Smart and Efficient Energy Solutions for Railways
The “Railenergy” Results

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1. Background

The European railway market has been challenged by various factors in the last decade: Firstly, the sector, highly depending on energy like electricity and fossil fuels, has been dealing with constantly increasing energy prices. Secondly, the railways have been facing a more aggressive competition from the other modes of transport, while turning their enterprises from state-owned enterprises into market oriented companies. Thirdly, a competition has started among train operating companies about lucrative passenger and freight services. So far the competition has mostly been between the different modes of transport. In recent time railways have started a competition among themselves for transporting passengers and goods. Thus, the European railway sector has been looking for solutions to keep and improve the market position and performance.

As energy plays an important role for moving passengers and goods, energy efficiency became a top priority on the agenda of entire railway sector. Exploiting energy saving potentials became a main task in railway business to control costs for staying competitive, since it was apparent that saving energy creates a market advantage allowing railways to offer services cheaper than the sector internal and external competitors.

2. Introduction into the Railenergy Project

The Railenergy project, targeted to increase the energy efficiency of integrated railway systems by investigating and validating solutions ranging from the introduction of innovative traction technologies, components and layouts to the development of rolling stock, operation and infrastructure management strategies, presents its final results with this paper. Railenergy has been the first rail research project investigating energy efficiency with a holistic perspective by using a system approach.

Technical solutions for cutting energy consumption in railway systems are provided, thereby reducing both life cycle cost and CO₂ emissions at the same time. The set target was an overall 6% reduction in energy consumption by 2020 compared to 2005.

In order to combine economic competitiveness with environmental friendliness, railway systems must increase their energy efficiency – not least to sustain the strong political support that rail has received thanks to its ecological advantage. The following three main future challenges were the main drivers for Railenergy:

- Rising energy costs
- Energy security & independency and
- Climate protection

2.1 The Railenergy Target

Railenergy set the target to reduce by 6% the specific energy consumption of the rail system by 2020 by addressing different systems, subsystems and components of the railways with a holistic approach.

In order to adhere to the business perspective while calculating the estimated overall savings, the deployment of the combinations of Railenergy solutions in the different countries has been envisioned accordingly with three different scenarios.

For each country, a specific scenario has been selected; then the relative and absolute savings have been calculated. As the project target shall be reached globally at a European level, the total saving has been calculated by adding the absolute values of savings of each single country. Such absolute value is then compared with the baseline in order to determine the overall percentage of energy efficiency gain that is achieved.

Based on the first calculations of savings from technologies and operational measures, it seems plausible to achieve at least 6% of energy savings throughout the entire European railway system. In
particular, by using the above described scenarios, with specific exploitation rates, calculations show that an average relative energy saving of more than 7% can be reached.

2.2 The Railenergy technologies investigated

The following technologies have been investigated in terms of their energy saving potentials from the technical and economic perspective:

<table>
<thead>
<tr>
<th>Railway Domain</th>
<th>Technologies and measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>Eco-driving (Level 1): Driver training</td>
</tr>
<tr>
<td></td>
<td>Eco-driving (Level 2): Driver advice system</td>
</tr>
<tr>
<td></td>
<td>Eco-driving (Level 3): Fluid traffic management</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Reversible DC substation</td>
</tr>
<tr>
<td></td>
<td>Real time power management</td>
</tr>
<tr>
<td></td>
<td>2 x 1.5 kV DC traction system</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical auto-transformer (AT) system</td>
</tr>
<tr>
<td></td>
<td>Parallel substation (2x25 kV AC)</td>
</tr>
<tr>
<td></td>
<td>Reduced line impedance</td>
</tr>
<tr>
<td></td>
<td>Increased line voltage (i.e., more than 4kV DC)</td>
</tr>
<tr>
<td></td>
<td>Trackside energy storage unit (electric double-layer capacitor/supercaps)</td>
</tr>
<tr>
<td>Onboard components</td>
<td>On-board energy storage (electric double-layer capacitor/supercaps)</td>
</tr>
<tr>
<td></td>
<td>Use of waste heat (for cooling)</td>
</tr>
<tr>
<td>Onboard traction</td>
<td>Superconducting transformers and inductances</td>
</tr>
<tr>
<td></td>
<td>Medium frequency energy distribution</td>
</tr>
<tr>
<td></td>
<td>Innovative hybrid diesel electric propulsion</td>
</tr>
<tr>
<td>Onboard optimization</td>
<td>Converter control technology (applied during vehicle coasting)</td>
</tr>
<tr>
<td></td>
<td>Active filtering technology to reduce input passive filter (reactors) losses</td>
</tr>
<tr>
<td></td>
<td>Reuse of converters’ energy losses</td>
</tr>
<tr>
<td></td>
<td>Medium Voltage loads management</td>
</tr>
</tbody>
</table>

