Implementing Sustainable Urban Mobility Transitions in Positive Energy Districts

Discussion Paper

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ABSTRACT

This paper examines Smart Cities transition with the focus on urban mobility. We demonstrate how a multi-stakeholder, multi-disciplinary approach can support integration of systems, data, people, and organisations with a case study on new integrated mobility solutions and urban decarbonisation.

CCS CONCEPTS

• **Information systems → Spatial-temporal systems**; **Information systems applications**; • **Human-centered computing**; • **Applied computing → Enterprise architectures**;

KEYWORDS

Sustainable Mobility; Positive Energy Districts; Enterprise Architecture; Urban Data; Location-Aware Information Access; Smart Cities

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1 INTRODUCTION

Smart city development is an inherently multidisciplinary, interdisciplinary, and multi-stakeholder topic. It connects traditional city-related disciplines with a range of other domains to build connections towards sustainable liveable cities. Digitalisation, urban data, and web-mediated systems provide a technical foundation and move from individual systems or data to an integration across urban systems and services. This shows in emerging fields such as urban computing, urban complexity science, big urban data, open city data, and urban sustainability.

The numbers are well known: Cities account for 80% of all greenhouse gas emissions; urbanisation will lead to an estimated 70% of the world population living in cities by 2050; and an estimated 40% of overall greenhouse gas emissions in cities come from the transportation sector. But what does this mean in practice? Cities are at the forefront of working towards sustainability goals and goal achievements, and are important drivers for climate change mitigation and emission reductions. Mobility systems and intelligent transportation systems are included in this transition as cities aim to achieve sustainability goals while keeping in line with changing industries and regulations.

The transition calls for larger integration and interoperability efforts in complex multi-actor settings, and can enable the municipality as facilitator and as defining framework conditions for a rapidly adapting and evolving local ecosystem. This includes a new connection between inhabitants, businesses, academia, and municipalities; innovative partnership and business models, which in many cases are strongly linked to data from the mobility need prediction or the energy system; new Apps, data integration backends, eMaaS platforms (electric Mobility as a Service), and web applications; strong need for open data, access, protocols, APIs; to enhance liveability and mobility services.

In this paper, we discuss our project +CityxChange [3, 4] that develops demonstrators for smart sustainable cities. Due to its complexity, we select one case study which can stand as an example for the developed processes and solutions. We focus on the case study of urban mobility, as a subset of smart city approaches, under a scenario of *Mobility Integration in Positive Energy Districts* through an action research methodology. We discuss specific systems and services that were developed, and discuss them within their critical context and processes. These include transport and infrastructures, climate change and emission reduction, air quality and noise, giving special attention to fostering alternatives to private vehicles and the use of more efficient and sustainable ways of transport. On a larger scale, these developments also influence urban planning, particularly through instruments such as sustainable mobility action plans and climate action plans, but also in how local physical planning has to adapt.

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To develop and transform mobility in cities towards emission reduction, we argue that joint and integrated efforts are needed in a multidisciplinary and multi-stakeholder understanding and approach and in practical coordination and collaboration between both private and public stakeholders [1].

In a larger context, this work addresses the UN SDGs (Sustainable Development Goals)[1] through our case study with a main focus on:

SDG Goal 9 Industry, Innovation, Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation

SDG Goal 11 Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient and sustainable

SDG Goal 13 Climate Action: Take urgent action to combat climate change and its impacts

The paper will briefly discuss background in terms of smart city and mobility approaches and the larger project, before doing a detailed exploration of the mobility case study.

2 BACKGROUND

2.1 +CityxChange Lighthouse project

+CityxChange develops demonstrators for Positive Energy Districts (PEDs) in smart sustainable cities. It is a complex large-scale demonstration project across 7 cities using a co-creation and living lab approach [3, 4].

