The Evaluation Tool

1 Description of criteria and values

The following table gives an introduction into the Evaluation tool. All evaluation criteria are explained and the evaluation procedure is made as transparent as possible.

Criterion	Explanation	Possible values	Explanation of the values
Technology field / underlying saving strategy	The technology field (e.g. traction technologies) to which the described technology belongs or the corresponding saving strategy is specified.	Mass reduction Aerodynamics and friction Space utilisation Traction technologies Regenerative braking and energy storage Innovative traction concepts and energy sources Non-conventional trains (Maglev etc.) Comfort functions Energy efficient driving Load factor and flexible trains Energy measurement and documentation Management and organisation	-
General information			
Description	The technology or measure is described in detail. This includes (as far as applicable) • underlying principle	-	-

	• technical details • relation to energy efficiency • fields of application • manufacturers In case the technology is not railway specific, the description covers both the technology in a general context and its application in railways		
General criteria			
Status of development	Status of development of railway application. For the status of development of the corresponding technology outside railways cf. *Application outside railways - Status of development*	Concept	-
		Research & experiments	
		Prototype	
		Test series	
		In use	
Time horizon for broad application	Period of time, until technology is expected to reach *broad* application in railways (*broad* = approximately 10 % of fleet segment to be considered for application)	In > 10 years	
		5 – 10 years	
		2 - 5 years	
		in < 2 year	
		now	
Expected technological development	The technological development potential of the *railway* application is specified along the following lines: • Performance	Highly dynamic	Quantum leaps expected through new materials or new construction principles. At the same time high development dynamics often imply low maturity at present and high degrees of uncertainty.
		Dynamic	Considerable optimisation expected mainly on the basis of present materials and construction principles

	• Energy efficiency • Mass and volume • Reliability (lifetime, liability to defect, complexity, maintenance) The main technological shortcomings and hot spots of the *railway* application are specified. For the development dynamics outside railways cf. *Application outside railways - Expected technological development.*	Basically exploited	Only minor optimisation expected
Motivation	Principal motivation for an introduction of the technology is given.	-	-
Benefits (other than environmental)	Benefits and positive side effects of the technology are specified such as: • Passenger comfort • Reduced wear • Cost savings other than energy costs • Safety • Capacity Environmental effects are described in detail in section *Environmental criteria* and are therefore excluded here.	None	There is virtually no benefit other than energy efficiency (or other environmental issues)
		Small	There are some minor non-environmental benefits, but main motivation for implementation lies in energy efficiency.
		Medium	The technology offers some additional benefits besides energy efficiency.
		Big	The technology is mainly driven by strong benefits other than energy efficiency.
Barriers	Barriers impeding or slowing down technology implementation are identified, such as • Costs	None	There are virtually no barriers impeding the introduction of the described technology.
		Low	Existing barriers are small and can be overcome with low efforts.

	• Acceptance by personnel (drivers etc.) • Acceptance by management • Acceptance by manufacturers • Technological shortcomings or uncertainties • Complexity & downtime • System incompatibility • Safety requirements	Medium	Overcoming of barriers requires substantial financial, R&D or communication efforts.
		High	There are major barriers, which can be overcome only at very high costs often involving structural changes within the company or technological infrastructure.
Success factors	Influence factors for a successful implementation are described. This may include a variety of internal and external issues such as • Policy and economic framework (market deregulation, energy prices etc.) • Developments in relevant mass markets • R&D efforts in industry and railways including feasibility studies • Dependence on other technological or strategic decisions within railways or manufacturers • Communication policy to improve acceptance	-	-
Applicability for railway segments	The railway segment is specified to which technology is applicable. Refit options are discussed if applicable. The applicability of the technology is quantified by using a reference fleet	Low	<10% of typical fleet
		Medium	10-20% of typical fleet