Table 1: The Railenergy technologies investigated
3. The Major Railenergy Outputs exploitable for the European railway market

3.1 The Overview

The Railenergy project provides a toolbox for the railway sector comprising guidelines and methods to cut the energy consumption for rail services including the infrastructure, as quickly depicted in the following figure.

Illustration 1: The Railenergy Toolkit

After exploiting the energy saving potentials in the different domains Energy Management, Infrastructure, Components, Traction and Topologies Railenergy delivered the following results:

1. Contribution to technical standardisation (Technical Recommendation - bilateral UIC/UNIFE standard, as input for the EN); e.g.: Sector-wide agreed methodologies for the calculation of energy consumption
2. Tools for the calculation of energy consumption in a defined railway system
3. Recommendations (Strategic Assessment Reports incl. technical and operational measures)
4. New technical components

3.2 Contribution to the European standardisation processes & Sector-wide agreed methodologies for the calculation of energy consumption

One of the most important outcomes is the contribution to the European standardisation processes, for instance the elaboration of joint UIC/UNIFE Technical Recommendations. A Technical Recommendation (TecRec) is a UIC/UNIFE standard aiming at accelerating the standardisation process and thereby improving the competitiveness of the European railway system.
3.2.1 TecRec 100_001 "Specification and verification of energy consumption for railway rolling stock"

The first Technical Recommendation 100_001 “Specification and verification of energy consumption for railway rolling stock” was developed by Railenergy and is developed to support procurement of locomotives and train sets. Such a specification has been missing in the railway sector and has already been identified in the UIC leaflet 345 “Environmental specifications for new rolling stock” in 2006.

The criterion for the energy consumption of rolling stock is the total net energy consumed – either via the rail pantograph or from the fuel tank – over a predefined service profile, which is either taken from the future operation of the train (timetable), or according to a standardised typical profile valid for the specific service category of trains.

The general purpose of such Technical Recommendation is to provide a comparative framework to evaluate energy performance values for train sets or locomotives on a common basis, thereby benchmarking and improving the energy efficiency of all types of rail vehicles. In fact, this method secures directly comparable results and represents the real operation of a train.

This recommendation is not suitable for making comparisons with other modes of transportation - or even for comparisons between diesel and electric traction - as it only deals with the energy consumption of the vehicle itself. For the same reason the TecRec 100_001 is not suitable for the evaluation of the carbon footprint of the worldwide transportation system as a whole.

The application of the UIC/UNIFE TecRec 100_001 “Specification and verification of energy consumption for railway rolling stock” is recommended for new projects in the tendering process as basis for the evaluation of the energy performance of new technologies or design options.

3.2.2 TecRec proposal “Technical Specification for a Reversible DC Substation"

Railenergy also delivered a second proposal for a TecRec, which provides a voluntary standard to be followed as a guide when implementing an electrical substation (ESS) in direct current (DC) to improve the line receptivity of DC power supply networks by feeding the train regenerative braking energy to the upstream grid (e.g. AC railway network or national grid) at a higher voltage level. Such TecRec is suitable for newly manufactured ESS as well as for their upgrading and renewal, taking into account the fact that dedicated economic analysis has to be provided. It also provides indications for the design phase in order to maximise energy efficiency by correctly installing this technology.

