FINE1

D2.2 Dominant energy efficiency parameters of system platform

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EXECUTIVE SUMMARY

The document is focused on the following main objectives:

- Identification of the most suitable energy related standard
- Selection of dominant energy related Key Performance Indicators (KPIs)

For the first objective, **prEN 50591** is confirmed as the most suitable energy related standard. This is concluded taken in to account recent improvements of the standard. The prEN 50591 group worked in improving the standard together with national committees, submitting amendments in July 2017 and June 2018. When submitting this document, it is not yet voted and notified if the standard is approved or not.

The prEN 50591 is accepted by the FINE1 energy group and promoted in energy related activities. It is selected as the key reference for a protocol evaluating energy consumptions related to eco-labelling. The same standard is used for standard profile definition both in **FINE1** T3.1 and in **IMPACT1/2** for the System Platform Demonstrators (SPDs) as well as in a new tender for the "Study on Use of Fuel Cell Hydrogen in Railway Environment" (aiming at analysing the technical and cost feasibility of the hydrogen in the railway sector.

For the second objective, Roll2Rail (R2R), FINE1 and IMPACT1 deliverables are analysed and a summary of most relevant energy related KPI is developed.

R2R KPI tool's assessment concluded that mass and efficiency of the components are the two most important groups for energy related KPIs.

Carbody shell mass improvements have the biggest impact on the rolling stock overall energy consumption for high speed, regional, metro and tram applications. Traction equipment and interiors improvements are the next two most important components.

Focusing on efficiency improvement, for regional and metro, traction group improvement's impact on overall rolling stock energy consumption are higher than carbody shell improvement's impact.

Besides, regarding technology improvement of efficiency, there is also a variation from case to case of the dominant KPI and general conclusions about most relevant component cannot easily be defined. The efficiency is not only related to components, it should also include an overall energy management. For future studies it is planned to include cross referenced impacts between components and integrated sensitivity analysis.

ABBREVIATIONS AND ACRONYMS

Acronym	Definition
ATO	Automatic Train Operation
CFM	Call for Members projects
DAS	Driving Assistance System
DX.X	Deliverable WP.Number
ETCS	European Train Control System
FC	Fuel Cell
FCH	Fuel Cell and Hydrogen Joint Undertaking
H2	Hydrogen
HVAC	Heating, Ventilation and Air Conditioning
IP	Innovation Programme
KPI	Key Performance Indicator
LCC	Life Cycle Cost
R2R	Roll2Rail, S2R Light-house project
S2R	Shift2Rail Joint Undertaking
SiC	Silicon Carbide
SPD	System Platform Demonstrator
TCMS	Train Control Monitoring System
TS	Technical Specification
WP	Work Package

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1. INTRODUCTION

This deliverable responds to Task 2.2 Internal Requirements Analysis and interface to external normative groups from FINE1. The document aims at responding to the two objectives stated in Grant Agreement-730818-FINE1.

On the one hand, the work carried out deals with the identification of dominant energy efficiency parameters of Systems Platform Demonstrators (SPDs). The activity was supported by S2R light-house projects (Grant Agreement-636032-Roll2Rail) and Call for Members (CFM) projects (Grant Agreement-730818-FINE1 and Grant Agreement-730816-IMPACT1 responding to S2R-CFM-CCA-01-2015). During this task, work done in previous projects is analysed and relevant energy related KPIs are identified.

On the other hand, the deliverable responds to the work done for the identification of the most suitable energy related standards.

Within chapter 2 background to defining the most suitable energy related standard is discussed and justified, including the latest improvements and the promotion on energy related activities. Within chapter 3 the identification of the dominant energy efficiency parameters is carried out. Besides, chapter 4 lists the interaction of FINE1 energy group in energy related external groups and pr50591 working group. Last but not least, chapter 5 summarises the most relevant key findings and conclusions.

2. DEFINITION OF MOST SUITABLE ENERGY RELATED STANDARDS

Roll2Rail D8.1 “State of the Art of applicable Norms & Regulations on energy efficiency for railway operation” deliverable stated the TS 50591 as the most suitable energy related norm. During FINE1, this statement was confirmed and efforts to improve prEN 50591 were carried out together with prEN 50591 members.

