Socio-technical scenarios and local practice – Assessing the future use of fossil-free alternatives in a regional energy and transport system

Thomas Magnusson a,b,⁎, Stefan Anderberg b, Sofia Dahlgren b, Niclas Svensson b

a Center for Innovation, Entrepreneurship and Learning Research, Halmstad University, Sweden
b Department of Management and Engineering, Linköping University, Sweden

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ABSTRACT

This article presents results from a project involving local practitioners in the construction of scenarios for a regional energy and transport system. The purpose is to demonstrate how sustainability transitions research can interact with local practice by means of socio-technical scenarios. Combining quantitative data with qualitative storylines, the article presents four scenarios, which describe different ways of using biogas, biodiesel and electricity in four different applications: city buses, inter-city buses, heavy-duty trucks and industrial processes. The article compares the four scenarios in terms of realization possibilities, energy efficiency and greenhouse gas reduction. Focusing on near-term realization on a commercial basis, the research findings suggest that collaborative scenario construction can be a useful strategy to manage conflicting agendas and engage key stakeholders in dialogues on transition pathways.

The article concludes by presenting policy lessons for practice-oriented transition management. The lessons point to the importance of flexibility in system delineations, the critical timing of near-term scenarios, and the use of scenarios to outline local practitioners’ agency.

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1. Introduction

Transition studies are a growing field of interdisciplinary academic research that investigates possibilities to transform large socio-technical systems with the intention to make them more sustainable (Markard et al., 2012). Multiple actors with different agendas, visions, and expectations are involved in such transitions. Hence, scholars argue that transition processes are non-linear, open-ended, and highly contested (Köhler et al., 2019). The multi-level perspective (MLP) is a key founding framework in this research field. This framework points at regimes as the prime source of stability and niches as potential sources of radical change (Geels, 2002). If supported by societal trends, debates, and movements at a higher landscape level, niches may gain power and eventually trigger transformations at the regime level. However, this is an uncertain process, full of contestation between various actors operating at the landscape, regime, and niche levels. In particular, the MLP describes a fundamental conflict between the entrenched socio-technical regime and alternative new system configurations that emerge through experiments and demonstrations in local niches. Transition scholars have assumed various kinds of tensions and contestation, as well as possible synergies and alignment between the MLP-levels as a basis for elaborations of different transition pathways (Geels et al., 2016b; Geels and Schot, 2007).

The MLP-framework and its related transition pathways has been adopted as a conceptual backbone for the construction of scenarios that describe transitions from current fossil-fuel regimes to future low-carbon energy and transport systems (Auvinen et al., 2015; Bergman et al., 2008; Geels et al., 2018; Nilsson and Nykvist, 2016; Raven and Walrave, 2018). Still, studies of low-carbon transport technologies have shown that conflicts and contestation do not only appear between the levels of the MLP-framework. Analyzing competing expectations associated with alternative transportation fuels, Alkemade and Suurs (2012) argue that it is important for proponents of new technology alternatives to raise expectations in order to attract resources. Their thesis finds support in automotive industry studies that show how proponents of innovative vehicle technologies have competed for R&D funding, supportive regulation, and infrastructure build-up at the niche level (Bakker et al., 2012). In a comparative case study of two competing sustainability alternatives for public transport, Magnusson and Berggren (2018) show how such niche-level contestation result in severe dilemmas for policymakers and they further argue that conflicts in niches can block transitions towards low-carbon transport systems.

⁎ Corresponding author at: Center for Innovation, Entrepreneurship and Learning Research, Halmstad University, Sweden.
E-mail address: thomas.magnusson@liu.se (T. Magnusson).

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Contestation between alternative new system configurations will become visible in local practice. Based on a review of transition studies, Hansen and Coenen (2015) argue that local practice has a significant impact on transformative processes. Local visions and policies can mobilize resources and trigger action; urban and regional plans may stimulate development and implementation of certain technologies, and informal institutions can push for regulation to facilitate innovation. Still, previously published scenarios in the transitions field have focused on the national and international policy domains (e.g. Hillman and Sandén, 2008; Nilsson and Nykvist, 2016; Geels et al., 2018; see Auvinen et al., 2015 for an exception). By contrast, this article focuses on a regional context, presenting socio-technical scenarios that involve critical decisions on different fossil-free alternatives in a regional energy and transport system. With the intention to improve energy efficiency and reduce greenhouse gas emissions, the scenarios describe processes that entail substitution of fossil fuels with renewables, as well as redeployment of renewable fuels into new application contexts, thus describing new utilization pathways (Patrizio et al., 2015).

The article highlights the critical role of local policymakers and actor constellations in sustainability transitions. The purpose is to demonstrate how transitions research can interact with local practice by means of socio-technical scenarios.

After this introduction, a theory section presents a conceptual background to transition management and socio-technical scenarios. Then we provide a brief description of the material and methods used in our socio-technical scenario construction. The subsequent section introduces the regional and national scenario context, followed by individual presentations of the scenarios, and a comparative assessment of the results. Thereafter we summarize the actual system/context evolution that took place concurrently with our study. A consecutive section discusses our research in the light of existing literature and a concluding section highlights the main contribution of our research.

2. Transition management and socio-technical scenarios

Sustainability transitions research emerged with the breakthrough of the goal of sustainable development in the 1990s (Loorbach et al., 2017). The basic motivation for this research is that incremental improvements will not be enough to cope with grand societal challenges such as climate change, loss of biodiversity or resource depletion. Instead, radical shifts will be required to transform systems that deliver vital societal functions such as energy, transport, food and clean water. Research in this field aims to explain how such radical transformations may occur without major disruptions in societies. Transition management (Rotmans et al., 2001; Loorbach, 2010) represents a practice-oriented research direction, which has contributed with a prescriptive framework for how researchers can engage with practitioners in collaborative processes to stimulate changes in different contexts. According to Loorbach (2010), transition management entails operational activities with 0–5 years’ time frames, tactical activities (5–15 years), and strategic activities (up to 30 years). In addition, transition management must involve reflexive activities, which are essential “to prevent lock-in and to enable exploration of new ideas and trajectories” (p. 170).