By following this Technical Recommendation, infrastructure managers (IM) would improve the energy efficiency of their fixed installations, reduce the amount of energy charge, and thus contribute towards a greener environment.

3.3 Tools for the calculation of energy consumption in a defined railway system & Recommendations

The Railenergy calculator (www.railenergy.eu)

The Railenergy calculator is a software-based decision support tool for the assessment of various energy efficiency strategies for the main decision makers in the railway sector.

The tool supports the system integrators assessing technologies to be used in rolling stock and infrastructure components. Likewise, railway operators and infrastructure managers benefit by being able to evaluate the operational, technical and strategic investment opportunities for energy efficiency solutions within procurement, leasing, operation and maintenance of railway systems.

The strategic evaluation is based on a simplified cost-benefit/ cost-effectiveness methodology including a strong lifecycle perspective. The tool enables the definition of the optimal mix of energy efficiency strategies at either vehicle or network level, with respect to both energy efficiency and costs (e.g. investments, payback time) regarding both possible techniques but also the uncertainty in the planning process (future traffic) and tariffs.
The nine steps to obtain the cost-benefit analysis for a specific train service on a defined line or network:

1. Inquiry Start
2. Scope & Target
3. Present Setup
4. Saving Potentials
5. Energy Sources
6. Energy & CO2 Performance
7. Energy Pricing and Life Cycle Costs (LCC)
8. Economic Performance
9. Sensitivity Analysis

By using a consistent methodology throughout the technical, operational and economic assessment phases it is possible for industrial partners to perform transparent and usable screening of any energy efficiency measure. Examples are shown in illustration 2 and 3.

**Energy Savings**

<table>
<thead>
<tr>
<th>Energy savings</th>
<th>Specific energy consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Energy savings chart" /></td>
<td><img src="image2.png" alt="Specific energy consumption chart" /></td>
</tr>
</tbody>
</table>

**Illustration 2: Example of technical results from the Calculator**

<table>
<thead>
<tr>
<th>Total annual energy savings in this inquiry</th>
<th>1.85 GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>In service mode</td>
<td>1.49 GWh</td>
</tr>
<tr>
<td>Out of service mode</td>
<td>356 MWh</td>
</tr>
<tr>
<td>Energy savings in percent</td>
<td>10 %</td>
</tr>
<tr>
<td>In service mode</td>
<td>9 %</td>
</tr>
<tr>
<td>Out of service mode</td>
<td>20 %</td>
</tr>
<tr>
<td>Your energy target</td>
<td>5 %</td>
</tr>
</tbody>
</table>
Cost-benefit results

Illustration 3: Example of economic results from the Calculator
4. The Railenergy Recommendations

Due to historical reasons the map of the European electric rail systems is highly inhomogeneous and therefore no holistic recommendation for energy saving methods in Europe can be provided. Railenergy had examined energy saving potentials in the four different main traction systems of the European continent:

1. Direct Current (DC) Railway Services
2. Alternating Current (AC) Conventional Railway Services
3. Alternating Current AC High-Speed Railway Services
4. Diesel Railway Services

and concluded with strategic recommendations for various service types (like regional traffic or high speed services) and dedicated technologies like the medium frequency transforms the re-use of waste heat as well as operational measures like energy efficient driving or parked train management. It is worth noting that Railenergy offers a benchmarking of energy saving potentials within the existing rail systems but does not recommend a specific traction system.

In the following, recommendations from project discoveries are reported, both for operational measures, thus applicable to all railway systems, and specifically dedicated to railway systems, subsystems (rolling stock, infrastructure), and service types.

Recommendations for Operational Measures

Eco-driving by means of driver training and on-board driving advice systems is highly promising. Saving potentials are between 3% and 10% depending on the actual operational regime and on the complexity of the introduced system.

