



Executive summary

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Chapter 2

Executive summary

Birte Holst Jørgensen, DTU

**Transforming urban mobility**

DTU International Energy Report 2019 focuses on sustainable mobility and transport systems in cities. The transport sector connects people across space and enables goods to be exchanged, but it also consumes energy, contributes heavily to CO₂ emissions and local air pollution, and imposes tremendous human and economic costs on society. Cities also offer opportunities for transforming urban mobility. Cities will require mobility solutions that are sustainable, affordable, secure, inclusive and integrated with the wider urban infrastructure and services, the ultimate objective being to create liveable and sustainable cities. For this to happen, a systemic transformation is needed, which will take place in the intersection between technology, infrastructure, multi-mode mobility and behavioural changes. This is summarized in three interrelated areas: how to avoid unnecessary transport, how to shift to eco-efficient modes of transport, and how to improve technologies, fuels and infrastructure. The report also addresses future educational needs in the area of urban mobility and presents a network analysis of the areas of research that are influencing urban mobility solutions.

Global outlook on transportation

The global energy outlook on transportation addresses the energy- and climate-related challenges in the transport sector and analyses two pathways through which the sector can contribute to a low-carbon future. Today the transport sector accounts for almost two-thirds of final energy consumption, produces approximately one-third of global energy-related CO₂ emissions and is primarily responsible for urban air pollution. Cities are expected to increase the impact on global energy demand and energy-related emissions. This represents a challenge but also an opportunity in transforming urban mobility. Growing population and income levels, flexible freight transport, e-commerce and digital technologies in cities are key drivers of transport activities. However, thanks to high population densities and travel patterns characterized by shorter distances, cities can be leaders in achieving active transport modes, public transport and the uptake of sustainable transport technologies such as electric vehicles (EVs). Getting transport on track to keep the rise in average global temperatures to well below 2 °C requires putting into practice a broad set of “avoid, shift and improve” measures.

In this chapter, the outlook for a low-carbon transport sector is analysed in two scenarios: the New Policies Scenario (NPS) and the Sustainable Development Scenario (SDS). The first scenario (NPS) analyses the out-

look towards 2040, taking into consideration officially declared policy measures and regulations, including Nationally Determined Contributions under the Paris Agreement, and taking known technologies into account. In this scenario, total energy-related CO₂ emissions rise by 10% in 2040 compared to 2017, which will result in a temperature increase of 2.7 °C. The second scenario (SDS) analyses how the energy and transport sectors can meet the Paris Agreement while also achieving a drastic reduction in air pollution and wider access to energy by means of the large-scale adoption of “avoid/shift/improve” measures in transport. The main mitigation levers include regulations to reduce the frequency of use of and distance travelled by energy-intensive modes of transport, a shift towards more efficient modes of transport, and the adoption of energy-efficient technologies for vehicles and of low-carbon fuels.

Mobility in cities in emerging economies

Future mobility trends will be determined by how cities in emerging economies address the huge challenges associated with increasing urbanization and growing per capita incomes. This chapter analyses mobility trends and challenges in four megacities in four emerging economy countries in three continents: São Paulo (Brazil), Beijing (China), Delhi (India) and Cape Town (South Africa). These four cities are quite diverse in terms of their demographic and economic characteristics and belong to C40 Cities. The four countries differ in terms of their respective developments, trajectories, mobility choices and impacts. All four cities have historically been densely populated and with time have further densified, except for Beijing.

In terms of mobility trends, Beijing has witnessed a decline in walking and cycling, whereas in other cities mode shares for non-motorized transport (NMT) have remained stable. São Paulo has most of its employment heavily concentrated in its central areas, while its low-income residents have settled on the peripheries, where a significant proportion of the poor population still walks. The situation in Cape Town is similar, with a large proportion of the population being poor and making many walking trips. Delhi is similar to many Indian cities, with mixed land use and a high share of walking and cycling trips (around 40%). The shift in modal shares from NMT is mainly to modes of public transport, where available, and to private vehicles.

