STORM

D2.1
Assessment of new needs and knowledge analysis gaps, defining requirements for analysis methods and data

Dissemination level

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Abstract

This report has the objective of identifying trends, knowledge needs, policy analysis needs and the potential roles and possibilities for new modelling for freight transport in the EU. A literature review of developments in freight transport was conducted, together with an online survey and expert interviews. In terms of the outputs and insight of freight transport modelling, this review has found some important areas where information and insights are lacking:

- Plausible projections of how the different aspects of change in logistics will drive structural change in logistics.
- Scenario simulations that are based on the interlinked system changes of new digitalised logistics structures and zero-carbon energy in freight transport.
- Policy package simulations that will deliver sustainability: since freight transport is facing non-marginal change, models that can represent processes of structural change will be needed to assess potential points of influence on transport system changes.

Reflecting the changes in freight transport and new data structures, models of freight transport are changing too. ABMs of transport decision making and movements are an active field of development. Models of new market structures in logistics and of low carbon freight transport systems are being developed, using GPS/AIS data and 'big data' analytics.

The modelling approaches to sustainability transitions offer general concepts for addressing structural and system change. This implies that what is required are clearer ideas of possible changes ahead in freight transport, to enable problem definitions that can be addressed by the approaches discussed here.

These views of future changes can be developed through qualitative techniques of foresight and scenario development with stakeholders, with many opportunities for using quantitative models as a part of such processes to develop combined qualitative and quantitative analyses.

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ABBREVIATIONS

3PL	third-party logistics
5PL	fifth party logistics
ABM	Agent based Model
AI	Artificial intelligence
AIS	Automatic identification system
B2B	Business to business
B2C	Business to consumer
BEV	Battery electric vehicle
CBA	Cost benefit analysis
CCAM	Public/Private Partnership under Horizon Europe about Connected, Cooperative, Automated Mobility
CAV	Connected Autonomous Vehicles
DCM	Discrete Choice Models
EEA	European Environmental Agency
GDPR	General Data Protection Regulation
GHG	Greenhouse gas
GPS	Global positioning system
HDV	heavy-duty goods vehicles
IAM-Integrated assessment Model	
ICT	internet communication technology
IoT	internet of Things
IWW	Inland waterways
LNG	Liquid natural gas
LT	Blockchain (distributed ledger technology)
MCA	Multi-Criteria analysis
MaaS	Mobility as a Service
PtX	Power to X synthetic fuels
R&D	research and development
SD	System dynamics
SRIA	strategic research and innovation agenda
SUMP	Sustainable Urban Mobility Plans
SULP	Sustainable Urban Logistics Plans
TCO	Total Cost of Ownership
V2X	Vehicle to vehicle and vehicle to infrastructure connectivity

EXECUTIVE SUMMARY

This report has the objective of identifying trends, knowledge needs, policy analysis needs and the potential roles and possibilities for new models for freight transport in the EU. A literature review of developments in freight transport was conducted, together with an online survey and expert interviews. We also wish to provoke debate about how freight transport modelling can develop to address the new knowledge and analysis needs identified.

The results of the literature review, survey, and interviews have confirmed and demonstrated common overall themes:

- Freight transport and logistics have moved into a period of rapid and fundamental change.
- Digitalisation is beginning to restructure logistics, while the policy and market pressure on logistics to decarbonise is increasing. Industrial actors are developing technologies and institutional structures to enable radical decarbonisation to meet the goals of the Paris Agreement.
- The Covid pandemic has accelerated the trend to online markets and retail; whether other behavioural changes will be permanent is unclear.
- These fundamental changes drive a need for new knowledge and policy assessments to analyse large-scale system change in both technologies and – an even bigger challenge for research – logistics structures and institutions.

Transport modelling is already a very extensive set of fields, using an extensive set of techniques including: 4-step models, techno-economic models/IAMs, network models, SD models and ABMs, geographical models, behavioural models, and planning models.

Reflecting the changes in freight transport and new data structures, models of freight transport are changing too. ABMs of transport decision making, and movements are an active field of development. Models of new market structures in logistics and of low carbon freight transport systems are being developed, using GPS/AIS data, and 'big data' analytics.

What seems to be missing so far is models that look at system change. Larger scale change in logistics structures could be caused through the realisation of ideas around digitalised logistics systems – the IoT or the physical internet. Modelling approaches applying transition theory offer very general concepts for addressing structural and system change. This implies that what is required are clearer ideas of possible changes ahead in freight transport, to enable problem definitions that can be addressed by these approaches.

These views of future changes can be developed through qualitative techniques of foresight and scenario development with stakeholders, with many opportunities for using quantitative models as a part of such processes to develop combined qualitative and quantitative analyses.

Current freight transport models are able to represent pathways of adoption of low carbon technologies to achieve large-scale reductions in emissions and achieve the Paris goals, although there are not many actual scenarios of such changes. However, **freight transport policy assessment models do not represent structural system change.** New operational patterns for zero carbon fuels are not considered. New operational patterns from new logistics structures are also not considered.

In terms of the outputs and insights of freight transport modelling, this review has found some important areas where information and insights are lacking:

- Plausible projections of how the different aspects of change in logistics will drive structural change in logistics.
- Scenario simulations that are based on the interlinked system changes of new digitalised logistics structures and zero-carbon energy in freight transport.
- Policy package simulations that will actually deliver sustainability – since freight transport is facing non-marginal change, models that can represent processes of structural change will be needed to assess potential points of influence on transport system changes.

Some proposals for directions in freight transport modelling are outlined here. These are intended to complement the current, very extensive, freight transport modelling field. We emphasise that freight transport modelling is intended to support decision-making processes.

'Big models' for 'Big Data'? Micro-Macro models

A major change is already happening in freight transport modelling, through the application of new 'big' data and increasing applications of approaches from complexity science, such as network models and ABMs. These non-linear models have 'irreducible complexity' as their basis. Discrete distributions of users, firms and vehicles are being used in contrast to aggregating and taking averages in 'large scale' or 'macro' models. Such models with feedbacks between the model elements combine SD and ABM approaches. They then generate changes in the overall system properties from changes in micro parameters – emergent behaviour as well as dynamics in the distributions of the elements. For large-scale analysis, this could lead to similar levels of model complexity to weather and climate modelling, which are very resource-intensive, but are able to provide relatively reliable short- and medium-term weather forecasts.

These models would need to use shared large datasets – using Blockchain technology for confidential data, if necessary to make sharing of data between companies more attractive. Another alternative would be to use simulated data based on smaller samples for GPS and AIS data for road vehicles, ships, and aircraft. These could calibrate models for **operational analysis** for e.g. predictive production and distribution.

A further aspect of this approach is the development of behaviour datasets that show the range of choice mechanisms and behaviours, to reflect the different circumstances of different individuals, households, or firms.

This Micro-Macro approach is one possible method for analysing the interlinked system changes of new logistics structures and zero-carbon energy.

Rapid response models for stakeholder processes

- Policy processes

To complement current modelling for policy assessment, this review has identified two potential areas. Models that run quickly and can have their parameters changed rapidly to address alternative policy combinations would enable a more interactive relationship between freight transport modelling and policy proposal assessment. Such models might be used to look at a broader range of scenarios than is currently undertaken for policy assessments. In particular, it would be useful to have models that can start from current scenarios as a baseline, but consider new market structures or operational patterns in freight. Secondly, models of system change, which are rapid to run and can provide material for discussion around possible system changes and policy goals could be part of the Foresight processes in development in the EU commission (Köhler et al. 2015).

- Transitions management and living lab programs

Similar to models for supporting policy processes, such rapid response models could also be applied in living labs, where new ideas and technologies are being tested. Simulation models can provide scenarios for the uses and diffusion of the innovations, relevant in e.g. networks for users or markets that will share experiences or generate other increasing returns to network scale. Transitions management processes involve the development of visions of sustainability, moving on to measures and scenario analysis of alternative futures. Models can be used to develop scenarios and test them against the stakeholders' views in an iterative process.

Such models that can be integrated into stakeholder processes could use distributions of variables such as patterns of cargo characteristics (including volume, weight, value, origin, destination, and urgency), trip structures in intermodal supply chains to identify short-term flow patterns together with nodes of production, warehousing, cross-docking, and delivery. Investment decisions in logistics management systems, vehicles, and infrastructures (transport, fuels, traffic management) could also be based on distributions of decision-making behaviour. Such distributions could be initially calibrated from the larger scale models and use approaches of discrete modelling of sets of agents (ABMs) or network models.

Support for legal processes

There are now examples of legal challenges to climate policies and plans. Examples are the ruling by Germany's constitutional court that the German 2019 Climate Change act is in part unconstitutional or the ruling ordering Royal Dutch Shell to reduce net emissions by 45% by 2030 vs 2019[1]. Modelling could be used as evidence in such cases to support the arguments. This might require the elaboration of standards for the use of modelling as evidence, which currently rests on the professional reputation of the expert providing technical evidence, or standards of transparency and reproducibility of the models.

Support for financing/business cases

Models of system change could be used to provide more convincing scenarios of future transport than models, which do not address the new developments in logistics and decarbonisation. These could provide consultancy expertise to companies having to address systemic uncertainty, where conventional market models are no longer valid. Here, system analysis (System Dynamics) or evolutionary/AI Learning methods could extend the assessments of possible future markets.

[1] 29th April 2021 Bundesverfassungsgericht https://www.bundesverfassungsgericht.de/SharedDocs/Pressemitteilungen/DE/2021/bvg21-031.html

26th May 2021 https://www.rechtspraak.nl/Organisatie-en-contact/Organisatie/Rechtbanken/Rechtbank-Den-Haag/Nieuws/Paginas/Royal-Dutch-Shell-must-reduce-CO2-emissions.aspx

1 Objectives

This report has the objective of identifying trends, knowledge needs, policy analysis needs and the potential roles and possibilities for new modelling for freight transport in the EU. A literature review of developments in freight transport was conducted, together with an online survey and expert interviews. The interviews were conducted in parallel to the online survey, to enable a more open discussion of trends and knowledge needs than is practicable in an online survey.

Transport modelling is a very extensive field of research, so we focus the review by starting with an assessment of current trends in freight transport and logistics. This leads to an assessment of new needs for knowledge and analysis. The review of trends shows that logistics is experiencing drives for sustainability and digitalisation that we consider will lead to far-reaching structural changes in logistics and freight transport systems. This is an important result that was used to determine the scope of the literature review of freight transport modelling. Within this scope, models were analysed along several dimensions – geographical/policy level, logistics and supply chain structural features, decision making and potential applications in Cost Benefit (CBA analysis and Multi-Criteria analysis (MCA). These dimensions are also considered in the analysis of trends and knowledge needs, where relevant.

We then briefly discuss some recent modelling developments in transport modelling that address the new trends, with an emphasis on these systemic changes. We identify some new requirements and propose some challenges for freight transport modelling.

We also wish to provoke debate on how freight transport modelling can develop to address the new knowledge and analysis needs identified.

2 Literature review: trends

New technologies can contribute to an enhanced sustainability in the logistics sector while improving customer satisfaction and companies' profitability. Research needs in that area not only include research in the respective technologies itself, but also issues of their integration into the logistics system. Most technologies are not primarily developed for sustainability reasons but out of a pursuit of economic advantages. Therefore, an assessment of whether, to which extent, and under which circumstances new technologies do ensure improved sustainability, and how this can be supported by policies, is also an important research area.

DHL (2021) highlights that global e-commerce grew around 20% every year and its turnover exceeded 3 trillion US$ in 2019. The Logistics Trend Radar features omni-channel logistics for extended customer services, digital technologies (Blockchain, AI, IoT), robotics, and automation in logistics systems as major enabling developments. A rising global awareness of climate change and other environmental issues, as well as living and working conditions is bringing a paradigm shift towards Sustainable Logistics, caused by policies and customer expectations. WEF (2016) identify e-commerce giving consumers more possibilities, logistics control towers, data analytics as a service, digital international logistics platforms, Autonomous Vehicles and drones for delivery, 3D-printing and crowdsourcing for production and logistics processes, the circular economy, and shared logistics assets as themes of the digital transformation of logistics, with an estimated potential of $1.5 trillion in value for the logistics industry.

With regard to research demands in these fields, Dong et al. (2021) identify three major areas:

(1) Business collaboration and systems integration
(2) Technologies and their integration
(3) Sustainability and policy assessment

2.1 Business collaboration and systems integration

ALICE AISBL (2016) highlight the importance of an integrated freight system support for sustainable development. Collaboration between actors will improve the efficiency of vehicle and infrastructure use. In order to ensure this, ALICE AISBL (2016) see a need for a definition of common goals and technical standards between actors, as well as mutual trust and willingness to cooperate.

