Müller-Eie and Kosmidis
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Sustainable mobility in smart cities: a document study of mobility initiatives of mid-sized Nordic smart cities

Daniela Müller-Eie[1*] and Ioannis Kosmidis[1]

Abstract

The smart city concept is being viewed as part of the urban future, integrating technological advances, multi-sectorial collaboration, and innovative open markets with strategic goals and ambitions to achieve sustainable urban development. Smart mobility is considered a vital element of the smart city, given that urban transport systems should become more efficient and sustainable. With this in mind, we raise the question: how sustainable is smart mobility? To answer this, we review smart city strategies and measures of fourteen mid-sized cities of the Nordic Smart Cities Network, identifying smart mobility goals together with proposed or implemented mobility measures. We evaluate how they align with sustainable mobility and how effective they are with the help of two analytical frameworks: a) the EU's Sustainable Urban Mobility Planning (SUMP) objectives and b) the S.M.A.R.T. objectives. In doing so, we assess to which degree smart mobility strategies and measures in Nordic smart cities contribute to sustainable urban mobility and development, and how they contribute to achieving sustainable and smart city goals in terms of feasibility and accountability. The study reveals that measures mainly address the SUMP objectives relating to efficiency and environment, with little focus on inclusive and safe mobility planning that caters to attractive cities and high quality of urban life. Another finding is that smart mobility measures are relatively conventional, and their goals and ambitions are often stated on an abstract level and rarely measurable with specific indicators. Thus, there seems to be a lack of feasibility and accountability related to smart mobility measures, as well as a lack of focus on social sustainability.

Keywords Smart mobility, Urban sustainable mobility, Smart city, SUMP, S.M.A.R.T. objectives

1 Introduction

Improving urban mobility is one of the most pressing challenges on the path to making cities more environmentally friendly, efficient, and socially just. This is happening against a backdrop of fast-paced climate change [1], pressure on urban land and services, immense development in transport technology and communication technology, as well as a call for more quality of urban life and social equity. While smart city approaches are gaining momentum as a panacea for a plethora of urban ails, the concept is still mainly driven by technological solutions. If technology is the answer, it is important to critically reflect on what the goal is. With regard to urban mobility, the main aim must be to cater to more sustainable travel patterns. However, doing so does not necessarily and exclusively rely on technology, but may also include a more conventional adaptation of urban form, infrastructure, policy, mobility services, and travel behaviour.

This seems particularly relevant in medium-sized cities, which are often more dispersed and therefore more

*Correspondence:
Daniela Müller-Eie
daniela.mueller-eie@uis.no
[1] Department of Safety, Economics and Planning, University of Stavanger, PB 8600, 4036 Stavanger, Norway

car-oriented than their metropolitan counterparts. Due to low densities and lack of critical mass or resources, public transport or active alternatives are often not competitive [2]. However, medium-sized cities may hold great potential for change due to the substantial share of the population residing there, while being thoroughly understudied [2, 3]. Nordic cities, in particular, seem to be among the frontrunners of digitalisation and smart city indices and are therefore of particular interest to study (Lindtvedt, Frøhaug, & Nesse, 2021), and Scandinavian countries have been cited to have a culture and tradition for broad and effective stakeholder involvement [4].

If smart cities are viewed as a way of achieving more sustainable development, it should be possible to review smart city approaches and examine their contribution to sustainability. Specifically for the subject of urban mobility, this raises the question of to what extent the measures described in smart city strategies contribute to sustainable mobility goals and how accountable they are. In extension of that, the question needs to be raised whether smart strategies are the most effective way to achieve sustainable urban mobility. It is therefore important to critically review the contribution of smart mobility strategies and initiatives, their manageability, and their contribution to sustainable urban mobility and development.

Smart city research is still at an early stage. Despite an ongoing critical discourse, there is little research into the contribution of the smart city agenda and projects to urban sustainability, and particularly empirical evidence on this relationship is largely missing [5–7].

This study is an attempt to provide critical reflection as well as a methodological framework to evaluate smart city initiatives in terms of their effectiveness and sustainability. The study has two objectives: firstly, to review smart strategies of Nordic smart cities and provide an overview of concrete smart mobility measures; and secondly, to evaluate the detected smart mobility measures in terms of feasibility and accountability, and whether they are in line with sustainable mobility goals. For this, we use a case study approach, reviewing strategic documents in Nordic medium-sized car-oriented smart cities, where we apply two distinct analytical frameworks: first, an evaluation of smart mobility measures according to objectives of the Sustainable Urban Mobility Plan (SUMP) objectives set by the EU [8], and second, an assessment of the smart mobility measures using the S.M.A.R.T. objectives framework [9]. This study reveals what types of mobility measures are part of smart city approaches, what their goals are, and how they contribute to urban sustainability. This in turn can give a better understanding of to which degree the smart city concept in general caters toward sustainable urban mobility.