2.1 PREN 50591 AMENDMENT

From 2015 November to 2017 June several meetings and workshops were held in order to integrate the various improvement and comments received from the national committees. The main modifications carried out in the updated version are listed below:

- The goal of the norm was clarified: “*the main purpose of the standard is the support of rolling stock procurement. This European Standard is applicable to the specification and verification of energy consumption of railway rolling stock. It establishes a criterion for the energy consumption calculation”* (taken from prEN 50591:2017 version)
- 3 different train operation modes are identified in the standard. With time integrating of the three of them, the entire Life Cycle Cost (LCC) picture is completed.
    - In-service mode with commercial operation; *covering normal operation of a train, the train is moving or at standstill with passengers and the Heating, Ventilation and Air Conditioning (HVAC) system is running.*
    - In-service mode without commercial operation; *the train is at standstill, the HVAC system is in operation as for commercial operation and there is no passenger in the train. This situation is quite frequent, for example when the train is waiting between two commercial runs.*
    - Parking mode; *the train is in parking mode when it is stationary in depot areas, with active power supply, without passengers on board. Usually, the HVAC system runs with reduced settings for temperature and airflow.*
- A well-defined and harmonised methodology for each mode is defined:
    - simulation of the energy consumption of the train for three energy categories, defining what loads need to be considered in each mode
        1. Traction and Auxiliaries (in-service with commercial operation mode, without HVAC);
        2. Traction and Auxiliaries (in-service without commercial operation mode and in parking mode, without HVAC);
        3. HVAC
    - verification of the simulation by undertaking measurements.
- Two different sorts of service profiles for *In-service mode with commercial operation* may be chosen:
    - user defined service profiles based on data from a real railway line, normally one or several lines out of the railway network where the train runs
    - standardised service profiles, included as an annex in the standard

- An informative application guide for procurement process is included as an annex with the goal of facilitating the procurement process and specifying intended service instead of solutions in order to stimulate energy efficient solutions.

With all this updates, a new version of prEN 50591:2017 was submitted and left to revision by national committees. The resolution of the vote and comments came back by mid-April. The same group worked during 3 months to submit the final reviewed version in June 2018.

The main modifications included in the following version (prEN 50591:2018) are listed below:

- The goal of the norm is clarified: the standard is not intended to validate any model or tool, indeed the norm does not include simulation result nor measurements
- HVAC methodology is improved
- The 3 operation modes are not clear enough. A small restructuration is included and modes names are updated avoiding redundancies. The following train modes are used in this standard:

  In-service with commercial operation mode: *covering the normal operation of a train, including several passenger load cases or a locomotive hauling a consist of freight wagons. The train is moving or is stationary and the HVAC system is running in its normal operation mode.*

  In-service without commercial operation mode: *the train is stationary, the HVAC system is in operation as for commercial operation but without passengers in the train. This situation occurs frequently, for example when the train is waiting between two commercial runs.*

  Parking mode: *the train is in parking mode when it is stationary in depots, with the power supply active, without staff or passengers being on board. Usually, the HVAC system runs with reduced settings for temperature and airflow.*

When submitting this deliverable, it is not yet voted and notified if the standard is approved or not. From 6 to 12 months are left for the resolution of this process.

It is also clarified, that the initial scope of the TS 50591 was mainline transport, not for trams or metro. A standard service profile for metro was added in the draft of the prEN 50591:2017, but not for tram. Although the basic methodology of the standard can be used for every service category defined in FINE1 D3.1, there are few open points.

For example:

- a load of only 50% seated and 0% standing passengers for traction energy may not be adequate for all service category operations.
- the methodology for HVAC energy consumption is based on steady state points defined in the standard EN13129 [11] that is dedicated to thermal comfort for mainline. These steady state points may not be adequate for all service category operations.
- No HVAC conditions in tunnel operation modes are defined

This may be solved in other standards.

2.2 PREN 50591 USAGE

The members of the FINE1 energy group participated in the amendment of the prEN 50591 standard and also promoted the use of this standard in different activities and fields.

prEN 50591:2017 is the basis for FINE1 D3.1 integrating relevant rolling stock characteristics and new profiles for quantification of improvements developed in S2R . FINE1 and IMPACT1-2 worked in collaboration for SPD definition based on prEN 50591:2017 standards.

The prEN 50591:2017 standard is also considered in relation to the new Hydrogen (H2) open tender launched jointly by FCH and S2R called “Study on Use of Fuel Cell Hydrogen in Railway Environment”. The aim of the study is to provide a business case and market potential analysis per rail application for the use of FCH technologies in the railway sector, in a multimodal perspective identifying technical and non-technical barriers for the implementation of FCH technologies. A dedicated team will carry out this study in collaboration with its advisory board made up by main system integrators, rolling stock operators, FC providers and H2 providers. For the generic analysis, Regional 140, Freight locomotive and Shunting freight applications are selected, based on prEN 50591:2017 condition definition. The team is neither a member of S2R nor FCH.