Montreuil (2011) describes the Physical Internet (PI) as the ultimate form of logistics systems integration. He also states that there remains a vast demand for further research concerning its characteristics. Besides technical issues (see technologies and their integration), he identifies the "need for a macroscopic, holistic, systemic vision offering a unifying, challenging, and stimulating framework", which includes a wide range of research disciplines. Rajahonka (2019) identifies research requirements for business collaboration and systems integration as follows:

- Standardisation of EU-wide transport and data management systems
- Research in new business models adopting of physical internet and the future of existing business models
- Definition and analysis of methods to motivate logistics service providers to leave their powerful positions in favour of a more flexible and competitive market structure.

Montreuil (2011) suggests research methods such as analytical and optimisation studies, software models, pilot, and demonstration projects in order to explore the possibilities of new technologies in logistics, transportation, manufacturing, distribution and retail from urban, regional, national, continental, or intercontinental perspectives (Montreuil 2011).

Lind and Melander (2021) see the need to include the views of actors from outside the classics logistics sector to business models analysis, e.g. technological start-ups or software firms.

In their conceptual model for the integration of freight transport in Mobility as a Service (MaaS), Le Pira et al. (2021) mention the importance of a review or feedback mechanism for agents within MaaS platforms. This should ensure reliability of carriers which in their view is crucial for the reliability and thus the success of the entire transport system. Additionally, they suggest analyse of which goods are most suitable for MaaS. They suggest agent-based models, interviews, surveys, multi-stakeholder multi-criteria analyses, pilot demonstrations, or gaming approaches for a proof of concept and to assess the impact on business models.

Giusti et al. (2019) develop a definition of success factors for the concept of Synchromodality, by which a high synchronisation along and between supply chains is described. They point out that further research on this concept is necessary, especially on its interaction with the role of fifth party logistics (5PL) and physical internet, and the approach for integrated platforms.

Trends in freight transport and logistics are also part of EU innovation structures and strategies. Current EU strategies for freight transport are being coordinated through SRIAs (strategic research and innovation agenda). The CCAM Partnership is the Public/Private Partnership under Horizon Europe about Connected, Cooperative, Automated Mobility. The CCAM SRIA has identified a range of development to be supported. These include physical and digital infrastructure, key enabling technologies: AI, Big Data and Cybersecurity, integration of vehicles in the systems and validation of data. The EU 2Zero partnership also has an SRIA, concentrating on zero carbon technologies for vehicles.

Further EU partnerships have also been developed to implement digitalisation including the Smart Networks and AI Data Robotics partnerships. The Made in Europe partnership for manufacturing has also identified the twin themes of ecological and digital transition. Also relevant is the Processes4Planet partnership, which is advancing the development of the circular economy in Europe.

2.2 Technologies and their integration

As described above, Montreuil (2011) highlights the importance of research on infrastructures, protocols, and technologies as enablers for the physical internet, as does Rajahonka (2019). Rajahonka (2019) sees standards as crucial for informed decision-making, as this requires reliable availability of comparable data. Montreuil (2011) and Ballot et al. (2020) see the need for development in the following technologies: accessible and fast data transfer tools, a reference IT architecture, and secure protocols for logistics networks, as well as physical interoperability between manufacturers, load units, and transport. They also highlight the importance of prototypes and public-private cooperation in technological development.

Besides a need for further research in technological fields like robotics, IoT, and data processing, the development of new kinds of containers and vehicles become necessary in such an integrated transport system (ALICE AISBL 2016).

For Giusti et al. (2019) research on enabling technologies for Synchromodality is important. Standards for traceability technologies and data management as well as digital twins are important to ensure seamless visibility of transported goods. The combined use of intelligent assistants and cyber-physical systems as an element of Synchromodality in order to reduce the need for human effort needs to be examined. They also see further research demand in Artificial Intelligence (AI).

2.3 Sustainability and policy assessment

Ballot et al. (2020) suggest further research on the economical and societal impact of the physical internet and possible gains in performance and resilience of transport and logistics systems through the physical internet.

Assessing crowd shipping, Mckinnon (2016) points out that the improvements depend on currently unknown factors such as the share of packages that might be transported by people who combine deliveries with their normal daily travel, rather than by those who discover deliveries with their private vehicle as a new business model. It is also uncertain if a shift to non-motorized modes of transport can be achieved by crowd shipping.

Giusti et al. (2019) and Rajahonka (2019) also mention that tracking systems should be developed in a way that allows the visibility of a product’s complete life cycle in order to assess its quality and sustainability.

Pernestål et al. (2021) refer to the COVID-19 pandemic and point out that a revision of development scenarios is necessary as recent trends, e.g. e-commerce, have been accelerated.

3 Online Survey

3.1 Survey design

The survey was divided into seven topics:

- Importance
- Expectations concerning future market development
- Fields of application
- Expectations concerning benefits
- Company plans and preparedness
- Climate impact
- Domains for further research

For every topic, the respondent was asked to name three technologies or trends that they considered most applicable.

In the second part, the respondent had to assess 12 different trends and technologies, which were arranged as matrixes with characteristics of the above-mentioned topics. The trends and technologies were taken from the trends and technologies overview in DHL (2018). In order to reduce the complexity of the questionnaire, we clustered trends, and technologies that we assumed to be similar (e.g. Self-Driving Vehicles / Unmanned Aerial Vehicles) or symbiotic (e.g. Artificial Intelligence / Big Data Analytics). On all pages of the questionnaire, a help button was available, which opened a pop-up window containing short descriptions of the trends and technologies. Depending on the question, one or more boxes could be ticked.

Those trends and technologies were:

- Artificial Intelligence / Big Data Analytics
- Augmented / Virtual Reality & Digital Twins
- Batch Size One / 3D Printing
- Bionic Enhancement
- Digital Work, Robotics & Automation
- Fresh Chain
- Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)
- Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain
- Tube Logistics (Hyperloop)
- Self-driving Vehicles / Unmanned Aerial Vehicles
- Sharing Economy / Servitization
- Sustainable Logistics / Grey Power Logistics / Green Energy Logistics

The survey was put online via EFS Survey Software by Tivian XI GmbH from June 18th to October 10th 2021 The survey link was distributed via the STORM network.

3.2 Survey results

The survey was completed by six contestants, but incomplete data of another seven contestants who aborted the questionnaire were considered as well.

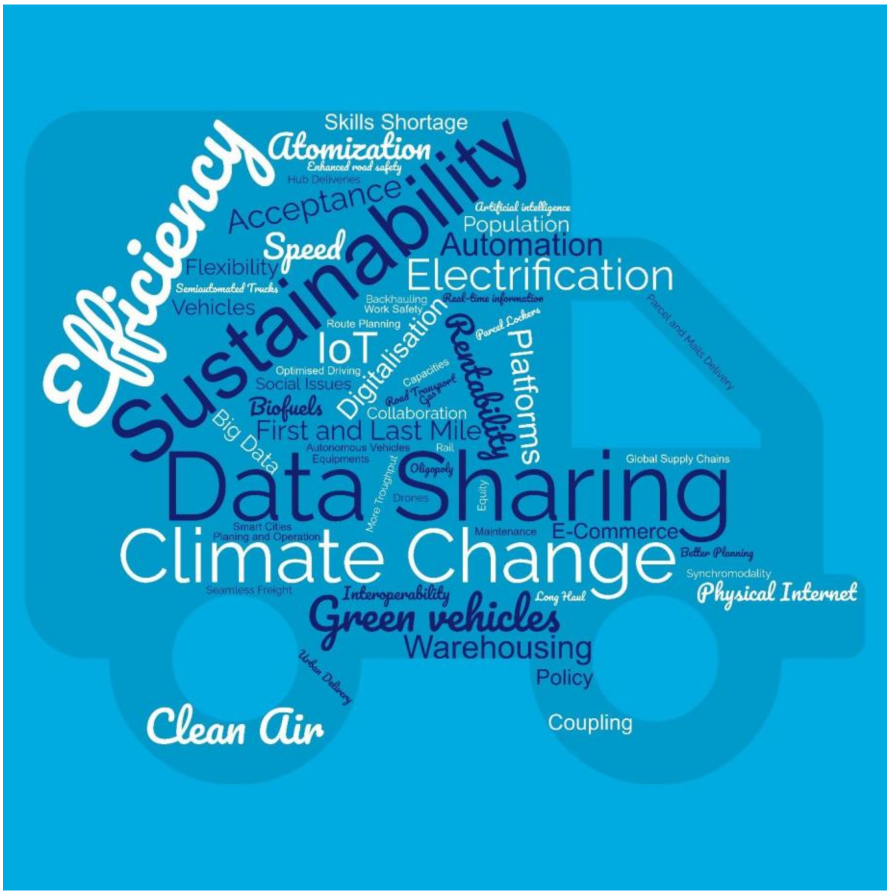
The contestants' national and professional backgrounds were distributed as follows:

- Country: Belgium 1, Finland 2, Germany 1, Spain 1, Sweden 1, UK 1, not specified 6;
- Sector: Logistics Industry: 2, NGO 1, Science 4, not specified 6.

From the proportion of break-offs before the end of the questionnaire and the low response rate we conclude that for future surveys we need a shorter questionnaire.

3.2.1 Keyword analysis

As the sample was rather small, all trends and technologies named in the first survey part for the seven topics were merged for the keyword analysis. In the next steps, some entries had to be filtered out and synonymous words were clustered. On the basis of the remaining keywords and the frequency of their occurrence, a word cloud was generated and is shown in Figure 1.



Source: Fraunhofer ISI

Figure 1. Word Cloud

3.2.2 Analysis of Matrix questions

Tables 1 to 7 show the answers to the classification questions.

In terms of importance Sustainable Logistics, Digital Work and Artificial Intelligence are the highest ranked trends and technologies. 3D Printing, Bionic Enhancement, and Tube Logistics seem to be the least important to the contestants (Table 1).

In the opinion of the contestants, Internet of Things, Logistics Marketplaces, and Artificial Intelligence will become important within the shortest time period. Altogether, almost all of the trends and technologies mentioned are expected to become important within the next six years. Only Bionic Enhancement (within the next 10 years) and Tube Logistics (not at all) are the two aspects where this does not apply (Table 2).

Most of the trends and technologies were considered important for inventory and warehousing. This especially applies to Digital Work. Fewer respondents think that the trends and technologies are important for transportation, of which the Internet of Things is the most important. Logistics systems planning and administration were considered the least important (Table 3).

Artificial Intelligence, Sustainable Logistics, and Self-Driving Vehicles are the trends and technologies that the contestants expect to generate the most benefits. Fresh Chain, Augmented / Virtual Reality, and Bionic Enhancement, are expected to deliver the least. Within the expected benefits, economic benefits such as increased competitiveness and better service were ticked more often than ecological benefits (reducing greenhouse gas emissions and reducing other environmental impacts) or social benefits (improved livelihood in cities) (Table 4).

As far as recent activities and plans are considered, most of the contestants addressed the development of internal know-how. Cooperation with partners and pilots were on the second and third place. Financial investments were undertaken by the least contestants. The trends and technologies, which were mostly subject to these activities and plans were Artificial Intelligence, Sustainable Logistics, and Internet of Things (Table 5).

Sustainable logistics, Self-Driving vehicles, Internet of Things, and Sharing Economy are considered to cause the strongest reduction of GHG emissions. Augmented / Virtual Reality on the other end, is on average considered to have no effect on GHG emissions at all. 3D Printing is the only technology considered to have an effect of increasing GHG emissions (Table 6).

The respondents saw the highest demand for further research in the legal and political framework, new services/ business models, and organisational issues. The smallest research demand is seen in hardware and sustainability issues. In terms of trends and technologies, Self-Driving Vehicles, digital work, and Artificial Intelligence are those with the highest need for further research. Bionic Enhancement and Fresh Chain are those with the lowest (Table 7).

Table 1: How important do you think the following trends and technologies will become in logistics?

Number of contestants who ticked this option. Displayed in descending order of their average importance.

	1: not at all important	2	3	4	5	6	7: very important
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	0	0	2	0	1	2	8
Digital Work, Robotics & Automation	0	0	1	0	2	6	4
Artificial Intelligence / Big Data Analytics	0	1	1	1	1	3	6
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-Generation Wireless)	0	0	2	1	2	3	5
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	0	0	1	2	1	7	2
Self-driving Vehicles / Unmanned Aerial Vehicles	0	0	2	1	3	4	3
Sharing Economy / Servitization	0	0	1	3	3	4	2
Fresh Chain	0	1	3	3	5	0	0
Augmented / Virtual Reality & Digital Twins	0	2	4	0	6	1	0
Batch Size One / 3D Printing	2	0	5	3	2	0	1
Bionic Enhancement	0	2	5	6	0	0	0
Tube Logistics (Hyperloop)	2	6	2	1	1	1	0

Table 2: Now we show you the same trends and technologies again. How soon will they become important?

Number of contestants who ticked this option. Displayed in ascending order of average development time.