In fact, the mode shares of private motorized vehicles have shown increasing trends except in São Paulo and Beijing. Beijing has experienced a peak in car use,

whereas Cape Town has traditionally been a car based economy, meaning that the share of car trips remains high. Delhi has a better public transport system than other Indian cities, despite which modes of private transport account for 36% of all trips, and car ownership has risen 3.5 times in ten years.

Cities in emerging economies are quite dense and provide opportunities for public transport and for shared and on-demand mobility solutions. Cities are investing in transit systems, mainly rail-based systems, to increase public transport. Although the ridership of these transit systems has increased, the share of public transport has not increased significantly, except for Beijing, which has a higher share of rides, as well as of public transport. China and India are witnessing a transformation towards on-demand transportation, accounting for three-quarters of the market for this mobility service. In China, ride-sharing is considered a mode of public transport and is led by the company Didi Chuxing. In India on-demand transportation has become an important mode of transport, provided by commercial taxis such as Ola and Uber.

Fuel efficiency has improved across all vehicle sizes, but efficiency in similar vehicle-size categories varies across countries. More fuel-efficient cars are also available in emerging economies, but the impact on overall fuel efficiency is being offset by increasing numbers of medium-sized vehicles. Electric vehicle (EV) policies are now in place in all four countries, but none of them, except for China, has any significant share of EVs. China is at the forefront of EVs, which make up 2.3% of the home market but 50% of the global EV market. China has implemented policies at all levels, including at city level, placing restrictions on the use of fossil-fuel cars and also providing incentives such as access to bus lanes, free parking, toll exemptions, insurance exemptions and local tax exemptions for electric vehicles.

Active transport modes

Cities around the world are currently trying to increase their shares of active transport modes, most importantly walking and cycling, in order to make themselves more sustainable and liveable. Social, environmental and individual factors influence when active transport modes are used.

Social factors and status associated with different transport modes vary considerably between countries and regions. The Netherlands and Denmark are the leading cycling countries in Europe, while East European countries like Romania and Bulgaria are dominant in

walking. Walking may reflect economic disadvantages and limitations in alternative modes of transport rather than preferences, but it may also reflect different cultures and traditions. Cycling is considered an everyday mode of transport in Denmark and the Netherlands, while people in other countries may consider it abnormal or associated with a low social status.

Environmental factors are related to urban densities and accessibility as preconditions for shorter travel distances and the use of active travel modes. There is a positive relationship between density, land-use mix and both walking and cycling. Walkability and bikeability are associated with access conditions, environmental qualities and infrastructure for pedestrians and bicycles. Preferences for route choices differ by region; cyclists in Copenhagen, for example, prefer elevated cycle tracks next to the road, whereas cyclists in Oregon put a relatively high value on off-street cycle paths. More generally, dedicated cycle tracks and sidewalks, separated from motor traffic, are considered a fundamental principle of road safety and active-mode mobility.

Individual factors are context-specific. In high-cycling countries all age groups and genders are well represented, whereas in low-cycling countries women and the elderly are underrepresented, which may be linked to differences in safety perceptions. Household mobility needs may facilitate car use, but bicycles can compete with the car in a city like Copenhagen that facilitates cycling. Travel mode decisions are influenced not only by functional but also by symbolic and affective motives, as well as by social norms. Cycling initiatives such as on-line platforms can fulfil both functional and social roles, while health-related motives also seem to be an important factor in cycling.

Modal shifts from cars to active modes of transport are influenced by “hard” measures such as better infrastructure and car-restrictive policies, as well as “soft” measures such as information provision and awareness campaigns. Infrastructural improvements and maintenance are not just about sufficient and safe pavements, but also about cycle tracks and sidewalks that are separated from motor traffic. Car-restrictive policies and parking-management policies are likely to increase the costs and difficulties of travelling by car, thus favouring other modes. Also, the taxation of cars and fuels influences choice of travel mode. In aiming to encourage voluntary changes in mode choice, theory-based interventions that include self-monitoring and intention-formation techniques have shown the most promising results.

