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OPEUS

Modelling and strategies for the assessment and **Op**timisation of **E**nergy **U**sage aspects of rail innovation

Deliverable Report

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Shift2Rail

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2	SAFT SAS	SAFT	FR
3	Union Internationale des Chemin de Fer	UIC	FR
4	Union Internationale des Transport Public	UITP	BE
5	Universitaet Rostock	UROS	DE
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CCTV – Closed Circuit Television

ESS – Energy Storage System

HVAC – Heating, Ventilation, and Air Conditioning

ICT – Information and Communications Technology

ITS – Information Technology Systems

LCC – Life Cycle Cost

LRT – Light Rail Transit

NFC – Near Field Communication

PEV – Plug-in Electric Vehicle

PM – Particulate Matter

PT – Public Transport

R&I – Research and Innovation

RFID – Radio Frequency IDentification

TCO – Total Cost of Ownership

UTO – Unattended Train Operation

WG – Working Group

EXECUTIVE SUMMARY

This document has been prepared in the framework of the EU co-funded OPEUS-project, which has been executed within Horizon 2020 - the EU Research and Innovation programme (2014-2020). OPEUS addresses topic S2R-OC-CCA-02-2015-Energy usage, generation and saving approaches (call identifier H2020-S2RJU-2015-01) as part of the Shift2Rail Joint Undertaking first open call and stands for "Modelling and strategies for the assessment and OPtimisation of Energy USage aspects of rail innovation", and is aiming to develop a simulation methodology and accompanying modelling tool to evaluate, improve and optimise the energy consumption of rail systems with a particular focus on in-vehicle innovation.

This document describes the investigations into the social, political, economic, environmental and operational requirements related to the energy usage in urban rail systems with in-vehicle focus. The key factors that influence energy consumption are:

1. **Social:** safety, security, comfort and convenience of urban rail, speed of the journeys, availability of the information about the journeys in real-time, transport accessibility;
2. **Political:** emphasis on low-emission policy, shifting from private to public transport, and optimisation of energy usage;
3. **Economic:** operator's attention on increasing revenue of urban public transport and decreasing total cost of ownership;
4. **Environmental:** global goals such as limiting the growth of the Earth's average temperature and decreasing the level of transport emissions and local pollutants in cities;
5. **Operational:** optimisation of energy usage in duty cycles, energy loss reduction in regenerative braking, introduction and usage of new technologies and materials for optimisation of energy usage.

The conclusion part presents the scope of the stakeholders' requirements influencing energy usage.

Thus, outcomes of this document are expected to support the WP07 of the OPEUS project that summarises all the results providing a critique of the energy consumption outlook leading to a global vision of energy in the urban railways.

1 INTRODUCTION

1.1 SCOPE – URBAN RAIL SYSTEMS

The EU population is 70% urbanised, and European cities are generating over 80% of the Union's GDP (EC, 2013d). Thus, mobility within cities and between suburban areas and towns is incredibly important. According to UITP (2016), in 2014 urban rail accounted for 44.3% of all local public transport journeys in Europe (13.6% - suburban rail, 16.2% - metro, 14.5% - tram/LRT). As the European economy is continuing to grow, so is transport demand.

Expressed in kWh/pax-km, the energy consumption of urban rail is 0.12 that is 7x less than an average car in urban context. Nevertheless, energy usage is one of the top cost factors operating urban rail systems (UITP, 2014a). The total urban rail energy consumption in Europe is around 11T GWh per year (UITP, 2014a). For comparison, total net electricity generation in the EU-28 was 3.07M GWh in 2015 (Eurostat, 2017b). Consumption Estimation of Urban Rail Systems is presented in Table 1.

The steady growth of the urban rail systems market is noticeable worldwide including the EU, with Asia leading the way in terms of length of new track being constructed (Dauby, 2016).

1.2 TARGETS AND EXPECTATIONS

The aim of this document is to highlight key energy requirements faced by European urban rail systems in aspects related to their societal, political, economic, operational and environmental targets and expectations.

Table 1: Consumption estimation of urban rail systems in Europe

CONSUMPTION ESTIMATION OF URBAN RAIL SYSTEMS IN EUROPE						
	Metro		LRT		Total urban rail	Comments
INFRASTRUCTURE DATA						
Cities #	41		177		184	*All metro cities but 7 do have LRT as well*
Lines #	141		1.074		1.215	
Km infra	2.588		14.116		16.704	
Stops	2.528		*23.500*		*26.028*	*for LRT, derived from assumed av distance between stops of 600m*
Underground	70%		0,10%		--	*for LRT, estimation 100 km of double track*
OPERATION DATA						
Patronage (10^6. pax/y)	9.333		7.688		17.021	
Passenger-km (10^6 pkm/y)	*55.998*		*30.752*		*86.750*	*Expert opinion: average trip in metro 6km and in LRT 4km*
FLEET DATA						
Fleet train	*5.664*		--		--	*Expert opinion: average metro train consists of 4 cars*
Fleet Coach	22.657		18.584		41.241	
Coach-km (10^6) /y	*2.265,7*		*1.115,0*		*3.380,7*	*Expert opinion: average yearly mileage: Metro 100,000; LRV 60,000*
ENERGY DATA						
Rolling stock GWh / y	*5.664,3*		*2.787,6*		*8.451,9*	*Expert opinion: average metro consumption 2,5 kWh/coach -km in UITP sample of 13 metros --- idem for LRV (not coach); calculated on RATP 2011 data*
Station GWh / y	*1.516,8*		*705,0*		*2.221,8*	*Expert opinion: av. metro station consumption: 0,6 GWh / year in UITP sample of 13 metros excl. tropical cities with AC-ed stations --- 20x less for LRT stations*
Total GWh / y	*7.181,1*		*3.492,6*		*10.673,7*	
kWh / pax-km	0,13		0,11		0,12	

Notes: Light-blue italicised text – "Data estimated"

Source: Data available UITP sources

The energy needs for urban rail traffic all over Europe are analysed also resulting from existing specifications, guidelines and best practices, notably from other R&D projects. Particularly relevant are the following documents:

– OSIRIS deliverable D1.1 A common set of environmental, societal and political requirements for energy saving, led by Newcastle University;

– Research by Newcastle University exploring the conditions that could favour urban modal shift to ultimately rail systems which include aspects related to its energy and environmental impact performance (Batty et al., 2015) as well as

research providing a holistic view of energy usage in urban rail systems for its technological, operational and strategic aspects (González-Gil et al., 2013, 2015; González-Gil et al., 2014);

– The extensive literature led by UITP on this topic e.g. the reports linked to the PTx2 strategic objective of doubling the market share of public transport by 2025 (Van Audenhove et al., 2014);

– Documentation generated by some UITP working bodies e.g. the Light Rail Committee, the Metro Committee with its subcommittees (e.g. Rolling Stock, Electrical Installations and Safety Systems), the Regional and Suburban Railway Committee. Input will also include current contributions to the work done at United Nations level in activities concerning climate change;

– The information being generated by the H2020's Roll2Rail. Specifically, its WP8.2 Energy calculation methodology will define and compile reference service profiles for urban (metro, tram) and suburban rail systems. This work was ready by October 2016, and it has been slightly updated by FINE1 project, which has shared the updated reference speed profile with OPEUS partners. Stadler Rail Valencia was directly involved in this Roll2Rail WP8.2 work and acts as a link within OPEUS-FINE1-Roll2Rail;

– Working groups, workshops and other current projects ongoing in UIC on the heavy suburban rail and the potential environmental effects savings by a modal shift to rail in metropolitan and urban areas. Specifically, the commuting and regional train systems WG and an ongoing project on the production of a Handbook on guidelines for suburban and regional rail transport systems.

The outcomes of this document will be used for summarising energy usage requirements and trends in WP07.

