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1. Executive Summary

The work presented in this deliverable D7.2 has been carried out as part of the OPEUS project and in the framework of the collaboration agreement between OPEUS and the S2R Members project FINE1 (Grant agreement No. 730818).

The document provides a brief overview on the current use of energy in railway systems as well as proposing areas of action enhancing its potential. Specifically, this document covers strategies being pursued that contribute to the sustainable rail agenda, framing them around the role of railways in decarbonising transport and meeting the targets aimed at curbing the effects of climate change.

An approach underpinned by an *Avoid-Shift-Improve* strategy is briefly introduced including a few examples illustrating the potential of the measures included. OPEUS actively contributes to this through the Shift2Rail agenda by i) being part of WA5.1 "Energy" and indirectly supporting several technology demonstrators (TDs), particularly where 'energy saving', 'energy reduction', 'energy optimisation' and/or 'management of energy consumption' features as a desired result, i.e. TDs; 1.1, 1.3, 2.2, 5.5 and 5.6, and ii) contributing to Shift2Rail's opportunities and capabilities plan.

Only a holistic approach to energy efficiency will deliver substantial benefits towards decarbonisation. Technical measures and improvements have a key role to play in this strategy, as demonstrated in the OPEUS project. However, it is of paramount importance to frame these efforts in a wider picture consisting of:

- Land-use and urban planning approach with mobility policy and a systematic support to the most energy-efficient rail modes;
- A regulatory framework and financial incentives supporting decarbonisation and an energy/emission transition towards decarbonisation;
- Technical improvements of assets and operation, including the procurement of clean energy source where relevant and possible;
- Continued support to integrated joint activities aiming at the decarbonisation of transport and the use of rail as the core mode to achieve this.

A significant and positive coordinated effort is being made by the sector in addressing issues related to energy usage as illustrated in this document. It is suggested that these efforts continue to be supported with an emphasis on a system approach that is two-fold:

i) underpin concerted endeavours on an *avoid-shift-improve* approach;
ii) maximise the potential of a holistic approach that optimises technological development with implementation strategies, let these be operational, policy, incentives or a combination of these.

2. Abbreviations and acronyms

Abbreviation / Acronyms	Description
ATO	Automatic Train Operation
C-DAS	Connected Driver Advisory System
CER	Community of European Railway and Infrastructure Companies
CO_2	Carbon Dioxide
COP	Conference of the Parties
EC	European Commission
EIM	Association of the European rail infrastructure managers
ERRAC	European Rail Research Advisory Council
ESS	Energy Storage System
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
LRT	Light Rail Transit
MWh	Megawatt Hours, a thousand of thousand-Watt Hours
NDC	Nationally Determined Contributions
UIC	International Union of Railways
UIC ESRS	Environmental Strategy Reporting System
UITP	International Association of Public Transport
UNIFE	Association of the European rail supply industry

3. Introduction

Scientific statements regarding climate change are alarming: Even if countries around the globe meet their commitments made at COP 21 in 2015 for 2020, the planet would warm up by 3°C by the end of the century[1].

In order to stay in line with the Paris Agreement[2], countries need to multiply their ambitions threefold and carbon neutrality should be reached before 2050. According to the Paris Agreement, countries must renew or revise upward by the end of 2020 their climate commitments ("Nationally Determined Contributions" or NDC) submitted in 2015. They must represent a progression compared to their previous copy, and correspond to the "highest level of ambition possible". The EU already tasked to increase its targets for 2030 and also works under the European Green Deal to become world's first carbon neutral continent before 2050.

The transport sector will be key to achieve the Paris Climate Agreement which actively supports implementation of EU vision towards competitive and climate neutral economy[3]. It is one of the only sectors where emissions are still rising even in developed countries. Rail transport accounts for up to nearly 30 billion urban public transport journeys in Europe and approximately 2,400 billion tonne-kilometres are transported annually, representing 6% of GDP and 18% of the market share[4]. Rail covers 8% of passenger transport demand while being the source of only 2% of transport's Greenhouse Gases (GHG)[5]. So, any meaningful solution for sustainable rail mobility on a European scale may have a significant effect towards sustainability.