PEDs are developed as local areas with upgraded buildings, infrastructure (both physical and ICT), and local renewables generation; so that the PED generates more energy than it needs for itself [11, 25]. The energy balance is counted over a year since the PED is intended to be an integrated part of the urban area and grid and not an autonomous disconnected system. This integration allows it to expand over time as it can share its surplus energy with the city around it. The development is supported by a large range of demonstrators, around energy exchange, energy trading between buildings and energy assets, building measures, mobility, strategy alignment, finance models, citizen and stakeholder engagement, and innovation labs, to name a few.

The case demonstrates how innovative systems, platforms, app, and specifically *innovation integrations* across systems can open up new possibilities, support changes in behaviour, make better services for inhabitants, unlock social value for inhabitants and municipalities, and create business value to operate it. It uses a quadruple helix innovation model coupled with open innovation and co-creation, across stakeholders, organisations, and inhabitants.

On the software and system side, the project follows an open architecture with loosely coupled components, to keep responsibility within the responsible and capable stakeholders, with an Enterprise Architecture approach to synchronise the work [5, 18, 19]. This is part of overall methods for modelling Smart City and sustainability transformations [6, 9, 15].

The details of the +CityxChange mobility case are described in Section 3. We focus on questions of integration of mobility and digitalisation, mobility and energy, and mobility and emission reduction. While the project operates in 7 cities, we use the example of Trondheim, Norway, to highlight key considerations and goals.

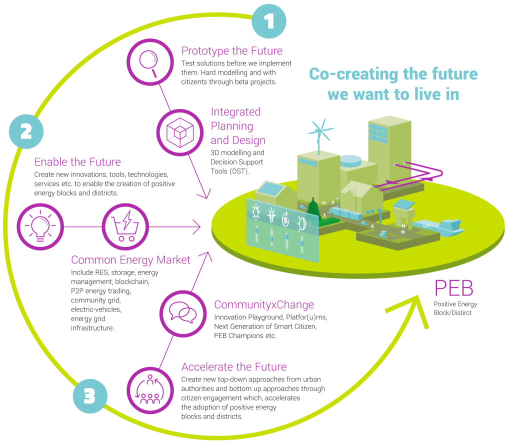

Figure 1: Overall +CityxChange approach [3]

2.2 Mobility approaches in smart cities

There are two main complementary goal categories around emission reduction we discuss here; to support the move away from greenhouse gas emitting modes of transport; and reduction of individual and group transport emissions by changes in the urban mobility system. This can take various forms, such as the potential to reduce emissions linked with reduction congestion or improvement of transport system capacity overall. Additional goals are often the need to reduce costs, and issues of increasing land use for building new transport infrastructure, in addition to its related emissions. In many cities, there is also a lack of space for such increased transportation demands. This also opens up stronger integration of these issues into urban planning and transport planning.

We give an overview of examples of general approaches:

- shift towards sustainable modes of transportation [1]
  - car to public transport, cycling, walking
  - modal shift away from individual transport to shared or public transport
  - better and more dynamic public transport
  - better usage of existing cars, reduction of the need for private car ownership (supported by sharing economy concepts)
  - mobility as a service, integration of different modes of transportation within one journey
- shift in urban planning towards higher densities and mixed use districts, reduction of commuting
- behaviour change towards more awareness (e.g. [12])
- combustion engines vehicles shifted toward EVs
- reduction of emission-intense transportation modes
- understanding of mobility patterns for better large-scale and small-scale city and mobility planning
- understanding the links between traffic and emission/pollution patterns for more targeted interventions

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[1] https://sdgs.un.org/goals

Most related transportation and logistics issues are out of scope for this paper, as are large-scale issues such as airplanes, trains, or long-distance boats. Logistics, including trucks and trains, or the last mile of logistics chains, goods delivery, and personal goods transport opens up opportunities as well and can be an important part of smart cities. The ones tested in our case include e-cargo bikes. Most of these need an ICT-based infrastructure and a way for citizens as users to interact with the services and platforms. This is usually done over the Web or through Apps. The backend integration is usually also web-mediated.