2 Background

Urban mobility is undergoing several changes, i.e., the electrification and automation of vehicular transport, an increase of shared mobility and micro-mobility [10], Mobility As A Service (MaaS), promoting active travel and walkability, and a stronger focus on environmental sustainability and social equality and justice. With the goal of reduced negative environmental impact, fewer traffic accidents, and better urban environments, a reduction of private car transport is inevitable, and a rethinking of urban travel and mobility space seems imminent. Seeing "smartness [as] […] one of many different ways of framing the urban sustainability agenda" [5], p. 426), a review of smart city and smart mobility initiatives and their contributions to sustainable urban mobility is essential.

2.1 Smart cities

According to the European Commission, smart cities are "cities using technological solutions to improve the management and efficiency of the urban environment" but they also go "beyond the use of information and communication technologies (ICT) for resource use and less emissions" [11]. Much of the academic discourse on smart cities revolves around goals, tools, and stakeholders. According to the smart city wheel (Fig. 1), a smart city consists of six components: smart government, smart economy, smart environment, smart living, smart mobility, and smart people [12–14]. From a strategic perspective, an approach that covers all six dimensions can be regarded as a holistic strategy and goal-posting of the smart city. Smart cities have been characterised through tools such as smart technology, Internet of Things (IoT), open data, public–private collaboration, competition, and user involvement, claiming that automatically collected data and inter-urban competition can lead to societal benefits, comfort, and better allocation of resources [15]. Important stakeholders in the smart city are the urban government, planners, politicians, technological consultancy companies, knowledge organisations, and inhabitants [15].

2.1.1 Smart urban mobility

With mobility being one of the six explicitly mentioned components, it is expected that most smart cities address mobility to some degree, Soe (2020 p. 4) states that "without doubt, smart cities research has clear focus on the smart mobility […] and smart mobility is an integral part of most research-based smart city frameworks […]". Brown, King, and Goh [16] find that 16% of the current and 24% of planned projects in 26 UK smart cities were within the sphere of smart transportation. This includes electric vehicles (EVs). driverless or computer-aided