Energy efficient traffic management (eco-driving level 3) will allow significant reductions in energy consumption in the railway system (between 10% and 14%). The implementation of such systems requires a high degree of cooperation between the different stakeholders.

Parked train management has not been simulated but is a very promising operational measure with a high saving potential (2% - 10%) and comparably low investment costs. It mainly focuses on a more efficient load and temperature management for parked trains.

4.1 Direct Current (DC) Railway Service

4.1.1 Recommendations for Rolling stock

Some promising technologies can be applied during refits for existing rolling stock, e.g. optimum motor and converter control (flux control, PWM (Pulse Width Modulation) patterns, auxiliaries). This can often be done by software, sometimes with minor changes in the hardware (e.g. additional
contactors). Many of these changes are highly profitable and have short payback times; hence they can also be applied also to rolling stock with limited life time expectation.

All on-board measures (except on-board energy storage) are similar to AC trains. It is recommended to use TecRec 100_001 “Specification and verification of energy consumption for railway rolling stock” for new projects, as a background for evaluation of technologies or design options.

4.1.2 Recommendations for Infrastructure

It is recommended to integrate costs for energy losses in substations and the catenary system into life cycle cost (LCC) calculations for any change to the DC power supply systems. Corresponding results will influence the optimum design of wire cross sections and selection of materials (“reduced line impedance”).

The integration of reversible substations and / or trackside energy storage units shall be considered for networks with medium traffic density. Their economical evaluation can only be made for individual cases, under precise consideration of network topology, catenary system impedances as well as rolling stock (train mass, speed) and operation (timetable). Measures could be combined for optimal results, e.g. strengthening the catenary system by additional feeders, plus one reversible substation in an ideal location. Rising energy prices may promote such solutions, which are often at the limit of probability today.

Special systems like the 2 x 1.5 kV DC system may be of interest only for increase of capacity of the power supply system (upgrade of existing systems when traffic is increased). They are always in competition with additional substations and / or lowering catenary impedances. The profitability of the 2 x 1.5 kV DC system must be carefully evaluated against alternative solutions, when energy savings are more an interesting side effect than the original reason for such investments.

4.2 Alternating Current (AC) Conventional Railway Services

4.2.1 Recommendations for Rolling stock

Motor flux management is a very promising efficiency technology with a saving potential between 2 % and 4 %. Since software changes are the only thing required to implement this technology, it is very profitable and presents short payback time. Equally promising is the energy management of auxiliaries with saving potentials between 2 and 6 %. Investment costs and complexity of changes are comparably low, thus resulting in short payback times. These technologies can also be applied also during refits for existing rolling stock.

Medium frequency traction transformer is an interesting technology to follow. It has an energy saving potential between 1 % and 6 %. Investment costs are relatively high and open questions remain.

4.2.2 Recommendations for Infrastructure

As AC systems - and especially the modern 25 kV systems - are very efficient in terms of energy use, the improvement options are rather limited. Due to relatively high effort and investment costs for infrastructure measures, payback times would be by far too long, if the measures would be implemented for energy efficiency reasons only. Nevertheless, it is suggested to include potential energy saving measures like the reduction of the overhead line impedance in the LCC assessment of upgrading measures for the catenary or for the dimensioning of new AC supply systems.

4.3 Alternating Current AC High-Speed Railway Services

4.3.1 Recommendations for Rolling stock

Recommendations for high-speed rail services fall into the two following parts
• Measures for the existing rolling stock fleet
• Measures for new rolling stock

**Measures for the existing rolling stock fleet**

*Upgrade with MV loads management and Converter control technology (applied during vehicle coasting)*

The proposed technology concerns optimized management of MV (Medium Voltage) loads for cooling systems. When the maximum cooling performance are not requested, fans and pumps can operate at reduced speed or turned off in order to reduce the energy consumption and the environmental impact (reduction of noise, dust hoisting, ventilation channels clogging in case of snow).