2.3 Smart Sustainable City developments

Smart Cities can be narrowly understood as an umbrella term denoting the increasing use of sensors and data analysis in the operation of a city as part of technological and organisational convergence, ideally connected to more transparency and availability of open data [7, 24]. They are based on complex system architectures and infrastructure connecting classical information systems, sensor networks, social networks, data streams and more to build new urban information systems [21]. A main driving force is to handle challenges in the growing complexity of urban management and to handle urban growth, optimise city use, and reduce emissions. Further goals include the development of more open, sustainable, liveable, and citizen-friendly cities [2, 17]. This focus on citizens and civil society opens up challenges and opportunities based on newly available data and application domains.

A useful definition of the Smart City is the combination of the physical space and infrastructure of the city, the social aspects of the citizens, and the urban information space. Similarly, smart cities have been described as empowerment of the spatially enabled society [20] which points towards the inclusion of citizens in shaping the city.

An even stronger social involvement has been claimed in that ‘cities are social search engines that help like-minded people find each other’ [24]. A combination of services and data can help to build new enabling services, which can then crosscut city silos and services, for both citizens and the city itself. It can further support citizen involvement in an inherently open and adaptable environment [24].

Our understanding combines these views into Smart Cities as complex and dynamic socio-technical constructs [2] which highlights the human aspects of smart cities and the social and human aspect apart from a purely technical approach.

3 MOBILITY IN +CITYXCHANGE IN TRONDHEIM

The mobility demo in +CityxChange in Trondheim comprises a number of components that overall enable an *integrated ecosystem of mobility and mobility services*:

- An ambition to reduce mobility emissions and decarbonise transport, in line with the municipality’s climate and mobility plans to ensure alignment and longevity of solutions;
- co-created mobility and integration solutions;
- the development and deployment of an eMobility-as-a-Service scheme (eMaaS) which allows for short-term rental of EVs from charging stations, with a respective partnership and business model;
- an integration of mobility with energy, especially the electricity grid: linking charging of electric vehicles (buses and EVs) with the energy planning for the district, and in particular the use of the car batteries as grid-available batteries in the local PED system through V2G chargers;
- individual adaptations in mobility partners’ backends, the PED backend, and the app frontend to enable this deep and complex integration;
- and the development, testing, and deployment of the Mobee mobility service platform that integrates these with a wide spectrum of real-time mobility options in the city (see Sec. 3.5).

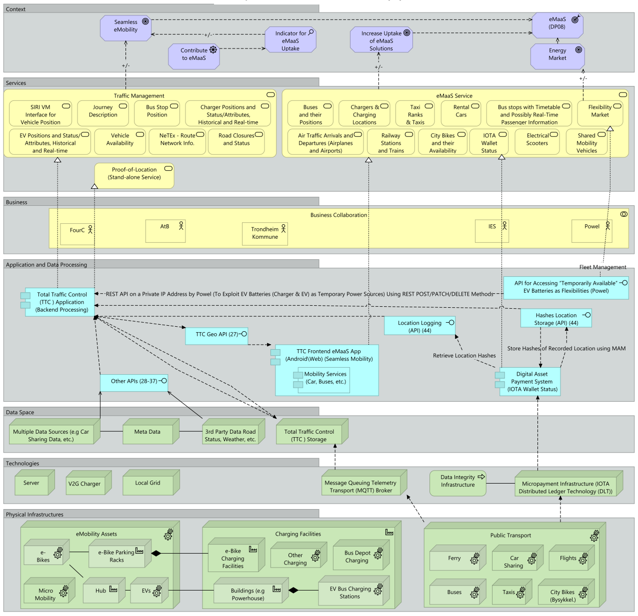

Figure 2: Enterprise Architecture view of the developed integrated mobility case. Final development has slightly adapted but core principles and structures remain (from [18])

More technical details can be found in the respective project reports [4, 22, 23], upon which parts of this paper are based.

To structure and understand the work, we have adopted an Enterprise Architecture view for part of the integration efforts, especially in the early stages. This was modelled for many cases in the project [18] and also examined in particular for early aspects of the mobility demos [8], as seen in Fig. 2 as a simplified view of the embedded complexity.

