large potential to further increase current use of biofuels based on biomass from the agricultural and forestry sector (Hillring, 2002) with recent estimates being 42TWh potential annually, in the order of four times the current annual biofuel use of 11 TWh (Börjesson et al., 2014). A long-term scenario with high levels of bioenergy in the transport energy mix appears to require imports of energy (Börjesson et al, 2016). Future scenarios are beginning to consider electricity alongside bioenergy for transport as there are currently strong efforts to pursue electrification of roads in Sweden and globally that show promise (Börjesson Hagberg et al., 2016). Energy security, which as noted earlier has been an important objective in the development of alternative fuels in Sweden, is likely to be one of numerous factors affecting the future development of bioenergy and electricity. Although it is not clear how important this is *apriori*, we will thus explore the influence of this objective in our case study.

1.2.2 Economic priorities

Sweden was the EU's eighth largest economy in absolute terms and had the EU's tenth highest per capita level in 2015 (Eurostat, 2015). In 2016, output growth in Sweden was 3.4% per annum, which is underpinned by strong export and investment growth according to the OECD (OECD, 2016). Unemployment is around 7% of the labour force. Figure 7 shows the change in GDP and unemployment rate in Sweden over the period from 2010 to 2015.

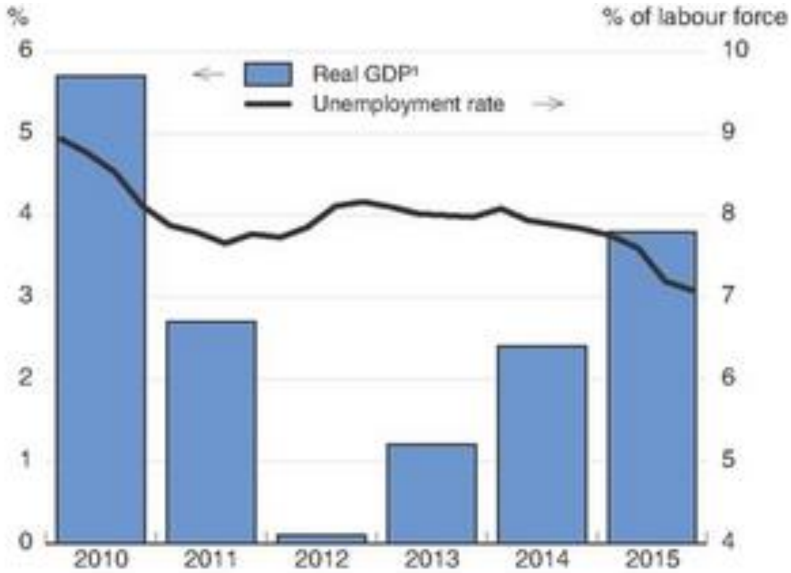

Figure 7: GDP growth rate, adjusted for inflation, and unemployment rate in Sweden over the period from 2010 to 2015

Source: OECD, 2016

According to the Observatory of Economic Complexity database, Sweden was the thirty-first largest exporter in the world by value in 2014 with a positive trade balance of USD 5.78 billion (Simoes and Hidalgo, 2014). Statistics Sweden identified road vehicles (including parts and accessories) as the largest import and export category in 2015 with a value of 138 billion kronor (EUR 14.75 billion) for exports and 132 billion kronor (EUR 14.11 billion) for imports (Statistiska Centralbyrån, 2015a)[7]. The next highest export categories in 2015, based on the United Nations Standard International Trade Classification (SITC), included non-electrical machinery and appliances, pulp and paper and pharmaceuticals. The largest import categories in 2015 included mineral fuels, electronics and non-electrical machinery and appliances. The Government of Sweden has made broad policy commitments to strengthen exports and export-oriented industries in its Export Strategy, released on 10 December 2015 (Regeringskansliet, 2015b).

[7] Exchange rate based on the average over 2015: 1 EUR = 9.3535 SEK, drawn from (European Central Bank, 2016)

Fluctuations in the global economy have the most significant impact on trade-reliant economies and Sweden's open economy is no exception. Economic growth rates in Sweden have dropped and risen in response to the adjustments following the financial crisis of 2007-08, as shown in the chart in Figure 8.