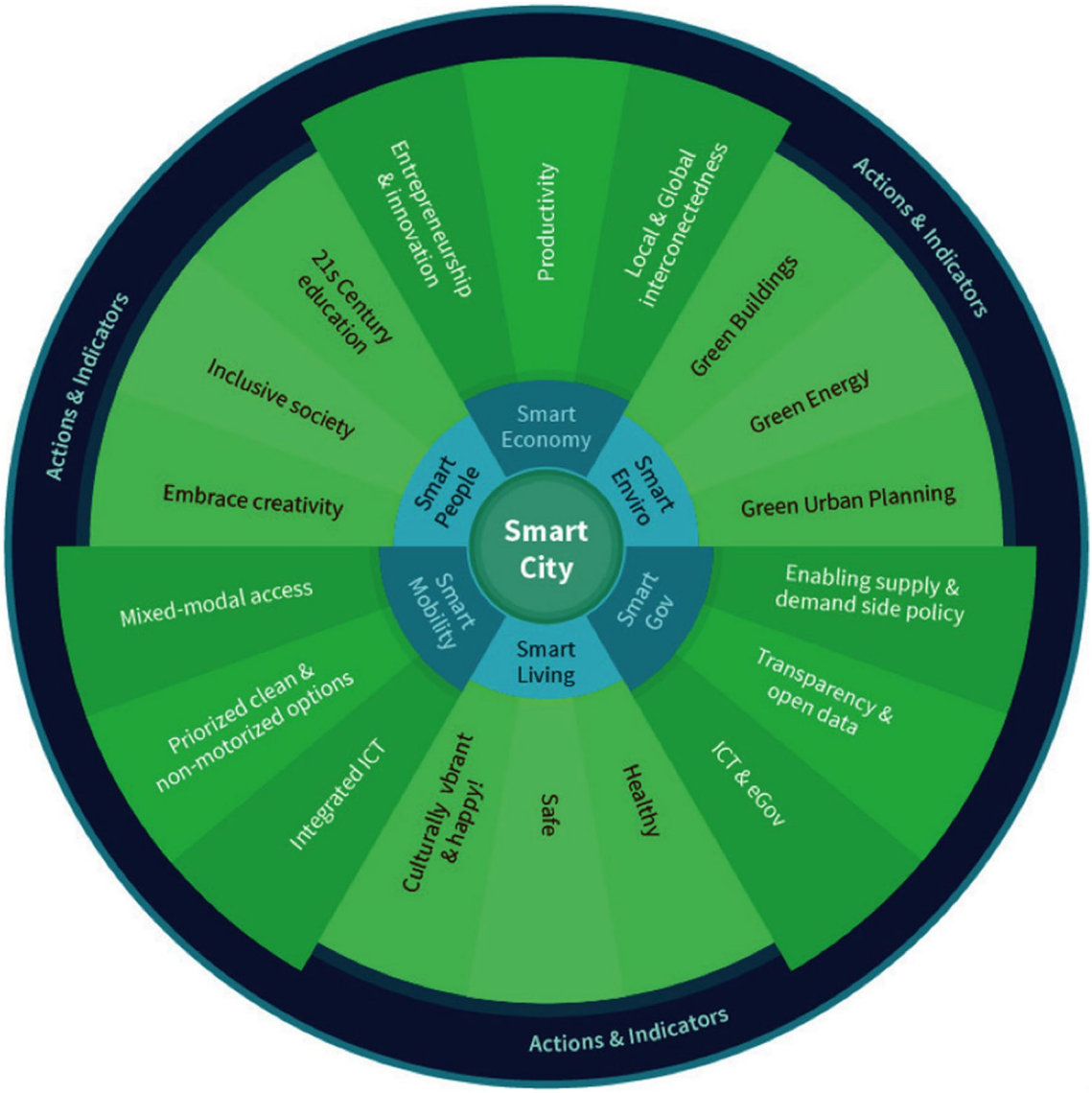

Fig. 1 Smart city wheel [12]

vehicles, smart traffic management, integrated ticketing, and Mobility as a Service (MaaS).

The objectives of smart mobility include mixed modal access, prioritised clean and non-motorised options, and integrated ICT [12], as well as the reduction of traffic congestion, transfer costs, air, and noise pollution, improved transfer speed and increased safety [17]. More broadly, smart transportation is seen to contribute to increased quality of life among citizens of smart cities [18]. This partly overlaps with conventional sustainable urban mobility objectives. According to Maldonado Silveira Alonso Munhoz et al. [19], the definition of smart mobility includes anything to do with mobility in the smart city, the sustainability of the transport network, integrated platforms, sustainable, intelligent and cooperative vehicle technologies, sustainable and safe environment, behavioural economics, e-participation, or crowdsourcing.

In terms of concrete smart mobility measures, Satyakrishna and Sagar [20] identify telematics, fleet management, smart parking administration, emergency service network (ESN), advanced driver assistance systems (ADAS) as important aspects; and Brown et al. [16] found smart transportation projects that include digital ticket booking, smart cards, tracking apps, smart traffic solutions, investment into and testing of autonomous

vehicles, mobility living labs, and EV charging points. Further, vehicular ad hoc networks (VANET), intelligent transportation systems (ITS), vehicle-to-vehicle (VV) and vehicle-to-infrastructure (VI) communication are mentioned [18]. AarhusKommune, Mobilitet, and Trafik- (2017) give a somewhat 'softer' definition, saying that smart mobility is about changing travel habits, active modes of transport, cross-sector collaboration, citizen participation and empowerment, testing and evaluation, and in general transforming the mindset from traffic to mobility [21]. And Benevolo, Dameri, and D'Auria [22] find that smart mobility includes ICT, transport technology (vehicle, fuel) as well as travel behaviour. While this extension to include citizens and behaviour represents a wider understanding of smart mobility, the concept has also been criticised for being too techno-centric and consumer-oriented and not taking into account the quality of urban space [23].

Thus, it seems that on the level of objectives, smart mobility aims at reducing the need for car travel and its negative environmental impact and encouraging alternative travel modes [22]. This is very much in line with conventional sustainable urban mobility planning, and some smart cities also apply conventional approaches to do so. This begs the question of what about these projects characterises them as smart, and what is the added value of smart mobility? The distinction between conventional and smart mobility approaches is clearer when smart urban mobility is defined by and sometimes limited to technological approaches to making traffic more efficient [24–27]. However, that is not always the case, and the delineation between conventional and smart mobility measures seems unclear.

2.2 Sustainability of smart mobility

When studying the goals and objectives of smart mobility, there seems to be a strong association between the concepts of urban sustainability and smartness, as evidenced by the emergence of the term 'smart sustainable' [28, 29]. Often sustainability of smart development is defined through the conservation of non-renewable resources, as well as the security and stability of vital infrastructure and services [18]. And many studies explicitly or implicitly assume smart approaches to be a means to achieve sustainable urban development [16, 24, 25, 29–33]. However, several researchers have pointed to a lack of consistency or gap between the two concepts [31, 34]. In a systematic literature review, Yigitcanlar et al. [7] confirm that cities cannot be smart without being sustainable, and they notice that smart city literature addresses the heavy techno-centricity, practical complexity, and a lack of sound conceptualisation of the smart city. Haarstad [5] critically examines the role of urban sustainability in the smart city discourse and concludes that sustainability often does not seem to be a main driver for smart cities and that related measures can be rather conventional or low-tech. Reviewing indicators for smart sustainable cities, Huovila, Bosch, and Airaksinen [35] point out that while integrated assessment systems have made a one-sided focus on smartness less relevant, the weighting between the concepts differs.

For smart mobility particularly, several studies have attempted to bridge the gap between sustainable and smart urban mobility by suggesting that new mobility solutions, such as Intelligent Transport Systems (ITS, electric vehicles (EVs), autonomous vehicles (AVs), Mobility as a Service (MaaS), are key components to addressing both [36–38]. However, these studies fail to theorize about the operational relationship between the concepts.