1.3 EXPECTED IMPACTS

Key relevant OPEUS outputs are (1) delivering an enhanced simulation methodology and tool allowing for the assessment of the potential benefits in terms of energy performance of novel technologies; (2) exploring energy improvement that can be derived from applying relevant S2R innovations, improved driving strategies, advanced ESSs and traction chain improvements; (3) providing critique of the energy usage in both urban and mainline railway systems highlighting areas and

solutions of particular interest to improve the environmental performance of rail systems while reducing the costs associated with the energy usage.

Outcomes of this document are expected to support the WP07 of OPEUS project that summarises all the results providing a critique of the energy consumption outlook leading to a global vision of energy in the urban railways.

2 ENERGY EFFICIENCY REQUIREMENTS RELATING TO URBAN RAIL SYSTEMS

2.1 SOCIAL REQUIREMENTS

2.1.1 SOCIAL REQUIREMENTS OBSERVATION

While European authorities are focused on a modal shift from private transport to public one due to the decreasing negative impact of public transport on the environment, passengers tend to pay attention to safety, cleanliness, comfort and convenience (OSIRIS, 2013). Upgrading and modernisation of the urban infrastructure and train fleet in terms of providing better quality, higher comfort and new services (HVAC, real-time information, infotainment, etc.) influence the overall energy consumption and require more energy for urban rail operation. Thus, encouraging the modal shift requires the formation of a good perception of public transport within society.

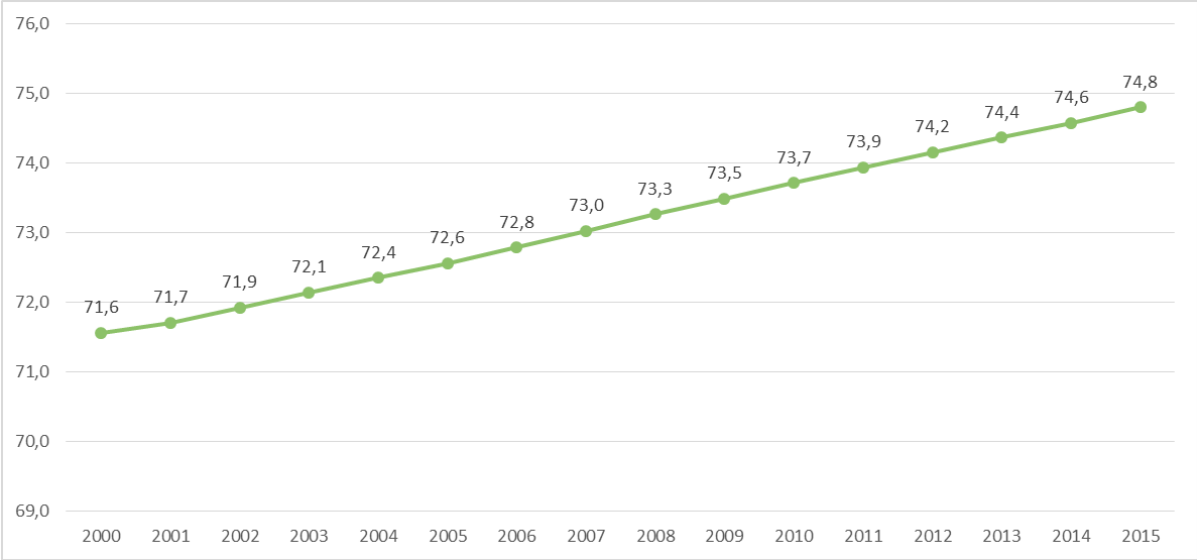
The passengers' attitude to innovations in urban rail influences the dissemination speed of new technologies. Despite the fact that these technologies (especially, automation and driverless trains) help to reduce energy consumption, society in some more conservative cities or countries may have some reservations for the introduction of urban rail innovations in terms of safety and security fears, fears of job loss, etc. (OSIRIS, 2013).

However, the safety records of driverless trains can boast excellent results, and acceptance has proven quick and enthusiastic in many locations where they have been introduced. A tendency we can see here: once a city has launched a UTO line, there is no way back: new ones are also designed as UTO, and older ones may be refurbished as UTO. Furthermore, passengers are expecting more and more from technologies in terms of real-time data providing for planning their journeys (Directorate-General for Research and Innovation (European Commission), 2017).

According to the United Nations (United Nations, Department of Economic and Social Affairs, Population Division, 2015) and the World Bank (The United Nations Population Divisions World Urbanization Prospects, 2017), the share of urban

population in 2050 is expected to be up to 82% (Fig.1) which will increase the pressure on transport e.g. access to jobs, health and education.

Figure 1: Share of urban populations in Europe, 2000-2015 (% of total population)



Notes: United Nations data are based on national definitions

Source: The United Nations Population Divisions World Urbanization Prospects, the World Bank

Batty et al. (2015) identified the following individual quality attributes for urban public transport (especially, urban rail) that influence public transport usage by passengers:

– High level of accessibility and available information. The urban rail operators are expected to provide pre-trip, in-trip and real-time information to travellers;

– Frequency and reliability: waiting time and high accuracy in the predictability of travel time. Regarding passenger's attitude, it means that they rely on the stated level of service to be provided;

– Comfort on stations and rolling stock: ambient air temperature, cleanliness, Wi-Fi provision (on station and in vehicles), availability of phone signals underground;

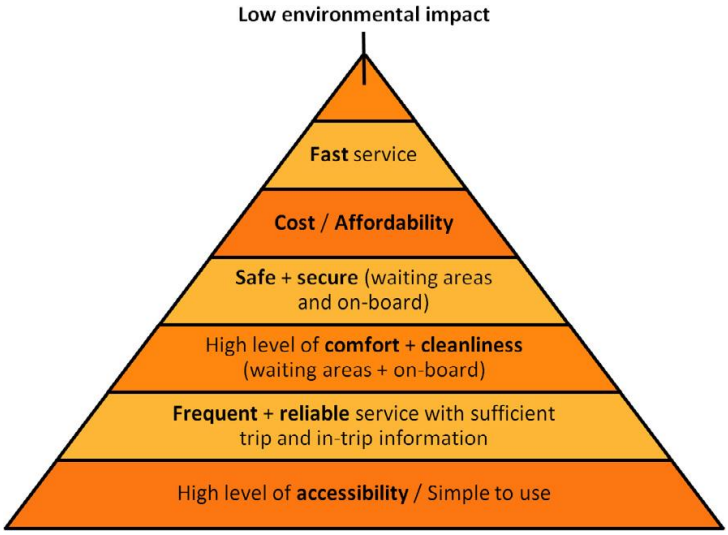
– Safety and security. From a technological point of view, it should contain CCTV, improved lighting, panic buttons, etc.;

– The price of a journey. There should be a balance between affordability and covering the operator's needs, incl. innovation development;

– Speed/journey time means how long it takes to get from one place to another and includes access time, waiting time and travel time.

The hierarchical pyramid of public transport passenger requirements is presented in Fig. 2.

Figure 2: The hierarchical pyramid of public transport passenger requirements.



Source: Batty et al., 2015

2.1.2 METHODS TO ADAPT TO SOCIAL REQUIREMENTS

The outcomes of OSIRIS (2013) identified several options when considering the reduction/optimisation of electrical power consumption during periods of maximum demand. These include the increased usage of regenerative braking (especially favourable in urban rail "stop-and-go" operation with short headways) and application of new types of energy production. Moreover, other services such as charging installations for electric private cars, buses or electric car-sharing could also – at least partially – fed from excessive regenerative braking energy that is currently not exploited for strictly train operation. This would help optimize further energy consumption and reduce further the net amount of braking energy losses (see 17% in the Fig. 9). In the same line, using advanced energy storage systems (ESS) and developing lighter trains can also decrease power consumption.

One more option for optimisation of energy usage is the implementation of full intermodality among rail, metro, tram/LRT, bus services and also cycling and

walking (UIC et al., 2013) to create so-called "green waves" of passenger streams. This policy also includes a tendency towards increasing the use of segregated rights of way, prioritising public transport modes at traffic lights, and utilisation of RFID and NFC in services for passengers.