Decarbonisation of the transport sector is possible, but will require an immediate and concerted turnaround of global policy action. For instance, synchronisation and integration of different mobility solutions with rail as the backbone of public transport has the potential to transform cities and suburban areas into more efficient, low carbon, clean air, people-centred and planet-sensitive solutions, and create seamless door-to-door travel experience between cities and countries[6].

Investments in low and zero carbon public rail transport yields substantial, long-term benefits by increasing social cohesion and equity and reducing disability and deaths.

Rail transport is an essential part of the solution for mobility especially in cities where space is scarce, congestion and other negative externalities is already costing up to 10% of GDP[7]. Rail transport offers cost-effective mobility solutions for everyone, generates benefits well beyond the mobility sphere and supports a wide range of urban policies. By contributing to the

[1] Intergovernmental Panel on Climate Change (IPCC), 2019
[2] https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[3] COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Brussels, 28.11.2018 COM(2018) 773 final
[4] Freight at UIC, 2018 - https://uic.org/freight/
[5] IEA-UIC, The Future of Rail, 2019, https://www.shop-etf.com/en/the-future-of-rail
[6] ERRAC / Rail 2050 vision
[7] UITP'S DECLARATION FOR SCALING UP CLIMATE AMBITION

competitiveness of cities and cohesion of territories, rail transport creates value for individuals, businesses, and public authorities.

4. Strategies towards a sustainable rail system

Safe, low carbon, efficient and affordable mobility, notably by expanding public, walking and cycling for all is essential to sustainable human development and must be enabled in the climate and sustainable development policies.

The most notable policy at international level is the above-mentioned Paris Agreement that aims to strengthen the global response to the threat of climate change and ability of countries to deal with the impacts of climate change[8]. Along with it, Goal 13: Climate Action of Sustainable development goals[9] has foreseen mobilising US$100 billion annually by 2020 to address the needs of developing countries to both adapt to climate change and invest in low-carbon development.

As an answer to the commitment to the Paris Agreement, sectorial organisations (e.g., associations and unions) launched different initiatives to support the response to the threat of climate change. For example, in 2014 UIC launched the "Low Carbon Rail Transport Challenge" regarding energy efficiency, CO_2 emissions and modal shift, and in 2015 a "Railway Climate Responsibility Pledge", in order to position rail as a solution to climate change and frame discussions with the United Nations and governments. The challenge was designed to illustrate how increased investment and modal shift to rail can help slow down climate change. The low carbon rail transport challenge includes three sets of voluntary objectives:

i. improve rail efficiency;
ii. decarbonise electricity supply;
iii. achieve a more sustainable balance of transport modes.

These commitments are supported by a set of targets at the global level, two of them being:

i. to achieve a 50% reduction in CO_2 emissions per passenger-km and tonne-km by 2030, and 75% reduction by 2050, relative to a 1990 baseline;
ii. to increase rail passenger market share by 50% in 2030 and then doubling in 2050. Moreover, in 2019, UIC proposes to go one step further by aligning its 2050 CO_2eq emissions target to what becomes more and more widely shared as a consensual target to reach the Paris agreement: Carbon Neutrality by 2050 (instead of 75% by 2050).

Regards the urban public transport, UITP's Declaration on Climate Leadership is an officially recognised collaborative action under the Marrakesh Partnership, a dedicated partnership

[8] The Paris Agreement https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement
[9] Sustainable Development Goals http://www.undp.org/content/undp/en/home/sustainable-development-goals.html

mechanism established by the Paris Agreement[10]. Since 2014, UITP publishes Climate Action reports annually demonstrating the progress on the members' projects' implementation. In September 2019, UITP launched a Climate Action Manifesto[11] as part of its 'One Planet, One Plan' campaign to ensure that decision makers recognise the importance of public transport in the fight against local emissions and climate change.

Railsponsible[12] is an industry initiative open to all railway operators and companies across the railway industry value chain that focused on sustainable procurement, with the aim to continuously improve sustainability practices throughout the railway industry supply chain.