	(cf. Section 3).	High	> 20% of typical fleet
Type of traction	Applicability to different traction systems is specified. Applicability to one traction type does not necessarily imply applicability to all vehicles of this traction type.	electric - AC	
		electric – DC	
		diesel	
Type of transportation	Applicability to passenger or freight operation is specified. Applicability to one operation field does not necessarily imply applicability to all vehicles in this field.	suburban lines	
		regional lines	
		main lines	
		high speed	
		freight	
Grade of diffusion into railway markets	Degree of market penetration is specified describing both the *Diffusion into relevant segment of fleet* and the *Share of newly purchased stock* equipped with the technology. The percentages given refer to the relevant railway segment only (cf. *Applicability for railway segments*).		
Diffusion into relevant segment of fleet		*0 %* *< 5 %* *5 – 20 %* *> 20 %*	-
Share of newly purchased stock		*0 %* *< 20 %* *20 – 50 %* *> 50 %*	-
Market potential (railways)	The market for the respective technology is evaluated. The market	None	Market potential in the order of less than 2 % of the total market for rail vehicles

	potential essentially results from the difference between the applicability (cf. *Applicability for railway segments*) of a technology and the current market penetration (cf. *Grade of diffusion into railway markets*). This difference is evaluated as a percentage of the total market for rail vehicles in a time frame of 30 years (being the typical lifetime of rolling stock).	Low	Market potential in the order of 2-10 % of the total market for rail vehicles
		Medium	Market potential in the order of 10-50 % of the total market for rail vehicles
		High	Market potential in the order of more than 50 % of the total market for rail vehicles
Example	An example of implementation (at least on a prototype level) is specified. As far as available, details including user experience, success factors, achieved energy savings etc. are given.	-	-
Environmental criteria			
Energy efficiency potential for single vehicle	The energy saving effect for a single vehicle is specified. This is done considering the following points: • In a first step the direct effect (e.g. mass reduction) of the technology or measure is quantified. • In a second step, elasticities (if applicable) (cf. Section 2) are used to derive the effect on total energy consumption of the vehicle. The total energy consumption includes the energy required for both traction and comfort functions. • Owing to different application contexts, the total energy efficiency potential is usually given as a range of possible values from best to worst case.	< 2 % 2 – 5 % 5 – 10 % > 10 %	

	• As far as possible, this saving potential is differentiated according to traction and transportation type or application context. The most important factors of influence such as vehicle type, timetable or topography are discussed.		
Energy efficiency potential throughout fleet	The system-wide energy saving potential is identified. Assuming a 100% diffusion into the relevant fleet segment, the fleet-wide saving potential for the reference fleet (Section 3) is derived. This value describes what can be achieved by introducing a specific technology but does not tell anything about the *probability* or *speed* of a fleet-wide implementation.	< 1 % 1 – 2 % 2 – 5 % > 5 %	
Other environmental impacts	Environmental effects other than energy efficiency are discussed. This includes: • pollution • hazardous substances • waste • passenger and personnel health • noise • long-term availability of energy	Negative	The balance of environmental effects (other than energy efficiency) add up to a negative effect.
		Neutral	The balance of environmental effects (other than energy efficiency) add up to a neutral effect.
		Positive	The balance of environmental effects (other than energy efficiency) add up to a positive effect.

	• resources • area consumption From these effects, an overall evaluation of environmental impacts (apart from energy efficiency) is derived.	Ambivalent	The outcome of the balance of environmental effects (other than energy efficiency) is highly dependent on the framework conditions (recycling rates, production processes etc.)
Economic criteria			
Vehicle - fix costs	The additional investment for the technology is specified. In the case of new vehicles this implies comparing to a reference vehicle. In the case of refurbishment measures, the costs for the required components and for refurbishment measure itself are specified.	None	No vehicle fix costs.
		low	< 1 % of initial investment of the vehicle
		medium	1 - 5% of initial investment of the vehicle
		high	> 5% of initial investment of the vehicle
Vehicle - running costs	Vehicle running costs directly caused or influenced by technology are identified such as: • Energy costs • Maintenance • Costs for operating personnel	Significant reduction	Strong cost reductions through energy savings (= energy efficiency per vehicle > 2%) and or major additional reductions in running costs (e.g. maintenance)
		Minor reduction	Minor cost reductions through energy savings (= energy efficiency per vehicle < 2%) and no major additional reductions in running costs (e.g. maintenance)
Infrastructure - fix costs	Additional infrastructure required by use of technology is identified and ranked by relevance. This also includes all fix costs not related to the vehicle such as training programmes, R&D etc.	None	No infrastructure investment needed
		Low	Only minor adjustments in existing infrastructure required
		Medium	Considerable investment in additional infrastructure components
		High	Major investment for area-wide roll-out of new infrastructure components
Infrastructure - running costs	Running costs of additional infrastructure or changed running costs of existing are discussed.	Reduced Unchanged Increased	-