3.1 Governance

Activities of the municipality, as any other organisation, need to be aligned with its goals and strategies. Cities are governed by very specific processes and documents, such as Climate Action Plans, Sustainable Mobility Action Plans, etc. Issues can also be addressed with direct regulation or legislation. For example, specific regulations were enacted in Norway to allow legal and regulated operation of taxi alternatives such as Uber or the now prevalent short-rental e-scooters of various providers.

For overall Smart City strategies, as well as for mobility systems, cities do not provide every service. Many aspects are handled by others, be they partners or independent actors. This also means that not all services need to be fully integrated into a smart city or linked to city systems. However, cities do take an interest and can provide a more level playing field or set specific framework conditions to enable desired development. In our case, it also included the municipality taking ownership and providing support, to ensure an integrated mobility platform and app was available in the city.

3.2 Co-Creation

The project follows an Open Innovation, Co-Creation, and Quadruple Helix Innovation model [3, 5, 10]. One part involved getting core organisations and business partners together, such as the carsharing company, the local public transport authority (which contracts bus operators), city bikes, etc. and then spread out to further mobility organisations, and an advisory group. The other part consisted of inhabitants and users, including testing system ideas, prototyping and validating ideas around the mobility platform. It also included identifying and fixing bugs in both front and backend development. Inhabitants were used for active user testing and feedback, which took place "in the wild" in the city. This included usual testing and also a "scavenger hunt" through the city on various modes of transportation [13] as well as testing other forms of mobility support, for example electric cargo bikes shared from a local furniture store to ease goods transportation.

Work has also included other ways to promote shared green mobility, for example testing different deployment at grocery shops in short-term "sprints" for fast feedback[2] and adaptation of strategy.

3.3 eMaaS scheme, backend and car integration

The electric-mobility-as-a-service demonstrator included the eMaaS platform and the integration of car sharing and other mobility options. The idea is to reduce the amount of cars needed by a suitable car sharing or short-term rental scheme with only EVs, and to connect other mobility modes as well to allow inhabitants and users an easier choice. This can have a substitution impact of up to 10:1, and may be higher if a combination of alternatives is offered[3]. To this end, the mobility platform backend integrates first the availability of shared EVs from the provider in the project, then broadened to include the options and detailed locations of additional car sharing providers, city buses and stations, city bikes, e-scooters from multiple companies, taxis, trains, trams, ferries, and planes from the local airport, as well as other stationary items such as charging stations or cargo-bike stations.

This was partly enabled by Norway's implementation of the MMTIS (Multi-Modal Travel Information Services) EU regulation[4] which enables or mandates public transport companies to make static and dynamic "transport object" positions (e.g. bus stops, bus timetables, vehicle positions, etc.) available using an open API to the real time data[5] provided by the Norwegian implementation of the "national access point"[6] for transport data. Other connections to bikes, other car sharing, taxis, or e-scooters were enabled by direct negotiation with the individual owners who made their data accessible through API endpoints for integration within the platform backend. Where possible, this is based on open standards, as increasingly mandated by regulations. In other cases, the available APIs and protocols needed to be used as-is, or specific protocols were defined in the project.

This is a strong data-driven integration effort, which the eMaaS backend integrates across all available forms of mobility in a sophisticated way. For the specific car-sharing case, additional backend integration on system-level was needed. A number of logistics issues around charging locations, grid connections, etc. had to be solved first [23]. The user-facing side of this integration is shown further below.

For the integration into the district energy management of the PEB (see also next point), they needed additional complex communications integration in multiple ways: The previous backend system of the provider needed to be updated to deal with the additional features of EVs, in particular battery charging status and ability to remote-control and -initiate the charging. Most EVs, if they have remote function, do this through a car-maker-provided app that runs through their servers, so integrating it into the fleet management backend was needed as a different path. Discharging of the batteries needs additional functionality. Some of this is not possible only remote, but the car and the charger need to negotiate the protocol and the charging scheme.