	In 1 - 3 years	**In 4 - 6 years**	**In 7 - 10 years**	**In more than 10 years**	**Not at all**
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	9	3	0	0	0
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	6	5	1	0	0
Artificial Intelligence / Big Data Analytics	7	3	1	1	0
Self-driving Vehicles / Unmanned Aerial Vehicles	2	8	1	1	0
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	9	1	0	1	1
Sharing Economy / Servitization	8	2	0	1	1
Digital Work, Robotics & Automation	4	5	1	2	0
Fresh Chain	4	4	3	0	1
Augmented / Virtual Reality & Digital Twins	3	5	2	1	1
Batch Size One / 3D Printing	1	5	2	2	2
Bionic Enhancement	0	4	2	5	1
Tube Logistics (Hyperloop)	0	2	2	2	6

Table 3: And now: In which fields will those trends and technologies become important?

Number of contestants who ticked this option. Displayed in descending order of total ticks.

	Inventory & warehousing	**Transportation**	**Logistics system planning and administration**
Artificial Intelligence / Big Data Analytics	7	7	7
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	7	8	5
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	6	7	7
Sharing Economy / Servitization	5	7	6
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	7	7	4
Digital Work, Robotics & Automation	9	6	2
Self-driving Vehicles / Unmanned Aerial Vehicles	7	6	1
Augmented / Virtual Reality & Digital Twins	6	1	4
Batch Size One / 3D Printing	6	3	2
Bionic Enhancement	7	1	1
Fresh Chain	2	4	3
Tube Logistics (Hyperloop)	2	5	1

Table 4: Again the same trends and technologies: Which benefits do you expect from them?

Number of contestants who ticked this option. Displayed in descending order of total ticks.

	Increased competitiveness	**Better service for customer**	**reducing greenhouse gas emissions**	**reducing other environmental impacts**	**Improved livelihood in cities**
Artificial Intelligence / Big Data Analytics	7	7	7	5	2
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	5	4	6	7	5
Self-driving Vehicles / Unmanned Aerial Vehicles	5	5	6	4	4
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	8	4	5	4	2
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	8	7	2	1	3
Digital Work, Robotics & Automation	5	3	3	4	4
Batch Size One / 3D Printing	4	5	2	5	1
Sharing Economy / Servitization	3	5	4	2	3
Tube Logistics	1	2	3	5	2
Fresh Chain	3	5	0	1	3
Augmented / Virtual Reality & Digital Twins	5	0	2	2	2
Bionic Enhancement	3	1	0	0	1

Table 5: Which activities have you already undertaken or planned regarding those trends and technologies below?

Number of contestants who ticked this option. Displayed in descending order of total ticks.

	Development of internal know-how	Cooperation with partners	Pilots	Investments
Artificial Intelligence / Big Data Analytics	6	3	3	2
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	4	4	4	2
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	4	3	3	2
Augmented / Virtual Reality & Digital Twins	3	3	2	2
Digital Work, Robotics & Automation	2	3	3	2
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	2	2	3	2
Self-driving Vehicles / Unmanned Aerial Vehicles	3	3	1	0
Sharing Economy / Servitization	2	4	1	0
Fresh Chain	3	1	2	0
Batch Size One / 3D Printing	2	1	0	0
Bionic Enhancement	2	0	1	0
Tube Logistics	1	0	0	1

Table 6: What impact on the GHG emissions in the logistics sector will those trends and technologies have in your opinion?

Number of contestants who ticked this option. Displayed in ascending order of average GHG emission reduction potential.

	1: Strong increase of GHG emissions	**2**	**3: No impact**	**4**	**5: Strong reduction of GHG emissions.**
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	0	1	1	0	5
Self-driving Vehicles / Unmanned Aerial Vehicles	0	1	1	4	2
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	1	0	1	4	2
Sharing Economy / Servitization	0	1	3	1	3
Artificial Intelligence / Big Data Analytics	1	1	2	1	3
Tube Logistics (Hyperloop)	0	1	3	3	1
Digital Work, Robotics & Automation	0	1	4	1	1
Fresh Chain	0	1	5	1	1
Bionic Enhancement	0	1	4	3	0
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	1	0	3	4	0
Augmented / Virtual Reality & Digital Twins	0	1	6	1	0
Batch Size One / 3D Printing	1	1	4	2	0

Table 7: In which aspects do you see a need for further research?

Number of contestants who ticked this option. Displayed in descending order of total ticks.

	Legal and political framework	New services and business models	Organisational issues	Software	Barriers and drivers	Hardware	Sustainability issues
Self-driving Vehicles / Unmanned Aerial Vehicles	7	4	3	2	4	3	4
Digital Work, Robotics & Automation	5	2	2	5	4	3	1
Artificial Intelligence / Big Data Analytics	4	3	2	6	0	3	1
Internet of Things (e.g. Smart Containerisation, Low-cost Sensor Solutions, Next-generation Wireless)	3	2	2	4	1	3	1
Augmented / Virtual Reality & Digital Twins	4	2	5	2	0	1	0
Sustainable Logistics / Grey Power Logistics / Green Energy Logistics	3	2	2	0	3	1	1
Logistics Marketplaces / Omni-channel Logistics / Cloud Logistics / Supergrid Logistics / Blockchain	2	3	2	0	1	0	1
Tube Logistics	1	1	2	0	4	0	1
Batch Size One / 3D Printing	1	2	1	1	1	2	0
Sharing Economy / Servitization	3	2	1	0	1	0	1
Bionic Enhancement	3	1	0	1	1	1	0
Fresh Chain	1	2	2	0	0	0	1

4 Expert interviews

This section describes the results of the expert interviews. Interview partners were selected to cover policy and transport planning, transport companies, and researchers. They covered road and rail modes including intermodal transport. 17 in-depth interviews were conducted with stakeholders from research (6), policy/transport planning (3), and transport companies (8). One researcher was in the US, the other interviewees were from EU countries: Finland, UK, Germany, Italy, and Spain. The researchers interviewed analysed transport at all levels, from global to urban. The policymakers interviewed operated at a national and regional level. The transport companies operated at a national or EU level, mainly in road or intermodal transport, interviewees were from business development and operations management. The interviews had the objective of identifying current trends and challenges in freight transport in the EU, leading on to a discussion of new analysis needs and knowledge gaps. The interviews were conducted as semi-structured interviews, see Appendix A1 for the structure and questions. Barriers to change were also discussed. Ideas for new model developments and the needs for transport modelling were discussed.

4.1 Trends - and a shock

Two main trends were identified: 1. Reducing environmental impact, especially decarbonisation and the demand from consumers/producers of consumer goods for sustainable products 2. Digitalisation.

A further major trend, whose effects are still uncertain is the response of society to Covid and the behavioural changes that have been observed and enforced.

Some general observations were also made. Logistics systems are changing much faster than say 10 years ago. These changes affect all aspects of freight transport:

- Modal split
- Demand - type of goods and size of loads
- Supply chains
- Decarbonisation

Digitalisation in particular is considered to be changing the market structures and organisation of logistics. Automation is developing rapidly – soon it will be possible to move a cargo without a human hand touching it. The roles and plans of large logistics actors are also changing, in particular consolidation is continuing through cooperation rather than takeovers. The structural changes through digitalisation are considered to be part of a general change in the technology of industrial society, the next (and ongoing) Kondratiev Wave. This emphasises the ideas and processes of system change in contrast to incremental change and the need to develop policies and new governance structures to influence the direction of system change to sustainability in contrast to the emphasis on decarbonisation of transport through CO_2 pricing and command and control instruments.

4.1.1 Reducing environmental impact, especially decarbonisation

The most important recent change is the new perception of a change in the structure of consumer demand to a willingness to pay for reduced pollution in goods and services. While this is still limited in its impact, according to the interviewees, it is no longer true to say that the logistics industry has to minimise costs and prices above all other considerations. A statement from an industry stakeholder was:

”Sustainability is also something driven by consumers: we have been telling companies to pay attention to sustainability, but only now that the consumer is asking for it, companies are considering it. In fact, now that customers are considering sustainability, it becomes a competitive advantage for companies to take care of sustainable logistics (packaging, means of transportation to limit CO_2 emissions, etc.).”

There is also movement in the maritime industry. Policy support for R&D in low carbon fuels and propulsion systems has funded numerous investments in demonstrations for low carbon fuels. Some customers are willing to pay the 10% extra cost for a dual fuel zero-carbon-ship. Finance can now be found from investors who want to manage the uncertainty of future regulations. The Poseidon principles[2] are an initiative by marine insurance companies with major industry players to require the industry to include environmental performance in investment decisions:

“The Poseidon Principles for Marine Insurance are a global framework for assessing and disclosing the climate alignment of insurers’ hull and machinery portfolios. They enable the insurance sector to implement transparency and they establish a common, global baseline to quantitatively assess, and disclose the climate alignment of the portfolios, in order to assess the environmental and climate impact of the business decisions. Thus they also serve as an important tool to support responsible decision-making.” (Poseidon Principles 2022).

An example from the aviation industry is the Swedish regional carrier Braathens Regional Airlines, which gives passengers an option to pay an extra fee (of $36 in 2018) per flight to fly with biofuel (Braathens 2022).

Low Carbon power trains and fuels

Achieving the energy transition to meet climate goals will require the complete phase out of fossil fuels in 2040 for all vehicles. The choice of low carbon fuels in freight transport is still unclear. While there is now an emphasis on battery cars and light-duty vans, several HDV (heavy goods vehicle) technologies: batteries, catenary infrastructure and electric vehicles, or fuel cells are in development. Basma et al. (2021) find that battery vehicles could be competitive with fossil fuel vehicles within the next 5 years with policy support. Catenary concepts and fuel cell vehicles are in an earlier stage of development, with demonstrations of these technologies and plans to build fuel cell HDVs on a commercial basis. All these technologies require a new energy supply infrastructure for long-distance use. Freight vehicles are long lived assets. It would take about 10 year to replace the fleet (in the case of the UK), which is a limitation on the uptake of new

2 https://www.poseidonprinciples.org/insurance/

technologies. Infrastructure life cycles can last for much longer periods e.g. the Forth railway bridge in Scotland was completed in 1890.

Further specific points discussed were:

- Stationary charging for battery vehicles is seen as a better alternative than charging while underway.
- Fuel cells were argued to be suitable for continuous use where batteries cannot be charged or remote areas/areas without electricity grids where stationary charging is difficult.
- Biofuels are not seen as a major alternative, because they are seen as often being not sustainable.

A possible global polarisation of energy provision could develop. Diesel could remain prevalent in poorer countries, because developing countries will not have renewable energy structure for some time. Such a polarisation can be avoided in the EU if there is EU support for zero carbon energy systems for member states that have limited capacity or resources to develop the necessary infrastructures. This contrasts with the development of renewable electricity and the development of Hydrogen systems in wealthy countries. (A comment from the project team here is that the ‘middle income’ countries: China, India and arguably Russia, Brazil, South Africa and Mexico show a mixed picture of renewables development in parallel to continuing deployment of fossil fuels**.**

4.1.2 Digitalisation

The most fundamental point raised is that the nature of the logistics business is changing. The critical aspect of a logistics business is now about software and algorithms, not about trucks and warehousing. New players have emerged. A good example of this is that the online retailer Ocado Retail ltd. is now the biggest grocer in the UK, bigger than Tesco. Ocado started out as home delivery agents, then developed their own website to offer goods from different suppliers and changed their business from warehousing to software.

Digitalisation could result in a breaking down of fixed market structures with a move to continuously shifting cooperation between individual actors: the cargo owners, logistics services providers, transport operators, and transport system suppliers. Software updates for IoT (Internet of Things) vehicles and containers/pallets could enable changed information and decision-making routines to adapt to new market conditions.

This is one aspect of increased connectivity (currently 5G technologies). These technologies generate new forms of digital data (WP3 Report) which are generating a new area of business for data analytics. This is new compared to previous uses of data in logistics because it enables AI-based decisions and communications. This data will come from digitised systems configured as neural nets. Another important technology, blockchain, is being applied to cybersecurity and cashless markets, although it is also contested.

However, one interviewee pointed out that “much of the digitalisation hype is what 3PL providers do already. This is a problem in the grey literature.” This means that some of the ideas being discussed in logistics are not actually new. This raises the question of how digitalisation is actually going to bring benefits to firms.

A further general issue is whether the ‘acceleration’ i.e. the drive to reduce delivery times in logistics will continue. One end point could be ‘24/7 logistics’, with operations continuous round the clock. However, even long-haul trucks have long stops for drivers, which constrains such concepts. With Autonomous Vehicles, this could be reduced.

Automation in terms of vehicle fleets is however, expected to take some time, so drivers are not expected to be affected by any technology for automation of the vehicles.