Many different factors play a role in the uptake of cycling and need to be addressed. What is required is an integrated package of complementary interventions that address people differently, taking account of their current travel behaviour and intentions, as well as the existing urban lay-out and infrastructure.

Smart mobility

New, smart mobility solutions are designed around individual needs, usually with operations using new technology and often with resource-sharing. Smart mobility enables many solutions, ranging from shared on-demand mobility (car-sharing, bike-sharing, ride-hailing etc.) to integrated solutions (mobility as a service, apps for informed multimodal trip planning).

Smart mobility is primarily rooted in recent technological progress and digitalization where sensors, information and communication technology, and developments in computer science define mobility smartness. The *sensors* constantly monitor the main constituents of a transport system, namely vehicles, infrastructure and people. The sensors in a car monitor the hardware, driving, position and environment. Infrastructure sensors are used for intelligent traffic management systems, environment and parking. Sensors in smart phones and wearable electronics can also be used as personalized mobility services. The totality of digitalization produces a giant digital footprint, which can be used to monitor online transactions and smart-card usage and to predict transport supply and demand. *Information and communication technology* in this context relies on wireless data collection from vehicles, infrastructure, people, the digital footprint and communication between them. Vehicle-to-everything communication expands the technical options and includes tests on the platooning of trucks and autonomous fleets, as well as facilitating intelligent traffic management, parking assistance, driving assistance and remote diagnostics and positioning. *Analysing* the vast amounts of data from sensors can support decision-making in respect of smart mobility, including user behaviour, transport demand prediction and autonomous driving.

These technological features are giving rise to four operational features of smart mobility: flexibility, responsiveness, personalization and efficiency. From a traveller's perspective, *flexibility* relies on cost-effective gains in terms of modal, spatial and temporal accessibility for handling anticipated changes in the operating environment. *Responsiveness* is achieved through demand prediction, supply optimization and the interplay

between the two. *Personalization* is achieved through interface design, product offering, payment and other service integration or information provision. Privacy challenges requiring data-processing and complexity are challenges addressed by research. Lastly, *efficiency* in smart mobility is related to resource allocation, mobility performance, safety, energy and the environment.

New mobility trends are based on rapid technological progress and are rooted in completely new business models. Shared and on-demand mobility are booming in densely populated cities and are particularly popular with the younger generation and medium to high-income urban populations. Future mobility is expected to be connected and autonomous, synchronized into fleets and using V2X communication and artificial intelligence. Traditional public-policy instruments such as investment, pricing or regulation can be complemented by nudges that redirect behaviour through slight interventions. Coordination among mobility providers will increase the availability of services, with smooth multi-modal transitions and the integration of payment and information.

Smart mobility has impacts on congestion, air pollution, road safety, noise, intermodality and costs, but not always in resource-efficient ways, as shown in recent studies. Nonetheless, substantial gains in energy and emissions can be achieved through significant changes in demand and the integration of the entire smart mobility eco-system, where stronger public-private partnerships may dramatically impact on modal shifts, mileage, emissions and accessibility.

Freight, logistics and delivery of goods

The transport of freight and goods in and out of cities spans a wide range of industrial supplies, finished goods and returns. The main challenge is how to minimize operating costs while minimizing the negative effects of urban freight transport. Private, public, commercial and industrial consumers demand goods to be delivered for consumption or further refinement, generating waste and other returns to be sent in the opposite direction. Urban freight and logistics are subject to the unit costs of the last mile due to low or medium fill rates in small- or medium-capacity vehicles operating in congested areas. The sector involves many different stakeholders, ranging from consumers living in the city, commuters and tourists to commercial businesses and industry and transport operators and shippers. Cities face the dilemma of how to make the city liveable with restricted or regulated traffic and access to good infrastructure while also allowing for multiple economic activities.