On the EU level, several strategic documents were published as the response to decarbonisation and climate change. White Paper 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system'[13] can be considered as the most important document issued by the EC for the transport sector. It highlights the necessity to make the transport systems sustainable and provides the vision for a competitive and sustainable transport system. Another recent document that should be mentioned is issued by the EC 'A European Strategic long-term vision for a prosperous, modern, competitive and climate neutral economy: A Clean Planet for all'[14] that is meant to set the direction of travel of EU climate and energy policy and to frame what the EU considers as its long-term contribution to achieving the Paris Agreement temperature objectives in line with UN Sustainable Development Goals, which will further affect a wider set of EU policies. The document highlights the importance of clean, safe and connected mobility.

Looking into European railway sector, ERRAC Rail vision 2050[15] describes today's rail sector in terms of its economic, societal and environmental contribution, the challenges and opportunities it faces arising from societal changes and other trends, and presents a view of what Europe's railway might look like in 2050. In addition, in 2018, the CER, the EIM and the UNIFE published a joint position paper 'EU Strategy for long-term greenhouse gas emissions reductions – The crucial role of rail'.

[10] https://www.uitp.org/climate-change
[11] http://oneplanet.uitp.org/manifesto/climate-action-manifesto/
[12] http://railsponsible.org/
[13] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52011DC0144
[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773
[15] https://errac.org/publications/rail-2050-vision-document/

Since 2008, CER defined voluntary targets that were adapted into a pledge for railways in 2015:

Topic	Baseline	Horizon	Target
Climate protection	1990	2020	-40% Specific GHG emissions (gCO_2eq/pkm & gCO_2eq/tkm)
	1990	2030	-50% Specific GHG emissions (gCO_2eq/pkm & gCO_2eq/tkm)
	1990	2030	Total CO_2eq emissions 30% below the baseline
		2050	Carbon free operation
Energy Efficiency	1990	2030	-30% Specific consumption (kWh/pkm & kWh/tkm)
	1990	2050	-50% Specific consumption (kWh/pkm & kWh/tkm)
Air Quality	2005	2030	-40% total PM & NOx
		2050	Zero emission

UIC is updating this pledge in 2019, proposing its members to strengthen these voluntary targets.

Rail Freight Forward, a coalition of European rail freight companies committed to drastically reduce the negative impact of freight transport through innovation and a more intelligent transport mix. This coalition has the ambition to double the modal share of rail freight to 30% by 2030.

The early achievement of these objectives has meant that, in 2019, some European stakeholders (e.g. UIC members) are considering strengthening their commitments by changing its relative baseline from 1990 to 2005, making the reduction target more difficult to reach. In addition, UIC is proposing new commitments to all its members, European and non-European, namely:

- Formally adding carbon neutrality by 2050 (not only the for European members);
- Stating that UIC members will aim to be Sustainable Development Goals (SDG) compliant.

5. Implementation of actions on climate change and decarbonisation

The rail sector through specific industry-wide initiatives (e.g., Shift2Rail[16]) or joining relevant international campaigns (e.g., UITP ONE PLANet campaign[17]) stands ready to support development, capacity and implementation of actions on climate change and decarbonisation.

Action plans to reduce transportation carbon footprint can be addressed through a three-tier *Avoid-Shift-Improve* approach consisting of following mitigation efforts:

1 - Avoid:

- Prioritise breathable and walkable streets through well-designed urban planning;
- Encourage rail operators to produce and/or use certified zero-carbon renewable energy;
- Pair power networks management and railway grids to avoid superfluous creation of infrastructure and reduce transmission losses;
- Creating direct links between renewable energy suppliers, consumers and ESSs in the network (railway can endorse both roles) to avoid the loss of overproduction;
- Settle regular railway flows and avoid unnecessary stops by using connected traffic management systems;
- Continue developing intelligent resource/material usage and management based on the circular economy principles.