Physical internet

The concept of the physical internet combines a limited range of shapes of transport modules with IoT for load and vehicle management (Montreuil 2011; Ballot et al. 2020). The physical internet can have greater flexibility of delivery, self-organisational systems – autonomous systems, continuous re-optimisation which can take the place of conventional logistics planning.

The physical internet in combination with e-markets offers the prospect of almost zero transaction costs. This could lead to the break-down of current contractual relationships in logistics market structures.

An important question is whether this contributes to sustainability or whether there is a rebound effect with lower transport costs leading to more transport demand.

Inventory reduction

Another prospect is that the new data from the physical internet or IoT for better forecasts will reduce inventory. This could lead to mobile inventory, where demand estimates are updated in real time and goods are sold that are already in transit over short distances. This could eliminate distribution/warehousing centres. Not only would inventory costs then be reduced, but also major savings in warehousing and fixed distribution centres might be achieved with renewable energy. However, the implications for fuel demand and emissions from vehicles has to be assessed.

4.1.3 Logistics organisation

Networking will lead to more mergers and alliances in logistics. If an alliance can access many different organisations’ distribution centres, it can consolidate distribution centres and more easily reach more end customers. Logistics chains are integrating and consolidating, e.g. Rotterdam Port is owned by three groups. Consolidation does not necessarily mean that there is just one surviving company. Alliances of companies are developing to offer a complete service. DHL, for example, concentrates on services for a part of the supply chain.

Retail and urban distribution in the US

An interview was conducted with an expert from the US. The US retail market is (2021) shifting from local small business to national chain megastores (Walmart, Target, Amazon). Large mega warehouses and distribution hubs are being established in rural areas at outskirt of cities by these corporations.

The pressure to accelerate supply chains is still felt: customers are demanding same-day delivery.

Proposals for change are:

- Increase the use of private citizens (e.g. Uber) for first- and last-mile delivery.

- Increase of post-office locker facilities as final delivery destinations.
- Long-distance transport moving towards intermodal systems, although the adoption of automated vehicles with platooning and electric drives could reduce the advantage of rail and reverse this.
- Further integration in the urban context was also identified.
- Integrating freight and logistics in the planning of urban space and its use is seen as fundamental to urban life in both ports and cities.

Another aspect of integration is to not only focus on freight and mobility, but have a mind-set of cooperation/co-petition with other service providers to aggregate different services (leisure time for the driver, integration of city planning with logistics, cooperation between passenger and goods transportation).

In summary, cloud based open markets combined with blockchain for secure, almost zero transaction cost contracts reduces costs of finding logistics suppliers and for logistics suppliers reduces the costs of consolidating loads. Therefore, logistics organisations can be decentralised and optimised for smaller, more narrowly defined markets. In combination with producing to orders in real time and real time updating of delivery routes, the technologies can remove the need for warehouses by using the transport as inventory holdings for consumer goods that are high volume, but widely distributed. Another possibility is to have more distribution centres for cross-loading to reduce empty trips/back-hauls. This needs to be considered together with optimisation systems for online retail with more, smaller deliveries to retail customers direct instead of to shops. The energy demand and emissions implications of such systems need to be considered.

4.1.4 The shock of Covid – logistics and behaviours

The Covid pandemic is considered to bring many changes to transport and logistics. There has been lower economic and passenger/freight activity growth. There has been a drastic reduction in public passenger transport. The question is now: are there long-term shifts in behaviour or will society resume its previous trajectory in transport?

Covid has already had a permanent effect on the global cold supply chains for vaccines, changing judgements on investments, as investments for cold vaccine logistics can be used for other things.

Online retail and home deliveries

An increase in home working is expected to become permanent, with a consequent permanent boost to online retail. The internet retailers such as Amazon and also the supermarkets will move to more distributed logistics for accelerated home deliveries.

Resilience

The resilience of supply chains, in particular globalised supply chains, has taken on increased importance. Sudden bottlenecks through the impacts of pandemics, loss of staff due to epidemics and quarantining, restrictions on international movements are adding to issues of border security and immigrants and increased costs of border controls. These effects provide a certain incentive for localising supply chains, reinforcing the ideas for regional production/consumption systems. The increase in extreme weather events may increase the standards adopted for resilience of transport systems as well as increasing the demand for disaster response logistics.

4.1.5 Political, ethical, and health-related topics and connections with other socio-technical systems

There are a range of themes identified. Consumer willingness to pay for low carbon transport is connected to issues of ethical and environmental standards through fair trade and ‘bio’ standards in products. These are being adopted by major retailers such as IKEA as well as the supermarket chains.

There are further society and policy driven changes. The adoption of the circular economy will require more reverse logistics, packaging recycling, and reuse/recycling systems. The move to decarbonisation brings with it the ‘exnovation’ – the policy to shut down established sectors, in this context as a contrast to innovation of fossil fuel industries – coal, oil, gas extraction, fossil fuel transport, refining, and delivery. These are a major proportion of current freight transport which could decline rapidly. Zero carbon energy supply chains will have a different spatial and market structure.

There are some important ethical considerations. Globally, countries may divide into wealthy, decarbonised nations and poorer, fossil fuel using countries. Within societies, there is an issue of ensuring that systems can be accessed by all sections and groups in society, some of who may have limited access to the internet.

4.2 Challenges

4.2.1 Sustainability

Whole system

A general challenge is the very high rate of investment in freight transport systems required to meet the Paris goals. For example in shipping, investment to achieve 1.5°C is of the order of $400Bn by 2030 and in addition $400Bn by 2030 for H_2 production (IMO 2020).

There are no clear roadmaps for the decarbonisation of freight. Freight transport policy is fragmented. An interview with an expert in the US summarised the situation in the US. In the US, the current federal government issued an executive order that targets 50% of vehicles sold in the U.S. to be zero-emission vehicles, but the road map to reach this goal is not clear. EU policy is concentrating on the development of CO_2 standards for HDVs.

The organisation for sustainable supply chains has to be developed. This requires further coordination along the supply chain, with new emissions monitoring, reporting, and verification systems.

A further issue is the energy supply chain. Where are the zero carbon fuels going to come from? The allocation between air, sea, road, and rail modes for zero-carbon electricity, synthetic fuels, and biofuels is unclear. The infrastructure for zero carbon vehicles needs to be developed.

Urban planning requires better coordination. City authorities, large freight operators, small operators such as cargo bikes, public transport, service providers, and user communities need to be included in the discussion to find the best fit for policy. Also, the combination of SUMP (Sustainable Urban Mobility Plans) and SULP (Sustainable Urban Logistics Plans) in cities is crucial for better policies. These need to be coordinated with interurban or long-distance freight transport.

Shipping and sunk assets

With long lived assets such as ships and aircraft, it is important for investors not to get stuck with assets with no residual value because their fuel cannot be used anymore. So flexible solutions – such as fitting for but not with new fuels or fuel systems is necessary. If a ship is fitted for but not with zero carbon fuels, then policy needs to create the conditions where the zero-carbon option is actually used.

The new propulsion systems may have characteristics that change the optimal size of containers. This issue is still not understood, also with respect to the modular systems proposed for the 'physical internet'.

4.2.2 Digitalisation and automation

A main challenge is to show how digitalisation provides value. There is a new level of data available, but it is not clear which type of data is useful to provide value. One issue here is determining monetary value of digitalisation benefits through risk management. Another is showing the monetary benefits of digitalisation for better traceability, reporting and checking, also monitoring of cargoes bulk and container.

For a small Finnish company with high wage levels: they work very closely with the customers who want to have the possibility to call by telephone and make orders, so digitalisation here is not necessary. Instead, personal relations, reliability, flexibility, and quality are important.

Automation of the loading and unloading operations at warehouses is essential in the future as the benefit is how to save time in loading/unloading of the vehicles. An associated issue is the optimal stacking of vehicles.

Interoperability amongst services and standards needs to be developed for several reasons: reduce time in operations, to ease interactions between different systems such as payments and paperwork. Related to city logistics management, a common urban platform to manage both transport for people and logistics, including the last mile delivery in the city is required.

4.2.3 Logistics organisation

From the **policy side,** the cooperation between freight operators, cities, and other stakeholders needs to be supported.

Joint effort and cooperation amongst different stakeholders to solve common issues with collaboration across markets and operators is required. Cooperation between large distribution and last mile delivery is a challenge to transport operation. New business models for new stakeholders are required for capacity sharing and cross-selling opportunities. Data analysis and data sharing are also expected to be an important field for new business models.

The **provision of new rail and (inland waterways) IWW infrastructure to support modal shift** away from road requires stronger policy intervention or new governance systems.

Workforce and labour rights

"We are constantly suffering from labour shortage, that is a common problem for all companies in the field and it is getting worse in the future." The working conditions in logistics businesses that are aiming to minimise costs and operate through sub-contracts to transport companies that are often owner operators seems to be causing problems in the industry. Important issues are driver recruitment, driver training, and driver retention. The drivers are on the road most of the time. They are away from family and social network. The turnover rate is high. Many develop health issue because of long hour of sitting in the cabin. Workforce acceptance of new technologies is also a problem. These issues may be reinforced in a period of system change, as has been identified in the trend analysis.

There are few courses at the universities that train the human resources for logistics and freight transport systems. Most of transportation systems graduate program in the US focuses on passenger transport. There is a shortage of qualified professionals who can address the competition between the companies in the sector for faster and faster deliveries while complying with the latest policies and changes in the landscape.

4.3 Barriers to change

The biggest barriers to change are **culture and mind-set.** There is the need to educate new generations of transport professionals. One example is cooperation: old generations are very resistant to collaboration based on their personal and professional life, whilst new generations are used to collaborative tools that they have been using since day 1.

Modal shift

Rail organisation and services need to be improved with smart waggons and vehicles. Rail (and IWW) innovating much slower than road.

Lack of valid business case for sustainability

Clear plans for financial incentives into the future are needed to create stable markets new and used vehicles.

Compared to current vehicle, low carbon vehicles have a long payback time and with EVs limited range. There is a continuing infrastructure chicken and egg – low numbers of operational vehicles do not provide incentives for investing in new infrastructures for low carbon energy, and vice versa.

“We don’t know what the resale price of the (Electric) vehicles will be. If we, for instance, would buy an electric vehicle, it would most probably be more expensive than the conventional, and as we do not know the taxation policy on a longer term, we cannot estimate the resale value of the vehicle”.

Legislation does not support the disruptive changes through IT systems, AI, and CAV (Connected Autonomous Vehicles). Many documentation requirements are created before PCs and smartphone were invented.

Automated systems need to be able to adapt to outsized loads.

4.4 Knowledge gaps and Analysis needs

4.4.1 Sustainability

Questions of how to accelerate development and adoption of zero emissions transport systems:

- What are the technologies and how can they develop for zero-carbon freight transport?
- What are the dynamics of mitigation measures? How fast will low carbon technologies diffuse?
- How to change decision criteria and behaviour in production and consumption?
- How to get modal shift away from road and air?
- Equity/Justice issues – how to do this without leaving some (poorer?) people/countries behind

Questions of Demand Reduction at the national, regional (EU) and global levels

How can demand be reduced? Possibilities include localising supply chains. How can all the stakeholders be involved in these changes? Local government can support these changes through demonstration effects of decisions and purchasing. Modellers tend to be behind policy trends: there is too little critical analysis of growth projections for national and EU or global activity (e.g. air and shipping). There is a need to consider lower growth scenarios including changing methods of forecasting away from economic growth driving more freight transport demand to investigating how the transport intensity of products can be reduced.

How can the growth of highly centralised hub and spoke logistics networks that add to transport activity be reduced, especially when logistics centres are sited in areas where it is possible to find (low cost) sites for development (e.g. Eastern Germany) but which are remote from the centres of logistics demand (Baden-Württemberg, Bavaria)?

Integrated Urban Planning

Urban level planning was emphasised as follows: "we need to re-think cities, and involve new approaches and technologies, and include the new trends in the existing city infrastructure". This requires an assessment of the SUMPS (Sustainable Urban Mobility Plans), with more concrete visions of system change in transport in cities. Also, the SUMPS need to consider freight transport with a higher priority than is currently the case in many SUMPs.

Alternative fuels and reduction in emissions intensity

The share of road freight will remain high. Therefore, low carbon systems for road freight need to be rapidly developed but in contrast to cars, the technology mix is highly uncertain. This requires more concrete scenario exercises for logistics organisation and analysis for a better understanding of the operational implications of low carbon fuels.

Questions of Fuel availability

Where does the renewable electricity and green H_2 for PtX fuels come from?

Is H_2 the best energy storage?

Will H_2 remain energetically inefficient?

Will the H_2 system be competitive with electricity systems?

What is the potential for price differentiation between peak and off peak, energy demand management?

Energy modelling for logistics organisations will need to take account of renewable energy characteristics. If energy systems are mostly renewables, there is stochastic supply and systems will be more sensitive to fluctuations if there is no rapid back-up from gas turbine plants.