The freight transport and logistics sector is exposed to an increasing demand for efficiency, availability services and sustainable solutions, while increasing levels of traffic and consumption are making freight logistics in cities even more complex. E-commerce and on-demand delivery impact on freight patterns both positively and negatively. In particular, same-day delivery services may lead to lower vehicle fill rates and more freight movements. As the freight logistics sector consists of a relatively high number of operators, many delivery vehicles may be servicing neighbourhoods and households, with impacts on congestion, noise, traffic safety and energy consumption. Operators are investing increasingly in new digital solutions such as booking platforms, track and trace features and on-demand services, helping operators deliver goods within strict time limits. New concepts and technologies are giving rise to interesting opportunities: automation facilitating cost-effective last-mile operations, freight delivery drones and even sideway robot drone technology, and highly automated operations in freight terminals and logistics hubs.

Today most freight transport is operated by diesel trucks, but they may be replaced by EVs or alternative fuels such as biofuels, hydrogen etc. Urban freight movements are ideal for deploying such alternatives due to the limited driving ranges and capacities of both the vehicles and urban areas. Semi- or fully automated vehicles likewise offer interesting opportunities to bring down costs and reduce energy consumption and emissions. Truck platooning is relevant not just for long-haul transport, but also for freight transport in cities, by using semi-automated technology to coordinate traffic flows, infrastructure and the flow of goods to and from warehouses and terminals. City logistics based on urban consolidation centres aim to bring down last-mile costs by consolidating goods from various shippers on to the same delivery vehicle.

Regulation plays a key role in making the sector more sustainable and efficient by banning certain vehicle types, favouring environmentally friendly vehicles or imposing road-charging schemes, all of which may also add to the last-mile costs. The future development of the freight logistics sector may take place in an urban living lab setting where operators invest in green vehicles (EVs and/or alternative fuels) while at the same time utilities, municipalities and others co-fund new infrastructure. In a similar setting, semi- and fully automated vehicles may be tested, providing operators with knowledge about off-hour deliveries. Finally, digitalization facilitates efficient planning and management and makes possible the

consolidation and coordination of freight transport and logistics in city transport corridors.

Living lab for integrated energy systems

In a low-carbon energy society, the power system is continually being challenged by variable power generation and increased demand. This calls for demand response in power consumption and for storage solutions. Although electro-mobility in urban settings represents an increase in electricity demand, it can also be used as a variable storage solution through the integration of EVs into the grid using so-called "vehicle-to-grid" technology (V2G). Thus EVs are flexible resources and as such offer flexibility to the electric power grid. Rapid developments in mobility, particularly urban electro-mobility, have already significantly impacted on the current power system. Autonomous transport, electric bikes and scooters for the last mile, delivery of goods by drones, shared vehicles and mobility as a service may likewise influence the electric power system. At the distribution level, the massive deployment of electric vehicles (EV) may generate local voltage excursions and grid congestion, but if EV charging and de-charging are being controlled, EVs can potentially help mitigate the self-incurred adverse effects.

Models, laboratory tests and proof of concepts are steps required in order eventually to roll out and scale up solutions supporting sustainable developments in urban mobility. In this context, living labs and super-lab settings represent the final step towards industrial and commercial realization. Coupling two or more energy systems and infrastructures is a prerequisite for a future with sustainable urban mobility. EVs and chargers can be used to create a coupling between transportation and the electric grid. Electrification of transportation, customer interactions, the roll-out of charging infrastructure and the integration of EVs are key elements driving achievements in sustainable urban mobility.