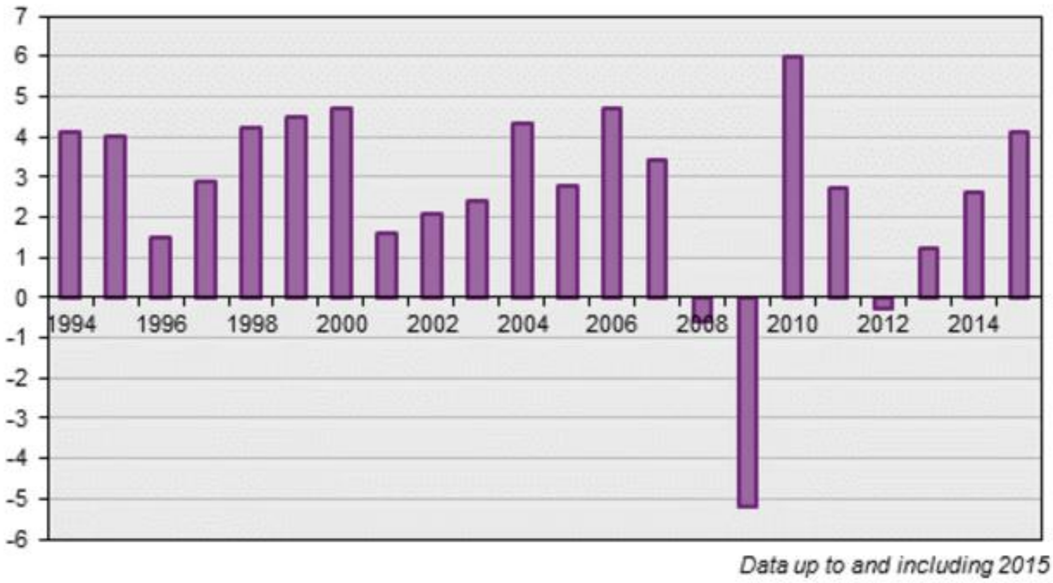

Figure 8: Change in GDP in Sweden as a percentage from 1994 until 2015

Source: Statistiska Centralbyrån, 2016a

Sweden is a leader in innovation and consistently ranks highly in regional and global indices. The European Innovation Scoreboard 2016 gives Sweden the top ranking (European Commission, 2016d) and the Global Innovation Index for 2016 ranks Sweden second (Global Innovation Index, 2016). Part of the reason for this may be the high investment per unit of GDP in research and development in Sweden. According to Vinnova, Sweden's government agency promoting innovation, total R&D investment in Sweden in 2009 comprised 3.6% of GDP, 70% of which was by the business sector (Vinnova, 2013). The transport sector's long tradition of support for innovations in alternative fuels, as outlined in Section 1.2.1.1, is an example of how R&D investment can influence a sector's development (Hillman, 2011; Nykvist and Nilsson, 2015; Nykvist and Whitmarsh, 2008). Vinnova itself is an important part of the enabling environment for innovation in Sweden with its support to business and research initiatives through both funding and technical support.

1.2.3 Societal priorities perspective on climate change

The population of Sweden was 9,920,881 with a population density of 24.2 people per square kilometre, as of 31 July 2016. Population is concentrated in urban centres in the southern part of the country while rural areas are sparsely populated, especially in the North. The country's total land area is 407,310 km^2 and 447,434 km^2 (when inland lakes are included) and its sea territory is a further 81,014 km^2 (Statistiska Centralbyrån, 2016b). The population is projected to reach about 13 million by 2050 assuming the same level of migration as today (Statistiska Centralbyrån, 2015b).

Sweden has been active in the development of the Sustainable Development Goals (SDGs), agreed at a United Nations Summit in New York on 25 September 2015. The Government of Sweden also initiated a High Level Group of nine world leaders with the aim of maintaining momentum after the SDGs adoption and driving implementation (Regeringskansliet, 2015c). While Sweden is identified as one of the best-prepared countries to take up the SDGs, there remain challenges where historically good performance could be undermined without sustained and concerted efforts. This includes sustainable consumption and production patterns where Sweden, like other high-income countries, has not taken strong action to reduce impacts from its consumption along international supply chains (Weitz et al., 2015). This is relevant to the development of the freight transport sector where technologies and fuels potentially depend on international supply chains where the use of land, water and materials are accounted for outside the territory of Sweden.

Sweden has comparatively low income gaps, with a historically strong preference for income redistribution and universal rights rather than means-tested welfare systems. This is often argued as a means of building social trust and cohesion in society and is possible through a greater willingness to accept higher taxation (Rothstein, 2005). However, income equality has been highlighted as one potentially challenging area for Sweden to meet in its national implementation of the Sustainable Development Goals. Although the rates of income inequality are amongst the lowest in the OECD, Sweden experienced the EU's largest increases in inequality between 1985 and 2010, owing in part to challenges related to social, political and economic inclusion of immigrants (Weitz et al., 2015).