Scale effects	Scale effects refer to price decreases due to mass production. In most cases it proves impossible to quantify these effects. Main qualitative indicators are the chances to follow external mass markets or reach critical mass within railway markets	None	No mass markets to be followed and no critical mass to be reached within railway markets
		Low	No mass markets to be followed and only minor scale effects for large vehicle series
		Medium	No mass markets to be followed, but critical mass may be reached within railway markets
		high	Mass markets to be followed
Amortisation	Period of time to pay back initial investment through reduced running costs	< 1 year 1 – 2 years 2 – 5 years > 5 years	
Application outside railways			
Status of development outside railway sector	Status of development of the technology outside the railway context.	Concept	
		Research & experiments	
		Prototype	
		Test series	
		In use	
Time horizon for broad application outside railway sector	Period of time, until technology will reach *broad* application in at least one of the application fields (*broad* = approx. 10 % of the market segment to be considered for application)	In > 10 years In 5 – 10 years In 2 – 5 years In < 2 years Now	
Expected technological development	The technological development potential outside the railway sector is specified along the following lines:	Very dynamic	Quantum leaps expected through new materials or new construction principles. At the same time high development dynamics often imply low maturity at present and high degrees of uncertainty.
	• Performance	Dynamic	Considerable optimisation expected mainly on the basis of present materials and construction principles

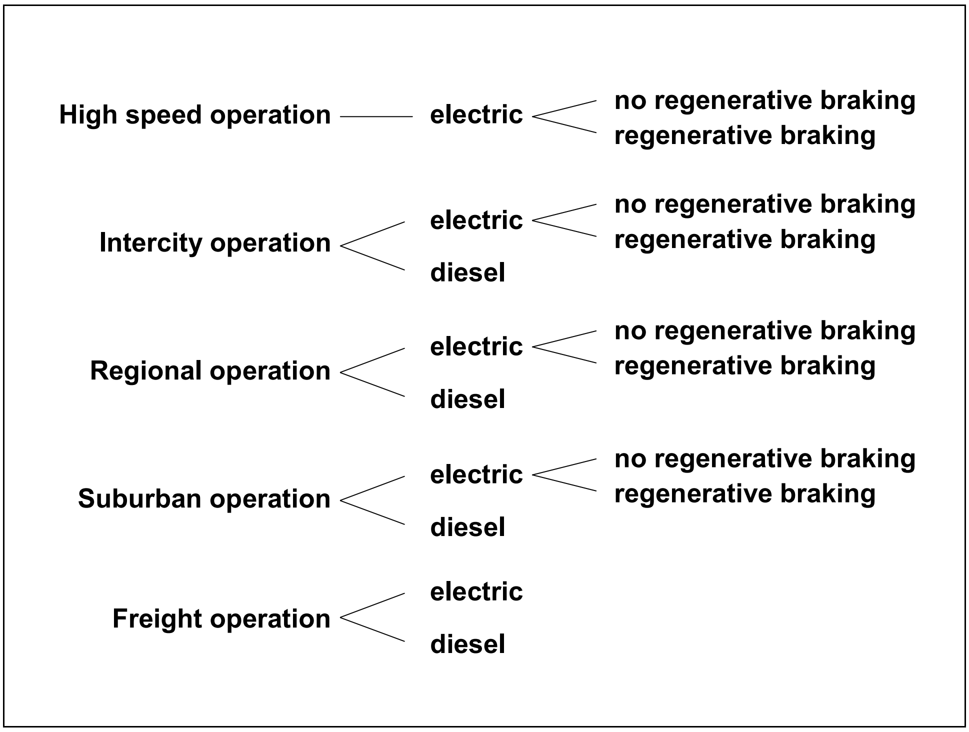
	• Energy efficiency • Mass and volume • Reliability (lifetime, liability to defect, complexity, maintenance) The main technological shortcomings and hot spots are specified.	Basically exploited	Only minor optimisation expected
Market potentials outside railway sector	The general market potential of the technology outside railways is estimated.	None	No market
		Small	Product meets a niche market (in the order of < 1 % of truck market)
		Medium	Product meets a big but no mass market (in the order of 1 - 10 % of truck market)
		High	Product meets a mass market (in the order of > 10 % of truck market)
Overall rating			
Potential	The different criteria of the above technology evaluation are condensed into an overall potential. This is done according to a key taking into consideration the following criteria: General criteria: • Benefits • Barriers Environmental criteria:	Very promising	For details cf. Section 4
		Promising	
		Interesting	