EnergyLab Nordhavn addresses multiple facets of new developments. Electro-mobility is one of several interconnected systems being highlighted. Chargers and fast-chargers for EVs have been installed in a multi-storey car park and are closely monitored. PowerLabDK includes a multiple location lab integrated with field testing areas on Risø (SYSLAB) and Test Zone Bornholm. The labs are interconnected through monitoring and control and boast a dedicated EVlab with several chargers and EVs. Various technical solutions for electro-mobility are being tested and validated at different levels of maturity. Results showed that EVs can effectively

replace conventional power plants in supporting the use of renewables in the electric power system. In addition, a 50% EV penetration would not pose a serious threat to the 400V distribution grid. However, to fully leverage the flexibility of EVs, the local grid should be moderately reinforced and smart grids must be expanded.

Other national demonstration projects are currently being undertaken in real-life settings. The Frederiksberg utility and partners are conducting commercial tests focusing on scaling up, real grid support, daily operations and the business aspects of how, when and how much to use EVs to support the electric grid.

These living labs have generated results and enabled learning otherwise difficult to obtain. This includes staging experiments in real-life conditions with real-life interactions and human behaviour. In order to improve technical developments and develop new business models taking note of human behaviour, it may be beneficial to exempt living labs from the ordinary legal and regulatory frameworks for a limited period. Further research also includes ethical and safety measures related to such smart, integrated energy and mobility systems.

Alternative fuels

Alternative fuels are important building blocks in reducing energy intensities and decarbonizing the transport sector. Liquid hydrocarbons like diesel, jet fuel and gasoline will remain essential fuels for transport, especially for shipping and aviation, and in an urban context especially for heavy transport of goods. For urban transport, candidate fuels are hydrogen, methane, methanol, ethanol, dimethyl ether (DME), synthetic gasoline and bio-diesel. They differ with respect to overall well-to-wheel efficiencies, production facilities, fuelling infrastructure and adaptations of vehicles and engines. Methane and methanol are promising fuels with view to the ease and efficiency of the synthesis while Fischer-Tropsch diesel, biodiesel, methanol to gasoline, upgraded pyrolysis oil and bio-ethanol are promising fuels with view to existing vehicle fleets.

Hydrogen is a promising transport fuel, also being important in alleviating shortages of biomass. Electrolysis is a well-known technology for producing hydrogen from renewable resources. Promising technologies include alkaline electrolysis, which is characterized by low-cost per-unit areas and excellent durability, but also low efficiency and production capacity per unit area. Polymer exchange membrane (PEM) electrolysis has matured

rapidly and has recently been scaled up to ~1MW. It is characterized by high production capacities and rapid response times. Solid oxide electrolysis is still at an early stage, with units of around 50kW and plants of 300 kW under construction. It is characterized by high levels of efficiency and modest cost per area, but improvements are needed in long-term durability and robustness. Improvements in the manufacturing processes of cells, stacks and modules are further needed to bring down overall costs and increase capacity.

Methane, a natural gas, is already widely used in the transport sector and can be produced from biomass via several thermal gasification routes or anaerobic digestion. Thermal gasification involves the high-temperature thermochemical conversion of biomass into a calorific product gas. It is scalable, efficient and fuel-flexible, but requires expensive and complex gas cleaning and is still in the demonstration phase. In a recent gasification-based SNG production project, its efficiency was doubled by integrating electrolysis to let hydrogen convert CO₂ to methane. Methane can also be produced via the anaerobic digestion processing of organic residues and liquid effluents from the food industry. Pilot-scale development and demonstration are still being undertaken to optimise the process. Not widely applied but very promising is the production of methane through the biological conversion of synthesis gas.

Alcohols and DME (Methanol) are energy-dense liquids. They have been produced commercially for nearly a century, but methanol derived from biomass gasification is still at the development stage. As with SNG, adding hydrogen to the process may boost the production per unit of biomass and thereby double output. Several projects aim at integrating electrolysis into the biomass-to-methanol process, as well as finding solutions to the problem of reducing the tar concentration. A full concept demonstration of electrolysis-assisted straw-to-methanol is currently being conducted at DTU. Ethanol is a widely used fuel produced from biomass, mainly sugarcane and corn. Concerns that biofuels may compete with food production have shifted the research effort towards second-generation bioethanol production from lingo-cellulosic residues. Another promising route for bioethanol production from lingo-cellulosic residues is via a syngas platform where high-temperature gasification is combined with downstream fermentation, creating high levels of energy efficiency and a high degree of carbon exploitation.