Employment in industries related to road freight totals around 136,000, but the Scandinavian Automotive Supplier Association argues that around half a million further jobs are dependent on the sector in addition to those directly employed by it (FKG, 2016).

1.2.4 Politics of energy development priorities

Energy policy in Sweden is often governed through political consensus to ensure long term stability of conditions for industry and consumers in the country. In this tradition, five major political parties in Sweden, including the coalition in Government, signed a Framework Agreement on Swedish energy policy in June 2016. The agreement sets out a road map, which is stated to govern "a controlled transition to an entirely renewable electricity system, with a target of 100 per cent renewable electricity production by 2040” (Regeringskansliet, 2016). How this political ambition translates to implementation is outlined in the policy overview in Section 1.2.1.

Energy security and the goal of becoming less dependent of foreign oil imports has historically been a key factor in energy politics in Sweden, as discussed in the context of alternative fuels in Section 1.2.1.1. Indeed the security of energy supply is one of three pillars in the Framework Agreement on energy policy in Sweden, the others being ecological sustainability and competitiveness. This is an important explanatory factor behind the historical focus on biofuels innovation (Hillman and Sandén, 2008a; Ulmanen et al., 2009). Similar to the way in which bioenergy became an important focus in the heat energy sector, these developments were accelerated by the oil crises of 1970s. For road based transport, the political discourse on biofuel is complex, with shifting priorities over time. Currently, this can be summarised as a lack of clear vision on how to prioritize further development of biofuels, particularly second generation ethanol production, since second generation biofuels have attained some priority at the EU level.

1.2.5 Conflicts and synergies of priorities

At this early stage of the case study’s development, we are not in a position to analyse conflicts and synergies of priorities discussed in Section 1.2. Here, we pose possible questions that might present themselves as we pursue our research. Some relevant questions, drawing from our research questions in Section 1.1 may include:

- Could a large-scale transition to any alternative fuels and drivetrains for trucks lead to problems in the supply chain for that fuel and technology?
- What resource constraints are there for large scale expansion of battery technology i.e., drawing on existing studies of Kushnir and Sandén, 2012?
- What trade-offs exist in the development and use of biomass for biofuels, drawing on existing scenario studies such as Börjesson Hagberg et al. (2016) and Börjesson et al. (2014)?
- What road safety and national security issues may be associated with the infrastructure to facilitate the development of new fuels and drivetrain technologies, for example public safety associated with vehicle collisions with or sabotage of overhead catenary lines for electric highways?
- What national security aspects might be of relevance in a large-scale transformation?

1.3 The Human Innovation System Narrative

Initial research questions for the case study, presented in Section 1.1, focus on defining the future freight task in Sweden, identifying changes required to meet transport and climate goals and determining the governance approach required, including both policies and industry initiatives, to support a sustainable transition to meet these goals. In order to better understand what a sustainable transition means in practice, our research will take a system-wide perspective with a focus on how shifts in the transport and energy sectors may lead to risks and uncertainties in the economy and society more broadly. In seeking to address these questions, the case study will undertake primary and secondary research and will also benefit from the economic and policy modelling capabilities of other TRANSrisk partners.

The initial scope of our research includes three aspects of the transition to fossil-fuel independent road freight by heavy duty vehicles in Sweden: (i) truck drivetrain technology and fuel development; (ii) system-wide scenario analysis and modelling of innovation and energy policy; and (iii) risk and uncertainty assessment of efforts to pursue the transition, including choices of technology, policies, actors' priorities, perceptions and other factors.

Our analysis of truck drivetrain technologies for road freight decarbonisation will include the associated fuels as well as the systems that surround the technologies and fuels. Fossil fuel-independent driven drivetrain technologies that are relevant in Sweden include: internal combustion engines fuelled by biodiesel or biogas, electric and battery hybrid engines and the long term possibility of fuel cells and hydrogen. Of these technologies and fuels, electrification has received the least attention in the literature (Berggren et al., 2015). There have been strong research and development initiatives on electrification of heavy duty vehicles in Sweden in recent years with pilot activities of two different technologies currently underway. One pilot is testing hybrid and/or battery electric trucks with in-road conductive configurations (electric tracks built into the road) while the other is testing overhead catenary lines (cables overhead similar to electric trains). These electrification pilots are shown in Figure 9.