The formation of an arena that gathers pro-active stakeholders in transition-oriented activities has a prominent place in the transition management framework (Loorbach, 2010; Hysysalo et al., 2019; Hölscher et al., 2019). The arena concept offers an alternative to the MLP framework in practice-oriented transitions research. Offering a “flat approach” (Jørgensen, 2012:997), this concept does not presume any levelled arrangements of structures, interventions, and agency. For research that adopts this concept, the agency of individual actors therefore becomes an empirical concern. According to Jørgensen (ibid), this feature is particularly useful for studies of actors’ involvements in ongoing system transformations.

Pointing at the need to engage stakeholders in structured dialogues about transition pathways, Turnheim et al. (2015) claim that it is fruitful to combine socio-technical analysis and initiative-based learning with quantitative scenario modelling. To serve their purpose, the scenarios must be considered plausible, socially acceptable and politically feasible by the actors involved (Geels et al., 2018). Scenario approaches are often presented as indispensable tools for discussion, analysis, policy design, and decision-making related to strategic development issues, which are characterized by large uncertainties (Pérez-Soba and Maas, 2015). Scenarios are neither predictions nor forecasts; they provide an image of the future by exploring different development paths that lead to the broadening of the range of plausible alternative futures. Scenarios can force imagination, make possible a well-focused strategic discussion on specific long-term issues, and provide a coherent framework for evaluating and comparing alternative future pathways. They can be important for evaluating desirable developments, identifying risks in connection with various developments, and for designing policies with the intention to stimulate advancements with few undesirable side effects.

Scenario approaches have been used in connection to sustainability issues in different scales since the mid-20th century and in recent years the number of scenario studies related to energy and transport futures, most often related to climate mitigation ambitions, has grown. There are several typologies and terminologies to characterize scenarios and scenario studies (Börjesson et al., 2006). Most often, one distinguishes between two basic scenario approaches: exploratory or anticipatory (Mahmoud et al., 2009). The former starts in the present and project different trends into the future, while the latter starts by producing an image of a future state, which most often is either desirable (based on agreed goals), undesirable (e.g. future crisis situations) or contrasting (radically different futures), followed by backcasting (originally from Robinson, 1982), trying to concretize how to get there or how to avoid such a situation. Another important distinction is between methodological and informal approaches. In the methodological approach, a certain method or model is employed for ensuring replicability, while the informal scenario construction differs from situation to situation. This does not mean that informal scenarios are unstructured or lack logical consistency, but they have a greater flexibility. The methodological scenarios are predominantly quantitative while the informal scenarios most often are based on a qualitative analysis.

Wiek et al. (2006) argue that scenarios fulfill certain crucial functions in relation to transition management: they can provide the basis for knowledge integration, assessment, and strategy building. Moreover, scenario construction can contribute to competence building by allowing different experts and stakeholders to participate in a mutual learning process. The socio-technical scenario concept was launched with the intention to address system innovation and identifying possible transition pathways in the beginning of the 2000s (Hofman et al., 2004; Hillman and Sandén, 2008). The concept was first a reaction to the predominance of macro-trends of computer model-based methodological scenarios and their inability to include sociopolitical developments: “actors, their decisions, interactions and learning processes” (Hofman et al., 2004:396). In recent years, there have been increasing efforts to combine model-based assessments that consider multiple technology options and sectors (Sandberg et al., 2019) with insights from socio-technical transition analysis and practice-based action research (Geels et al., 2016a), and to merge quantitative and qualitative data to frame and constrain actor-based storyline (Auvinen et al., 2015). Socio-technical scenarios hence include qualitative descriptions, which relate them to the context in which they evolve. Since we share many of the perspectives, ambitions and challenges with these studies, we use the concept of socio-technical scenario in our study.

3. Material and methods

Our socio-technical scenarios show results from a joint research project, in which our university, the local publicly owned energy utility, the municipality and the Public Transport Authority (PTA) were partner organizations. Besides these local partners, representatives for an internationally operating bus and truck manufacturer as well as an internationally operating energy utility with experience of electric bus implementation in other cities were associated with the project (Table 1). Together, the project partners formed a focus group with a dual purpose: to investigate possibilities...
for electric bus implementation while stimulating a further development of biogas production and use in the region. Gathering the partners in recurrent meetings, the project formed an arena for transition-oriented activities. During the project, we arranged 10 half-day meetings. The local partners were represented in all of these meetings and the international partners were represented in seven meetings. We also invited external guests to give presentations in several meetings and we involved other stakeholders in a one-day scenario workshop with 24 participants from 12 different organizations.

We executed the 3-year project concurrently with the PTA’s preparations for the tendering of a forthcoming contract period for their city bus operations. The first half of the project was devoted to investigations, interviews, study visits and simulations1 with the intention to learn about different options. The material gained from these activities served as a basis for scenario construction, which we performed jointly during the second half. The material included operational data obtained from the partners on biogas production, public transport fuel consumption and traffic patterns, publicly available data on regional development trends, as well as data and experiences from electric bus operations in other cities.

Our socio-technical scenarios translate national scenarios proposing a massive implementation of electric city buses down to a local level. We ask what such nation-level scenarios can imply for a region where there is an established production of biogas, and where public transport city buses are a primary application for this fuel. Our scenario construction resulted in four different scenarios, including a baseline scenario based on a projection of recent regional development trends until 2030 without any structural changes of public transport fuel use, and three alternative scenarios characterized by different extents of electric bus implementation and associated changes of biofuel use (see Section 5). The scenarios were based on a combination of approaches. The baseline scenario that provided a common frame for comparing the contrasting scenarios for 2030 is an exploratory scenario that makes projections based on recent development trends. It is based on official statistics of energy use and traffic patterns for the region and it provides a basis for the construction of the other scenarios. Using this well-established scenario approach made it possible for us to create a quantitative image of the future that was easily comprehensible for the project partners and workshop participants. This also added to the plausibility of all scenarios, making it more legitimate to use them in discussions with the involved stakeholders. The alternative contrasting scenarios were anticipatory and based on different what-if assumptions, but within the frame provided by the baseline scenario. We used them for integrating the knowledge developed in the project, for comparing different options, and as a basis for strategic discussions with the project partners. The scenario assessment was primarily focused on identifying central actors and possibilities of realization, an approach that is similar to the focus of backcasting scenarios.