2.2 POLITICAL REQUIREMENTS

2.2.1 CURRENT LEGISLATION

EU legislation relating to energy efficiency and the optimisation of energy usage in urban rail systems is related to the EU position on global climate change (OSIRIS, 2013). EU activities on climate and energy issues are based on the long term perspective which the Commission laid out in 2011 in the Roadmap for moving to a competitive low carbon economy in 2050, and the Transport White Paper (EC, 2011a, 2011b). Furthermore, based on the Paris agreement adopted on 12 December 2015 at COP21 and signed by 195 states in 2016, the EU is promoting the following targets (Council of the EU, 2016):

- Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and limiting the temperature increase to 1,5°C;
- Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development;
- Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

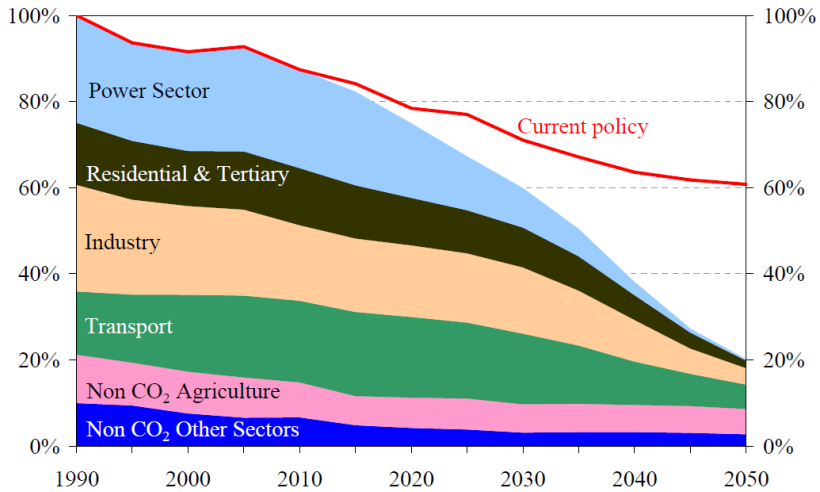
The Paris Agreement vindicates the EU's path to low carbon economy (EC, 2016b). Preceding the Paris Agreement, European Commission issued the 2030 climate and energy policy framework and a blueprint for tackling global climate change beyond 2020 (EC, 2013a, 2015b). Supporting the Energy Union and Climate Action initiatives, the Commission proposed an update of the 2012 Energy Efficiency Directive in 2016, including a new 30% energy efficiency target for 2030 (EC, 2016d).

The EU set an ambitious target of 40% greenhouse emission reduction by 2030, and 80% - by 2050 (Fig. 3) (EC, 2011b).

In order to create the necessary environment for low carbon transition, a framework strategy for a resilient Energy Union was developed which links the transport and energy systems (EC, 2015a, 2016c). Its key features are:

- Reducing the dependency on particular fuels, energy suppliers and routes;
- Completion of the internal energy market (full integration) and more efficient energy consumption;
- Decarbonisation of the economy.

Figure 3: EU GHG emissions towards an 80% domestic reduction



Notes: 100% = 1990

Source: A Roadmap for moving to a competitive low carbon economy in 2050 (EC, 2011b)

In general, the EU has committed to invest at least 35% of Horizon 2020 budget into climate and energy-related activities. For instance, the EU has set an EU target of at least 27% for the share of renewable energy consumed in the EU in 2030. This new approach requires smart grid management at the local level and opens new opportunities for ESS systems applied to urban rail (EC, 2011b).

Particular attention is paid to the transport sector, as transport represents more than 30% of the final energy consumption in Europe (EC, 2015a). The EU transport policy is recognising the role of modal shifting from private vehicles towards public transport which can contribute to achieving 60% reduction in greenhouse gas emissions called for by the Commission's White Paper "Roadmap to a Single

European Transport Area – Towards a competitive and resource efficient transport system" (EC, 2013d, 2013b, 2014a). In 2016 the EC presented "A European Strategy for Low-Emission Mobility" which offered changes of the EU regulatory framework due to new low-emission policy (EC, 2016c):

- Optimising the transport system and improving its efficiency:
  - Digital mobility solutions for seamless door-to-door mobility, integrated logistics and value-added services;
  - Fair and efficient pricing in transport;
  - Promoting multi-modality;

- Scaling up the use of low-emission alternative energy for transport:
  - Effective framework for low emission alternative energy (revision of the current legislation);
  - Roll-out of infrastructure for alternative fuels;
  - Interoperability and standardisation for electro-mobility;

- Moving towards zero-emission vehicles:
  - Improvements in vehicle testing to regain trust of consumers;
  - Post-2020 strategy for cars and vans (new post-2020 carbon dioxide standards for cars and vans);
  - Post-2020 strategy for lorries, buses and coaches (the certification of carbon dioxide emissions and fuel consumption of the vehicles and the monitoring and reporting of such certified data).

Rail is considered as a less greenhouse-gas intensive mode of transport which can help tackle decarbonisation. Moreover, restrictions and charging for individual cars, high fuel taxes, and high taxes for the purchase of conventional cars support the increase in public transport use, especially urban rail (IEA & OECD, 2016; UIC et al., 2013). Furthermore, the EU updated a variety of directives relating to energy efficiency (EC, 2014b, 2016e, 2017).

2.2.2 POLITICAL MOTIVATORS – FUTURE CHALLENGES

In the OSIRIS project, the 2011 European Transport White Paper was mentioned as a set of 40 concrete initiatives to achieve the EU emission reduction and energy

optimisation targets (OSIRIS, 2013). In 2016 the Commission Services published an Implementation report on the 2011 White Paper, where updated trends and developments of relevance for transport were presented (EC, 2016a):

– *Demographic and urbanisation trends.*

1) The proportion of the population aged 15-64 is projected to decline from 66% to 57% by 2060, while those aged 65 and over will become a much larger share (rising from 18% to 28% of the population). Moreover, the ageing society will require more emphasis on the provision of safe, secure and reliable transport services featuring appropriate solutions for users with reduced mobility.

2) The urbanisation rate in Europe is expected to continue growing: from 73% in 2014 to 82% in 2050. The progressing urbanisation will further contribute to the problems affecting many agglomerations, such as congestion, pollution, noise, saturation of transportation hubs.

– *Collaborative economy.*

The trend of sharing economy is rapidly expanding. The ridesharing market is becoming a major global industry. In 2014, car share programs were available in over 30 countries, and in hundreds of cities. Nowadays, the global carsharing services revenue is predicted to grow from $1.1 billion in 2015 to $6.5 billion in 2024. Thus, the popularity of carsharing services leads to potential congestion relief and development of new positive services (for instance, with the adoption of plug-in electric vehicles (PEVs) in carsharing services, which is expected to increase as car manufacturers promote this technology for carsharing).

– *Automation and connected vehicles.*

Deployment of automated vehicles in urban rail can positively affect energy consumption. Firstly, the traffic flow can be smoothed out by controlling speed and acceleration. Secondly, driver errors are excluded. A stumbling block for the EU authorities is a lack of harmonised framework conditions (legal, coexistence with conventional means of transport, social implications, required interoperable infrastructure and interfaces). Furthermore, the legislative framework appears to be lagging behind. Security, liability, privacy protection, employment and safety are issues that are not fully resolved at the moment.

– *Digitalisation and mobility as a service.*

Big data and information in real time through the Internet, apps, and smartphones are key trends in public transport digitalisation. Data collected from different sources (ticketing systems, sensors in vehicles and PT infrastructure, traffic signals, surveys, social media, smartphone apps, etc.) can be used to analyse passengers' preferences and habits for providing better services in trains and infrastructure objects. Another opportunity for the usage of Big Data analysis is predictive maintenance and high-quality asset management. There several important factors influence the growth of mobility service: good public transport, a mobile broadband roaming policy and strong broadband connections.