Then the energy management needs to communicate to both the smart charger (and possibly the building it is connected to) and the car. The communication with the car has to run through the fleet management system, which then in turn communicates with the car, to enable it to negotiate with the charger, which is connected to the energy management system. This is because in most cases, neither chargers nor cars alone cannot initiate the charging or discharging without their respective backends. The cars are usually connected through their own 4G mobile online connection or an additional telematics kit for the car sharing functionality, while the chargers either have their own communication module over 4G or are integrated into the building management system. Optimising the charging should be done in combination with the district energy management and the fleet management (see next item).

3.4 Energy integration

There are two main drivers for the energy integration: EV numbers are strongly rising and they need to be charged and managed in a way that does not put undue stress on the grid. On the other hand, they have a large potential for electricity grid optimisation through smart charging and the use of their batteries in the district. The local renewable energy generation of the PED can then also cover the energy for the mobility demand in the district. This also provided a welcome testbed for the partners.

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[2] https://cityxchange.eu/testing-car-sharing-at-trondheim-grocery-stores/

[3] https://www.toi.no/forskningsomrader/atferd-og-transport/en-delebil-kan-erstatte-10-15-privatbiler

[4] https://eur-lex.europa.eu/eli/reg_del/2017/1926/oj

[5] https://data.norge.no/datasets/f8327e57-60fa-440f-9ecd-a8765ca13ae6

[6] https://transport.ec.europa.eu/transport-themes/intelligent-transport-systems/road/action-plan-and-directive/national-access-points_en

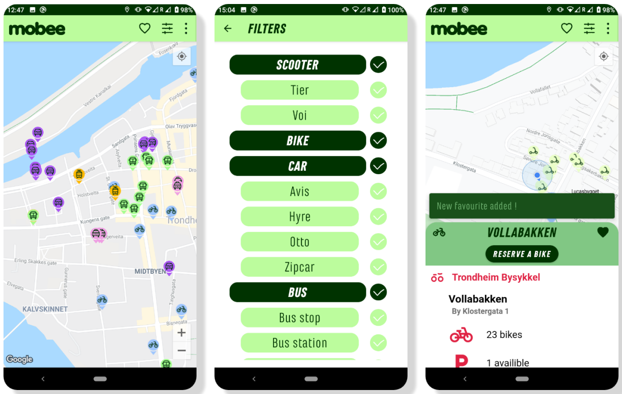
Figure 3: Deployed shared EVs in an outdoor location, and in a parking garage with a V2G charger (from [23], photos by Trondheim kommune)

Using EV's batteries can significantly reduce the need for large physical batteries in the district. However, they need to be sufficiently available. In Norway the availability is expected to be a significant issue as the transition to EVs is going strong. In 2023 it had a rate of over 80% of new cars fully electric EVs[7]. The overall fleet composition is catching up. Using the batteries for the district mandates the use of V2G chargers (Vehicle-to-Grid) which allow the cars to discharge as well. We could use a few first prototypes of V2G chargers to demonstrate the concept. However, many normal chargers can be used to at least do smart charging, where the district energy management could determine when and how much they charge, providing additional flexibility and helping to balance the grid.

Suitable charging and discharging strategies then also mandate additional analysis modules in the fleet management. For an individual's car, it is hard to predict when it will be needed and how much capacity it would then need. Therefore, only a very small part of its battery capacity could be made available. With more prediction, such as through the carmaker apps, car owners can already optimise their charging and run it for example later at night when prices are lower. Scaling this to the fleet gives very useful effects of scale. First, the car-sharing system can have an overview of reserved cars, and can update this even more with machine learning on historic data. Then, it also has many more cars available. Some car batteries can be fully dedicated as district batteries, as other cars could be rented out instead. The optimisation potential here is large and not yet fully explored.

For its PEDs, the project created a local energy and flexibility market and platform [14, 16]. It abstracts most installations into so-called energy assets with different configurations. In this view, the car battery becomes an energy asset that has a capacity and a dynamic target for its charging state. A dynamic fraction of its capacity can be made available as a battery for the grid system. Capacity and power limits apply. This allows trading between the EVs through their chargers with the buildings, local energy generation, and the grid.