To address the research questions in this case study and consider the potential for technologies and fuels to support the decarbonisation of road freight in Sweden, there appears to be a need for primary research on electrification technologies. The pilots in Sweden and access to the stakeholders involved also provide a unique opportunity for primary research. The case study can draw from a larger volume of secondary sources on the other identified technologies and fuels, particularly biofuels where literature incorporates both future scenario analysis and life cycle assessment. While detailed analysis of upstream fuel and technology supply chains is outside our case study scope, secondary sources provide good analysis to draw from.

Overhead catenary lines pilot
Photo: Region Gävleborg

In-road conductive pilot
Photo: eRoadArlanda

Figure 9: Pilots of heavy duty vehicle electrification in Sweden

As the research is explicitly future-oriented, the case study also includes consideration of the development of future freight transport demands and associated responses in how these services are supplied. On the demand side, this could include possible shifts in the volume and patterns of demand (e.g. industries becoming more service-oriented and an enhanced focus on local circular economy) as well as technological disruptions (e.g. 3D printing). On the supply side this could include interaction between road freight and other modes of transport (rail, sea, air and others) and newer emerging business models that may influence the development of truck technology and service provision (e.g. advanced information technology related to logistics operations and driverless technology).

1.3.1 TIS life cycle value chain: a cradle to grave analysis

Our conceptualisation of freight transport decarbonisation is represented by freight demand (the movement of goods domestically and import/export) and freight supply (truck industry, fuels and technologies, logistics), alongside the enabling/limiting environment (authorities, agencies, policies, conventions and external factors) and facilitating services and infrastructure (academic and R&D, businesses, finance and road infrastructure). A short description of the specific nodes in our conceptual value chain is presented in Table 3. A draft system map for the case study is presented in Figure 11 (see Section 1.4), which places the value chain nodes in the context of the stakeholders and concepts involved in the enabling/limiting environment and the facilitating services and infrastructure.

Table 3: Value chain nodes for road freight decarbonisation in Sweden

Value chain node	Description	Associated stakeholders
Freight task	Demand for the movement of goods generated by industries dependent on imports and exports as well as the domestic trade.	• Freight-dependent industries
Freight operations	Arrangement, dispatch and receipt of goods by major roads within Sweden to service demand generated in the freight task, including to and from ports, airports, intermodal road/rail junctions, major industrial centres and sources of natural resources such as forests.	• Logistics industry
Heavy duty freight vehicles	The different truck types and configurations that move goods by major roads within Sweden.	• Truck industry
Truck components	The build components of heavy duty vehicles that are relevant to energy use, including the drivetrain and chassis types.	• Truck industry
Propulsion type	The engine type used by each heavy duty vehicle type, including the internal combustion engine, biofuel-modified internal combustion engine, electric hybrid engine among others.	• Truck industry • Academic and R&D
Energy supply:	The means of supply of energy to the different engine types such as diesel and biodiesel fuel for internal combustion engines, while electric roads include batteries, in-road conductive or overhead catenary lines in addition to diesel and/or biodiesel.	• Technology supply chains • Fuel supply chains • Road infrastructure • Truck industry • Academic and R&D
Energy carrier:	The means of delivering the energy supply to the different truck types, which includes the electricity grid, imported fuel and domestic fuel production.	• Fuel supply chains
Energy source	The feedstock for the energy supply, which includes domestic and international oil extraction and processing, crops and residues from agriculture and forestry, industry residues and electricity.	• Fuel supply chains
Materials, land, air and water	Inputs and outputs from production, distribution and use of technologies and fuels.	• Technology supply chains • Fuel supply chains

Each value chain node also includes stakeholders characterised as “authorities and agencies”, “finance” and “road infrastructure”, which are part of the enabling/limiting environment and facilitating services linked to the value chain. More information on the stakeholders identified in this case study is presented in Section 1.5.

1.3.2 Enabling environment: policy mixes in the socio-economic system

The most critical areas of policy relevant to the case study are the policy mixes on energy, climate and greenhouse gas emissions. Selected policy instruments in these areas are presented in Table 4, together with broader policy themes that may influence the decarbonisation transitions in the road freight sector.

One area where numerous policy instruments exist at both national and EU levels relates to bioenergy. Sweden has relatively high taxes on fossil fuels through both energy and CO_2 taxes, whereas biofuels are often exempted. Swedish biofuels legislation in turn implements the visions and goals in the EU renewable energy directives. As discussed in Section 1.2.1.1, less favourable taxation has, since 2009, resulted in blending of biofuels in diesel rather than pure biofuels such as E85.

Beyond specific policy instruments, energy policy in Sweden is influenced by broad policy themes and strategies. National security and, specifically security of energy supply, is among these longstanding themes of Swedish energy policy. While this constitutes a key pillar of the recent Framework Agreement on Swedish energy policy, as discussed in Section 1.2.4, there are no specific policies governing this, rather it is usually implemented through incremental changes to the regulatory system in terms of monetary policy, bans, emission standards, taxation as presented in Table 4.