We based the scenarios on three major objectives in accordance with conventional scenario requirements (Anderberg et al., 2000). Firstly, the scenarios should be easy to understand for the actors involved. Secondly, the development of the scenarios and their central assumptions should be satisfactorily explained and motivated. Thirdly, the scenarios must be adapted to their purpose, which in our case was to offer a frame for discussions and decisions on the future use of fossil-free fuel and energy alternatives in a regional context.

Our scenarios focus a regional energy and transport system, including factors that directly influence the development of this system. Together with the relatively simple and straightforward alternative scenarios, the regional focus served to strengthen the relevance and understandability for the practitioners involved. To increase credibility and comprehensibility, we made efforts to explain and motivate the assumptions behind the scenarios. To increase the transparency and the logical consistency, the quantification of the different scenarios is based on consistently applied assumptions and several factors are kept constant in the different scenarios. The quantitative evaluation concentrates on changes in energy efficiency and greenhouse gas emissions.

4. Scenario background and context

For realizing national energy and emission goals, national governments depend on successful local implementation. In Sweden, this dependence is recognized by the fact that each county since 2007 must have a regularly updated energy and climate strategy. The county in focus for our study is Östergötland, which has the city of Linköping as its capital. This county is a national frontrunner for biogas production, a result of close collaboration between the local energy utility, owned by Linköping municipality, and the PTA. The collaboration started in the early 1990s as an initiative to improve the inner-city air quality by substituting diesel buses with gas-fueled buses (Fallde and Eklund, 2015). By means of local biogas production and upgrading, it was possible to implement CNG2-buses even though natural gas was not accessible. Today (in 2019), the local energy utility operates one of the largest biogas production plants in Sweden, a plant that constitutes the core of a well-established regional biogas system and a role model for biogas development in other cities and regions (Ottosson et al., 2019). The production is based on a combination of organic wastes gathered from meat processing, agriculture and households. Local city buses use about 30% of the produced biogas and the utility also supplies biogas to public transport buses in neighboring cities, as well as to public filling stations for use in cars. In a recently published analysis, Mutter (2019) shows how the regional biogas system has a considerable influence on how local professionals imagine the future evolution of energy and transport in the region.

4.1. Transport trends in the region

In terms of population, Östergötland is the fourth largest county in Sweden with 457,000 inhabitants. It is continuously growing with workplaces concentrated to the three major cities Linköping, Norrköping and Motala. Östergötland is very car-dependent, though public transport, biking and walking are common in urban areas. According to a regional travel habit survey by the PTA, 57% of the weekday trips were made by car, 14% by public transport and 26% by bike or foot. In 2016, there were 215,000 registered cars, corresponding to 477 cars per 1000 inhabitants. This figure is very close to the national average but considerably higher than in the three big city regions in the country (Stockholm, Göteborg and Malmö). The regional use of public transport, primarily city buses but also trams and commuter trains, is also limited. The average distance traveled by public transport per inhabitant is only half of the national average. All city buses in the county run on biogas, while diesel buses run in intercity and rural traffic. In 2016–2017, the PTA substituted fossil diesel almost totally with the biodiesel HVO (Hydrotreated Vegetable Oil).

Östergötland is an important industrial region, and freight transports are thus vital. Besides the local and regional transports (83% of the freighted goods in the region is transported less than 150 km), the transit

### Table 1

Organizations associated with the project.

<table>
<thead>
<tr>
<th>Local partners</th>
<th>International partners</th>
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<tr>
<td>Östgötatrafiken – authority responsible for the regional public transport system</td>
<td>Scania – vehicle manufacturer with business activities in heavy-duty trucks and buses</td>
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<tr>
<td>Tekniska verken – energy utility with business activities in electric distribution grid operation and biogas production</td>
<td>Vattenfall – energy utility with business activities in power generation, electric grid operation and electric vehicle charging</td>
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<tr>
<td>Linköping municipality – city council responsible for local public service and urban planning</td>
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1 The simulations considered implementation of alternative electric bus systems in Linköping city. Details about the simulations are provided in Lindgren (2017).

2 Compressed Natural Gas.
traffic is important with several major roads in the country passing the county, e.g. Route E4, the major connection between the national capital Stockholm and the southern and northern parts of Sweden.

The growth of population, transports and related energy use has been significant in recent decades, and there are no signs of slowing down. Table 2 summarizes the change of indicators for transport and energy during the most recent decade. The number of cars grew more than the population. The number of trucks increased by 27%, which indicates a growth of freight transport on short distances. The commuting between cities grew by 32%, which indicates increasing economic integration and labor expansion. Since the growth of public transport has been far less substantial, it seems obvious that public transport has only been able to catch a limited part of the recent expansion of commuter flows. Despite an improved fuel efficiency of cars and trucks, the energy used for transport grew by 20% between 2005 and 2016.

4.2. National visions of fossil-free transport

The Swedish Government has announced a national vision of zero net greenhouse gas emissions by 2045. Nuclear, biomass, and hydropower currently dominate the national energy mix, and the portion of wind power is increasing. This means that transport and manufacturing industry are the most significant fossil fuel users and emitters of greenhouse gases (IVA, 2019). Hence, national strategies and policies for emission reduction tend to focus on these two sectors (Riks djagen, 2017). In 2013, an elaborate enquiry issued by the Swedish Government presented detailed scenarios for a transition to a fossil-free national road transport system (SOU, 2013). Ever since the original reporting of its results, the investigation has had a significant effect on national transport and climate policies. The report claimed that a transition to fossil-free transport depends on significant infrastructural changes and changes in mode of transport, as well as more energy efficient transport operations and substitution of fossil fuels with electricity and biofuels. The report further outlined scenarios for three vehicle categories: cars, city buses, and heavy-duty trucks. The scenarios suggest that biofuels will continue to be important for heavy-duty trucks, whereas electricity will be increasingly important for cars and city buses. In the case of city buses, the report proposed a rapid pace of electrification, arguing that this will result in substantially improved energy efficiency, and that the fixed routes and restricted area of operation will favor electrification of city buses. Furthermore, the report suggested that public procurement can enforce implementation, arguing that this will not only result in reduced greenhouse gas emissions but also in lower noise and better urban air quality. The scenarios presented in the investigation report therefore suggested that already by 2030, 83% of the city bus traffic in Sweden can be based on electricity and by 2050, 100% of the city bus traffic can be based on electricity.