However, the—partly theoretical and conceptual, partly methodological—discussion on how smart mobility contributes to achieving sustainable urban mobility needs to be further explored. Not only that, but the question of whether smart solutions are the best way to achieve sustainability, also remains unresolved. Therefore, the relationship and possible misalignment between smart mobility and sustainable urban mobility needs to be examined more explicitly.

2.3 Evaluations of smart initiatives

Due to abstract descriptions and the lack of commonly accepted definitions, few thorough, holistic and commonly accepted evaluation systems for smart city initiatives are available. It is therefore difficult to measure the success and added value of smart cities. However, there are some notable exceptions [35, 39]

While it is possible to evaluate smart city initiatives, it seems difficult to assess them from a holistic point of view considering environmental, economic, or social sustainability [40],Alkış, Çaldağ, & Gökalp, 2019; [5], and choosing appropriate assessment methods also depends on the context [35]. Existing models for evaluation include built infrastructure, economy, environment, governance, government, management and organisation, people and communication, technology, attributing each component to certain success criteria, and thus generating a set of indicators that can be evaluated [41]. Studies of frameworks for smart city assessment have found that such assessment systems focus more on technological, social, and economic aspects and, less on environmental impact [35, 40]. Furthermore, Ahvenniemi et al. [40] encourage a focus on both output indicators as well as impact indicators.

The absence of comprehensive and effective evaluation frameworks is noted for smart cities in general and for smart urban mobility solutions specifically [42, 43]. It seems particularly challenging and complicated to find indicators for smart cities and smart transport systems [44, 45]. However, several studies have attempted to do so [45, 46]. Zapolskytė et al. [43] for instance developed an evaluation of smart mobility systems and investigated the relative importance of 23 indicators across five factors. They find that traffic light management systems, vehicular communication systems, and park and ride systems are most important to establish the 'smartness' of a mobility system, while modern parking solutions, emissions testing and mitigation, and smart street surfing are least important. Maldonado Silveira Alonso Munhoz et al. [19], on the other hand, identify urban mobility plans, public policies, environmentally friendly policies, accessibility, walkability, safety, maintenance, multimodal integration, traffic accident detection and support systems, data collection systems, public accessibility to real-time information, and smart traffic lights to being most important.

While these assessments are useful in isolation, they assess the smartness of mobility rather than the sustainability of smart mobility, i.e., explicitly linking smart mobility to sustainable mobility in terms of content and outcomes. And despite evidence to support the effects of individual smart measures in certain contexts, a systematic body of knowledge on different smart mobility measures, their effects and impacts as well as their interactions with other measures is lacking. It also seems unclear to which extent the goals of smart mobility initiatives are made explicit, and how and if they are measured or achieved.

3 Methodology

This study's objective is to review smart mobility strategies and concrete measures of Nordic smart cities and to evaluate the detected smart mobility measures in terms of feasibility and manageability, as well as contribution to sustainable mobility goals. Smart mobility is often discussed on two levels: (1) the strategic level and (2) implemented measures. Therefore, both the strategic goals and mobility measures were evaluated separately. To do this, a two-fold methodological approach is used, consisting of two analytical frameworks: a) the objectives of Sustainable Urban Mobility Plans (SUMP), and b) the S.M.A.R.T. objectives. The first set of criteria directly examines sustainable mobility, i.e., the overlap between the smart mobility strategies and initiatives of a city with the objectives of the EU's Sustainable Urban Mobility Plan (SUMP). The latter assesses the feasibility and accountability of goals with the help of the S.M.A.R.T. framework

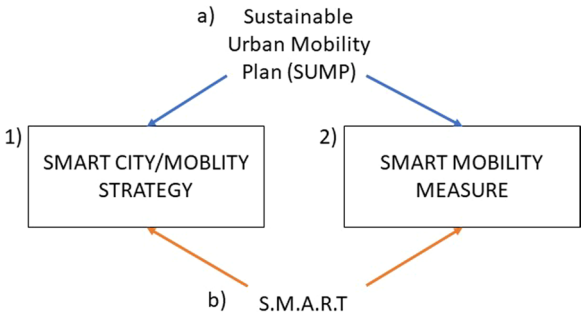

Fig. 2 Application of analytical frameworks (a, b) to different strategic levels (1, 2)

from management disciplines. The two analytical frameworks have been applied to both the strategic and concrete level (Fig. 2).

3.1 Case study selection

Nordic countries have long stood out due to their seeming eagerness and readiness to perform as smart and digitised cities, as evidenced by several top-tier listings in smart city indices [47]. We therefore specifically consider the smart cities of the Nordic Smart City Network (NSCN), which was established as a consequence of the international research collaboration Nordic Urban Living Labs 2018–2020, focusing on best practice and transnational collaboration within the spheres of mobility, street furniture, waste management, and data collection and sharing [48].

At the same time, there is a need to focus research on medium-sized cities, due to the large share of urban population living in such urban environments [2, 3]. Medium-sized cities, particularly in the Nordic countries, are also often characterised by dispersed urban structures and therefore challenges to cater to sustainable urban mobility in such settlements [47]. Therefore, only the medium-sized smart cities of the Nordic Smart City Network with between 100.000 and 350.000 inhabitants are selected as case studies.