– *Further changes in supply chains: globalisation, ICT and 3D printing.*

Global competitive pressure, availability of effective ICT changing consumer behaviour and increasing customisation of products, and the development of 3D printing are three major aspects that will continue to influence transport policy in freight transport operations.

– *Circular economy.*

The policy of circular economy directed on the usage of recycled materials and restored products/components will require new schemes of transportation of goods back from users to producers. It means that the demand for transport might increase.

– *Increasing role of active modes in the urban transport mix.*

Walking and cycling are not new phenomena, but they should be taken into account in the integration of different means of transport. Bike sharing and expanding of pedestrian areas are the increasing trends of the last few years.

– *Increasing security threats.*

Due to increasing threats of terrorist attacks in the EU, public transport requires special prevention solutions and surveillance measures. Furthermore, digitalisation, automation and network solutions in transport will amplify cyber security threats. Nowadays, a common and coordinated defence against cyber threats is lacking.

In addition, a coordinated deployment of Urban Intelligent Transport Systems (ITS) that optimises the use of existing infrastructure through a variety of means requires a series of decisions: supplement the existing legislation on access to traffic and travel data, providing specifications on Real-Time Traffic Information and Multimodal Information Services, as foreseen under the framework of the ITS Directive (2010/40/EU), facilitation the deployment of vehicle to vehicle and vehicle to infrastructure communication systems in urban areas (EC, 2013d, 2013c).

2.2.3 OTHER EU PROJECTS AND EU INITIATIVES

Previous projects related to energy optimisation in urban rail:

1. MERLIN[1] project (Sustainable and intelligent management of energy for smarter railway systems in Europe: an integrated optimisation approach) in the EU 7th framework programme (2012-2015). The project was devoted to energy management in railway systems and was aimed at providing an integrated and optimised approach to support operational decisions leading to a cost-effective intelligent management of energy and resources. While urban rail was out of scope for this project, MERLIN did address smart energy management aspects of suburban services in the major urban conurbations, which is relevant to OPEUS.
2. OSIRIS[2] project (Optimal Strategy to Innovate and Reduce energy consumption In urban rail Systems) in the EU 7th framework programme (2012-2015). OSIRIS was aimed at enabling a reduction of the overall energy consumption of Europe's urban rail systems by 10% compared to current levels by the year 2020. To achieve this objective, the following deliverables were produced: definition of needs and operational requirements for the development of a global approach for energy usage in urban rail systems, standardised duty cycles and key performance indicators for tram, light rail and metro, developing a holistic model framework assembling existing proprietary traction and power network simulation modules into a complete urban rail system model, employing optimisation methodologies for the identification of efficient, reconciled strategies for realising low energy consuming urban rail systems, etc.

[1] Information about the results of the MERLIN project: http://cordis.europa.eu/result/rcn/186794_en.html
[2] Information about the results of the OSIRIS project: http://cordis.europa.eu/project/rcn/102008_en.html

Ongoing project related to OPEUS project:

The FINE1[3] project (Future Improvement for Energy and Noise) conducted in the framework of Shift2Rail, within the EU HORIZON2020 programme (2016-2019) is aimed at reducing operational costs of railways by means of a reduction of energy use and noise related to rail traffic. The objective is addressed to the reduction of greenhouse gas emissions, life cycle costs and the costs of vehicle operation.

2.3 ECONOMIC REQUIREMENTS

2.3.1 ENERGY AND TRANSPORT

According to World Energy Outlook of IEA and OECD (2016), the oil price is expected to increase and is predicted to be at least 80$ per barrel (bbl) in 2020. This, together with volatility in the energy markets and power generation security pressures adds to the need for increased optimisation of resources in railways.

Therefore, the main goal related to energy is avoiding an economy driven by fossil fuels by developing alternative energy and optimisation of energy usage (EC, 2015b). Thus, the main attention is paid to electric modes of transport, and, especially to public transport – urban rail systems.

2.3.2 DEMAND AND CAPACITY OF URBAN RAIL

In terms of modal shift from private to public transport in metropolitan areas, urban rail is the preferred mode thanks to its superior mass transit capability allowing for a far higher throughput of people in a given unit of time compared to road, and usually requires considerably less land use (UIC & CER, 2015). From 57.6 billion local public transport journeys in the EU made in 2014, around 44% are undertaken via urban rail systems: trams/LRT account for 14.5% of total travel, metro systems for 16.2% and suburban railways make up the remaining 13.6% of the total (UITP, 2016). Furthermore, the capacity of urban rail systems is much higher than other modes of transport. The comparison is shown in Tab. 2 and in Fig. 4.

In addition, companies seek opportunities to reduce their dependency on state funding. They are encouraged to develop secondary, non-fare income. Thus, traditional business models in the public transport sector are under transformation (e.g. retail opportunities in stations, advertising, real estate development in and around rail facilities, digital signage, station naming auction, etc.).

Table 2: Capacity characteristics of urban transport modes

Generic Class		***Private***		***Street Transit***		***Semi-rapid Transit***		***Rapid Transit***	
Characteristics	***Unit/ Mode***	***Auto on Street***	***Auto on Freeway***	***RB***	***SCR***	***BRT***	***LRT***	***RRT***	***RGR***
Vehicle capacity, C_v	sps/veh	4–6, total	1.2–2.0 usable	40–120	100–250	40–150	110–250	140–280	140–210
Vehicles/TU	veh/TU	1	1	1	1–3	1	1–4	1–10	1–10
TU capacity	sps/TU	4–6, total	1.2–2.0 usable	40–120	100–500	40–150	100–750	140–2400	140–2000
Line capacity,[c] C	sps/h	720–1050[b]	1800–2600[b]	2400–8000	4000–15,000	4000–8000 20,000[b]	6000–20,000	10,000–70,000	8000–60,000
Productive capacity,[c] P_c	10^3 sp-km/h	10–25[d]	50–120[d]	25–90	35–150	75–200 –600	120–600	700–1800	800–4000

Notes: [a] Abbreviations: sps = spaces; veh = vehicles; TU = transit unit; RB = regular bus; SCR = streetcar; BRT = bus rapid transit; LRT = light rail transit; RRT = rail rapid transit; RGR = regional rail.

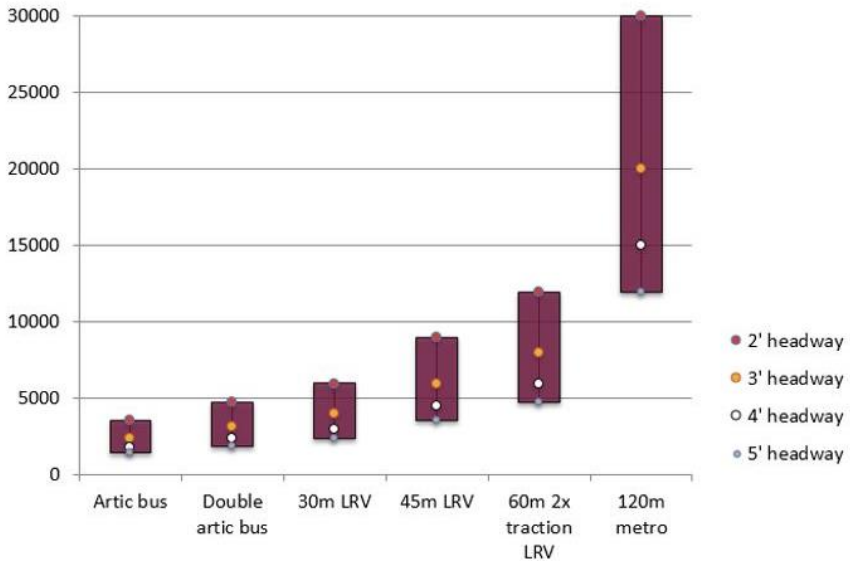
[b]With multiple parallel lanes and overtaking at stations.