Already in 2014, Swedish PTAs reported that 60% of their operations were based on renewable fuels, and the route towards fossil-free public transport has continued since then (Xylia and Silveira, 2017). In 2016, the share of renewable fuels was close to 80% (Aldenius, 2018). Until now this development is due to the uptake of different biofuels, both compressed biogas (CBG) and liquid biofuels such as HVO and RME (Rapeseed Methyl Ester). A massive implementation of electric buses, as proposed by the governmental investigation, implies that these biofuels will substitute fossil fuels in other applications.

5. Overview of the scenarios

The time frame for our scenarios is 2019–2030. All scenarios assume an increased demand for public transport with 58% increase of passengers and 30% increased fuel consumption by 2030, based on the same mix of fuels as in 2017. We assume an even distribution of the increase among different types of vehicles and bus lines. Moreover, we assume that the bus lines will follow similar routes as today. Factors such as higher filling rates of the buses and technological progress to enhance their energy efficiency explain how the number of passengers can grow more than the energy demand. Table 3 presents a brief summary of the four scenarios.

Scenario 1 is a baseline scenario based on a projection of recent development trends in the region. Scenario 2 and 3 are based on the national scenarios outlined in SOU (2013), which suggests electrification of city buses and use of biofuels in inter-city, rural and long-distance transport. Scenario 2 describes a limited implementation of electric buses and an alternative use of biogas, which is restricted to the regional public transport system. By contrast, scenario 3 entails a full-scale translation of the national scenarios, with an extensive implementation of electric buses. In search for alternative biogas utilization pathways, the scenario goes beyond the public transport system and redeploy biogas for use in heavy-duty trucks. Scenario 4 emerged in discussions with the energy utility as a plausible alternative to scenario 3, with industry as an alternative biogas utilization pathway. This also corresponds to national strategies and policies to reduce industrial greenhouse gas emissions. Dahlgren et al. (2019) provide a more elaborate analysis of the possibility to use biogas in different applications.

5.1. Scenario 1: baseline scenario

Scenario 1 is a business-as-usual scenario that provides a starting-point for the construction of the non-baseline scenarios 2–4. The scenario does not involve any structural changes, but the public transport traveling is assumed to increase more than private car traveling. By 2030, population, number of workplaces and traveling continues to increase in the same pace as in the period 2005–2016. These are further concentrated to the most populous cities. Commuting and other traveling between the municipalities and particularly between the largest cities continues to grow. Commuter flows become more complex with increasing commuting out of the major cities (that since long are the dominating commuting targets). Biking and public transport increases more than car traveling. The share of public transport of the engine-borne traveling increases. Moreover, the number of cars grows, but the distance driven per car decreases and the share of households without cars grows. Carsharing systems become more common and

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<td>Development trends in Östergötland*.</td>
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<td>Commuting (2005–2016)</td>
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<td>No of cars (2005–2016)</td>
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<td>Public transport passengers (2005–2016)</td>
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<td>No of trucks (2005–2016)</td>
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<td>Transports (energy consumption) (2005–2016)</td>
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* All the figures are based on statistics from the Swedish national Bureau of Statistics SCB (Statistiska centralbyrån).

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<th>Table 3</th>
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<td>Summary of the scenarios.</td>
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the share of collectively owned cars thus grows. Road freight transport grows dramatically, particularly the local transport and the transit transport through the region. The use of fossil fuels primarily decreases via increased blending of renewable fuels (biodiesel, ethanol) in diesel and petrol. The share of electric cars in the car fleet is 20% by 2030. Table 4 summarizes the scenario.

The only element in this scenario that is not based on current trends is the assumption that public transport will increase its share from 20 to 25% of the engine-borne traveling. The current (in 2019) public transport traveling in Östergötland is relatively small and it has not grown as much as in the most comparable regions in the country. However, with a continued increase of commuting and other inter-city traveling, there should be opportunities to improve the service and make public transport more attractive, which could stimulate increased use. Since this increase will mainly occur on the routes between the major cities, we expect that this will result in higher vehicle filling rates. Since total traveling increases by 30% and the share of public transport from 14% to 17%, this will result in an increased number of passengers by 58%. The shares of biogas and diesel buses will remain the same as in 2017. The waste-to-biogas for use in public transport is well-established and it enjoys strong local support since it contributes to the green image of the region. Still, an expansion of the biogas use seems unlikely since diesel buses that run on HVO are regarded as more flexible and cost-efficient.

5.2. Scenario 2: electricity and biogas in public transport

In scenario 2, there will be electric city buses on four high-frequency bus lines in Linköping by 2030. The biogas that these bus lines use in Scenario 1 is instead used for public transport buses on regional inter-city lines. Currently, these buses run on HVO which, according to the scenario, will substitute fossil diesel in trucks.

5.2.1. Specific assumptions

The bus lines 1–4 in Linköping are suitable for electrification because of their high degree of utilization. If fast-charged electric buses are preferred, they can be supported by two 600 kW or twelve 200 kW charging stations, or a combination of charging stations and an electric road system (Lindgren, 2017). In 2017, these bus lines carried 45% of the total bus passengers in the city. They are responsible for 30% of the biogas consumption by city buses in Linköping and the electrification will affect about 10% of the current local biogas production.

5.2.2. Realization of the scenario

The realization of scenario 2 depends on investments in both vehicles and infrastructure. The implementation of an electric bus system depends on different actors. The PTA is the key actor that needs to select charging strategies, design and plan charging infrastructure and integrate this in the planning of future bus services. Handling the local electric grid, the energy utility must enable grid connection and make sure that the grid can support the charging. Moreover, landowners must allow space for charging stations and the municipality must allow building permits. The installation will also involve charging system suppliers and construction firms.

Before it is possible to take electric buses in operation, the PTA must develop procurement routines. These routines should consider operation of buses and charging stations, as well as if and how these operations should be separated and regulated with different contracts. The acceptance of a standard interface between the charging stations and the electric buses will simplify this (Borghei and Magnusson, 2018). The development of routines must consider the ownership of the buses (most likely the bus operator) and the charging systems (probably the local energy utility), as well as the possibility of a third actor that will operate the charging stations. To enable operation, manufacturers must supply buses and charging stations and the system must be validated by the bus operator and the PTA.