Besides, the prEN 50591:2018 is selected as the key reference for a protocol to be used for the eco-labelling proposal to be made in FINE1 T2.1. The protocol specifies how to measure energy usages having different functions and making the energy usages of different product models comparable. prEN 50591:2018 describes the methodology, operational simulation requirements, standard service profiles, verification conditions and post-processing acceptance criteria.

3. IDENTIFICATION OF DOMINANT ENERGY EFFICIENCY PARAMETERS

This chapter discusses the dominant energy efficiency KPIs based on the different sources that were analysed.

3.1 ANALYSED SOURCES

3.1.1 Roll2Rail

The Roll2Rail (R2R) project aimed to develop key technologies and to remove already identified blocking points for radical innovation in the field of passenger rail vehicles, as part of a longer term strategy to revolutionise the rolling stock for the future. This project was supported by the Horizon 2020 program of the European Commission. R2R was one of the lighthouse projects of S2R and contributed to Innovation Program 1 (IP1), starting in May 2015 and finalizing in October 2017.

The System Integration Work Package (WP) focused on the definition of the adequate methodology for evaluating system-level impact in the desired areas. It quantified the performance at component level in all aspects that can influence the global impact and use of the proposed methodology to achieve global impact figures, including energy.

The main outcome of R2R regarding KPIs are D9.1 valuation Methodology Description [1] and the KPI tool [2].

From these deliverables, the following KPIs and sublevel KPIs related to energy are identified.

- KPI 1.2.1 - Reduction in energy costs due to reduction of weight
    - Proposed KPI 1.2.1.1 Inverters (including cooling) weight
    - Proposed KPI 1.2.1.2 Auxiliary converters (including cooling) weight
    - Proposed KPI 1.2.1.3 Motors (including gearbox) weight
    - Proposed KPI 1.2.1.4 Traction and Control Monitoring System (TCMS) equipment weight
    - Proposed KPI 1.2.1.5 Weight of the carbody
    - Proposed KPI 1.2.1.6 Weight of bogies
    - Proposed KPI 1.2.1.7 Weight of interiors

- KPI 1.2.2 - Reduction of energy costs due to technology improvements
    - Proposed KPI 1.2.2.1 Inverters (including cooling) efficiency
    - Proposed KPI 1.2.2.2 Auxiliary converters (including cooling) efficiency
    - Proposed KPI 1.2.2.3 Motors (including gearbox) efficiency
    - Proposed KPI 1.2.2.4 TCMS energy consumption
    - Proposed KPI 1.2.2.5 Energy consumption of interiors (powered components)

3.1.2 FINE1

The FINE1 project aims to reduce operational costs of railways by a reduction of energy use and noise related to rail traffic. The project results are expected to enable an increase of traffic in Europe and to enhance the attractiveness of railway in relation to other modes of transport.

The project activities support the innovation process within the S2R Technical Demonstrators (TD) by providing methodology and know-how to enable development of low noise and low energy TDs.

The reduction of energy use for rail vehicles will indirectly lead to reduced green-house gas emissions, also with most rail transport powered with electricity. Further, reducing energy use will lower the life cycle cost and the costs of vehicle operation.

The main outcome of FINE1 regarding KPIs are D4.2 [5] and D4.3 [6].

From these deliverables, the following future technologies related to energy are identified. Additionally, referenced KPIs related to the defined technologies are proposed:

- medium frequency transformer with electronic converter, Silicon Carbide (SiC) converter and Independently rotating wheel with gearless permanent magnet synchronous motor
    - Proposed KPI: traction modules efficiency
    - Proposed KPI: traction modules mass
- energy reduction in parking mode
    - Proposed KPI: efficiency in parking mode
- battery drive for non-electrified lines
    - Proposed KPI: catenary (train level) energy consumption

- composite carbody shell with fiber reinforced plastic
    - Proposed KPI: carbody shell mass
- Light weight running gear with new materials and concepts
    - Proposed KPI: running gear mass
- automatic train operation (ATO) grade 4 (unattended driving) based on European Train Control System (ETCS) and Connected Driver Assistance System (DAS) considering real time traffic information
    - Proposed KPI: catenary (train level) energy consumption
- double fed power supply for 50Hz overhead lines with increased substation distance and no switches for separation of overhead line sections
    - Proposed KPI: distribution system efficiency
- high speed freight wagon (120 - 160 km/h) with reduced weight, improved aerodynamic, electrification and automatic couplin
    - Proposed KPI: freight wagon efficiency at train level
    - Proposed KPI: freight wagon mass including improved aerodynamic
- Hybrid shunting locomotive with small diesel engine and Li-ion traction batteries, Electric mainline locomotive with powerful diesel and Li-ion battery and Electric mainline locomotive with Li-ion battery for last mile
    - Proposed KPI: locomotive level energy consumption
- The eco-labelling proposal in task 2.1 also proposes the KPI "catenary (train level) energy consumption"