	• Energy efficiency potential throughout fleet Economic criteria: • Vehicle - fix costs • Vehicle - running costs • Infrastructure - fix costs The other criteria are taken as a qualitative background in order to modify the result of the above quantitative approach if needed. The details of the procedure are laid out in Section 4.	Not promising	
Time horizon	The time horizon for technology implementation is specified. This refers to the time horizon for the railway use of the technology. This criterion is therefore not identical with the *Time horizon for broad application*.	short-term	< 2 years
		mid-term	2 - 10 years
		long-term	> 10 years

2 The concept of energy elasticities

The energy consumption of a train is influenced by a number of parameters such as mass, efficiency of traction equipment, running resistance and comfort functions. Most energy efficiency measures and technologies influence one or several of these parameters. The concept of elasticities helps to calculate the corresponding effect on the total energy consumption of the train. For example, an elasticity of energy consumption with respect to running resistance of 0,4 means that reducing running resistance by 10%, cuts energy consumption by 0,4 $\times$ 10 % = 4 %.

Obviously these elasticities heavily depend on the individual train and operation context. However, a number of typical operation contexts can be given which yield good estimates for a wide range of real train runs. Within in the EVENT project the following 13 train/operation types were chosen as representative:



For these 13 types the elasticities of total energy consumption with respect to mass, running resistance and efficiency of the power train were calculated. The results are given in the following table:

	Traction	Recuperation	Elasticities with regard to		
			traction efficiency	mass	running resistance
High speed train	**electric**	**no**	1,00	0,17	0,63
		yes	1,11	0,12	0,66
Intercity train	**electric**	**no**	1,00	0,19	0,61
		yes	1,12	0,14	0,65
	diesel	**-**	1,00	0,19	0,61
Regional train	**electric**	**no**	1,00	0,52	0,27
		yes	1,33	0,44	0,31
	diesel	**-**	1,00	0,52	0,27
Suburban train	**electric**	**no**	1,00	0,64	0,15
		yes	1,42	0,57	0,18
	diesel	**-**	1,00	0,64	0,15
Freight	**electric**	**no**	1,00	0,29	0,71
	diesel	**-**	1,00	0,29	0,71

Example: *Medium frequency transformer*

Efficiency of medium frequency transformers: > 94%

Efficiency of conventional transformers: ~ 92%

This corresponds to an increase of efficiency of the transformer of 2 – 3%. This efficiency gain directly translates into an equal gain in the overall efficiency of the power train (since it is the product of the efficiencies of the individual components). This yields the following table specifying in the last column the effect on the total energy consumption for the individual train classes.

	Traction	Brake energy recovery	Effect on efficiency of power train	Elasticity with regard to efficiency of power train	**Effect on total energy consumption**
High speed train	Electric (16,7 Hz)	no	2 – 3 %	1,00	**2 – 3 %**
		yes		1,14	**2 – 3 %**
Intercity train	Electric (16,7 Hz)	no		1,00	**2 – 3 %**
		yes		1,15	**2 – 3 %**
Regional train	Electric (16,7 Hz)	no		1,00	**2 – 3 %**
		yes		1,43	**3 – 4 %**
Suburban train	Electric (16,7 Hz)	no		1,00	**2 – 3 %**
		yes		1,55	**3 – 5 %**
Freight	Electric (16,7 Hz)	no		1,00	**2 – 3 %**
				Range:	**2 – 5 %**

Source: IZT

3 The reference fleet

For some of the evaluation criteria, fleet-wide effects are estimated. This of course requires the definition of a "typical" railway fleet (concerning diesel vs. electric traction and passenger vs. freight operation), which serves as a reference frame for calculations. The following reference fleet was defined:

	Electric	Diesel	Sum
Passenger operation	55%	10%	65% (regional/main line: 45%/20%)
Freight operation	30%	5%	35%
Sum	85%	15%	100%

Source: IZT

Weighting issues

The most natural approach to defining a reference fleet would be a vehicle count. However, it is hardly reasonable to count one locomotive or one passenger coach with the same weight as one high-speed train or DMU. Since the target quantity of the EVENT project is energy efficiency and fleet-wide effects eventually refer to this quantity, it was decided to take energy consumption as the weighting criterion for the individual fleet segments. When counting diesel and electric traction an additional weighting issue arises: how to compare diesel and electric power consumption. Two approaches seem reasonable:

1. take costs as a weighting factor
2. take primary energy as a weighting factor

The first option is closer to the economic reality of railway operators, the second one is more relevant in an environmental perspective. Since energy prices (both diesel and electric power) vary extremely between railway companies, the cost approach is hardly feasible. Therefore a primary energy perspective was adopted by this study.