Higher hydrocarbons and other heavy fuels are fuels with properties close to those of diesel and gasoline. *Syngas* can be converted into liquid hydrocarbons, for example, diesel by the Fisher-Tropsch process, or to methanol, which then can be converted into gasoline in the methanol-to-gasoline (MTG) process. The large-scale gasification of biomass and syngas clean-up are still at the demonstration level and rely on well-known, downstream methanol and Fisher-Tropsch technologies. *Pyrolysis oil* is produced in a process in which dry biomass is rapidly heated. It can be catalytically hydro-treated to form hydrocarbons similar to gasoline and diesel, but is challenged by the formation of char and coke. Combining pyrolysis and hydro-treatment in catalytic hydro-pyrolysis is currently at the demonstration stage. Historically *bio-diesel* has been produced from plant oils, but it can also be produced from waste oils such as cooking oil and fats. However, due to shortages in the supply of waste oils for bio-diesel, alternative feedstocks have been explored, such as micro-algal and single cell oils.

Environmental sustainability of different transport modes

Modern society depends on transporting people and goods from A to B, but it comes with substantial negative impacts such as climate change, energy consumption, air pollution impacts on human health, chemical pollution and the reduced availability of metal resources. It is crucial to assess these negative impacts when deciding on the development of a sustainable transport future. In order to assess all the impacts of a transport system, a systems perspective is adopted capturing all aspects of the life-cycle of the system's physical elements - the fuels, vehicles and infrastructure, from the extraction of resources to the end of life.

The life-cycle assessment (LCA) is a tool for comparing the eco-efficiency of products, services and the systems that provide them. For individual transport technologies, the quantitative measures include the number of persons, the weight or volume of goods, the distance over which the transport occurs and the frequency with which it occurs. Person transport is expressed in person.km and freight in ton.km or m³.km. Qualitative measures include, for person transport comfort, the duration of the trip and the ability to take luggage, while for freight, duration may be an issue for certain goods.

The degree of interdependence between the eco-efficiency of the technology and the level of demand is also assessed. There may be a rebound effect when the economic benefits of a more fuel-efficient car are more

attractive relative to other modes of transport, such as public transport. The implementation of new transport technologies may have unintended consequences, for example, an uptake of EVs sufficiently large that it requires the construction of additional power plants. Therefore the full consequences of changes to the existing transport system should be analysed at the planning and design stage to ensure that all the relevant elements have been assessed.

LCA studies primarily of passenger cars reveal that regional location is a determining factor in the performances of EVs. One location-specific factor is the local climate, which impacts on the need for heating or cooling vehicles and cabins.

For internal combustion engine vehicles, the life-cycle environmental impact of the fuel typically predominates over the impacts of the vehicle itself. With regard to vehicles using biofuels, the environmental burden may remain for the vehicle but shift from a climate-change impact to a land-use impact. For EVs, the fuel life-cycle may be as important as the vehicle, depending on the supporting electricity mix. The environmental impacts of infrastructure (e.g. charging stations) seem to be insignificant compared to the impacts of any other life-cycle stage of the system. Infrastructure typically has a long life over which it supports a high number of vehicles and thus has a relatively small impact measured as per.km driven at the entire fleet level.

Getting the technology and system right requires car-design strategies aimed at increasing eco-efficiency and improving fuel efficiencies in the use stage and reduced energy use through light-weight constructions. It is not easy to make urban transport modes eco-efficient, and there may be rebound effects in consumption or use. Several top-down approaches to determining absolute environmental sustainability targets at different levels have been proposed.