The use of biogas on inter-city traffic requires specifically adapted vehicles. For passenger capacity and comfort reasons, the PTA prefers double decker coaches on these lines. Since the bulky compression tanks are difficult to fit to a double decker coach, such biogas-fueled vehicles have not been available until now. However, biogas liquefaction is a possible strategy to reduce the tank volume, something that increases the prospects of using biogas for inter-city traffic. To make liquid biogas (LBG) available for the coach buses, there is a need for coordinated actions involving the PTA, as well as the local energy utility’s biogas production and distribution. Moreover, equipment suppliers and construction firms, as well as the municipality that owns the bus depots, must be involved. To initiate operation there is also a need to involve bus manufacturers and bus operators.

PTAs must minimize public expenditure, and therefore cost estimates are important for their decision making. Electric buses have a higher investment cost and lower operational cost than traditional buses. Based on a comparative analysis assuming an annual driving distance of 60,000 km and considering costs of vehicles, batteries, infrastructure, maintenance and energy, Xylia et al. (2019) suggest that the life-cycle cost of an electric bus is slightly lower than a CBG-fueled bus, and slightly higher than a HVO-fueled bus. A longer driving distance will favor the electric bus alternative. If the current global trend of falling vehicle battery prices (Nykvist et al., 2019) continues, this will favor the electric bus alternative. The investments and operational costs for LBG-fueled coach buses in relation to HVO/diesel buses and future HVO price developments are also important. The cost of LBG-fueled coach buses is currently difficult to estimate because of limited availability of vehicles that match the PTA’s specifications.

The possibilities to realize the scenario depends on governmental policies, including subsidy schemes for biogas, as well as investment grants for electric and LBG-fueled buses, electric bus charging, and LBG production and distribution infrastructure. Moreover, it depends on local actors’ willingness to take part in critical activities and coordinate the needed changes. In particular, the PTA and the local energy utility will have to take leading roles in the implementation. PTAs close deals with private bus operators for contract periods up to ten years. Requirements and pre-conditions for the bus operations are preferably kept stable during these periods. Delaying the implementation until current contracts expire will simplify the implementation. An early limited implementation may be favorable to prepare for a large-scale implementation, as described in scenarios 3 and 4.

5.3. Scenario 3: electricity in city buses and biogas in trucks

In scenario 3, 90% of the city buses in Linköping will be electric by 2030. The biogas will be converted to LBG and used in heavy-duty trucks, which currently run on diesel.

5.3.1. Specific assumptions

Electrification of the bus lines 1–17 and 24 in Linköping would involve almost all city bus traffic, only leaving out a few low-frequency lines. This
would require thirteen 200 kW charging stations as well as 1600 m electric road (Lindgren, 2017). The corresponding biogas, which is about three times more than in Scenario 2, will be liquefied and used in heavy-duty trucks that are refueled in the region. In 2015, such trucks consumed about 600 GWh diesel in Östergötland.

5.3.2. Realization of the scenario

The realization of Scenario 3 raises similar challenges as Scenario 2 in terms of bus electrification, but the investments in vehicles and infrastructure are considerably larger.

The use of LBG to fuel heavy-duty trucks requires that trucks adapted for liquid gas are available and it moreover depends on the establishment of a network of refueling stations. To establish regional and national networks for liquid gas, there is a need for coordinated actions involving biogas producers, gas distributors, equipment suppliers and construction firms, as well as truck manufacturers and haulers that operate trucks.

During the last few years, substituting fossil diesel with HVO has been a relatively simple way to reduce the climate impact of freight transportation. Since suppliers of diesel fuel now have to increase the percentage of renewables in their fossil fuels in order to respond to comply with regulatory demands on CO2-reduction, it is likely that the HVO price will rise, which in turn can make LBG-trucks a more favorable alternative for haulers looking to reduce their climate impact.

The realization of the scenario depends on the development of governmental policy. This may include subsidy schemes for biogas, as well as investment grants for electric and LBG-fueled trucks and LBG production and gas distribution infrastructure. Moreover, the realization depends on haulers’ willingness to invest in vehicles for liquefied biogas, as well as transport buyers’ willingness to demand and pay for transports that use renewable fuels.

5.4. Scenario 4: electricity in city buses and biogas in manufacturing industry

Like scenario 3, scenario 4 entails a 90% electrification of the city buses in Linköping by 2030. In scenario 4, the biogas will substitute fossil gas in industrial manufacturing processes in the region.

5.4.1. Specific assumptions

This scenario builds upon the assumption that biogas will be an increasingly attractive substitute for fossil gas in industrial manufacturing. In 2017, the Swedish manufacturing sector used 4 TWh of LPG – Liquid Petroleum Gas (Energigas Sverige, 2018a) and 8 TWh of natural gas (Energigas Sverige, 2018b). As a comparison, the national production of biogas was 2 TWh.

As a basis for this scenario, we made an inventory of the industrial use of fossil gas in Östergötland. Although detailed data for individual industries is confidential, it was possible to make approximations from public reports (e.g. Klimatskyddsbyråen, 2016), annual company reports and municipal energy plans. We identified three major concentrations of industrial users with annual LPG use of 80–130 GWh: one steel company in the southwestern part of Östergötland.

![Industrial LPG users in Östergötland. The larger dots are the locations of the larger LPG users (more than 40 GWh) and the smaller dots are locations where there are companies using smaller amounts of LPG.](image-url)
part of the region, and the cities of Finspång and Norrköping in the north with important industrial users (Fig. 1). In south, one company uses 40 GWh LPG. There are also companies that use less than 10 GWh LPG, such as Toyota Material Handling in Mjölby that uses around 9 GWh LPG each year.