Table 4: EU and Sweden policy instruments related to the road freight transport

Policy themes	EU	Sweden
Energy	• Renewable energy directive • State aid rules preventing direct state support for companies • Broad policy strategy on energy security of supply	• Electricity and fuel tax (both on energy and CO2 emissions) • Exemptions from tax in energy intensive industry • Renewable energy certificates • Local incentives and tax differentiation for regional development purposes • Regulation of energy market (electricity market is deregulated) • Broad policy strategy on energy security of supply
Climate	• Not available (i.e. road-based sector not captured by the EU ETS)	• CO_2 tax exemptions for biofuels, and plug-in electric vehicles. • Policy vision of fossil free transport sector and fossil free welfare state.
Technology	• Fuel efficiency standards for heavy duty vehicles possible in the future	• Public procurement for innovations • Grid infrastructure regulation including safety regulations and permits/ concessions
Air	• Emission standards	• Emission standards
Resource use	• Renewable energy directive	• Biofuel blending, biofuel policies
Agriculture and water*	• Common Agricultural Policy (CAP), land use policy, Water framework directive (WFD)	• Bioenergy crops regulation, forest management law
Biodiversity*	• Habitat Directive	• Protected areas • Land use policy generally: ○ National level (e.g., road infrastructure is of "national interest") ○ Locally, municipal planning monopoly

<u>Note:</u> ** Agriculture, water and biodiversity policy is linked to the road based transport sector through biofuels policy and coherence between these two policy areas is important and clearly non-trivial (Nilsson et al., 2012b). In general, planning policy/practices has a direct link to biodiversity loss due to fragmentation of habitats and landscapes and is included in the table. However, such analysis will be beyond the scope of this case study.*

1.3.3 Enabling environment: government institutions

Road-based transport in Sweden is steered through public actors at all levels of government and elected bodies, as illustrated in Figure 10. The national level contains the government, authorities regulating the sector, as well as temporary agencies in the form of Commissions of Inquiry, which are important temporary bodies of authority that are commissioned in the early stages of the legislation process. The Government and its agencies are represented regionally by the County Administrative Board. National roads are owned, maintained and governed by these governmental bodies of authorities. At the regional level the elected county councils are responsible for local and regional transport (public transport in particular) and regional planning including transport. Municipalities also have a very strong role with essentially a planning monopoly with regard to land use, including all roads that are not private or national roads.

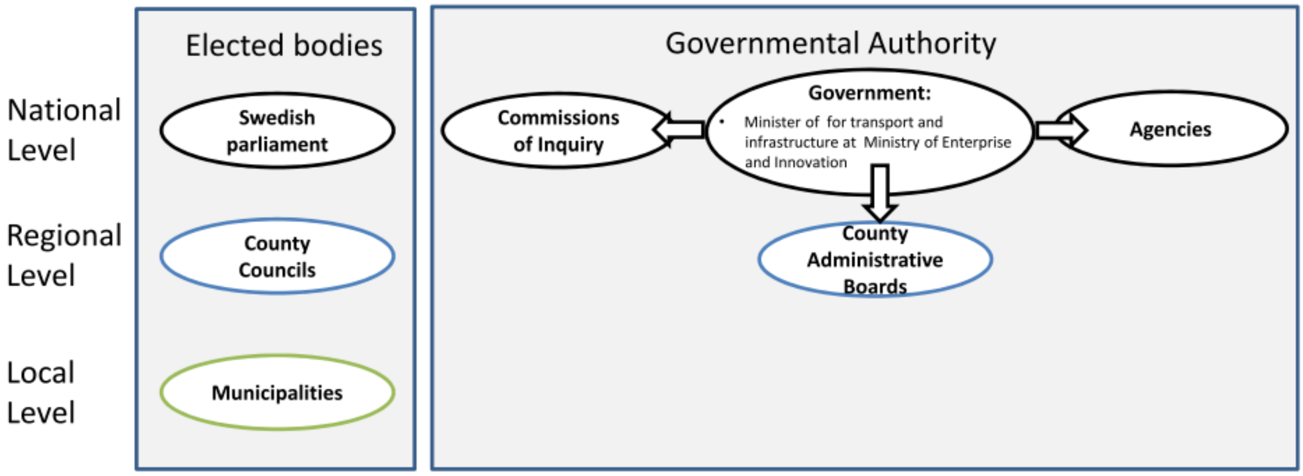

Figure 10: Map of minsters, authorities and bodies involved in public steering of road transport sector in Sweden

The role of agencies in Sweden is unique in that they have strong influence on policy and occupy a rather independent position from government ministries. Table 5 summarizes the agencies related to transport in Sweden, either directly or indirectly, through the energy, environment or innovation policy areas.