With the larger capitals (Copenhagen, Stockholm, Helsinki, Oslo/Bærum) and smaller cities (Syddjurs, Torshavn) being excluded, this resulted in a homogenous sample of 14 cities: Aarhus and Vejle in Denmark; Espoo, Oulu, Tampere, Turku, and Vantaa in Finland; Reykjavik in Iceland; Bergen, Kristiansand, Stavanger, Trondheim, and Tromsø in Norway; and Malmö in Sweden.

3.2 Analysis

To assess smart mobility measures in these cities, we reviewed publicly available English documents on smart strategies and mobility intervention of the mid-sized cities of the Nordic Smart City Network. This so-called grey literature includes published smart city strategies as well

as web pages. The documents were identified by reviewing official smart city representations of smart cities of the network online (see Additional file 1: Appendix 1).

A qualitative review of the available documents was conducted independently by the two authors. The assessment criteria and the prompts used to rate them are described in detail below. When ratings differed between the reviewers, consensus was reached based on discussion.

We applied two different analytical frameworks to the case studies.

3.2.1 Sustainable urban mobility plan (SUMP) objectives

First, the overlap between smart mobility initiatives and sustainability goals is explored. In this study, the contribution of the reviewed strategies and measures to the objectives of European Sustainable Urban Mobility Plans (SUMP) is used for qualitative assessment. According to [8], SUMPs should address the following topics:

- *Inclusion: Ensure that all citizens are offered transport options to enable access to key destinations and services;*
- *Safety and Security: Improve the safety and security level of the transport system;*
- *Environment: Reduce air and noise pollution, greenhouse gas emissions, and energy consumption;*
- *Efficiency: Improve the efficiency and cost-effectiveness of the transportation of persons and goods;*
- *Attractiveness and quality of life: Contribute to enhancing the attractiveness and quality of the urban environment and urban design for the benefit of citizens, the economy, and society as a whole.*

The reviewed smart mobility measures are qualitatively evaluated based on whether they explicitly mention or address any of the five topics. We documented whether the criterion was mentioned, partly mentioned, not mentioned, or if the measure actively/explicitly contradicts or counteracts the criterion. This is done to assess each measure's contribution to a more sustainable urban transport system with the help of a qualitative and descriptive review of the different strategies and initiatives.

3.2.2 S.M.A.R.T. objectives

Originally proposed by Doran [9] and applied in business management, the S.M.A.R.T. framework is now an established tool for efficient objective-setting across disciplines. The framework consists of five criteria [9, 49]:

- *Specific: Target a specific area for improvement*
- *Measurable: Quantify or at least suggest an indicator of progress*
- *Achievable/attainable: There should be a realistic chance that a goal can be accomplished [originally 'assignable': specify who will do it]*
- *Relevant: Goals should be consistent with the general vision and ambitions and should not conflict with other goals [originally 'realistic': state what results can realistically be achieved, given available resources]*
- *Time-bound: Specify when the results can be achieved*

In the current study, S.M.A.R.T. criteria are used to evaluate the quality and robustness of smart mobility strategies and measures, similar to Elgazzar and El-Gazzar [50]. A qualitative assessment is performed by evaluating whether each criterion is sufficiently addressed in each smart mobility measure. The assumption behind this is that when projects have concrete and measurable goals, the effects and success can be evaluated in an accountable manner. While Bjerke and Renger [51] urge for caution and context-sensitivity when applying S.M.A.R.T. criteria and recommend a stepwise rather than simultaneous approach, in this study we treat them as equal indicators for the quality of smart mobility objectives.

Like the SUMP objectives, criteria were rated as either mentioned, partly mentioned, not mentioned, or failed.

4 Smart city initiatives in Nordic mid-sized Smart Cities

To test and validate the proposed methodology, it was applied to the medium-sized cities of the Nordic Smart City Network [48].

Addressing the first research objective, concrete measures were identified in the review of available documents and online sources of the smart cities under investigation (Table 1). While the Norwegian smart cities have fewer specific mobility initiatives, the Finnish and Icelandic ones have several, and the Danish smart cities seem to be the ones most focused on mobility measures. The Danish smart cities Aarhus and Vejle display most smart mobility measures, followed by Turku, Espoo, and Malmö.