3.1.3 IMPACT1

The objective of IMPACT1 is to help maximise the impact of S2R by analysing the socioeconomic impact of the S2R developments, identifying the future application use cases by SPD scenarios and assess the impact of the development by using KPIs.

One WP is responsible for the definition of SPDs that represent future application use cases and another WP is defining KPIs that enable the monitoring and assessment of the S2R overall target achievement.

The main outcome of IMPACT1 regarding KPIs structure is D4.2 [7]. From this deliverable, the following KPIs and sublevel KPIs related to energy are identified.

- Journey Energy Usage
- Distribution line losses

3.1.4 prEN 50591

The main purpose of this standard is the support of rolling stock procurement, especially in light of **LCC** assessment. This European Standard is applicable to the specification and verification of energy consumption of railway rolling stock. It establishes a criterion for the energy consumption of rolling stock to calculate the total net energy consumed, either at current collector or from the fuel tank, over a predefined service profile, in order to ensure that the results are directly comparable or representative of the real operation of the train.

Additionally, the following groups of energy consumption indicators are proposed to add:

- Energy consumption
  - In-service with commercial operation mode
  - In-service without commercial operation mode
  - Parking mode

3.2 SELECTION OF DOMINANT ENERGY KPI

Energy related KPIs are classified mainly into two groups. KPIs related to efficiency and mass, both impacting energy consumption.

The mass of the rolling stock can always be divided into components of the vehicle. Logically, the reductions of mass of the heaviest components result always in a higher energy consumption reduction but maybe there is more potential to reduce the mass of the lighter components. Besides, efficiency needs to be added. However, the efficiency is not only related to components, it should also take into account an overall energy management. The different operating modes, as catenary free zones, automatic operation or parking mode, for example, need different energy management strategies for overall train efficiency improvement.

Additionally, due to different vehicle types and characteristics, the same improvement on one component may result in a different impact over the overall train energy consumption.

For example, braking improvement for a metro service which is constantly braking or the same improvement for a high-speed service with 2 stops in the journey, cannot give the same results. As another example, for high-speed trains aerodynamic resistance is also important and the drag coefficient might also be seen as a KPI. This said, the dominant energy KPI for one service, vehicle and operating mode cannot be the same for another specific service.

However, taking into account weighting factors used in R2R, some hints are given below for specific cases and the balance between mass and efficiency for specific cases is analysed:

Carbody shell mass improvements have the biggest impact on the rolling stock overall energy consumption. In this case, being the component with the biggest mass share in every application, the carbody shell is the dominant mass related energy KPI for high speed, regional, metro and tram applications. Traction equipment and interiors improvements are the next two most important components.

Regarding technology improvement or efficiency, there is a variation on the dominant KPI depending on the application. For high speed application defined in R2R, carbody and traction improvements are dominant and the next subsystem is far away of being relevant. However, for regional and metro, traction group improvement are higher than carbody shell improvement.

FINE1 is monitoring individual benefits from different energy related S2R projects but there is not any compilation of benefits or sensitivity analysis over the same metric at the moment. Due to the early stage of technology, the estimations are generic and cross referenced impact over other components is not feasible. For FINE2, integrated innovative clusters can be made, trying to estimate overall energy consumption and cross influence, together with sensibility analysis. If required information from TD experts is available, FINE2 experts might be responsible of developing the groups and integrating the benefits. Above the conclusion, a sensitivity analysis could be also useful.

From integrated energy usage perspective, IMPACT1 is using data from FINE1 rolling stock, grouped as a vehicle and without distinctions over the components. Regarding railway system, at the moment, IMPACT2 project has not included distribution energy consumption and losses in the analysis, passenger stations and signaling consumption is not taken into account.

4. EXTERNAL GROUPS PARTICIPATION

Members of the FINE1 energy group participated in the following meetings in order to improve the standard which was selected within the FINE1 Energy group as the most suitable energy related standards, prEN 50591.