There are also energy imports/storage for demand management – how does this fit in to transportation systems using renewables-based fuels/electricity?

Research is required on what an H_2 Infrastructure would look like. H_2 systems are different to the LNG supply chain being developed for ships, as LNG is based around large refineries that produce LNG for industry. This does not exist for H_2.

Infrastructure on motorways will have the highest potential and best business case for public support.

With respect to electricity charger locations, catenary systems, and grid changes, it was said that we can assume that operating patterns will be similar in the future as they depend on logistics activities. (But the project results so far suggest that it is doubtful that the structure of logistics will stay the same).

4.4.2 Digitalisation in logistics organisations

The following questions were discussed:

Digitalisation (including tracking of information) is an active field of research, but its application is lagging behind for different reasons, including policies designed for pre-digitalisation systems and lack of practical skills in the workforce). **How can the application and achievement of benefits from digitalisation be accelerated?**

What are the changes in consumer demand – **e-commerce impact** on size of loads and logistics?

How will digitalisation change **logistics market structures**? DHL (e.g.) already coordinates across suppliers/supply chains – but there is limited feedback and optimisation between the links. Control towers are just a linear extension of what DHL and other 3PLs are already doing. What are the possibilities for new forms of collaboration/business models?

Physical internet and global collaborative networks support 'mass individualisation, omni-channel distribution, further reduction of delivery times and 'encapsulation' (the standardisation of package sizes for goods). How can the physical internet change routing and distribution centre geography to maximise the benefit of collaborative networks? What are the dynamics of the physical internet? What is the impact on load factors and empty trips?

What are **new forms of last mile delivery**? This includes organisation for automation, last mile delivery (with Connected Automated Vehicles CAV), new ideas for delivery points, pooling of warehousing and distribution resources.

How can new IT systems be integrated onto the existing IT systems? What are the dangers of lock-in to technologies that are rapidly developing? What are the social externalities, the implications for working and social conditions in new logistics systems with ICT?

What are the requirements for standardisation? What are the possibilities for open web systems or partly jointly owned systems?

A fundamental aspect of digitalisation in freight transport is vehicle to vehicle and vehicle to infrastructure connectivity (V2X). Technologies such as short range WiFi 5G and cellular network communications as well as satellite systems with decentralised communication will generate very large quantities of data and data flows. This raises the questions of how such data can be collected or sampled and used for logistics systems analysis.

These issues identified by interview are compared with the review of digitalisation technologies in Wang and Sarkis (2021). They propose a series of research areas:

"- Diffusion of digitalisation technologies across various freight transport and logistics industries

- Theoretical developments and rethinking theory in this emergent digitalisation environment using formal analytical modelling

- Advancing analytical modelling and decision making for the planning, integration, adoption, and maintenance of emergent technologies

- Systems and adaptive model requirements in the integration of transportation-technological systems; their interaction and standalone capabilities and limitations

- The social, environmental, and economic implications of digitalisation technologies on industry, community, and regulatory policy for freight transportation

- Entrepreneurial activities in freight transport and logistics and how industry business models may change

- Operations and supply chain modelling for emergent digitalisation of freight transport and logistics

- Technological forecasting and outcomes including potential roadmaps based on theoretical, historical, and scenario planning for freight transportation and logistics

- Competitive and game theoretic modelling aspects of emergent digitalisation of freight transport and logistics

- Big data, predictive analytics, and decision making in freight and logistics optimisation

- Data driven business models and concepts

- Intelligent freight transport concepts (e.g. digital rail, smart motorways, and smart port) and their implications

- Applications of artificial intelligence such as robotics and truck platooning, machine learning, and virtual agents in freight transport and their disruptive effect

- Immersive technologies (such as augmented, mixed, or virtual reality), simulation, and behavioural change

- The emergence of distributed ledger technology /blockchain technology and its value creation in logistics and freight transport e.g. smart contract, product provenance, asset management, and disintermediation

- Effects of social media networks and social commerce on freight transport and logistics

- Industry 4.0, IoTs and digital twin and related structural, process, and relational changes imposed

- Intersection between various digital technologies and their integrative impact on future of mobility

- Applications of new technologies in freight urbanisation, cross-border integration, multimodality, and sharing economy"

(Wang and Sarkis 2021, p. 6).

These include some themes which have not been identified in the review so far:

- Formal analytical modelling for theories of transport in a digitalised environment.
- The integration of transportation-technological systems
- Competitive and game theoretic modelling of digitalised freight transport and logistics
- Applications of artificial intelligence such as virtual agents in freight transport and their disruptive effect
- Applications of virtual reality and digital twins
- Coordination applications in cross-border integration, multimodality, and the sharing economy.

4.4.3 EU and Global level Policies and governance

Knowledge needs in this field were identified as follows.

What are the possibilities of the EU Green **Deal** and what is the effect of the green deal on the physical internet? How can the innovation objectives of the EU partnerships, in particular the CCAM (Connected, Cooperative, Automated Mobility) and 2Zero (zero carbon fuels in the freight transport sector be addressed?

New fuels will be more expensive than HFO, also in the long run, so there is a need for supportive policy to start the transition. Policies may need to be implemented at the different governance levels, from local through national to EU and global.

The point was made that **regulation feels detached from reality**: legislators are trying to be closer to the daily reality of logistics, but for example in the Urban Mobility Plans logistics are often forgotten or overlooked. Regional governance important as well as national and EU, at least in countries with a federal political structure such as Germany or Spain.

Where does the control of **global supply networks** reside? Given international ownership and control structures, who controls global logistics? What are the requirements for anti-trust legislation in different regions for globalised, digitalised supply chains?

How can global governance problems for logistics be better addressed for digitalisation and decarbonisation?

4.5 Modelling

4.5.1 Modelling uses

The following new uses for freight transport modelling were suggested:

User perspective (citizens and drivers): their impact on and reactions to freight need to be taken into account to be sure freight is sustainable and fit with people's needs. **Gamification** is an approach that can be for interactions with stakeholders/decision makers/customers in many different ways.

Modelling for investment funds: influencing investment can bypass inadequate policy and investment funds are now addressing climate change in the oil industry. It is considered that logistics will be in focus soon. People will take governments to court for not meeting climate change goals (also in relation to freight transport) and there is a need for modelling to support this by providing evidence, like a fact checking service.

Life-cycle analysis as well as TCO (Total Cost of Ownership) analysis is required for low carbon vehicles/investments. This addresses the use of models for Cost Benefit Analysis (CBA).

Since logistics is changing rapidly, the industry faces very high uncertainty as well as complexity. Reactive models could represent and analyse major policy interventions occasionally and then adjustments to allow for the high levels of uncertainty.

How can the uncertainty in scenarios be communicated such that a single (often average) scenario is not assumed to be the future?

Modelling of **urban distribution** needs to include current changes. These include:

Online shopping

Semi-automated devices, drones, robots

New urban delivery systems

Distribution in restricted (regulation and physically) areas

4.5.2 Modelling requirements and approaches

Issues identified were:

- Technology uncertainty needs to be addressed beyond techno-economic modelling, develop models that recognise the irreducible complexity of logistics.
- It is important for models to cover the whole distribution of applications and actors, not just an average, or extremes.
- There is a **lack of Meso-level analysis** i.e. analysis at the logistics fleet operations level, between macroeconomic or aggregated and individual vehicle (trip optimisation) analysis.
- Models are required that can analyse rapid system change in logistics: how to model radical changes in behaviour and systems? A system view of transitions to zero carbon, digital logistics, and markets are required. This includes electrification solutions based on logistics (system analysis) not just vehicles.
- 'Big data' cannot be handled by old models, so new models need to be developed.

- Models of logistics change and decarbonisation need to consider characteristics of market, adaption of technologies, innovation niches, development of infrastructure.
- Models of change in logistics that can address heterogeneity are required. They should enable insights into early adopters, niches in the global system e.g. H_2 'advantage 'countries.

There is little current representation of specific supply chains. Strategic network modelling is required that models actual supply chains. Currently supply chain models only use aggregate data and modelling. This would require numerous data. Higher resolution models e.g. domestic fleets can address the operational details, land transport to ships interface, and port call scheduling. Models need to represent operational details to find niches, the sequencing of new infrastructure development. Models should be able to represent supply chains for optimal organisation of zero-carbon fuel supply chain and fuel/bunker infrastructure. Currently supply chain analysis is modular, with limited interactions, so models for a better understanding of the interactions are required.

Large-scale models could be developed for whole system analysis of logistics organisations and supply chains. One possibility is short-term demand and activity assessment and forecasts –a similar approach to climate models and weather forecast models (which are relatively accurate for short-term forecasts of the complex weather system). Policy assessment should be much more adaptive/reactive because of increasing uncertainty and impacts from climate change. As with Covid, models could be developed to deliver continuous data that can be used to inform short-term decisions on lockdown etc.

Agent-Based Models (ABMs), which have a detailed representation of decision making could be used to model movements of single loads/agents in combination with automated vehicles and could be developed for whole systems. One issue for research is then: how to make the calculations for a whole supply chain ABM computationally practicable. Would cloud share computing or supercomputers be necessary?

Artificial Intelligence (AI) approaches could be used for models to train themselves for 'big data'.

4.5.3 Data

Digitalisation is generating new levels of data, so-called **'big data'.** The challenge is to develop methods for meaningful data analysis, including the use of telematic data-specific data requirements have also been identified. There is a need to research and define, for all freight transport modes, a **digital form of capacity data** (common format and standards). Data could be developed for **trips in value and volume** and not just tonnes.

With a fully digitalised logistics system, it would be possible to tag every individual good produced e.g. paint – what type, what size container – to enable value, volume, weight information to be shared.

Logistics data includes origin, destination, volume, weight, classification of content. Such data, including vehicle movements data exists in trucking companies, shippers, or receivers, but access is limited. Operators place a high priority on vehicle data to manage their operations. Data from the manufacturers is reliable.

"At present, at most we can do (in the US) to collect freight transport data is to use the GPS locations and time of the freight vehicles. There is a requirement to establish a **standard protocol** to collect freight origin address, destination address, size, weight, content classification without privacy intrusion."

Parking spaces information along highways is required as real-time information for truck drivers. Resting areas availability and the possibility of booking a parking space remotely is a crucial point to assess driving resting times and positioning of electric charging infrastructure.

Automatic identification system (AIS) Data

AIS data is now continuously available for ships and aircraft. There is now an industrial sector of AIS data firms, but their services are expensive. In principle it is a very useful data source. Large companies use AIS data analysis internally for operations management, checking fuel reporting etc. AIS can be used for transparency in operations, to monitor compliance with the Poseidon principles, checking fuel data and carbon intensity. However, it requires numerous resources to build the necessary analysis tools. UCL has had a long running programme, with software code publicly available, but the necessary funding to maintain the capability to utilise AIS data is much greater than the already high costs of the raw AIS data. These make the use of AIS data in academic research very difficult. One possibility could be to set up an academic network for AIS data analysis. This data could then feed into the transport system models.

Barriers to sharing data are a recurring theme for researchers. To analyse new operational structures with alternative fuels, access to individual vehicle movements to define individual trip chains is required, as well as fuel consumption data. The problem is that sharing data with competitors to improve the overall efficiency of a supply chain is not in an individual operator's short term interests, if they think they have competitive advantage in costs. Samples of data would be an improvement, as these can then be used to develop 'realistic' synthetic data for analysis (see e.g. Miller et al. 2020). The EU's General Data Protection Regulation (GDPR), integrity and competitive challenges between companies result in limitations to sharing data. This can be partly solved by trusted data sharing houses. The ideal is a global logistics database, accessible for analysis. A further issue is that of privacy of individuals' data and controls to ensure that personal data is not shared without individuals' consent. The Digital Logistics Forum is working on data availability (https://www.dtlf.eu/).

4.5.4 Legitimacy of models

The consultation process raised the question of legitimacy of models. Models employing simulation methods for 'big data' such as AI learning, neural nets, or ABM approaches are seen to be intransparent. This implies that the assumptions underlying such models are not clear to stakeholders in the decision-making processes. This is a serious issue, because the STORM project is proposing adding new methods and model structures that are very different from current freight transport models used for policy assessment and therefore stakeholders are unsure of the models' scientific credibility. We argue, however, that current models used for policy analysis are also not transparent. Transparency in modelling is achieved in scientific terms when the results of an analysis can be repeated by other researchers not involved in the model development. This is not common practice in environmental policy assessment. In terms of new modelling approaches proposed here, this means that the structure and assumptions of the models need to be carefully explained and, in more depth, than for models using well-known methodologies.