[c]Values for C and Pc are not necessarily products for the extreme values of their components because these seldom coincide.

[d]For private auto, capacity is product of average occupancy (1.2– 1.3) and max. frequency, since all spaces cannot be utilized.

Source: (Vuchic, 2007)

Figure 4: Comparative hourly capacity (pphd) at given headways



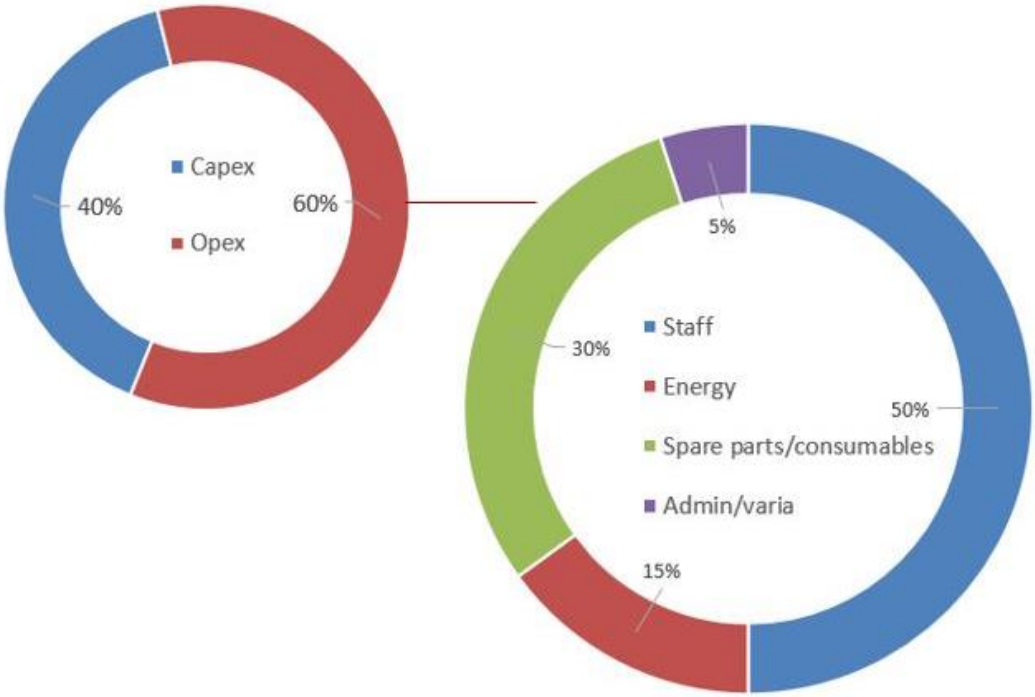
Source: UITP, 2016

2.3.3 TOTAL COST OF OWNERSHIP (TCO)

The expression "life cycle cost", covers the cost of all initial activities that created the system and the cost of future activities that will be required to keep that investment available for continued use, including energy consumption (Tinubu & Allen, 2005). For example, energy represents 15-20% of the operating expenditures of an LRT/tram network, and it is the second largest expenditure after staff costs (UITP, 2014b) (Fig. 5). So, to remain a cost-effective public transport mode, urban rail systems should find opportunities to save energy and reduce waste.

Thus, the operators should pay attention to the train TCO when they procure new rolling stock, and keep an appropriate balance between initial price for the train and cost during a life cycle (energy efficiency, maintainability, etc.). Sometimes more expensive but energy-efficient trains at the initial stage might save costs in further operation.

Figure 5: Indicative urban rail rolling stock capital and operational expenditures



Notes: This LCC representation is indicative as cost split varies strongly from country to country according to labour costs, energy cost, fleet structure (size, age, etc.), alignment (segregated, mixed traffic, topology, distance between stations, etc.) and infrastructure conditions (wear and tear, etc.)

Source: UITP, 2017

2.3.4 ADDITIONAL REVENUE AND ENERGY USAGE GROWTH

Recently, the share of non-fare income has started to grow due to a desire to decrease the dependence on public funding. However, additional commercial revenue might require additional energy usage (e.g. advertising and TV screens in rolling stock and stations, or new services for passengers). The examples of such advertising are presented in Fig. 6 and 7.

This however negligible increase of energy usage from additional sources of revenue (advertising revenue, additional passengers through higher comfort) could be covered in the grand scheme by regenerative braking power.

Figure 6: Digital signage advertising in the London Tube

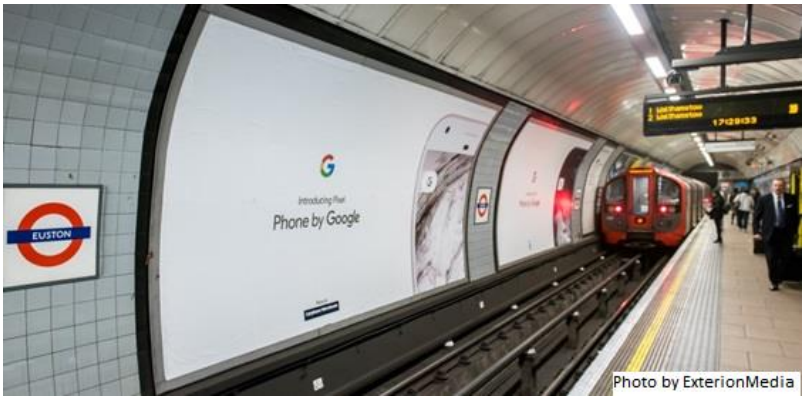


Figure 7: Digital signage advertising in public transport in Tokyo, Japan

2.4 OPERATIONAL REQUIREMENTS

2.4.1 STANDARDISED DUTY CYCLES OF URBAN RAIL

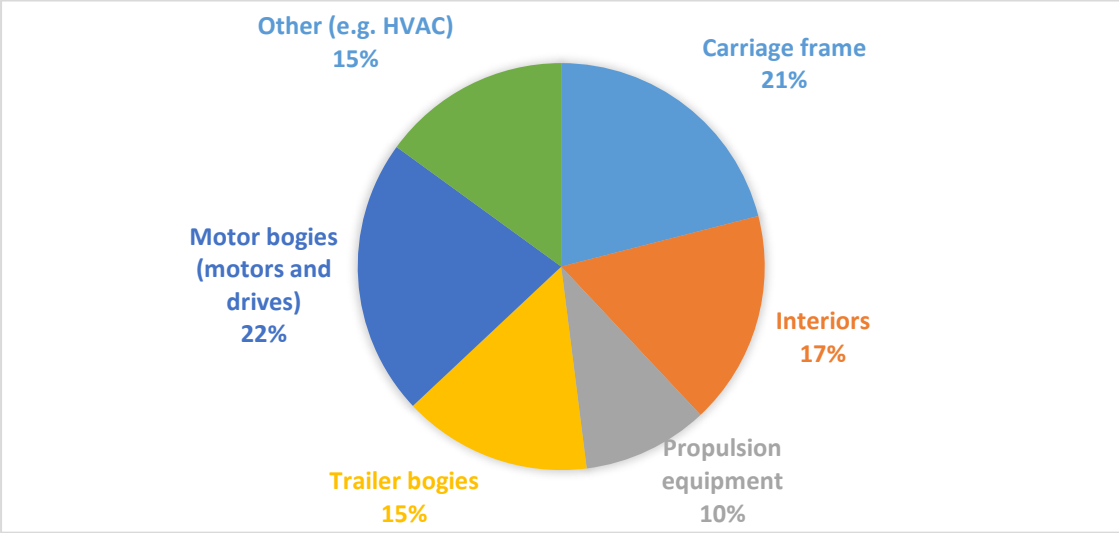
Understanding duty cycles and their modules (interstations and average speed in the interstations) is an essential operational requirement for urban rail operators. Development of duty cycles was one of the targets in the OSIRIS project. A proof of concept was achieved, but not yet realised by field measurement. The designing of duty cycles was continued in the OPEUS. So, duty cycles of urban rail are described in D.3.1 based on Roll2Rail (FINE1 project).