Examples:

- *Through the efforts of its mother company Stadtwerke Munich, metros and trams in Munich run on clean renewable electricity sourced from local production capacity of photovoltaic panels on tram depots (79 MWh), of two solar plant facilities in Germany and one large in Andalusia;*
- *Tenerife LRT cover 14% of its total energy needs from its own photovoltaic plant, i.e. 1275.5 Mw/h (annual report 2019)*
- *Dutch Railway operator, Nederlandse Spoorwegen (NS) managed, in 2017, to achieve a 100% share of renewable energy[18] to supply traction energy for virtually carbon free train operations.*

[16] https://shift2rail.org/ Shift2Rail is the first European rail initiative to seek focused research and innovation (R&I) and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. Shift2Rail promotes the competitiveness of the European rail industry and meets changing EU transport needs. R&I carried out under this Horizon 2020 initiative develops the necessary technology to complete the Single European Railway Area (SERA).

[17] http://oneplanet.uitp.org In September 2019 as part of the #ONEPLANet campaign, UITP launched with its members a Climate Action Manifesto which details a four-step action plan to reduce transport emissions in cities.

[18] https://www.ns.nl/en/about-ns/sustainability/energy/sustainable-energy.html

2 - Shift:

- Strengthen the role of rail as the backbone of all mobility services by highlighting railways efficiency and passenger/merchandise movements through bottom-up reporting (as done with UIC ESRS) and by working with cities to optimally integrate railways in urban planning with multiple stakeholders partnerships;
- Identify modal shift potentials by assessing and modelling freight and passenger flows of other modes to support efficient urban planning;
- Enable and enhance multimodality possibilities by considering stations as hubs, helped by digitalisation;
- Promote modal shift towards energy-efficient rail transport[19] (e.g. system extensions, communication campaign).

Fostering modal shift, without requiring any new technology, research and development, will have huge impact. Shifting the mobility towards rail and clean public transport services such as metro and/or electric buses will result in:

- Million tons of CO2 and particle emissions reduction;
- Decreased congestion;
- Reduction of fatalities due to accidents and air pollution;
- Reduced noise.

Examples:

- *Between 2015 and 2018, ridership growth for LRT and metro in Europe (+1 369 million passengers, +7%) was twice as high as the supply growth (+ 451 km of new infrastructure, +3.5%)*
- *2019 will see the opening of another 142 km of LRT and 17 km of new metro in Copenhagen (opened in Oct. 2019).*
- *By introducing the TGV on the Paris-Nantes route, air traffic share decreased by 30%. It was even more drastic for the Madrid – Seville route that changed the air/rail passengers split from 67:33 to 16:84[20]. For instance, a 300-km long HS line (such as the Oceane Line in France), will release 1.5 million tonnes of CO_2. This is offset during the revenue period because of the CO_2 savings due to the traffic shift from road (50 000 tonnes per year) and air (80 000 tonnes per year) to rail. This means that the carbon balance, which is heavily negative at the end of the construction period, improves year on year of operation[21].*

[19] WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, Brussels, 28.3.2011 COM(2011) 144 final
[20] Matteo Prussi and Laura Lonza, "Passenger Aviation and High Speed Rail: A Comparison of Emissions Profiles on Selected European Routes," Journal of Advanced Transportation, vol. 2018, Article ID 6205714, 10 pages, 2018. https://doi.org/10.1155/2018/6205714.
[21] High Speed Rail Brochure 2018, https://uic.org/passenger/highspeed/

3 - Improve:

- Offer financial incentive and a suitable regulatory framework to (re)invest in transition to ambitious emission goals;
- Identify and map energy waste sources, quantify them and implement sensible measure to mitigate / suppress them (e.g., rate of fleet renewal, ESS, reversible sub-stations);
- Develop and deploy more energy efficient technologies for rail transport (traction, auxiliaries, stationary consumers, energy efficient design);
- Use ATO eco-mode and smart time-tabling to optimise braking energy regeneration;
- Provide reinforced eco-drive training and in-cab driver energy consumption advisory device;
- Improve trains' efficiency by combining optimised train-driving patterns and traffic management (e.g. C-DAS, ATO).

Other relevant initiatives supported by representatives of the rail industry (e.g. UIC) include Action towards Climate friendly Transport (ACT), aiming at achieving a holistic understanding of sustainable transport action based on the Avoid-Shift-Improve (A-S-I) framework.

In order to achieve these, the rail sector is expected to require investment aiming at improved maintenance of its infrastructure, renewal of its rolling stock and making it attractive, comfortable, secure and reliable to customers. Systems and policies aiming at fair payment of all modes for infrastructure usage and the overall impact on society of such modes should also be considered (e.g. road pricing, congestion charges).