In addition to a normal battery, it will disconnect much more often, and often in a planned way, because of the prediction or reservation status of the fleet management. The district energy management may interface with the fleet management, but will also update its own prediction model across all assets in the district. Due to the markets, there is a price for the use of assets and batteries. This can incentivise EV owners to allow the system to manage a determined fraction of their battery capacity. In the preliminary testing and based on vendor experience, the small scale discharging does not seem to have a strong influence on battery capacity.



New favourite added !

Trondheim Bysykkel

Vollabakken
By Klostergata 1

23 bikes

1 availible

Figure 4: Mobee app views: map view, filter options, details and forwarding to bike sharing app (source: Mobee)

An additional integration of a mobility energy asset is a high-capacity charger for electric buses. The bus charger is installed within one of the PEDs at the terminal stop of a bus line. In this case, the bus is modelled as a short-term energy consumer, as its battery is not available for discharging. Due to an integration with the mobility backend and its real-time locations of buses, predictions for the charging need are much more precise and the district system can ensure sufficient capacity for example by pre-charging local batteries.

3.5 Mobee Platform and App with frontend & backend integration

Electric mobility as a service needs new apps and interfaces for the citizen. Overall goals are to support greener choices and provide easier access to them, provide greener and more sustainable transportation, improve quality of life, enable behaviour change towards sustainability goals through better access to information, pilot new modes and approaches to transportation and provide integrated solutions, and in short, making it easier to make sustainable choices.

As one project result, Mobee[8] is a mobility service solution with an app for Android and iOS (Fig. 4), developed by FourC in partnership with Trondheim kommune and partners in the +CityxChange project. The app is free for users, backend connection for other service providers is subject to agreements. It was intensely co-developed and tested in the Innovation Playgrounds as described above. It is the user interface to the backend data and systems integration of all relevant mobility sources.

The platform and app integrates all the data sources of available car sharing, buses with real-time locations and stations and schedule, taxis, e-scooters, bike sharing, parking options, chargers, and more for Trondheim and the surrounding county of Trøndelag.

Users have a map view of all available options, which can be filtered down to what is wanted. Booking of the mobility options

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[7] https://ofv.no/aktuelt/2024/nybilsalget-i-skandinavia-i-2023-kraftig-fall-i-norge-%C3%B8kning-i-danmark-og-stabilt-i-sverige

[8] https://mobee.no/

is usually forwarded to the respective own app of the provider. Usually, other providers do not accept booking outside their own app. The EU MDMS initiative[9] could change this, as it might require non-open mobility providers to allow open sales of tickets. The car sharing option is opened to all collaborating providers. The ones from the project are at fixed stations also to ensure the energy integration, while others may have "floating" vehicles.

4 CONCLUSION AND FUTURE WORK

We have demonstrated a mobility case that makes strong use of a multi-stakeholder multi-domain approach. It integrates a variety of perspectives and technical concerns to develop a new way to optimise and decarbonise mobility. Success criteria were the integration of data, systems, organisations, domains, users, inhabitants leading to an integrated mobility service and app for citizens and inhabitants. It was based on an open innovation approach and the ideas behind an enterprise architecture view with open boundaries between different actors. Such an open system of systems approach is considered critical to build up or facilitate an ecosystem.

Future challenges will include scaling up the solutions, and gathering more data from its operation, standalone and from the energy view, by the industry stakeholders, to further finetune the solutions and discuss results with the municipal and other quadruple helix stakeholders. Similar collaboration approaches have been undertaken in Limerick and in other project cities. For example, in the case of Písek, Czech Republic, e-mobility was strongly focused on electrification of buses and an integrated smart management system that links different forms of transport, gives people live updates on their travel, and link it to support for more cycling and walking in the city [4].

While many of the challenges were of a technical nature, it was regularly highlighted how the collaboration across organisational boundaries and silos and the collaboration with inhabitants was a critical prerequisite for a successful technical development that brings value to the citizens.

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