2.4.2 LIGHTWEIGHT TRAINS

Mass reduction of rolling stock can also be considered as an energy efficiency strategy. Two types of lightweight design are to be distinguished: component-based (focus on the elements of the system "train" without any changes to the basic principle of the train configuration) and system-based (weight-optimisation of the whole system) (UIC, 2011).

Fig. 8 shows the proportion of total train mass that is presented by each sub-system for a standard rail:

Figure 8: Typical train mass distribution



Source: RSSB, 2008

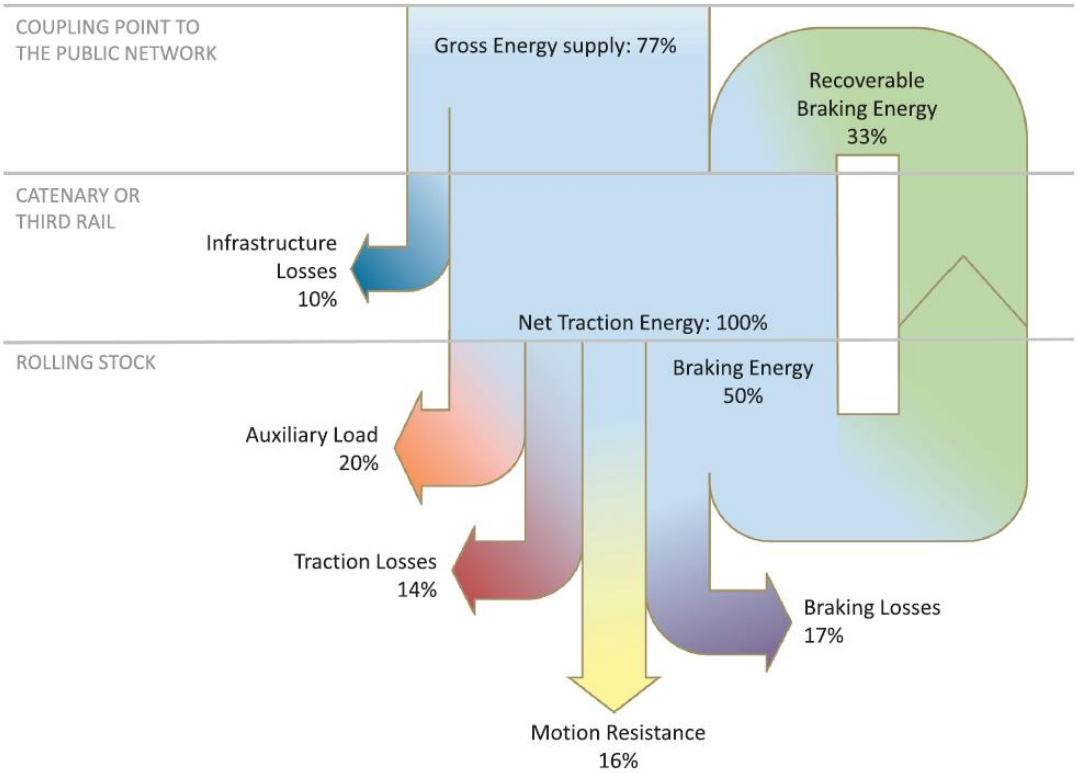
Analysing each element (sub-system) in the system "train" for the possibility of weight reduction is a core principle of this strategy. Thus, reduced mass would benefit the operating company in terms of lower energy usage and brake pad/disc wear, in addition to lower wear & tear on the infrastructure/track.

2.4.3 ENERGY CONSUMPTION AND REGENERATIVE BRAKING

Energy for rolling stock is used to power onboard auxiliaries e.g. HVAC, traction systems, safety equipment, lighting systems. Fig. 9 shows a typical traction energy

flow chart for urban rail systems, based on an extensive literature review by González-Gil et al. (2014).

Figure 9: Typical traction energy flow in urban rail systems



Source: González-Gil et al., 2014

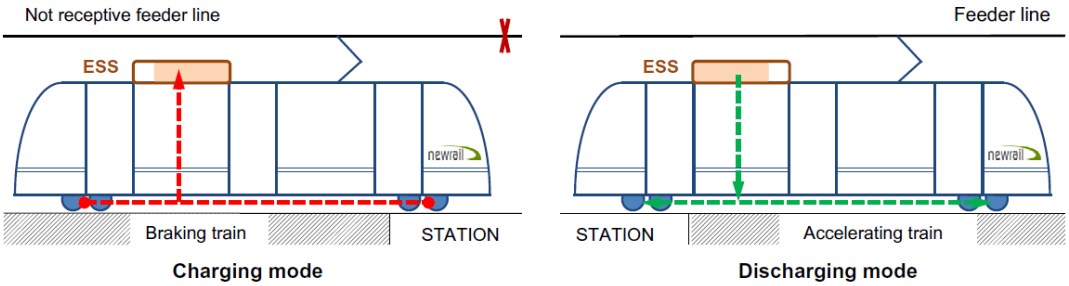
Infrastructure losses refer to losses at the point of common coupling to the pantograph or collector shoes and depend on the voltage level: from 6% to 22%. Auxiliaries consume a significant share of the total energy of rolling stock, where HVAC equipment is responsible for the most massive part of this consumption. Another great share of the traction energy relates to the movement of the rolling stock: traction losses – 14% and motion resistance – 16%. However, the greatest portion of traction energy is wasted in braking processes – around a half of the power entering the rolling stock. Potentially, regenerative regeneratingbraking can help to return from 10% to 45% of energy loss back to a grid or direct the power to other rolling stock, but the coefficient of useful action is not as high as expected. The examples of practical evaluations of the energy flows in the UK, Spain and Sweden show: from 83.3% to 91.2% energy is consumed at the pantograph, but from 7.2% to 9.6% of energy returns to catenary (with some loss of rheostatic energy) and from 1.7% to 2.6% - returns to grid (González & Pilo, 2015). Thus,

energy regeneration can be improved by the further development of energy efficient technologies (regenerative trains, ESS, reversible substations, etc.).

Nowadays, braking energy recovery technologies can be classified in three families that can be used by public transport operators (Devaux & Tacoen, 2014; González-Gil et al., 2013):

– Mobile storage applications consisting of onboard energy storage systems on a vehicle. In the case when the recovered energy cannot be used by other vehicles nearby, the energy is directed to the storage system and after can be utilised by the vehicle for accelerating or supplying the power to auxiliaries (Fig. 10).

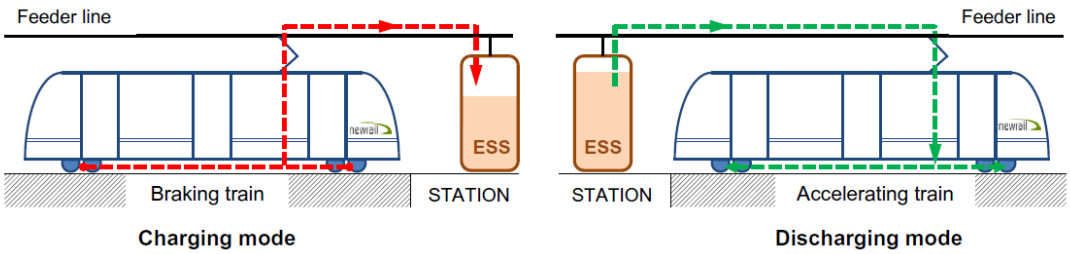
Figure 10: Schematic of onboard ESSs operation in urban rail



Source: González-Gil et al. (2013)

– Stationary or wayside storage applications consisting of one or several energy storage systems placed along the tracks. The systems can be used for recovering the energy from any braking vehicle and for powering any accelerating vehicle within the area of influence of the system (Fig. 11).