The goal of interfacing on norms and regulation inputs to CEN (European Normalisation Committee) and CENELEC for energy matters was successfully achieved with the submission of the last version of prEN 50591 [10] for definitive voting.

Group	Objective of the meeting	Attendant	Location	Date
prEN 50591 standardisation	Technical meetings to complete the norm	Ruth Arregi – CAF Holger Dittus – DLR	Erlangen Paris Berlin Utrecht	2016.11.08-9 2017.02.15-16 2017.05.30-06.01 2018.06.12-14
UIC Energy Network	Workshop on Energy Efficiency of future trains	Holger Dittus - DLR	Rome	2017.10.04

5. CONCLUSIONS

The document describes the work carried out in FINE1 Task 2.2, Internal Requirements Analyses and Interface to external normative groups and responds to its two objectives.

During Roll2Rail D8.1 State of the Art of applicable Norms & Regulations on energy efficiency for railway operation [4] several standards were analysed and TS 50591 was chosen as the most suitable in that specific moment. Responding to the first objective of this report, FINE1 confirmed the choice of TS 50591 as the most suitable standard.

However, the standard had to be improved and significant amendments were introduced after several official revisions. The last submission was executed during the end of June 2018. FINE1 energy group contributed actively in this improvement for the description of boundaries, methodology and expected conclusions. prEN 50591 defines now accurately the minimum operational, simulation, verification and post-processing conditions, justifying required calculation and operational points. As a novelty, HVAC methodology is implemented, where EN13129 state study points are taken as reference. Overall methodology is valid both for small fleets and singular tenders, where climatic chamber option and field measurements are accepted.

As a consequence of the choice of prEN 50591 as the preferred standard, it is promoted in energy related activities too.

- Firstly, this standard is selected by FINE1 T2.1 participants as the key reference for a protocol to be used when evaluating the energy consumption related to eco-labelling.
- Besides, the same standard is also used for standard profile definition both in FINE1 T3.1 and in IMPACT1/2 overall activities. The SPDs defined in these last projects are focused on use cases that are based in the standard profiles proposed by prEN 50591:2017.
- Lately, the “Study on Use of Fuel Cell Hydrogen in Railway Environment” tender was launched analysing the technical and cost feasibility of the hydrogen in the railway sector, choosing three applications to analyse in detail. For the generic analysis the condition definition is based on prEN 50591:2017 for a Freight locomotive and Shunting freight applications that is selected.

Responding to the second objective of this report a summary of most relevant energy related KPI is developed and are based on the preferred standard and other S2R projects. It is concluded that mass and efficiency of the components are of significant importance when discussing rolling stock energy consumption. The dominant energy KPI for one service category, vehicle and operating mode might not be the same for another specific service. Although choosing the relevant parameter for all applications and conditions is not easy and valid for all cases, the following generic conclusions can be taken using R2R studies as reference:

- For carbody shell mass improvements have the biggest impact on the rolling stock overall energy consumption for high speed, regional, metro and tram applications.
    - Traction equipment and interiors improvements are the next two components that follow, but not so closely.
- For technology improvement or efficiency, there is a variation on the dominant KPI depending on the application.
    - For high speed application, carbody and traction improvements are dominant, and the next subsystem is far away of being relevant.
    - For regional and metro, traction group improvement's impact is higher than carbody shell improvement.

REFERENCES

[1] R2R-T9.2-T-DAP-009 – R2R KPI tool

[2] R2R-T9.2-D-CAF-007 – R2R D9.1 Evaluation Methodology Description

[3] FINE-WP3-D-DBA-009 – FINE1 D3.1Energy Baseline

[4] R2R-T8.1-D-BTD-005 – R2R D8.1 State of the Art of applicable Norms & Regulations on energy efficiency for railway operation

[5] FINE-T4.2-D-BTG-002 – FINE1 D4.2 Data gathering from S2R TDs - interim report

[6] FINE-T4.2-D-BTG-006 – FINE1 D4.3 Data gathering from S2R TDs

[7] IMP-WP4-D-DLR-070 – IMPACT1 D4.2 Subsystems structure and sublevel KPIs.

[8] TS 50591 “Specification and verification of energy consumption for railway rolling stock”

[9] prEN 50591:2017 “Specification and verification of energy consumption for railway rolling stock”. Draft, submission 2017.06 – distributed in January 2018

[10] prEN 50591:2018 “Railway Applications – Rolling Stock - Specification and verification of energy consumption”. Draft, submission 2018.06

[11] EN13129:2017 “Railway applications. Air conditioning for main line rolling stock. Comfort parameters”