Urban mobility in transformation: demands on education

The digitalization and integration of city infrastructure are giving rise to a transformational change in urban transport that will involve fundamental changes to the future skills of urban planning and engineering professionals.

Matching the supply of and demand for skills in the area of urban mobility is a social challenge. Anticipating the development of such skills should take into ac-

count sectorial, occupational and geographical changes and differences, as well as forecasting the medium to long-term demand and availability of workforce and anticipating developments in occupational structures and educational needs. The skills of urban planning professionals are already undergoing change in respect of their analytical, methodological, visionary, creative, social, communicative and inter-cultural skills. Also important is continuous curriculum development in technical engineering skills, planning and process skills, customer skills, and organizational and managerial skills. For transport engineering professionals, mathematical and statistical models and computer-based modelling and simulation tools continue to be important, but are used rather as a tool to embrace the uncertainties within a wider methodological paradigm. Also, a further development of route planning and operation management is needed to capture the developments of new business models, customer expectations and on-demand deliveries. For both groups of professionals, curriculum development should take stock of the rapid innovations in technologies, business models and business eco-systems, something which also requires life-long learning, upgrading skills and re-skilling.

Examples of key drivers of change in urban mobility impacting on critical skills include big data (data collection, analysis and use), artificial intelligence and its implications for restructuring tasks, autonomous and connected vehicles, block chains in financial services, electrification of transport, densification of the built environment with new transport modes and infrastructure, and ensuring the safety and security of digital and power systems against operational disruptions, cyber-attacks etc.

For both groups of professionals, skills in systems design and operations are needed, together with co-working in multi-disciplinary teams and projects, combined with niche knowledge regarding AI, privacy and security, logistics etc. Exploiting the ability to engage local stakeholders in open-data platforms or civic laboratories requires enhanced skills and competences in change- and participatory innovation management. Thus, educational shifts, reskilling and upgrading skills are needed to manage radical transitions in the context of the new prominence of urban mobility. Apart from technical skills, this also encompasses ethical and participatory, mediating or governance issues related to the new technologies.

A network view on research and development in sustainable urban mobility

Developing solutions for sustainable urban mobility

requires connecting knowledge and technologies from a diverse and large range of actors. Thus, educational shifts require navigating a whole spectrum of multiple research areas that are part of a complex and interdependent whole. The ways in which they connect with each other will affect how urban mobility is designed and managed.

The data-driven mapping exercise presented in this chapter provides a representative overview of the content and collaborations of DTU researchers over the last 35 years. For example, DTU researchers have links with more than forty countries and three hundred institutions working on topics related to sustainable urban mobility solutions. Collaborations are geographically dispersed, covering a wide range of organizations. Although most collaborations are in Europe, organizations such as MIT (US) and the University of Queensland (Australia) rank high as well. Furthermore, collaborations with the USA, China and other non-European countries are growing.

Based on a co-occurrence network and cluster analysis, the spectrum of research influencing sustainable urban mobility solutions and how they are linked to each other can be identified. DTU research is clustered analytically into six different topic groups, mostly created by five research communities: 1) synthetic fuels and other alternative fuels; 2) life-cycle assessment and other general sustainability aspects related to transport; 3) energy policy; 4) energy grid, energy storage and energy production; and 5) transport-specific research. Only one of the five research communities can be defined as transport-specific, the energy policy community being a shared interface between the other four communities.

The mapping of key R&D trends reveals that DTU's contribution is characterized by a topical shift towards sustainability-related areas a more systemic approach with a focus on mobility, human behaviour and design and increasing uncertainties in urban mobility. Moreover, alternative fuels, algorithms for decision-support systems, inclusion of the built environment and active transport are among the high-growth, high- occurrence topics.

These findings point towards the deep interconnections between energy, policy, infrastructure, new electric and alternative fuel technologies, system modelling, the increasing importance of new modes of transport, and the shifting preferences, attitudes and behaviour of mobility users.