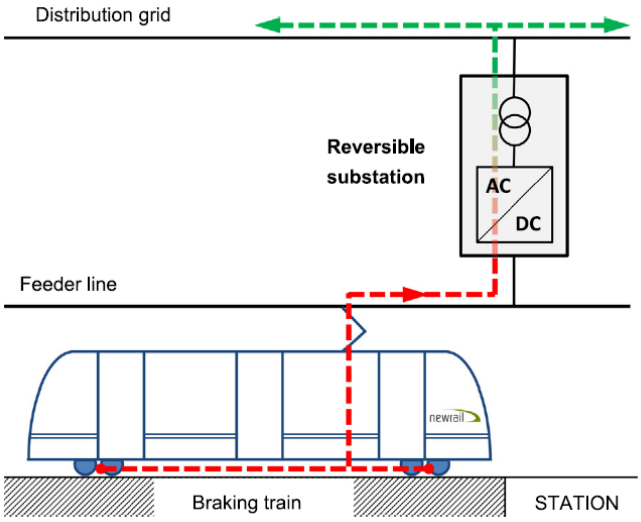
Figure 11: Schematic of wayside ESSs operation in urban rail



Source: González-Gil et al. (2013)

– Stationary 'back to the grid' applications (or reversible substations) don't store the recovered energy (however, can do it if an ESS is integrated in the substation), but send it to the main electrical grid to be used by other consumers or sold back to the energy distributors (Fig. 12).

Figure 12: Schematic of reversible substations in urban rail



Source: González-Gil et al. (2013)

In general, the following energy storage technologies for urban rail applications can be identified: electrochemical double layer capacitors, flywheels, and batteries (lead-acid, nickel-based, lithium-based, sodium-based, and other emerging battery technologies), and superconducting magnetic energy storage (González-Gil et al., 2013).

Regarding automated trains, their operation has a straight and evident impact on potential energy savings as they are usually characterised by very high frequencies. Furthermore, automatic systems can improve the line receptivity by synchronising the acceleration and deceleration phases of the vehicles.

2.4.4 NEW SOURCES OF ENERGY CONSUMPTION

Urban rail systems are complex, and their energy consumption depends on different factors. Even if improvements in energy savings are made in one area (e.g. traction), other areas can increase the energy consumption, as it was with ITS technologies

(e.g. Big Data collecting and analysing and providing real time information for passengers and trains/infrastructure maintenance staff). Furthermore, passengers require more advanced comfort features from public transport: quality air-conditioning, Wi-Fi access, and infotainment (interactive maps, real-time information, etc.) that also lead to energy consumption growth.

2.5 ENVIRONMENTAL REQUIREMENTS

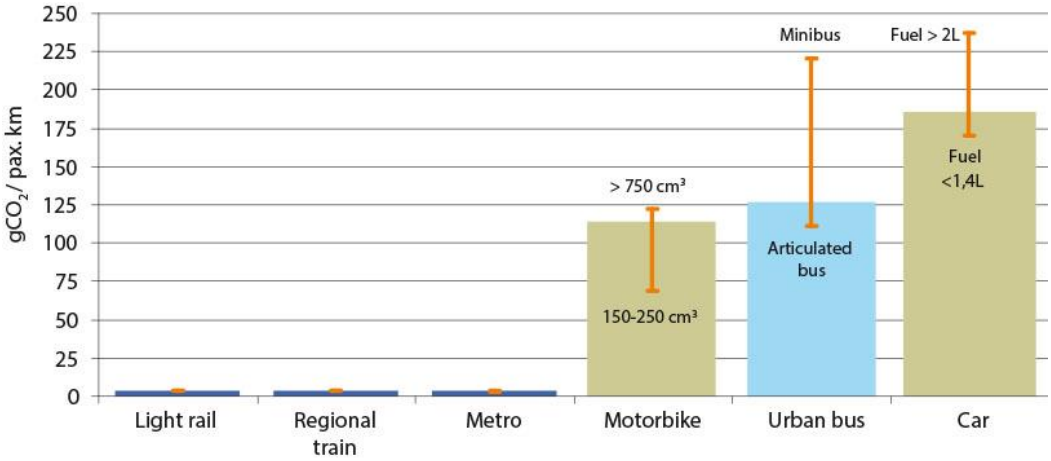
2.5.1 CLIMATE CHANGE AND GREENHOUSE GAS EMISSIONS

Climate change is a large-scale, long-term shift in the planet weather patterns or average temperatures. There is overwhelming evidence that the earth's climate is changing and the average temperature of planet surface has risen by 0.89 ℃ from 1901 (after the first industrial revolution) to 2012. Moreover, the temperature could rise by 3-6 degrees Celsius by 2100 without urgent actions (OECD, 2017a).

One of the factors that influence the global warming is greenhouse gas emissions produced by the combustion from fossil fuels. Despite the fact that greenhouse gas emissions from the rail, which are generated through electricity production, are much lower than those of road transport, the total urban rail energy consumption is still around 11 T GWh per year (UITP, 2014a).

In general, transport is one of the biggest contributors to energy usage and CO_2 emissions. Around 23% of global CO_2 emissions from fossil fuels belong to transport that is the second-largest emitter after electricity and heat generation (42%) (EC, 2013d; OECD, 2017b). Furthermore, without a relevant policy, transport gas emissions have increased globally by 57% between 1990 and 2012, and in the EU, they increased by 36% from 1990 to 2007 (OECD, 2017b). Additionally, in European urban areas, public transport is responsible for around 10% of transport-related greenhouse gas emissions (Ticket to Kyoto, 2014a). For example, according to the case study of Kyoto project (2014), carbon emissions from urban transport modes in France in 2008 were the following (Fig. 13):

Figure 13: CO2 emissions of urban transport modes in France



Notes: in passenger. kilometres

Source: DELOITTE, 2008; Ticket to Kyoto, 2014

Nevertheless, as it can be observed from Figure 13: , the contribution arising from urban rail systems is negligible.

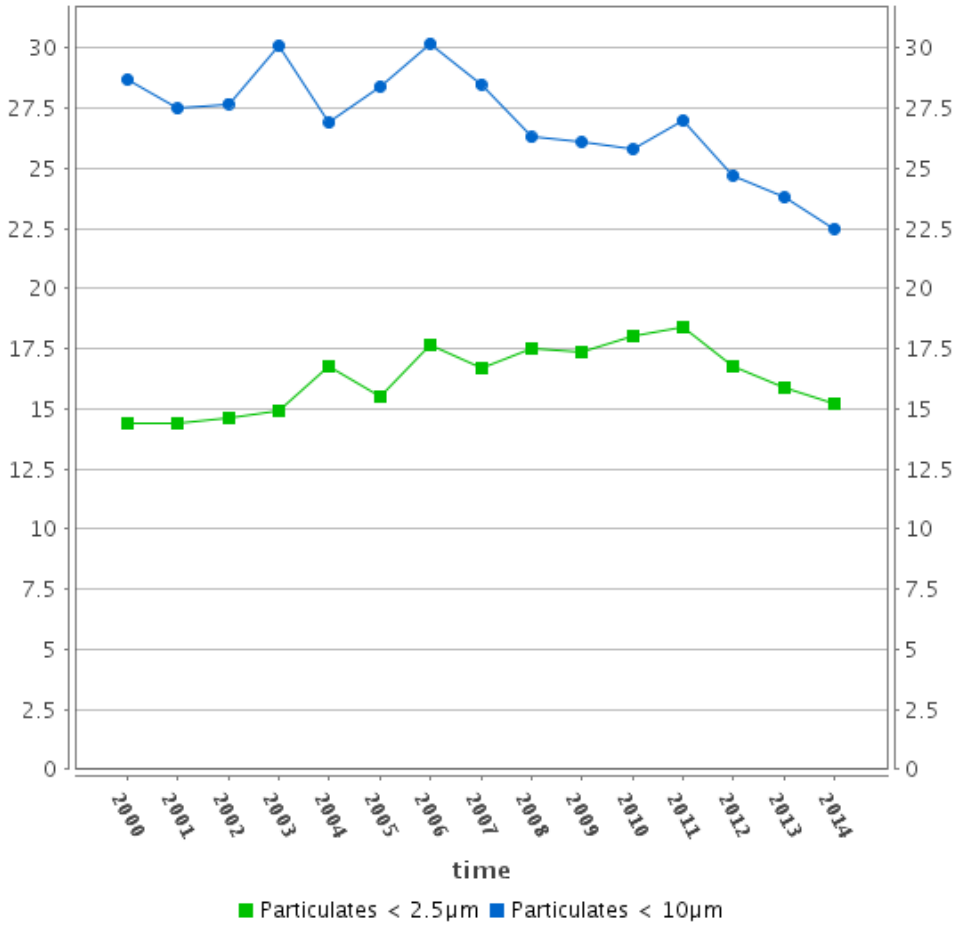
2.5.2 LOCAL POLLUTANTS

The largest amount of transport gas emissions are concentrated in urban areas where the number of private cars is high. Occupancy rates for such cars are low, and emission rate is high.