5.4.2. Realization of the scenario

The challenges related to bus electrification and LBG production in this scenario are identical to scenario 3. However, in this scenario the key is the industrial demand for LBG. The energy utility must promote LBG as a potential substitute for fossil gas in industrial manufacturing processes. The regional biogas production capacity is currently too small to be able to supply enough gas for the largest industrial users in the region, but locally produced LBG can be a viable option for smaller users. Timing is important here. Companies that are preparing for investments in their manufacturing systems will be more prone to changes than companies that have realized such investments. For example, it is probably not economically feasible to convert to LBG at the steel plant in the southwestern part of the county, since parts of their facilities recently have been converted to run on LPG. For smaller companies located far away from the center of the region, it may be attractive to coordinate the conversion to LBG.

6. Scenario comparison

This section first gives a qualitative comparison focusing on the actor involvement required to realize the four scenarios. Thereafter it presents a quantitative calculation and comparison of the scenarios in terms of energy efficiency and reduction of greenhouse gas emissions.

6.1. Actor involvement in the scenarios

All scenarios assume an increased demand for biogas in the region, and that the local energy utility will be the sole supplier of biogas. In all the non-baseline scenarios, the PTA is a central actor with several roles to play. Especially so in scenario 2, where the PTA not only needs to plan and validate the electric city bus operation, but also the alternative use of biogas in intercity buses. However, even more paramount than the individual activities are that all actors coordinate their work. It does not matter if the PTA plans the electric bus service, the requisite charging infrastructure and the procurement routines if, for example, the energy utility has not verified the electric grid capacity to enable grid connection of charging stations at suitable locations. The ownership of charging stations remains an open question; we have assumed that the energy utility will consider them as extensions of the grid and thus assume responsibility for the investments. Moreover, the assignment of responsibility for charging system operation is still open: whether to assign it to the bus operator, to the energy utility or to a specialized third actor.

Scenario 3 and 4 assume that the interest in LBG will increase among haulers and manufacturing firms, respectively. This depends on projections of future costs for biogas and other fossil-free alternatives, compared to the costs for the fossil fuels they currently use. Haulers and manufacturing firms have limited previous experience of biogas. Therefore, reaching out to these new users will be challenging for the energy utility. Moreover, since haulers is a very disparate groups of actors, scenario 3 will make projections of the biogas demand more difficult for the energy utility.

Future regulations and other national policies to promote phase-out of fossil fuels will have a considerable influence. All scenarios depend on the government for subsidies and investment grants. As the current situation of policies for renewable fuels in Sweden is uncertain, this may have a negative effect on actors’ willingness to invest in fossil-free energy and transport systems. Table 5 presents a summary of the key actors and their key activities in the four scenarios.

### Table 5

Key actors and activities in the scenarios.

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas producer/distributor</td>
<td>Increasing the production capacity</td>
<td>Increasing the production capacity</td>
<td>Increasing the production capacity</td>
</tr>
<tr>
<td>Public transport authority</td>
<td>Planning for increased bus services</td>
<td>Planning for increased bus services</td>
<td>Planning for increased bus services</td>
</tr>
<tr>
<td>Bus operator</td>
<td>Investing in CBG-fueled city buses</td>
<td>Investing in and validating operation of electric city buses</td>
<td>Investing in and validating operation of electric city buses</td>
</tr>
<tr>
<td>Energy utility</td>
<td>n.a.</td>
<td>Facilitating grid connection</td>
<td>Facilitating grid connection</td>
</tr>
<tr>
<td>City authority</td>
<td>n.a.</td>
<td>Providing building permits</td>
<td>Providing building permits</td>
</tr>
<tr>
<td>Vehicle manufacturer</td>
<td>Supplying CBG buses</td>
<td>Supplying electric buses</td>
<td>Supplying electric buses</td>
</tr>
<tr>
<td>National government</td>
<td>Subsidizing</td>
<td>Subsidizing and offering investment grants</td>
<td>Subsidizing and offering investment grants</td>
</tr>
<tr>
<td>Others</td>
<td>Landowners: Allowing space for charging infrastructure</td>
<td>Landowners: Allowing space for charging infrastructure</td>
<td>Landowners: Allowing space for charging infrastructure</td>
</tr>
</tbody>
</table>

6.2. Assumptions for the calculations

Based on reported data on energy consumption from previous field experiences, corroborated by the internationally operating energy utility, we assumed that the electric buses would require 2 kWh electricity/km (filled 18 m bus). Apart from the electricity, the buses were also assumed to require 0.67 kWh biogas/km for compartment heating during 4 winter months each year (Borén et al., 2015).

Energy consumption and greenhouse gas emissions will differ in the production of electric vehicles and combustion engine vehicles respectively. However, lifecycle assessments suggest that these differences are negligible for city buses. Relatively small batteries and long driving distances means that the use phase dominates the life-cycle comparison,
especially in the case of fast-charged electric buses with relatively small battery packs (Nordelöf et al., 2019).

To calculate the amount of fossil fuel that the biogas can substitute in inter-city buses and heavy-duty trucks in scenario 2 and 3, we assumed that in highway traffic, the energy consumption of a biogas-fueled vehicle with an Otto engine will be 15% higher than the energy consumption of a corresponding diesel vehicle (Börjesson et al., 2016; Scania, 2018a). In scenario 4, we assumed that the energy efficiency of a manufacturing process using LBG is similar to a process using LPG.

To compare the energy use in the scenarios, we used primary energy with data derived from the median values in the JRC well-to-tank report (Edwards et al., 2014), together with the added shares of fossil energy content in the respective fuels. Moreover, we derived the data for the calculations on greenhouse gas emissions from the JRC well-to-tank report for diesel, biogas (based on municipal food waste) and LPG. Additional data on upgrading and distribution of CBG and LBG were based on the type of biogas upgrading that exists in Linköping (amine scrubbing with district heating). For electricity, the data is based on Goda et al. (2011) and the Swedish electricity mix during 2016. Our quantitative assessment corresponds to the approach suggested by Gustafsson et al. (2018).

6.3. Quantitative assessment

The four scenarios differ in the degree of bus electrification and in the biogas use. Electric buses are different than the current biogas buses regarding their energy efficiency, and there is also a difference in the energy efficiency between biogas and diesel as well as the amount of non-renewable energy needed to produce each kWh of fuel. Apart from the energy efficiency, the fuels also differ in greenhouse gas emissions. There will thus be a difference in the amount of energy used and emitted greenhouse gases between the four scenarios.