Examples

- *Energy braking regeneration is the most popular measure in urban rail: in Brussels (Belgium), its introduction in the metro led to annual savings of 3,060 tonnes of CO_2. In London (UK), all new trains have regenerative braking and on one line, when combined with other technology (signalling and power systems) has led to energy reduction by 34%. In Barcelona (Spain) this feature was enabled in 2018 on two additional metro lines, allowing to recover 30% of braking energy. In Rotterdam (Holland) around 10 tonnes of CO_2 is avoided through this programme implementation on the metro network.*
- *Promotion through research and innovation agenda (e.g. Shift2Rail MAAP[22])*
- *In Bielefeld (Germany) three inverters and a flywheel accumulator were introduced in 2015, saving more than one gigawatt-hour of energy and in late 2017, new energy efficient light rail vehicles were ordered which are expected to go into service in spring 2020.*
- *In December 2018, Paris (France) saw the testing of the metro's new automatic control system which will help to reduce energy consumption by 20% and help improve passenger comfort, with reduced interior noise levels by 40%.*

[22] Shift2Rail Multi-Annual Action plan
https://ec.europa.eu/research/participants/data/ref/h2020/other/wp/jtis/h2020-maap-part-a-shift2rail_en.pdf

6. OPEUS contribution to the agenda

The overall aim of the OPEUS project is 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.

The work conducted in OPEUS contributes to the aim and objectives of the Shift2Rail joint undertaking as defined in its Multi Annual Action Plan (MAAP). This contribution is twofold:

1. To its overall vision to "*deliver, through railway research and innovation, the capabilities to bring about the most sustainable, cost-efficient, high-performing, time driven, digital and competitive customer-centred transport mode for Europe*". To this extent, OPEUS outcomes actively contribute to the cross-cutting activity WA5.1 "Energy" and indirectly supports several technology demonstrators (TDs), particularly where 'energy saving', 'energy reduction', 'energy optimisation' and/or 'management of energy consumption' features as a desired result, i.e. TDs; 1.1, 1.3, 2.2, 5.5 and 5.6;
2. To its future opportunities and capabilities plan[23] stemming out of the vision above, identifying nine key features of the future railway and twelve capabilities to achieve this. OPEUS contributes to this agenda by directly supporting feature #4 aiming at reducing traction energy consumption, feature #5 minimising carbon emissions by adopting energy-efficient solutions and energy recovery systems. Equally, OPEUS results do contribute to acquiring capability #5 "optimum energy use" though the provision of a technological innovation assessment tool to estimate the energy implications of integrating novel features into rolling stock.

As an illustration of the above, OPEUS has performed an iterative assessment of selected innovations developed as part of the Shift2Rail MAAP. These indicate that the most positive outcome, for high speed rail services running at 250km/h as per standardised duty cycle[24], the combined effect of reduced weight (about 2.4% weight reduction), improved efficiency for gearbox and converters/transformers (about +1% efficiency each) results in performance improvements related to a decrease of 2% traction energy at the wheel level, which leads to a total net energy reduction of 5.4% at the energy source. [25].

Overall, the main contribution of OPEUS to the decarbonisation agenda is the development of a robust, stable and readily available assessment methodology and associated tool. This tool has to be the basis on which to build a more accurate, inclusive and integrated platform supporting the improvement of the already excellent railway energy usage track record.

[23] Multi Annual Action Plan, Executive View, Part A (2017)
[24] Baseline standardised duty cycles have been produced by a combination of the information generated by previous projects (e.g. Roll2Rail), the existing draft standard prEN50591 and the joint effort of the OPEUS-FINE1 group
[25] Deliverable D 3.4 S2R innovation second periodic assessment

7. Conclusions

Only a holistic approach to energy efficiency will deliver substantial benefits towards decarbonisation. Technical measures and improvements have a key role to play in this strategy, as demonstrated in the OPEUS project. However it is of paramount importance to frame these efforts in a wider picture consisting of:

- Land-use and urban planning approach with mobility policy and a systematic support to the most energy-efficient rail modes;
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