Next to greenhouse gas emission, energy production and internal combustion engines produce particulate matter (PM) and local pollutants. The pollutants subject to legal limitations in Europe are CO, HC and particulate matters (PM). Multiple policy areas focus on measuring and regulating air quality within the EU (Eurostat, 2017a). Accepted directives helped to decrease the level of urban population exposure to air pollution by PM10 (Fig. 14).

New directives have placed a requirement to assess and reduce population exposure to concentrations of PM2.5 by 2020.

Figure 14 14: Urban population exposure to air pollution by particulate matter in EU-28, µg/m3



Source of Data European environment agency (EEA)

Last update: 26.07.2017

Date of extraction: 09 Aug 2017 16:30:36 CEST

Hyperlink to the graph: http://ec.europa.eu/eurostat/eurostat/tgm./drawGraph.do&init=1&plugin=1&language=en&pcode=tsdph370&toolbox=legend

Disclaimer: This graph has been created automatically by Eurostat software according to external user specifications for which Eurostat is not responsible. Graphic included

General Disclaimer of the EC website: http://ec.europa.eu/geninfo/legal_notices_en.htm

Short Description: The indicator shows the population-weighted concentration of PM10 and PM2.5 to which the urban population is potentially exposed.
Fine and coarse particulates (PM10) are those whose diameter is less than 10 micrometres, whilst fine particulates (PM2.5) are those whose diameters are less than 2.5 micrometers. Particulates can be carried deep into the lungs where they can cause inflammation and a worsening of the condition of people with heart and lung diseases. The smaller the particles the deeper they travel into the lungs, with more potential for harm. According to the recommendations of the World Health Organisation (WHO) the annual mean concentration is the best indicator for PM-related health effects.
In 1996, the Environment Council adopted Framework Directive 96/62/EC on ambient air quality assessment and management. The first Daughter Directive (1999/30/EC) relating to limit values for PM10 and other pollutants in ambient air fixed an annual limit value of 40 micrograms of PM10 per cubic meter (40 µg/m3). Note that the WHO guideline value is 20 µg/m3 (annual mean).
More recently, the Directive 2008/50/EC set a framework to define and establish objectives for ambient air quality and to harmonise methods and criteria among the Member States. This does have limits for PM2.5. The limit value that was due to be met on 1 January 2015 is 25 µg/m3, which falls to 20 µg/m3 by 2020. Note that the WHO guideline value is 10 µg/m3 (annual mean). The directive 2008/50/EC also places a requirement on Member States to assess and reduce population exposure to concentrations of PM2.5 by 2020. The magnitude of the required reduction depends on national average concentrations between 2009 and 2011. Where concentrations for those years were greater than 22 µg/m3, all appropriate measures should be used to reduce below 18 µg/m3 by 2020.

Code: tsdph370

Thus, in addition to the lower level of greenhouse gas emissions (see chart above), another advantage of rail transport is that LRT/trams, regional trains, and metro systems have zero emissions at point of use, while road vehicles emit nitrogen oxides (NOx), exhaust PM, and other pollutants such as HC and CO. As it was mentioned, these emissions have a negative impact on people's well-being and lead to respiratory and other health issues. Increasing the share of electric transport within the cities (especially, urban rail) contributes to air quality improvement regarding mentioned directives[4].

2.5.3 SMART CITIES AND SUSTAINABILITY

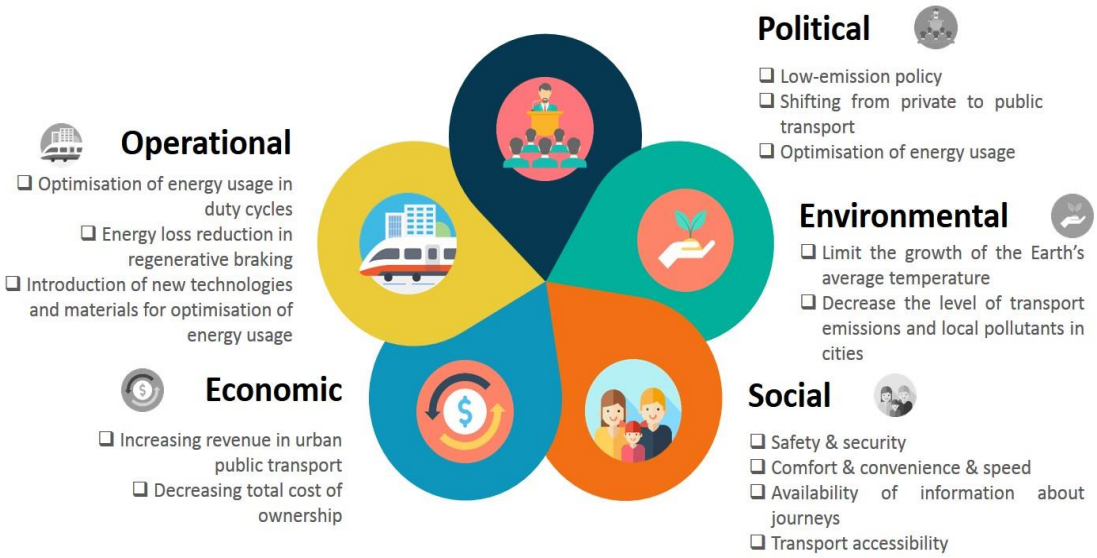
The concept of 'Smart city', which uses information and communications technologies to enhance its liveability, workability and sustainability, is relatively new in urban development (Hurtado, 2016). It means ICTs solutions for public transit, renewable energy systems, and resource-efficient buildings in the cities. Thus, smart cities and digital technologies help to create "green cities" with a high level of efficiency. Thus, integrated urban public transport is responsible for reducing congestion in public transport and energy consumption in urban rail (Koceva et al., 2016).

[4] Modern LRT mostly uses electric multi-articulated units, single tram unit or trailer operation being found in older systems. However, dual electric/diesel-powered LRVs have also been developed to run on un-electrified outer lines (e.g. Stadler Citylink in Chemnitz (Germany) and Alstom Regio Citadis in Kassel (Germany)). Such systems represent a marginal fraction of the market and that is why they are not taken into consideration in this document.

3 CONCLUSION: KEY ENERGY REQUIREMENTS FACED BY EUROPEAN URBAN RAIL SYSTEMS

A comprehensive review of existing investigations into social, political, economic, operational and environmental requirements related to energy usage in urban rail systems was carried out. The scope of the requirements influencing energy usage in urban rail with a focus on vehicles is presented in Fig. 15:

Figure 15: The scope of requirements influencing energy usage in urban rail



Source: UITP, 2017

The consideration of optimisation of energy usage in urban rail should take into account targets, expectations, and needs of the different spheres of life: political, environmental, socioeconomic and operational. Some requirements can be contrasted (e.g. decreasing energy consumption and providing more comfort for passengers at the same time), and when the new system is developed and introduced the balance between these requirements should be found.

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