The largest difference between the scenarios is the degree of city bus electrification: from 0% in the baseline scenario to 90% in scenario 3 and 4. Since electric vehicles require less energy than combustion vehicles in the use phase, the amount of energy needed is reduced with increasing electrification (Fig. 2). The difference between scenario 3 and 4, which assume the same degree of electrification, is a result of the respective use of biogas.

Regarding greenhouse gas emissions, scenario 3 and 4 have larger reductions than scenario 2 since more fossil fuels will be substituted (Fig. 3). However, in contrast to the energy use reduction, the greenhouse gas emission reduction is almost equal for scenario 3 and 4. This is because fossil diesel is a more significant emitter of greenhouse gases than LPG.

Another aspect that differs between the scenarios is the impact of the substitutions. Public transport has been a major user of biogas in the region since its introduction in the 1990s. With biogas use in inter-city buses, scenario 2 continues a similar track. The redeployment of biogas in scenario 2 can cover over 20% of the public transport bus operations in Östergötland that currently use HVO. However, even though the amount of redeployed biogas in scenario 3 and 4 is higher, the impact in the respective sectors would be less significant. According to a projection, heavy-duty trucks in Östergötland will use 840 GWh of energy in 2030 (Anderberg and Dahlgren, 2019). The biogas in scenario 3 can only cover 3% of this. In the industrial use case, there are records of at least 350 GWh LPG being used annually in Östergötland. An assumed growth of this to 400 GWh by 2030 would mean that the biogas in scenario 4 can substitute 8% of the LPG used in regional manufacturing processes.

7. Visions, controversies and system evolution

We started preparing our scenario study in 2015 and the joint research project started formally in January 2016. At this point in time, a possible implementation of electric buses was a contested issue in the region, and our project was located in the midst of the controversy. Local politicians urged the PTA to investigate the electric bus option and manufacturers of electric buses promoted their products, arguing that experiences from other cities now showed that this was a preferable alternative. Still, representatives for the PTA maintained that they were satisfied with the current biogas bus operation and the local energy utility feared that an implementation of electric buses would destroy the well-established regional biogas system. The PTA furthermore dismissed the possibility of using biogas in inter-city traffic since no suitable coach buses were available. As the PTA was preparing the tendering for the forthcoming contract period, the local energy utility lobbied for a continued use of biogas-fueled city buses.

All our local project partners accepted and embraced the national vision of zero net greenhouse gas emissions by 2045, considering themselves as local lead actors in the requisite transitions. By the start of our project, Linköping municipality had already formulated a target of becoming CO2-neutral by 2025 and their energy utility had communicated a vision “to build the world's most resource-efficient region” (Tekniska Verken, 2014:4). Moreover, the PTA considered their services as a “tool for a sustainable regional development” and “climate-positive traveling” (Region Östergötland, 2016:6). Still, in January 2016, a future implementation of electric buses in the region appeared distant.

Early in our 3-year project, the energy utility initiated a study to evaluate the commercial feasibility of biogas liquefaction in Linköping. At this point in time, a full-scale liquefaction plant using suitable process technologies was under construction in Norway, and the Linköping feasibility study showed promising results; liquefaction would make distribution and storage of biogas less problematic and it could open new market segments (Johansson and Nordell, 2017). The utility subsequently applied for – and received – governmental investment grants for the construction of liquefaction facilities, and they closed a deal with the company Toyota Material Handling for the supply of LBG to their manufacturing plant. In an interview, a representative for Toyota said that they had been searching for a decade for a renewable substitute to the fossil gas they currently use.
and LBG fulfilled their requirements (Toyota, 2018). A 10-year contract regulates the supply of LBG, thus providing the utility with a long-term and stable demand in an equivalent manner that public transport does. Toyota is not alone in this emerging interest for biogas in industrial manufacturing. During our project, an increasing number of Swedish manufacturing companies reported substitutions of fossil gas with biogas (e.g. Biogas Syd, 2017; Haaker, 2017; Tekniska Verken, 2018). One reason for this is a recent gradual phasing out of tax exemptions for industrial use of fossil gas (Swedish Tax Agency, 2018), which makes it more attractive to convert to renewable fuels.

When announcing their decision to invest in LBG facilities, the energy utility declared plans to start production in 2020. Besides supplying LBG for industrial use, the utility will offer LBG as a fuel for heavy-duty trucks. In 2017, the Nordic market leader Volvo Trucks introduced a new generation of trucks with engines for liquid gas (Volvo, 2017). At this point in time, the market runner-up Scania already offered such vehicles, and so did Iveco, which is another large European manufacturer. This means that haulers can select from a broad range of vehicles offered by leading manufacturers. In 2018, Scania also launched a gas-fueled coach bus with tanks for liquid gas (Scania, 2018b). With increasing availability of liquid natural gas (LNG) in Europe, other manufacturers are likely to follow. Thus, in a near-term future, it should be possible to purchase buses that match the PTA’s specifications for inter-city traffic and can run on locally produced LBG. While centrally located tank stations at bus depots can support public transport buses, trucks require a more extensive refueling network. In 2018 the Finnish gas supplier Gasum announced that they were about to build a network of 50 LNG-tank stations in the Nordic countries (Gasum, 2018). The Swedish Environmental Agency co-funds the investments. LNG is interchangeable with LBG – the same vehicle can use either fuel – so, with a network of LNG filling stations, haulers will be able to access the fuel they need.

Already in 2007, Lantz et al. (2007) claimed that Swedish biogas policies are problematic. The current national support system differs from other European countries’ systems and breaks with European competition regulation. Thus, the EU Commission has only permitted it on a temporary basis, and this has had detrimental effects on the willingness to invest in production facilities (Lönqvist et al., 2017). In 2018, the Swedish Government issued an investigation on how national policies can support a significant expansion of the domestic biogas production. As the Government assigned the investigation with the intention to create long-term and stable market conditions, Swedish biogas producers expect that this will help them reach new market segments. Another influential factor relates to the use of biodiesel. In 2017, the Swedish Government decided on mandates of blending fossil diesel with renewable drop-in fuels. Other European nations have announced similar plans. The stipulated percentage of biodiesel is supposed to increase in a stepwise manner, and this will most likely result in raised biodiesel prices. Thus, users may opt for LBG as a substitute. Moreover, the environmental performance of HVO – one of the most widely used biodiesels – has been debated because PFAD (a rest product from palm oil production) is a common feedstock (Soam and Hillman, 2019). As a result, in 2018, the Swedish Government decided to change the classification to discourage the use of PFAD-based HVO (Regeringskansliet, 2018; ICC, 2018). This has forced PTAs and haulers to search for other alternatives.