4.6 Summary: new analysis and modelling needs

The results of the literature review, survey, and interviews have confirmed each other and demonstrated common overall themes:

- Freight transport and logistics have moved into a period of rapid and fundamental change.
- Digitalisation is beginning to restructure logistics, while the pressure on logistics from policy and market to decarbonise is increasing. Industrial actors are developing technologies and institutional structures to enable radical decarbonisation to meet the goals of the Paris Agreement.
- The Covid pandemic has accelerated the trend to online markets and retail, whether other behavioural changes will be permanent is unclear.
- These fundamental changes drive a need for new knowledge and policy assessments to analyse large-scale system change in both technologies and – an even bigger challenge for research – logistics structures and institutions.

The knowledge gaps and new needs for analysis are now summarised. The possible uses of models are also considered, as some possible new roles for modelling have been suggested.

4.6.1 Logistics Organisations: What does a digitised, low carbon logistics system look like?

- What are feasible pathways/roadmaps of transition to zero carbon transport systems (to meet the goals of the Paris Agreement)?
- What are operating profiles of low C systems?
- How might digitalisation such as crowd sourcing and blockchain change business models and operational structures in logistics?
- How do new logistic supply chain and market structures interact with low carbon transport technologies and fuels?
- How will digitalisation and e-trading/retail affect the environmental performance of logistics systems?
- Where are the zero carbon fuels going to come from?

Implications for analysis are that system analysis of transport operations is required, not just for individual vehicle characteristics e.g. Electrification solutions based on logistics (system analysis), not just vehicles.

Since emissions are directly dependent on fuel use, the conventional analysis in which transport activity determines fuel use, which then determines emissions is still required.

4.6.2 Decision making for sustainability

- How to change decision criteria in logistics?
- What are possible business cases for sustainable freight transport? What policy/governance measures can support such business cases?

4.6.3 Transport planning at Urban and National levels

- How to support localising supply chains, how to involve all the stakeholders in these changes?
- How to bring freight transport planning into Urban Mobility Plans in combination with mobility planning? How include the new trends in existing city infrastructures?

- When and how to limit growth in freight transport activity?

4.6.4 Digitalisation in logistics organisations and supply chains

- Digitalisation must provide value first – how to identify the benefits of digital technologies?
- How can new IT systems be integrated into the existing IT systems?
  - How can the performance of new digitised logistic systems be assessed?
  - Research and define a capacity of all kinds of freight transport modes in a digital form (common format and standards).
  - Develop supply chain data sets (B2B, B2C), vehicle data sets, transport infrastructure technological capabilities description, with communication standards, methods, and mathematical models for processes simulation (to create its digital twin)
- What analysis is possible with the 'big data' available from digitalisation (Internet of Things, Physical Internet)?
  - How can it be used for assessment of value and sustainability?
  - How can it be used in digitised logistics systems?
  - How can it be used for policy analysis?

4.6.5 New roles of research and models in freight transport

Large-scale models and big data

Who is the user or customer for the analysis and how can logistics operators use such models?

There is a potential to develop models of digitalised market structures including new business models.

One application is real-time data for elastic logistics, a concept of using real time ordering and production data, combined with GPS information about vehicles and stocks to determine production and distribution operations. Another could be load consolidation in the sense of the physical internet with a high level of load consolidation from different suppliers and customers. This could model integration through Cloud sourcing platforms and Blockchain contractual relationships, omni-channel logistics etc.

Transition pathways

- Analysis of processes of radical system change in addition to current models of incremental innovation. As explained below, the sustainability transitions field is one literature that addresses system change in socio-technical systems such as transport.
- Models of alternative internet-based logistics operations, markets, and institutions. Automation of vehicles and cargo handling is an area where considerable knowledge has been developed. However, the ideas such as applications of the physical internet (Rajahonka 2019) have not yet been analysed or applied to operational systems. The area of most rapid change is software and internet applications. Current developments are reviewed in (Wang and Sarkis 2021).

Logistics operations and supply chains

- Analysis of complete supply chains including environmental assessment. Vlachos (2021) discusses the implementation of logistics control towers as an aspect of the impact of digitalisation on sustainability in logistics. Trzuskawska-Grzesińska (2017) reviews logistics control towers. Junge and Straube (2020) review the impact of digitalisation on sustainable supply chains. Strategic network modelling is required that models actual supply chains, with the collection and application of empirical data.
- Extension of models for 'elastic logistics' where supply capacity can be adjusted in near to real time to match short-term changes (Choi 2021; Dag 2021). Use demand prediction to produce and ship goods to (almost) exactly meet retail demand, such that vehicles loaded at the production site can deliver directly to the retail site to eliminate warehousing.
- The sustainability impact of digitalised logistics systems needs to be assessed. Computing methods such as Blockchain or Cloud computing applications can be highly energy intensive and therefore have a significant impact on the emissions from a supply chain.

Transport policy and logistics sector governance in a process of system change

Links to policy making could provide opportunities for new forms of involvement of modelling in policy making processes. This includes foresight activities in the EU commission and European agencies, in particular the EEA, which is using ideas of system analysis and sustainability transitions in their environmental assessments.

Further application

- Models as part of transdisciplinary research – living labs, transitions management projects
- Gamification – for social investments, stakeholders in transport planning processes.
- Use of modelling in legal cases of claims on governments and industries for measures that are (claimed to be) not compliant with GHG mitigation legislation or environmental legislation.

Transport Planning

Issues identified are:

Urban/local level

- How to support localising supply chains, how to involve all the stakeholders in these changes?
- How to bring freight transport planning into Urban Mobility Plans (SUMPs) in combination with mobility planning? How include the new trends in existing city infrastructures?
  EU/National level
- Why, when and how to limit growth in freight transport activity?

5 Transport Modelling: Decarbonisation, Digitalisation, and system change

5.1 The challenge of modelling system change

From the literature review, two trends are clearly identified as the main drivers of change in logistics: zero carbon transport systems (DHL 2021) and digitalisation of logistics/supply chains (WEF 2016). We argue that the fundamental problem for transport modelling is that both zero carbon propulsion technologies and digitalisation in logistics involve changes in the structure of transport systems.

Tavasszy (2020) emphasises that “The different innovations in logistics introduce many new elements into the freight transport system which are currently only represented to a very limited extent in freight transport models.” (Tavasszy 2020, p. A4). Aspects such as crowd-sourcing of services, collaborative networks, information networks are not represented in current transport models. The impact of low carbon energy carriers on logistics operations has a very limited scientific literature.

Furthermore, these two sets of system changes will interact through logistics organisation, vehicle management, load management and the development of new market structures posing new types of questions in the logistics industry and freight transport.

The analysis of these fundamental changes requires models that represent these innovations. In terms of policy assessment, the need is to support the development of policies that can influence the system changes in support of transport policy goals. This requires forward-looking scenario assessment of pathways of change in the transport systems. Since environmental issues are one of the two main sets of trends, we argue that concepts of innovation for sustainability are a relevant direction from which to assess the potential for new modelling methods.

In terms of digitalisation in logistics, it is more difficult to find a single conceptual approach to system change. Tavasszy (2020) is not able to identify any literature that systematically reviews approaches to digitalisation in logistics. To our knowledge, this is still the case. Tavasszy (2020) considers that freight transport models need to address ‘reorganisation effects’ in logistics and proceeds to discuss changes in decision making and how these can be addressed by agent based modelling approaches. These issues are also addressed in the sustainable innovation modelling literature.

Given the lack of overall discussions of digitalisation, we use the literature on modelling sustainable innovation to enhance the ideas in the transport modelling literature for ABMs and decision making in logistics. The argument for this is that recent advances in the understanding of sustainable innovation for decarbonisation have come to adopt ideas of system change, following from the literature on Kondratiev Waves of economic growth as waves of social and technical change to new socio-technical systems (Freeman and Louçã 2002). These concepts have been applied to digitalisation (Freeman and Louçã 2002) and have been adapted more recently to transitions to sustainability as transitions to new socio-technical systems, including transportation.

The result of the trends analysis, that the two major trends of decarbonisation and digitalisation are driving system change in logistics and supply chains was used to limit the scope of the literature review. Within this scope, modelling approaches are analysed for their ability to represent these system changes and whether or how they address the further dimensions of geographical/policy level, decision making, and potential applications in Cost Benefit (CBA analysis and Multi-Criteria analysis (MCA).

We then use the results of our review on knowledge needs to suggest how the approaches in the two literatures might be applied to the knowledge and analysis needs identified through our review, survey and interviews.

5.2 Modelling sustainability transitions

Köhler (2019) reviews the developments in modelling methods for sustainable innovation. For change in the structure of complex systems such as transport systems, the sustainable innovation literature has developed theoretical approaches which have come to be known as sustainability transitions (Köhler et al. 2019). There is now a developing literature on approaches to simulation modelling in this field. Moallemi and Haan (2019) provides an overview of this field. Köhler et al. (2018) considered the features of sustainability transitions and derived requirements for simulation models to address these features.

“Socio-technical transitions:

1. Profoundly alter the way a societal system[3] functions and the actors, practices, institutions, and technologies involved in production and consumption. During a transition, new products, services, business models, regulations, norms, organisations, and infrastructures may emerge, complementing and/or substituting existing ones. Transitions can be differentiated from other kinds of social or technical change because they address a system change, which alters the ways a socio-technical system functions. They involve a change from one socio-technical regime to another in which the new is simultaneously constituted as the old unravels;
2. Have dynamics that typically start slowly due to multiple sources of inertia (STRN 2010) manifesting in the old regime (although various transition patterns have been distinguished in the literature);
3. Are polycentric processes of societal system change, i.e. are multiple actors, multiple factors, multiple temporal, and spatial scales relevant for shaping transition dynamics. They can hence be initiated and driven from various directions (behaviour/social practice and expectations, cultural changes, technology and economy trends, institutional change, environmental changes, policy) and from various levels (e.g. citizen-initiatives or EU policy);
4. May be triggered purposively or emerge from ongoing developments;
5. Are open, path-dependent processes with uncertain outcomes whose dynamics are not only determined by external developments and conditions (“landscape developments”) but also emerge endogenously from interactions within the system. The nature, timing, and intensity of interactions are crucial for the unfolding dynamics. “(Köhler et al. 2018).

These are then used to propose the following features for models of sustainability transitions:

[3] Societal systems as we use the term here include the regime as defined by STRN 2010 as well as niches that relate to the same societal function as the regime.

"Necessary modelling features are:

- Capability of representing non-linear behaviour

Transitions occur over periods of time in which change is happening faster or slower. An archetypical pattern is that of an S-curve, in which the rate of change is initially slow, then accelerates, and slows down again as the new regime configuration stabilises. A transitions model should be able to reproduce such variations of the rate of change and other dynamics through which the end-state of the transition is not proportional to changes in the initial state. A special class of non-linear behaviour that is particularly pertinent to transitions is path-dependence.

- Capability of representing *qualitatively* different system states

A transition implies that the configuration of elements fulfilling a particular societal function changes i.e., new elements are included, old ones are dropped, elements might adapt, and the interactions between elements are reconfigured. Therefore, a transition is not just change towards more or less of the same. This aspect of a transition should be (explicitly or implicitly) captured by transitions models.

- Capability of representing changes in social values and norms

Transitions to sustainability also involve changes in the value system of society and actors. This will lead to changes in the decision-making rules (preferences, in the language of economics). Models should be capable of representing changes in their decision-making structure.

- Capability of representing diversity and heterogeneity

Transitions involve different actor groups (producers, consumers, politicians, NGOs etc.) and actors within these groups are heterogeneous (e.g., producers following different strategies, consumers having different preferences). These differences must be represented in the structure of a transitions model.

- Capability of representing dynamics at and across different scales

There is also a consensus in the literature that transitions bridge micro and macro scales. As is acknowledged by Geels and Schot (2010, in Grin et al., 2010) among others, this can be seen as an application of Giddens' Theory of Structuration (1984), in which agents act within a set of social structures, and their actions can change those structures of social systems, such that there are potentially feedbacks between the micro and macro levels in societal systems. Transitions are shaped by interacting processes that happen in different scales, be they spatial (e.g. local, regional, global), temporal (e.g. years, decades, centuries), functional (e.g. in societal sub-systems – economy, policy, science, education, etc.), epistemological (e.g. microeconomic vs. macroeconomic) or institutional (e.g. in the legal context constitutions, laws, and directives) scales. For example, an energy transition is influenced by global climate agreements, by national or federal regulations, as well as local initiatives that become engaged in energy production and become new players in the game. The different scales may be the emergent modelling result, or a feature of how the model is set up (e.g. input variables on different scales).

- Capability of incorporating open processes and uncertainties or contingencies

Transitions are influenced by unpredictable events that by their very nature cannot be predicted, such as the development of radical innovations and political decisions. If the system is responsive to these events (or not), the future dynamics might change direction (or not)." (Köhler et al. 2018).

Using this approach, Köhler et al. (2018) assessed the suitability of alternative modelling methodologies to address these features. Three theoretical frameworks are considered:

Eco-innovation (energy-economy models and Integrated Assessment Models)

Evolutionary economics

Complex systems analysis methods (complexity science)

Socio-evolutionary systems.