Table 5: List of governmental authorities involved in governance of road transport sector in Sweden

Authority	Type	Sector	English title	Responsibility / Link to case
Transportstyrelsen	Agency	Transport	The Swedish Transport Agency	Overall responsibility for commercial transport on roads in Sweden
Trafikverket	Agency	Transport	Swedish Transport Administration	Responsible for long-term planning of the transport system for all types of traffic, as well as for building, operating and maintaining public roads and railways
Trafikanalys	Agency	Transport	Transport Analysis	Reviews bases for decisions, assesses measures and is responsible for statistics
Statens väg- och transportforskningsinstitut (VTI)	Agency	Transport	The Swedish National Road and Transport Research Institute (VTI)	Government agency, but functions as independent and internationally prominent research institute in the transport sector with principal task is to conduct research and development related to infrastructure, traffic and transport
Energimyndigheten	Agency	Energy	The Swedish Energy Agency	Works for a sustainable energy system, combining ecological sustainability, competitiveness and security of supply. Relate to transport sector through energy use
Naturvårdsverket	Agency	Monitoring e.g. GHG emissions	Swedish Environmental Protection Agency	Monitoring of all emissions from all sectors, including GHG emissions from transport sector. Most important agency with regard to Sweden's environmental goals.
Verket för innovationssystem (Vinnova)	Agency	R&D funding	Sweden's innovation agency (Vinnova)	Promote sustainable growth by funding needs-driven research and stimulating collaborations between companies, universities, research institutes and the public sector. Relate to transport through funding of transport research and procurement of projects to stimulate transport innovation
Svevia	Gov't owned company	Transport	Svevia	Builds and maintains the Swedish road infrastructure

Additionally, there are three government-owned companies related to transport: Green Cargo AB for train freight transport (largest actor in sector), SAS AB for aviation transport (largest actor in sector) and SJ AB for personal rail transport (largest actor in sector). Notably this list does not include a state-owned road-based transport company as this sector is to a larger degree privatised whereas rail and air transport have a long history of government ownership not only of infrastructure but also of operators.

1.4 The Innovation System

The draft system map in Figure 11 presents the case study's conceptualisation of the current system for innovation towards fossil fuel-independent heavy duty vehicles in Sweden. It presents the value chain nodes identified in Section 1.3.1 in the context of the enabling/limiting environment and the facilitating services and infrastructure presented in Section 1.3.2. It maps the stakeholder categories introduced in Section 1.3.3 to the enabling/limiting environment or facilitating services and infrastructure. The system map will be further developed during the case study, including by outlining the links between concepts in the value chain, enabling/limiting environment and facilitating services and infrastructure.