*Reuse of converters’ energy losses*

Part of the waste energy produced by operation of power and auxiliary converters, braking rheostat, main transformer and inductors can be recovered for a possible reuse on the vehicle by means of a diathermic oil heat exchange. A hydraulic system provides for the circulation and control of the diathermic oil for the heat recovery. Higher saving potential is expected for EMU (Electric Multiple Units) towards Loco, because of a higher reuse of waste energy for coaches heating/cooling.

**Measures for new rolling stock**

*Medium frequency energy distribution*

This technology replaces a classical transformer with four-quadrant (4Q) converter connected for more complex high voltage power electronics. The key differences to a conventional transformer are:
- reliability, availability and redundancy must be considered in a much deeper way
- complexity and effort increases with line voltage (25 kV versus 15 kV)
- relatively high low-load losses and low high-load losses
- overload capability is limited

Saving potentials are highly dependent on drive style (coasting running, all-out-mode), tightness of schedule and chosen line. For comparability same operational cycle must apply.

4.3.2 Recommendations for Infrastructure

Since AC systems and especially the modern 25 kV systems are already energy efficient, the improvement options are rather limited. Due to relatively high effort and investment costs for infrastructure measures, payback times would be by far too long, if the measures would be implemented for energy efficiency reasons only. Nevertheless, it makes sense to include potential energy saving measures like the reduction of the overhead line impedance in the LCC assessment of upgrading measures for the catenary or for the dimensioning of new AC supply systems.

4.4 Diesel Railway Services

4.4.1 Recommendations for Rolling stock

Motor flux management is a very promising efficiency technology with a saving potential between 0.5 % and 1 %. Since it can be done by software changes only, it is very profitable and has a short payback time. Equally promising is the energy management of auxiliaries with saving potentials between 2 and 6 %. Investment costs and complexity of changes are comparably low, thus resulting in short payback times. These technologies can be applied also during refits for existing rolling stock.
5. The Railenergy Vision

The Railenergy vision is a step-by-step approach towards a modern, energy efficient railway system including rolling stock and infrastructure and their interfaces, taking well into account the historically developed limitations and restrictions like different catenary systems, gauge, rail-wheel etc.

In the figure below the three Railenergy scenarios
- Business-as-usual
- Coordinated Efficiency Efforts
- Sector-wide Integration
are illustrated. Each scenario is described by the interaction between technological and operational measures.

Even for the “Business-as-usual” strategy characterised by mainly independent implementation of technical and operational efficiency measures the average energy efficiency improves until 2020. But due to a lack of coordination on the one hand and little focus on systemic optimisation the efficiency gains are small and large potentials remain unexploited.

The “Coordinated Efficiency Efforts” strategy can be described a common approach of three of the main stakeholders of the project - the train operating companies, infrastructure managers and system integrators - to increase energy efficiency in a coordinated effort. This effort focuses on simultaneously improving technological and operational performance and therefore allowing for the exploitation of a larger efficiency potential until 2020.

Railenergy can be seen as a pilot project for the implementation of this energy efficiency strategy. Based on the first calculations of savings from technologies and operational measures, it seems plausible to achieve at least 6% of energy savings throughout the entire European railway system. In particular, by using the above described scenarios, with specific exploitation rates, calculations show that an average relative energy saving of more than 7% can be reached.

The continuative long term strategy “Sector-wide Integration” is distinguished by a harmonised and sector-wide approach to energy efficiency where the strategies and actions of all relevant stakeholders including the railway undertakings, infrastructure managers and system integrators as well as European, national and regional regulative bodies and energy suppliers are coordinated and integrated. In addition to optimising energy efficiency on the system level by joint implementation of innovative technical and operational measures, this proactive strategy aims at systematically removing barriers and improving political, institutional and contractual framework conditions and thus allowing for the optimum exploitation of efficiency potentials.