A recent study showed that there is a significant potential to increase the production of biofuels in Östergötland (Lindfors et al., 2018), and the local energy utility have announced plans to increase their biogas production to meet expectations of an increased demand. Moreover, other companies have initiated feasibility studies for the establishment of new biogas plants. Increasing possibilities to supply biogas to a broader range of users have triggered these expectations.

In January 2019, just a few weeks after the ending of our joint project, the PTA officially announced that there will be a limited implementation of electric city buses in Linköping during the coming contract period, which runs 2020–2030 (Östgötatrafiken, 2019). At this point in time, the local contestation around electric buses seemed to have vanished.

8. Discussion

According to Loorbach (2010), transition management involves strategic, tactical and operational activities, distinguished by their different time frames. Relating our scenario construction to national visions on fossil-free transport and connecting these to the local project partners’ operations, our socio-technical scenarios formed a link between strategic visioning and operational practice. In terms of operational activities, socio-technical transition theories have furthermore highlighted the need to initiate local experiments to learn about new technology options (Schot and Geels, 2008). However, in our case the new options were already demonstrated in cities outside our focal region. Rather than executing experiments on our own, we therefore tried to learn from study visits, interviews, external guests, and international partners with experience from other locations. Concurrently, our local partners were preparing for implementation on a commercial basis. For business reasons, these preparations were separated from the joint project; the local partners had to maintain discretion on when and how to reveal their tactical plans. Still, the resulting scenarios appear to be well-aligned with these plans. A key explanation for this is our collaborative research approach, which was based on repeated meetings and workshops where we iterated ideas, propositions, and tentative scenarios with the local and international partners, as well as with a broader group of stakeholders.

Because of the need to construct scenarios which key stakeholders consider plausible, acceptable and feasible (Geels et al., 2018), we could not start with a desired future state for the regional system, using anticipatory scenario techniques (Robinson, 1982). Due to the initial controversies around electric buses, it was difficult to agree on a joint local vision that would entail such vehicles. However, if we included a baseline scenario as a plausible alternative, construction of exploratory scenarios with electric buses was still feasible. Because exploratory scenarios describe possible rather than planned realities (Mahmoud et al., 2009), the project partners could contribute to the scenario construction without making any commitments. This meant that the scenarios helped eliciting conflicting arguments, investigating the underlying basis for the arguments, and searching for common standpoints. This was helpful to overcome the observed conflicts.

Following recommendations by Turnheim et al. (2015), our project combined quantitative scenario modelling, qualitative storylines, and socio-technical system analysis with initiative-based learning. The instance of learning assumes reflexive activities, which according to Loorbach (2010) should be an integrated part of transition management. Our scenario construction started in the intersection between two partly overlapping regional systems – biogas and public transport. This narrow initial system delineation served as a focusing device for the scenarios, making the electric bus implementation very concrete for the project partners. However, while it was clear from the start that it would be necessary to search beyond public transport to identify new applications for biogas, it was not obvious on beforehand where to look for favorable utilization pathways. This called for a reflexive approach that stretched the boundaries of the established regional biogas system. Thus, we had to consider system delineation as a dynamic and integral part of the analytic exercise. Evaluating the practical influence of the joint research project in our last meeting (December 5th, 2018), the involved local partners acknowledged that their project participation had broadened their understanding and thus strengthened their ability to assess different technology options. Highlighting the complexity of individual decisions, the alteration between different system delineations encouraged reframing of expectations and assumptions, which was instrumental for the learning process.

9. Conclusions

Concentrating on transformations in a regional energy and transport system, this article has outlined four scenarios that describe different transition pathways. The scenarios describe both substitution of fossil fuels with renewables and redeployment of renewable fuels to new application contexts (Magnusson and Berggren, 2018). Our socio-technical scenario
As a research field, transition studies have given experimental activities and demonstrations a prominent place in its founding frameworks, emphasizing the value of stakeholder engagements in elaborations of alternative socio-technical system configurations. While the multi-level perspective assumes that experiments take place in niches (Geels, 2002; Geels and Schot, 2007; Schot and Geels, 2007), transition management scholars offer the arena concept as a useful starting point for our research study. However, with its emphasis on commercial operation rather than pre-commercial experimenting, our findings convey an important contribution to transition studies. Moving towards commercial operations means that business concerns will guide actors’ initiatives and decisions. Whereas experiences from pre-commercial experiments and demonstrations may be openly discussed in arenas, terms of competition will restrict the propensity to reveal business plans. Our research findings suggest that collaborative scenario construction can be a useful method to circumvent such restrictions.

Our research moreover highlights the importance of flexibility in system delineations to facilitate reflection and learning in multiactor scenario exercises. According to Tornheim et al. (2015), socio-technical scenarios provide useful structures for multi-actor dialogues about transition pathways. While our findings suggest that concentration of such dialogues on near-term implementation may be advantageous in that it facilitates involvement and engagement, a near-term focus also means that timing will be critical. A too short-term focus means that the scenario construction runs the risk of becoming obsolete before it is finalized. This may not be problematic if the joint scenario construction provides useful inputs to transition-oriented decision-making. However, if the scenario exercise turns into a reconstruction of reality, it runs a risk of losing its relevance. Keys for transition researchers, policy makers and other change agents to reduce this risk is a dual empathy for local practice and sensitivity for contextual developments, as well as a retained ability to respond to issues that emerge during the process. Understanding local practice is important to be able to construct scenarios that practitioners will consider relevant. Nonetheless, observing and reflecting on the potential influence of national and international trends, and related events that take place elsewhere, will be just as important. Whereas our socio-technical scenarios describe dependencies between local practice and context changes, the joint scenario exercise served to outline the local practitioners’ agency. In other words, it forced them to ask what decisions they could and should take, considering developments that took place within and outside their individual spheres of influence.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tridp.2020.100128.

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