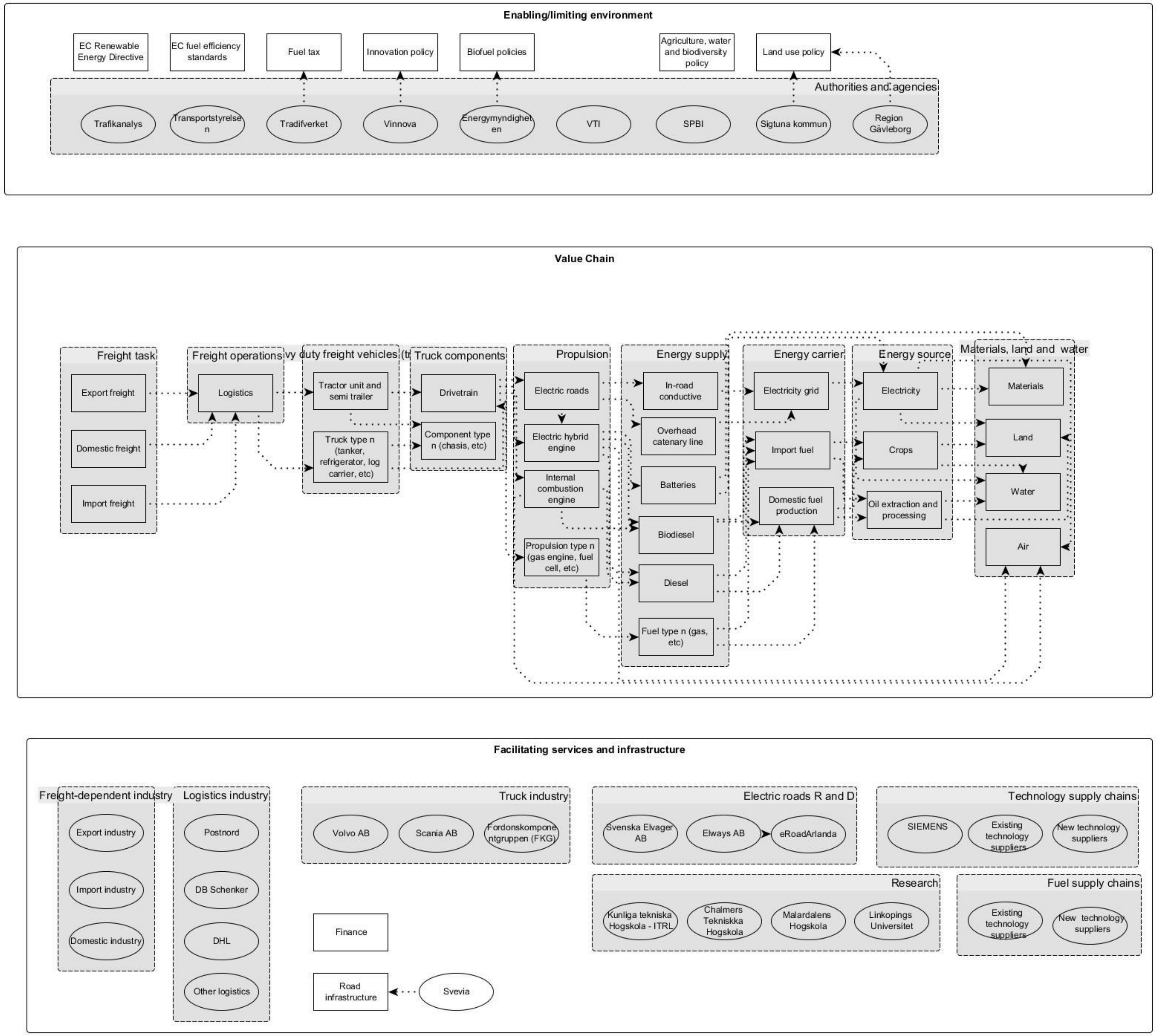

Figure 11: Draft system map for the freight transport decarbonisation

Source: Authors' own analysis

1.5 Stakeholder engagement

Case study stakeholder workshops will have policy, industry and research stakeholders at the same table, contributing to new analysis of the sector. Our initial stakeholder identification process has identified twenty-nine stakeholders across the market chain, the breakdown for which is shown in Figure 12. As can be seen from this chart, most value chain nodes are well represented in the case study's initial stakeholder list, but there are a number of gaps where specific stakeholders are still to be identified, including in the logistics industry, freight dependent industries and finance and road infrastructure sectors. We have identified potential stakeholders for all of these gaps and the most relevant for the case study's research are currently being determined.