The measures can be categorised based on whether they aim at (i) reducing car travel or making it more efficient, (ii) a modal shift towards and improvement of public and active travel modes (mainly biking), (iii) the collection of data and knowledge, or iv) testing or piloting measures. Table 1 shows that the integration of different travel modes (multimodality), mobility hubs, and MaaS seem to be among the most prevalent smart mobility measures (present in six cities). Other initiatives focus on technological advances within motorised vehicles (EVs, AVs), shared cars, or bikes, as well as the improvement of conditions for biking and e-biking. There are also a few softer mobility measures, such as campaigns,

Table 1 List of smart mobility initiatives in mid-sized Nordic smart cities (X = present, (x) = considered, Grey = assessed in-depth in Sect. 4.1)

	DK		SE	N					IS	FI				
Smart mobility measure/initiative	Aarhus	Vejle	Malmø	Bergen	Kristiansand	Stavanger	Trondheim	Tromsø	Reykjavik	Espoo	Oulu	Tampere	Turku	Vantaa
Autonomous vehicles (incl. ferries)		X					X			X		X		X
Bicycle infrastructure/parking/prioritising (e.g., super-highway, winter route, RADICAL)	X	X	X										X	
Bicycle-sharing/rental system		X	X						X	X			X	
Car-sharing / Car-pooling	X			X					X	X			X	
Digital/intelligent/cooperative car parking system		X				X		X						
E-bike trial / car-replacement trial (e.g., 365 days)	X													
Electric vehicles (e.g., buses, waste collection) & charging infrastructure		X	X			X						X	X	
Intelligent prioritising of emergency vehicles											X			
Intelligent transport management / traffic control	X	(x)								X	X	X		
Mobility hubs / MaaS (multi-modal travel, integrated ticketing, last mile solutions)	X			X		X				X			X	X
Public transport app									X		X			
Voluntary travel behaviour change program (campaigns, trial periods, personal travel planning) (e.g., super commuters)	X		X											
Travel information app (e.g., drive now)	X								X					
Travel/trip data collection		X	X											X

provision of information, and trial periods, indicating a broad understanding of what constitutes smart mobility.

4.1 Evaluation of selected smart mobility initiatives

Not all cities had explicit and detailed data on the found initiatives, and therefore only some cases are discussed in detail below. For in-depth assessment, we selected smart mobility measures based on the availability of information. At the same time, we included measures across different categories. This resulted in the selection of 12 measures across six smart cities: the "introduction of AV" and the "cycle super-highway" in Vejle, the "bicycle city" and "drive now" app in Aarhus, "EV charging in lampposts" and "Mobility hub" in Stavanger, the "Neighbourhood Smart Parking Assisted Living ecosystem" in Tromsø, the "Föli Bikes", the use of biogas as a fuel for heavy vehicles, the "12-km winter cycling test route" and the "electrification of public transport" in Turku, and the "bike rentals" in Reykjavik.

4.1.1 Do the selected smart mobility measures meet SUMP objectives?

When applying the SUMP framework, the descriptions of the measures are evaluated on social inclusion, traffic safety and security, environmental impact, efficiency, attractiveness, and quality of life (Table 2).

All measures using technological advances (i.e., AV, EV, biofuel, E-PT) aim at reduced environmental

Table 2 Assessment of SUMP and S.M.A.R.T. objectives of the selected smart mobility measures (+ mentioned, (+) partly mentioned / in principle measurable, o not mentioned, - potential to undermine / failed to meet criterion)

Category	Smart mobility initiative	SUMP objectives					S.M.A.R.T. objectives				
		Inclusion	Safety & Security	Environment	Efficiency	Attractiveness & quality of life	Specific	Measurable	Achievable	Relevant	Time-bound
New mobility technology	Introduction of autonomous vehicles, Veile (DK)	o	o	+	+	+	+	(+)	o	-	(+)
	EV charging in lampposts, Stavanger (N)	o	o	+	o	+	+	+	(+)	(+)	o
	Clean logistics/ using biogas as a fuel for heavy vehicles, Turku (FI)	o	o	+	o	o	+	+	o	+	+
	Electrify public transport, Turku (FI)	o	o	+	(+)	+	+	+	o	+	+
Sensor-data	"Drive now" app, Aarhus (DK)	o	o	o	+	o	+	(+)	o	-	o
	Neighbourhood Smart Parking Assisted Living ecosystem, Tromsø (N)	o	o	o	+	o	+	(+)	o	+	o
MaaS / Shared mobility	Mobility hub, Stavanger (N)	o	o	o	+	o	+	-	o	+	+
	Föli-fillarit (Föli Bikes), Turku (FI)	+	o	+	+	+	(+)		+	+	+
	Bike rentals, Reykjavik (ISL)	o	o	+	o	o	(+)	(+)	o	+	o
Bicycle infrastructure (incl. campaign / behaviour change)	"Cycle super-highway", Veile (DK)	+	o	+	+	+	+	(+)	o	+	(+)
	12-kilometre winter cycling test route, Turku (FI)	o	+	o	+	o	+	+	o	+	+
	"Bicycle city", Aarhus (DK)	+	+	+	+	+	o	(+)	o	+	o

impact, by reducing energy consumption and emission. The same is true for bicycle sharing or rental systems and improved bicycle infrastructure. Other measures, such as apps telling the traveller when to drive or where to park, however, assume little environmental effects, or at least they are not explicitly mentioned.

By reducing traffic congestion (e.g., AVs) and travel time (e.g., bicycle highway, drive now), increasing the operational performance of public transport, sharing available parking spaces, or making year-round cycling more attractive, urban mobility can also become more efficient.