In addition, two simulation approaches are assessed:

Computational social science: Agent-Based models

System Dynamics (SD).

These modelling approaches can address many of the required characteristics that differentiate sustainability transitions from other socio-economic dynamics or innovations. The most difficult aspects are the inclusion of qualitatively different states and changes in norms and culture leading to changes in behaviour (Freeman and Louçã 2002; Grin et al. 2011). There are still very few simulation models that address these issues. ABMs of complex social systems such as Epstein (1996) or evolutionary economics models including recombinant innovation (Frenken et al. 2012; Zeppini et al. 2014) are examples of research addressing these problems.

5.2.1 Different fields of application

Halbe et al. (2015) consider the possible different application fields of simulation modelling in transitions and identify three types: understanding transitions, providing case-specific policy advice and facilitating stakeholder processes. Stakeholder processes can include multi-actor workshops and decision fora, living labs and foresight processes for longer term assessment. Models can help to generate scenarios to investigate different combinations of assumptions about the future.

The 'gamification' approach of specific models with a dedicated user interface can also help to illustrate and discuss the structure of a transport issue.

5.3 Recent transportation models and methods

The use of computer models in freight transport and logistics analysis has generated a major literature, which has developed rapidly since Hensher and Button (2008). In freight transport, the 4-step approach is still common e.g. Gonzalez-Feliu (2019) for urban freight, Southworth (2018) for modelling in the US. Most of the National /EU level policy models for (freight) transport in the EU use this approach or Origin-Destination data: the TREMOVE, PRIMES, ASTRA. The E3ME model uses a macroeconometric approach. Thaller et al. (2016) presents a typology of what might be called 'conventional' freight demand models. Implicitly, these are large scale or aggregated models. These have been extensively used for transport policy assessment. These models include technology characteristics and decision making for modal split. They can generate scenarios of technology change in vehicles, but not the organisational system changes emphasised by (Tavasszy 2020) and identified in the trend analysis described above.

Crainic et al. (2018) review freight transport models. They find that while recent modelling has emphasised environmental modelling in the urban context, there is little work on multi-criteria analysis and therefore extended cost-benefit analysis. System change in freight transport is not addressed, so this is also a limitation of this extensive literature on regional transport network models.

More recent developments in modelling methods for freight transport activity have addressed the freight transport system using ABMs for a more detailed representation of decision making in logistics systems (Tavasszy et al. 2020). Bok and Tavasszy (2018) develop an ABM for urban freight transport. Utomo et al. (2020) is another example of how an ABM can be applied to the new problem of limited ranges of vehicles with alternative fuels. Alves et al. (2019) develop an ABM to look at last mile deliveries. Gatta et al. (2017) use an ABM to study choices between e-groceries and shopping.

There are also new forms of network models, using development from complexity science. Cavone et al. (2018) review Petri Net Models[4] of discrete choices for representing decision making, which can be applied to the intrinsic discrete dynamics of systems when deriving a model to be used for simulation, analysis, optimisation, and control.

A further new area of research is optimisation of new infrastructures for alternative (low carbon) fuels. Leite et al. (2019) derive a multi-level optimisation problem for electric vehicle infrastructure.

Combined methods

Gatta et al. (2017) propose a methodology for urban freight planning that combines desk research, living labs and modelling (Discrete Choice Models – DCMs – and/or ABMs) in a framework that addresses transdisciplinary roles noted in section 4.6.5 above. In a similar spirit, Köhler et al. (under review) and MAN (2020) applied a stakeholder based qualitative scenario approach with an iterative implementation of a numerical simulation model (the MATISSE-SHIP model) to develop combined qualitative – quantitative scenarios of transitions in ship propulsion.

System change in logistics structures

This topic is not often addressed in 'conventional' transport models. One example is Ottemöller and Friedrich (2019) who consider centralisation through vertical integration of logistics in the German poultry industry. They use a scenario methodology with a spatial model.

Considering system change through decarbonisation, the aggregate models given as examples above and aggregate techno-economic models of energy systems including transport energy demand (e.g. Markal) have been used to calculate scenarios of radical decarbonisation. These have already generated important results, in particular the necessity of very rapid action if the Paris Agreement goals are to be attained. However, these models derive overall timelines of change. They usually do not address the structural changes that these timelines imply: the change in patterns of logistics operations with low carbon fuels or the interactions with supply chains for low carbon fuels. Furthermore, they usually completely neglect the impacts of ongoing

[4] "A Petri net is a directed bipartite graph, in which the nodes represent transitions and places. The directed arcs describe which places are pre- and/or postconditions for which transitions occurs." https://www.definitions.net/definition/PETRI+NET accessed 02/02/2022

digitalisation in logistics. In one sense, this is reasonable, because such aggregate models are not intended to model the micro or meso level of e.g. cloud sourced market models for load consolidation or trip planning with BEVs and predictive demand from retailers. Therefore, we now consider some of the ideas for research on digitalisation.

Digitalisation

Wang and Sarkis (2021) introduce a special issue on digitalisation and summarise the ongoing developments in modelling new logistics structures. "End-to-end supply chain visibility goes beyond a focal organisation's boundary and extends to freight ecosystem partners - customers, suppliers, freight forwarders, logistics service providers, transport node operators as well as government agencies such as a customs agency." (Wang and Sarkis 2021, p. 3). The digital platforms have been expanded to the concept of digital ecosystems. These platforms and ecosystems also support horizontal collaboration by enabling rapid and almost costless communication and data sharing across all stakeholders: customs, forwarders, shippers, shipping lines, terminal operators, inspection agencies, transport operators, charter parties in shipping etc.

'Big data' and blockchain technologies are being developed to apply the IoT and in particular data from IoT smart logistics elements. Data from IoT, planning systems and social media are part of 'big data'. This has made Big Data Analytics an important area of development, leading into AI and learning in logistics systems and for Autonomous Vehicles. New business models such as direct links between end consumers/customers, producers, and product designers are made possible. Blockchain (or distributed ledger technology (LT)) is currently seen as an enabling technology e.g. for end-to-end supply chain management and horizontal collaboration, reducing intermediaries in the supply chain and enabling secure sharing of information on consignments and containers. However, perhaps an equally significant potential is for blockchain to enable widespread development of online platforms, by ensuring security and transaction tracing through the platform blockchain software.

Wang and Sarkis (2021) introduce some examples of models for these areas. Choi (2020) looks at elastic logistics using a stochastic dynamic programming approach. Xu et al. (2020) looks at the impact of an online platform competing with offline retail and supply chain coordination through cost sharing contracts. Machine learning is applied to container planning in Fazi et al. (2020). Miller et al. (2020) develop a method for Big Data Analytics to infer (US) state-wide traffic patterns from GPS trajectory data.

Crowdsourcing is another new area of digital logistics. Punel and Stathopoulos (2017) are a recent example of modelling in which they develop a Discrete Choice Model for crowd sourcing of grocery deliveries with 'occasional' drivers. Surprisingly, DHL (2018) and DHL (2021) do not mention crowdsourcing. This could be because they prefer an industry that stays consolidated. This suggests that there is a need to re-examine competitive market structures in digitalised logistics systems.

These examples illustrate the fields of analysis and modelling that are being opened up in response to digitalisation in logistics and how new logistics structures are being developed.

5.4 Summary: state of the art

Transport modelling is already a very extensive set of fields, using an extensive set of techniques: 4-step models, techno-economic models/IAMs, network models, SD models, and ABMs, geographical models, behavioural models, planning models among others.

Reflecting the changes in freight transport and new data structures, models of freight transport are changing too. ABMs of transport decision making and activity are an active field of development, as discussed in 5.3 above. There are models being developed of new market structures in logistics and of low carbon freight transport systems, using GPS/AIS data and 'big data' analytics.

While specific applications of digitalisation are being addressed, what seems to be missing so far is models that look at system change of whole supply chains or logistics systems. Larger scale change in logistics structures could be caused through the realisation of ideas around digitalised logistics systems – the IoT or the physical internet. The modelling approaches outlined in 5.2 offer very general concepts for addressing structural and system change. This implies that what is required are clearer ideas of possible changes ahead in freight transport, to enable problem definitions that can be addressed by the approaches discussed here.

These views of future changes can be developed through qualitative techniques of foresight and scenario development with stakeholders, with many opportunities for using quantitative models as a part of such processes to develop combined qualitative and quantitative analyses.

6 Conclusions: Proposals for model requirements and new directions

It is not possible or desirable to propose specific modelling methods or tools unless the specific problem to be addressed is precisely defined. Therefore, this section makes proposals for requirements and has a general discussion of the approaches that might be used. The following work packages in the STORM project will elaborate modelling approaches for a few specific examples – data and operational modelling of electric heavy-duty trucks, integrated assessment modelling for freight transport, rapid response modelling for policies addressing freight transport system change and analysis of urban logistics.

6.1 Topics and Modelling Requirements

Digitalised logistics

The far-reaching changes in logistics that are developing (DHL 2021; Tavasszy 2020) suggest that it could be useful to approach transport modelling from a new direction. Rather than modelling vehicles, loads and trips i.e. transport activity, models of digitalised market structures could be developed. Such models could then consider the changes in logistics institutions, services/business models and provide insights into how can they change freight transport. Models of platforms for load and capacity matching across combined networks of warehouses/distribution centres i.e. collaboration between different 3PL providers for bundling flows (Tavasszy 2018) could address routing and back hauls. Models of mass-customised production through blockchain markets could address the consequent diversity of supply chain configurations. In general, models could explore the impacts of fully networked logistics based on IoT consignments, vehicles, handling devices warehouses and infrastructures. This is particularly important, because modelling of these changes through digitalisation are mostly only considered as a small scale (Orji et al. 2020; Pernestål et al. 2021; Pervez and Haq 2019; Choi 2020; Xu et al. 2020). Lind and Melander (2021) is an exception, but is a qualitative study. (Choi 2020) does use an optimising approach to look at the adoption of an internet based elastic logistics system, one of the few examples of quantitative simulation of system change.

New market and institutional structures in logistics

Vertical integration along the logistics supply chain could be addressed with system dynamics (SD) models of information flows, which model the nodes of production, warehousing and distribution, connected by transport activity. The challenge is to model the necessary data flows to enable the coordination of the supply chain, a new feature in addition to the transport activity of (most) current models of logistics systems.

Horizontal cooperation enabled by blockchain based internet platforms also requires data sharing between actors who do not necessarily have a fixed contractual relationship. Data on loads, capacity of individual vehicles/ships/barges/waggons/aircraft, warehousing/container storage, and orders needs to be shared to enable a decentralised system of logistics with reduced warehousing. Again, this is in addition to data on prices, the idea being that blockchain technology can enable contract arrangements that prevent actors gaining control of the system by consolidation. The requirement then is for the design of the new contractual arrangements. This could reduce the organisational and contractual barriers to the development of regional production and distribution systems, e.g. direct sales from farm shops and other applications where there is limited capacity for the development of new (local) structures.

A further application could be crowdsourcing platforms for logistics services. This could enable the vision of the 'physical internet', with modular small loads being cross-docked more frequently than with current supply chains, to be realised. This would require new models of logistics operations, where cross-docking operations and routes are optimised in real time. The necessary algorithms and adaptive systems would need to be developed.

Along with these developments, the sustainability impact of digitalised logistics systems needs to be assessed.

Low carbon fuels operating patterns

The overall goal should be to develop models to determine trip planning strategies for operations with zero carbon fuels for digitalised logistics operating patterns and business models. The first step is the development of tools for optimised operations using GPS tracking data with low carbon vehicles and energy infrastructures. Transport network models or Petri-net models might be applicable here. Further development could then combine the current research on decarbonised freight transport systems and their operational requirements with the new market and coordination structures in logistics. This will require the combination of models for the digitalised institutions and market structures with the transport models along supply chains. The structure of goods demand and the geography of loads need to be set in a context of institutions for both coordination and cooperation, along and between supply chains.

Predictive demand, production, and supply/distribution

ABM model systems could be used for short-term forecasting of demand, supply, warehousing, and routing. Micro level models of demand for the range of goods from the distribution of retailers/home orders would need to be combined with models of the sourcing and supply chain in an operational model combining trips, warehousing, and load transfer activities. This would require a transport model with goods flows along links, connected to geographical distributions of demand and sourcing. Such models would require learning algorithms for predictive production following predictive demand algorithms, with geographical as well as time distributions for retail goods. Network models could be combined with time series models of demand and production. Optimisation could be undertaken using AI methods and/or ABM approaches.