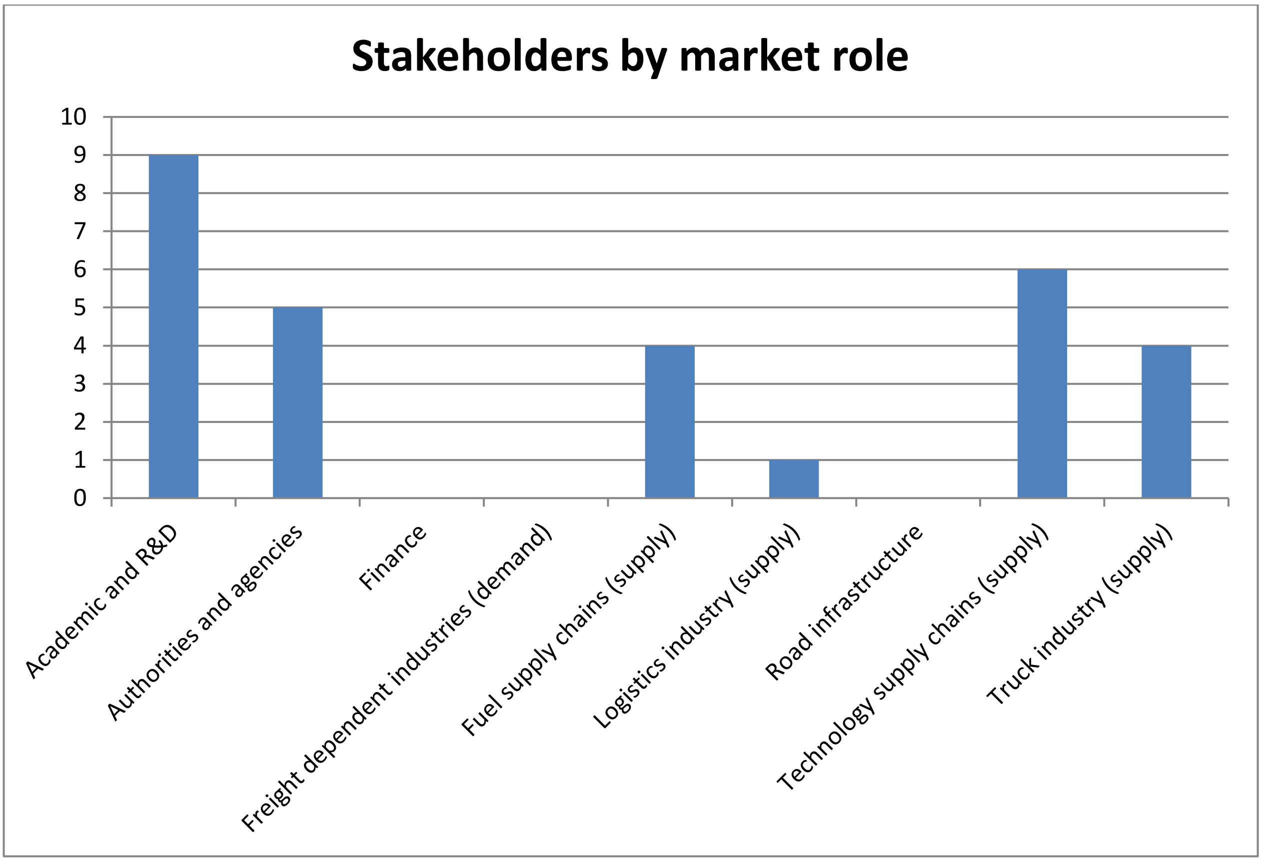

Figure 12: Case study stakeholders by market role

Source: Stakeholder Attribute Matrix, developed by the authors.

Potential benefits for participants to engage with the case study's research are presented in Table 6. This identifies benefits for policy stakeholders and those representing industries.

Table 6: Potential benefits to stakeholders from participation in case study research

Potential benefits of participation in case study research	Policy stakeholders	Industry stakeholders
Opportunity to shape policy research and analysis to contribute to sound policy design that integrates different perspectives on innovation and industrial competitiveness.		✓
Possibility to spread the knowledge from Sweden's relatively advanced discussions/analyses to other countries and regions to understand whether similar options may or may not be appropriate	✓	✓
Access to analysis and modelling of possible transition pathways. TRANSrisk will assess how energy supply and truck technologies may develop and the effect of energy and innovation policies on the industry and other sectors.	✓	✓
Insights from an assessment of risk and uncertainty associated with the transition in Sweden as well as the implications for the energy and technology value chain.	✓	✓
New perspectives on the interaction between technological developments, policies and decision-making roles, through a participatory analysis of innovation systems.	✓	
Opportunity to obtain insights into technology development and new business models as well as the needs and constraints for industry.		✓

Over the course of its implementation until August 2018, we will engage stakeholders in consultation events where the case study's research will be developed, presented and refined. This will include individual interviews and surveys, small group discussions and workshop events. Stakeholders' participation in the case study to date is presented in Table 7 and our initial event plans are summarized in

Table 8, highlighting the participatory stakeholder engagement processes involved.

Table 7: Stakeholder Engagement

	Type of stakeholder	Position in the organisation	Economic sector	Type of engagement	Month and year contacted
1	Business	Chief Executive Officer & Sustainability Manager	Transport	Initial meetings	March and August 2016
2	Research & Academic	Communications Manager	Transport	Initial meeting	September 2016
3	Research & Academic	Director	Transport	Informal discussions	August 2016
4	Government (national)	Policy Officer	Energy	Informal discussions	April 2016
5	Business	Engineer	Transport	Informal discussions	April 2016

Table 8: Initial consultation event plans, timing and expected outcomes

	Stakeholder event	Indicative timing	Consultation outcome
1	Initial discussions/ Interviews/surveys	August 2016 - February 2017	Define scope and case study research questions
2	Focus groups	November 2016 - March 2017	2030 transition visions, pathways and scenario framework: participatory development
3	Workshop	October 2017	Analyse and model pathways with different scenarios
4	Informal discussions	January - August 2018	Further feedback on transitions analysis and modelling

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