Some measures also claim to have a positive impact on public health by improving air quality or through increased physical activity (biking). Increased passenger satisfaction, as reported in the electric buses of Turku, can also be said to contribute positively to urban quality of life and attractiveness. However, only around half of the studied initiatives mention these aspects.

Only a few of the initiatives targeting bike use (e.g., Föli bikes, super cycle highway, bicycle city) mention inclusiveness and accessibility, e.g., the cycle super-highway aims at connecting different neighbourhoods and Föli bikes want to make cycling more accessible. Aarhus bicycle city aims at encouraging children and commuters to bike, as well as targeting increased traffic safety for citizens. However, none of the other initiatives mention social or safety aspects.

Generally, this shows that the selected smart mobility measures have a stronger focus on, environmental impact, efficiency, and health and well-being. The social sustainability aspects, however, seem somewhat neglected or at least under-communicated. While these findings are generally encouraging in terms of smart mobility measures addressing environmental aspects, this indicates a narrow understanding of sustainable urban mobility with environmental and economic aspects prioritised over social aspects.

4.1.2 Are the selected smart mobility measures S.M.A.R.T.?

When using the S.M.A.R.T. framework, the descriptions of the selected measures are assessed on whether they are specific, measurable, achievable, relevant, and time-bound (Table 2).

In terms of specificity, all selected measures stated specific targets to be achieved through the implemented or proposed initiative. Some initiatives for instance explicitly aim at reducing car dependency and promoting car-free lifestyles (e.g., cycle super-highway, Föli bike), as well as reducing traffic congestion and CO_2 emissions (e.g., cycle super-highway, AVs, drive now). Some targets are also phrased through encouraging greener modes of transport such as EVs, biofuel, or biking (e.g., EV charging, E-PT, green logistic, cycle super-highway, Aarhus bicycle city) or improving travel time (e.g., drive now). Other initiatives want to encourage behaviour change (e.g., Aarhus bicycle city) and increase biking all year round (e.g., cycle super-highway, winter cycling route). Finally, making it easier to switch between transport modes (e.g., mobility hubs), sharing available parking spaces, and improving health and well-being (e.g., cycle super-highway) are also among the smart mobility targets. This means that in almost all measures the target of the intervention is specifically described.

A few initiatives aim at measuring the effect of the implemented smart mobility measures, such as the number of EVs (e.g., EV charging), the use of biogas fuel, increased bike share use, and satisfaction with biking (e.g., Föli bikes, winter bike route), or the reduction of CO_2 (e.g., E-PT). Most initiatives, however, did not mention measurable targets, even though it may have been possible to measure the specifically mentioned goals through indicators such as car use, bike use, congestion, emissions, travel time, or transport energy consumption. While eleven initiatives are measurable (according to our assessment), only five of them are proposed to be measured. Not assessing the effects of the mobility measures, results in a low degree of measurability and accountability.

Likewise, it is theoretically possible to achieve all targets. However, none of the reviewed measures has a concrete benchmark for when the project would be considered a success (or failure). This lack of concrete goal-posting again makes it difficult to assess smart mobility initiatives.

The relevance of the introduced smart mobility measures is assessed on whether the measure itself or its goals and outcomes are in line with or in conflict with other goals. While most of the studied smart mobility initiatives are in line with, for instance, carbon neutrality or the promotion of public and active travel, introducing AVs, EVs and making driving and parking more effective can conflict with the goal of making sustainable transport modes more attractive and reduce car dependency. Such goal conflicts can generate suboptimal results, particularly if the goals have varying degrees of priority, support, and acceptance among policymakers and the population.

This is particularly true when combined with the fact that only five measures are time-bound. Though the specificity of schedules varies. Föli bikes and public transport, for instance, are regularly evaluated since 2018, and the introduction of mobility hubs in Stavanger was to be concluded in 2020, while the winter bike route in Turku is supposed to be 80 km by 2025. Other measures use more general time-posting, like short-term (e.g., cycle super-highway) or medium-term (e.g., AVs). More than half of the initiatives do not mention any specific timeframes for goal achievement, which makes it difficult to have accountable assessment.

Thus, the reviewed smart mobility measures seem to be well-defined in terms of targeting specific goals and are relevant and well-aligned with the aims of other smart mobility solutions. However, they lack measurability, success benchmarks for achievability, and specific timeframes for goal achievement. This is worrisome as it can result in measures being introduced without plans of effect evaluation and therefore little sense of accountability.

5 Conclusion and discussion

The study reveals that the mid-sized cities of the Nordic Smart City Network all work strategically toward becoming or being smart cities. However, not all are equally focused on and committed to smart mobility or urban sustainability.