Policy and National Transport Planning

The overall requirement is for models to support National and EU policy development for sustainability transitions in freight transport. The European Green Deal with the pledges of member states to reduce emissions by 55% compared to 1990 levels by 2030 ('Fit for 55') on the way to climate neutrality is now an overarching goal of EU economic and environmental policy. The new direction here for modelling is to develop models that concentrate on system change in logistics, supporting new fuels and zero carbon power trains in digitalised logistics systems. Outputs of such models will include scenarios of change for policy making: how digitalisation will impact uptake of low carbon technologies (propulsion and fuel supply chains), including interactions with other socio-technical systems such as food and energy. Models need to represent non-price barriers to change, capacity limits to the diffusion of innovations, and cost/price dynamics through the processes of system change.

Models should support governance for system change. Governance (rather than policy) means that the structure of policy making may need to be considered, for example the balance of policy development between EU, nation and local levels of governance. For the system changes discussed above, foresight activities in the EU, transitions management in local/regional transport are areas that can develop policy processes to support system change towards sustainability.

For policy support, modelling will need to address how new digitalised logistics will impact the uptake of low carbon technologies. This should include the development of policy measures to enable changes in decision making in consumption and logistics.

It would then be possible to assess the potential impact of specific measures. Specific outputs should include:

- Developing zero-carbon fuel supply chains
- Scenarios of changing global trade patterns
- Scenarios of lower growth
- Scenarios of regionalisation of production

Urban Transport planning

In the context of urban freight transport, there are some specific issues in addition to the more general requirements for all levels of transport policy and planning. In particular, the issue of bringing freight transport into SUMPs has been identified. Another area of continuing development is urban freight modelling with new urban distribution business models and modes. The literature review in section 5.3 above has indicated that a range of approaches to new urban freight systems are being developed.

6.2 Challenges for freight transport modelling

This report is not a general review of freight transportation modelling. It has identified trends in freight transport – decarbonisation, digitalisation, and also Covid – that are changing freight transport systems and logistics.

The overall finding is that **freight transport is in a phase of systemic change.**

Current freight transport models are able to represent pathways of adoption of low carbon technologies to achieve large-scale reductions in emissions and achieve the Paris goals, although there are not many actual freight transport scenarios of such changes. However, **freight transport policy assessment models do not represent structural system change.** New operational patterns for zero carbon fuels are not considered. New operational patterns from new logistics structures are also not considered.

This does not mean that scientific research is ignoring these issues. Rather, the developments are taking place through new models that have explicit representation of ‘micro level’ processes. The development of GPS/AIS data and dynamic simulation approaches from complexity science, in particular ABMs and network models are extending the capabilities of transport network models. ABMs in particular place a new emphasis on simulation individual decisions, in contrast to models based on a single decision process for all elements of supply and demand. Models using GPS/AIS data are being developed to represent operational patterns of vehicles powered by low carbon energy. Simulation analyses are also addressing new systems in urban distribution. A further general issue for modelling is the incorporation of barriers to change into realistic models of technology dynamics (or innovation) and diffusion. Culture and mind set and the lack of a business model for sustainable innovation need to be incorporated into models of change and policy packages (Nelissen et al. 2016; Tavasszy 2018).

What current modelling is unable to deliver

In terms of the outputs and insight of freight transport modelling, this review has found some important areas where information and insights are lacking:

- Plausible projections of how the different aspects of change in logistics will drive structural change in logistics.
- Scenario simulations that are based on the interlinked system changes of new digitalised logistics structures and zero-carbon energy in freight transport.
- Policy package simulations that will actually deliver sustainability – since freight transport is facing non-marginal change, models that can represent processes of structural change will be needed to assess potential points of influence on transport system changes.

'Big models' for 'Big Data'? Micro-Macro models

A major change is already happening in freight transport modelling, through the application of new 'big' data and increasing applications of approaches from complexity science, such as network models and ABMs. These non-linear models generate emergent behaviour, with the 'irreducible complexity' as the basis of the model. Discrete distributions of users, firms, vehicles are being used in contrast to aggregating and taking averages in 'large scale' or 'macro' models. Such models with feedbacks between the model elements combine SD and ABM approaches. They then generate changes in the overall system properties from changes in micro parameters – emergent behaviour as well as dynamics in the distributions of the elements. For large-scale analysis, this could lead to similar levels of model complexity to weather and climate modelling, which are very resource-intensive, but are able to provide relatively reliable short and medium term weather forecasts.

These models would need to use shared large datasets – using Blockchain technology for confidential data if necessary to make sharing of data between companies more attractive. Another alternative would be to use simulated data based on smaller samples for GPS and AIS data for road vehicles, ships, and aircraft. These could calibrate models for **operational analysis** for e.g. predictive production and distribution.

A further aspect of this approach is the development of behaviour datasets that show the range of choice mechanisms and behaviours, to reflect the different circumstances of different individuals, households, or firms.

This Micro-Macro approach is one possible method for analysing the interlinked system changes of new logistics structures and zero-carbon energy.

Such ‘big models’ using new modelling structures need to establish their legitimacy with stakeholders in the policy process.

Rapid response models for stakeholder processes

In addition to the requirements for policy assessment modelling discussed in section 6.1, new areas for modelling in policy processes have been identified.

- Policy processes

This review has identified two potential areas. Models that run quickly and that can have their parameters changed rapidly to address alternative policy combinations would enable a more interactive relationship between freight transport modelling and policy proposal assessment. Such models might be used to look at a broader range of scenarios than is currently undertaken for policy assessments. In particular, it would be useful to have models that can start from current scenarios as a baseline, but consider new market structures or operational patterns in freight. In a similar way, models of system change, which are rapid to run and can provide material for discussion around possible system changes and policy goals could be part of the Foresight processes in development in the EU commission (Köhler et al. 2015).

- Transitions management and living lab programs

Similar to models for supporting policy processes, such rapid response models could also be applied in living labs, where new ideas and technologies are being tested. Simulation models can provide scenarios for the uses and diffusion of the innovations, relevant in e.g. networks for users or markets that will share experiences or generate other increasing returns to network scale. Transitions management processes involve the development of visions of sustainability, moving on to measures and scenario analysis of alternative futures. Models can be used to develop scenarios and test them against the stakeholders’ views in an iterative process.

Such models that can be integrated into stakeholder processes could use distributions of variables such as patterns of cargo characteristics (including volume, weight, value, origin, destination, and urgency), trip structures in intermodal supply chains to identify short-term flow patterns and nodes of production, warehousing, cross-docking, and delivery. Investment decisions in logistics management systems, vehicles, and infrastructures (transport, fuels, traffic management) could also be based on distributions of decision-making behaviour. Such distributions could be initially calibrated from the larger scale models, but use similar approaches of discrete modelling of sets of agents (ABMs) or network models.

Support for legal processes

There are now examples of legal challenges to climate policies and plans e.g. the ruling by Germany’s constitutional court that the German 2019 Climate Change act is in part unconstitutional or the ruling ordering Royal Dutch Shell to reduce net emissions by 45% by 2030 vs 2019[5]. Modelling could be used as evidence in such cases to support the arguments. This

[5] 29th April 2021 Bundesverfassungsgericht https://www.bundesverfassungsgericht.de/SharedDocs/Pressemitteilungen/DE/2021/bvg21-031.html

26th May 2021 https://www.rechtspraak.nl/Organisatie-en-contact/Organisatie/Rechtbanken/Rechtbank-Den-Haag/Nieuws/Paginas/Royal-Dutch-Shell-must-reduce-CO2-emissions.aspx might require the elaboration of standards for the use of modelling as evidence, which currently rests on the professional reputation of the expert providing technical evidence, or standards of transparency and reproducibility of the models.

Support for financing/business cases

Models of system change could be used to provide more convincing scenarios of future transport than models, which do not address the new developments in logistics and decarbonisation. These could provide consultancy expertise to companies having to address systemic uncertainty, where conventional market models are no longer valid. Here, system analysis (System Dynamics) or evolutionary/AI Learning methods could extend the assessments of possible future markets.

6.3 Applying the results on analysis needs and modelling requirements

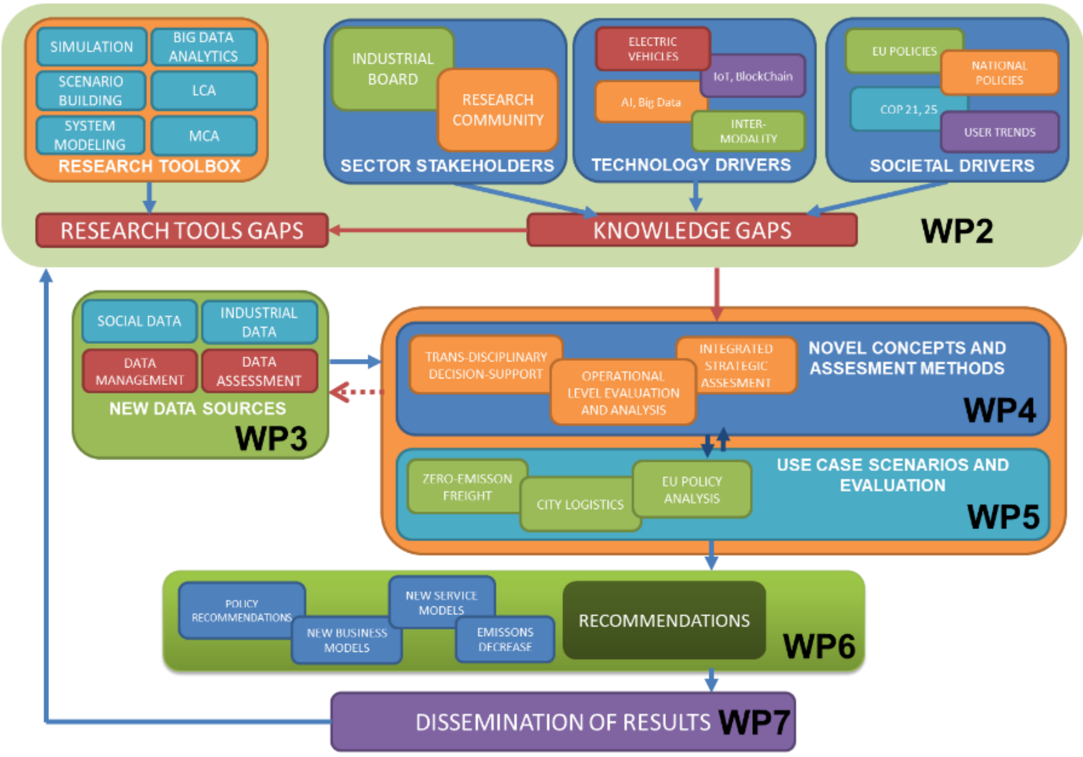


Figure 2. PERT chart of WPs

The requirements for analysis summarised in 6.1 and the challenges for modelling summarised in 6.2 will be used for the subsequent work in the STORM project, as outlined in Figure 2. In particular, the question of data for vehicle movements and development of new operational patterns will be developed in WP4 for a case study in WP5 of operational level analysis in electric heavy-duty vehicles and electric charging infrastructure. This will address the knowledge gap around low carbon fuels operating patterns. A further case study will address urban distribution, where new distribution technologies, but also distribution systems are being developed. The case study will provide information on how new distribution systems are being deployed and analyse the impacts of the new systems.

A final analysis and case study will address policy questions at the EU level, to illustrate how modelling can address EU level policy questions of how new logistics systems could impact the drive for decarbonisation. This will address the knowledge gap in scenarios of system change in logistics and search for points of policy influence on the changes happening in logistics. The study will illustrate the application of combined qualitative and quantitative analysis.

In addition to illustrating this new approach to freight transport analysis at the EU level, proposals for developments in current modelling to address the new policy knowledge needs about decarbonisation in digitalised logistics will be developed in WP4.

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Appendix 1 - Interview Structure

Interview Structure 02/07/2021

The STORM project (website) is an EU H2020 project that is assessing future research and modelling needs for freight transport for the EU. We are conducting interviews to discuss trends in freight transport, the drivers of such trends and also the needs for new kinds of knowledge and analysis to address the changes happening in freight. The structure of the interview is shown below and is planned to take around 30 minutes.

We would like to conduct one of the interviews with you. We guarantee that the data collected will be used only within the project team for use within the STORM project for a period of up to 2 years until September 2023. The data will be anonymised and only reported in aggregate form. We have one further request: would it be possible to record the interview, just to check the notes of the interview? We will delete the recording when the notes are completed.

1. Brief STORM presentation

    Partners

    Objectives: Screen trends and challenges; analysis needs and knowledge gaps

    Work plan: Who we are interviewing and surveying.

2. Trends and challenges:

    Trends in freight transport

    Drivers of change

    Barriers to change

    Challenges in freight transport

    Logistics/freight transport operations

    Freight transport planning

    Freight transport policy

3. Analysis needs and knowledge gaps

    New needs in freight transport research

    i. Knowledge gaps
    ii. Analysis needs
    iii. What can current models and analysis methods not do?

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