The question of whether smart mobility projects are in line with sustainable urban mobility is assessed with the SUMP framework. We find that smart mobility measures can contribute to sustainable mobility, for instance through promoting active travel and reduced transport emission, and they have a particular focus on making urban travel more efficient, for instance by reducing travel time. Within this, there is sometimes a focus on technological aspects without explicitly mentioning the

added value compared to conventional or passive solutions, such as when using data for improving car flow or promoting EVs, compared to creating physical infrastructure to make the bike more attractive. As Haarstad [5] points out, the smart city and its interventions are 'technology-driven', meaning they build on the belief that increased efficiency and market opportunities are the way toward sustainability rather than reduced consumption. This begs the question, whether the smart city agenda makes us overlook alternative ways towards more sustainable urban transport that lay outside the scope of smart mobility (i.e., increased use of ICT, vehicle efficiency, technology), but rather revolve around reduced transport and behaviour change. This begs the question of whether the focus on smart mobility solutions deters cities from conventional transport measures that may be equally or more cost-effective and efficient in achieving environmental goals. It also seems that the social aspects of sustainable urban mobility, such as traffic safety, social inclusion, attractiveness, and quality of urban life receive less focus and are only mentioned rarely as explicit targets of smart mobility measures.

When investigating whether smart mobility measures are well-designed to achieve urban mobility goals with the help of the S.M.A.R.T. framework, we find that most measures have specific goals or targets and are relevant to contributing sustainable urban mobility through aiming at the improvement of travel quality, reduction of environmental impact and an increase in public health. However, some measures also display conflicting goals, for instance, when making car use more efficient as opposed to promoting green travel. A general challenge is that many smart mobility projects are not well-described and often seem to be put in place because they are smart and possible but may lack explicit justification for implementation. Another pressing issue is that smart mobility projects often lack any explicit aim at measuring or benchmarking effects within a certain timeframe. This is concerning, as it makes goal assessment difficult. Ideally, it should be possible to assess effects and base further policy decisions on accountable and verifiable data, whenever projects are funded publicly. However, this is also true for conventional transport projects.

Another challenge is that there are very few reports on smart lessons to be learned, i.e., whether a project was successful, and if so in which context and why. The Roadmap for smart and sustainable cities and communities in Norway encourages to highlight the positive effects of smart city initiatives [52]. However, we know that negative results are underreported in academia and professional contexts, which then does not give a balanced view. Given that the investment in smart cities in a European context is a large social experiment, reported results must be neutral and objective.

In the field of transport and mobility, it is widely acknowledged that sustainable urban mobility must cater towards more active and public travel and less focus on private car use [53, 54]. In smart city practice, however, there are examples where technological transport solutions are implemented without clear goals of improving urban mobility. While part of the solution may lay in smart technology, co-creation, education, or governance, it is also possible that other solutions may be more efficient or cost-effective that are currently not given enough attention due to the strong focus on smart cities and technological development. For smart mobility initiatives to be relevant over time, they must become more measurable and accountable, not least in their contribution to sustainable urban mobility.

As for the validity of the methodological approach, we found that the two analytical frameworks of Sustainable Urban Mobility Plans (SUMP) and S.M.A.R.T. were useful in revealing insights into the level to which sustainability is addressed through smart mobility initiatives, and whether the measures use meaningful objectives. While the method is qualitative, it is possible to say which topics are addressed more frequently or dominantly, i.e., inclusiveness, safety, environment, efficiency, or quality of life. It is also possible to evaluate the appropriateness of the objectives of the introduced and proposed measures in terms of relevance and accountable goal achievement. As such, the methodology is beneficial in assessing whether smart mobility strategies are posed in a concrete and accountable manner and allows to evaluate the relevance of smart mobility initiatives for sustainable urban mobility. The combined application of the two frameworks, therefore, inspects initiatives in terms of their manageability as well as contribution.

However, the methodology has several shortcomings. One caveat is that we only report on publicly available online documentation in English. It is, therefore, possible that there are other smart mobility strategies and measures, or more information and details on the included projects, that are not accessible to us. Should that be the case, this study still reveals a lack of explicit statements of social sustainability goals and measurable outcomes in the public international sphere. It is also possible that the available documents are coloured by successful or desirable measures, and therefore less popular or effective measures are not presented. Also, the approach offers a tool for qualitative evaluation of smart mobility strategic goals and measures but does not offer direct comparisons between measures or cities. Even though the smart mobility measures are rated according to the same criteria, it is not

possible to make absolute comparisons. I.e., where a quantitative evaluation of effectiveness in terms of car share reduction or reduced CO_2 emissions would have allowed for direct comparison, the current analytical framework does not allow this. Therefore, the outcomes can mostly be discussed as individual results or single cases.

Nevertheless, we regard this way of reviewing smart mobility measures, and transport measures in general, as a positive contribution in two ways. Firstly, it does not only evaluate smart city and mobility measures in themselves but rather in their contribution to sustainable development. This is important to commit smart cities to work coherently towards sustainable urban futures. Secondly, such an assessment can pinpoint shortcomings in policymaking by requiring policymakers to reliably deliver on set objectives as well as overarching goals of urban sustainability.

Supplementary Information

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Additional file 1. List of reviewed information.

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References for case studies and analyses are attached in the appendix.

Declarations

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