The concept of primary energy refers to the total energy consumed along the entire energy chain. In the case of diesel traction this includes the whole process of exploiting and refining and producing of diesel from crude oil as well as the transport of diesel fuel to the locomotive tank. In the case of electric traction, the efficiencies of power plants and the pre-chains of all the involved fossil energy sources based on the national energy mix are taken into account when calculating the primary energy.

Derivation of an "average" fleet

Naturally, there are pronounced national differences in the composition of railway fleets. Taking primary energy as a reference parameter introduces differences in national energy mixes as an additional factor. However, a closer look at some of the major European railways shows that for the purposes of the EVENT project, a reference fleet can be defined which is sufficiently accurate for most European railway companies in order to give rough estimates on system-wide effects. The reference fleet was derived by comparing those railway companies for which primary energy figures are available (complete figures from SBB, Trenitalia, Deutsche Bahn and DSB, partial figures from SNCF). Given the similarities between the big railway companies in Italy, France and Germany, average values were derived from their fleets (expressed in terms of primary energy consumption). This procedure has the drawback of not taking into account the specific national situation in countries such as Denmark (dominant role of diesel traction) or Switzerland (no diesel traction). However, it is argued that it is preferable to have a reference fleet which properly reflects the situation in many countries than to have one that is the average taken across all countries but does not correctly represent the situation in any country. Nevertheless it is important to keep in mind the limitations of the reference fleet given above. This means that those evaluation criteria, which are calculated on the basis of a reference fleet (e.g. energy efficiency potential throughout fleet) have to be treated with great care since some railways do differ considerably from the reference fleet defined for this evaluation tool. Despite these limitations, we believe that the definition of a reference fleet helps to give a reasonably accurate estimate on fleet-wide effects.

4 The overall rating

In order to set up a quantitative procedure for evaluating the Overall potential of a technology, three main implementation factors (with corresponding criteria) have to be considered:

- Energy efficiency performance (Criterion: *Energy efficiency potential throughout fleet*)
- Benefits and constraints (Criteria: *Benefits (other than environmental), Barriers*)
- Economic factors (Criteria: *Vehicle - fix costs, Vehicle - running costs, Infrastructure - fix costs*)

This selection does not cover the whole range of criteria used in the evaluation tool. However the criteria were chosen in such a way that a comprehensive view of the technology is guaranteed:

- The main key factors are included.
- Some of the criteria considered have in itself an accumulative character such as *Benefits* or *Barriers* and therefore cover a variety of issues.

For a given technology an overall potential is derived from these criteria as follows:

Step 1: Values assigned to each criterion

The possible values of the individual criteria are represented by numbers from 1 to 4 according to the following key:

Criterion	Numbers assigned to the individual values
Benefits (other than environmental)	None = 1
	Small = 2
	Medium = 3
	Big = 4
Barriers	None = 4
	Low = 3
	Medium = 2
	High = 1
Energy efficiency potential throughout fleet	< 1 % = 1
	1 – 2 % = 2
	2 – 5 % = 3
	> 5 % = 4
Vehicle - fix costs	None = 4
	low = 3
	medium = 2
	high = 1
Vehicle - running costs	Significant reduction = 4
	Minor reduction = 2
Infrastructure - fix costs	None = 4
	Low = 3
	Medium = 2
	High = 1

Step 2: Point score

For each technology the total number of points is calculated by adding up the points of the individual criteria (*Energy efficiency* is accounted for with a weighting factor of 2):

Total score = Benefits + Barriers + 2 x Energy efficiency potential + Vehicle fix costs + Vehicle running costs + Infrastructure fix costs

Step 3: Overall potential

Step 2 yields a number between 8 and 28. From this total score an overall potential is derived according to the following key:

< 14	→	Not promising
14 - 16	→	Interesting
17 - 19	→	Promising
> 19	→	Very promising

Step 4: Plausibility check

The result is checked for plausibility using the criteria not considered in the algorithm as a qualitative background. In a limited number of cases, this step will lead to a modification of the result from Step 3.

Note:

The technology database contains a number of energy efficiency strategies that are concepts rather than technologies (e.g. LCC-oriented procurement). It is evident that for these database entries the above quantitative procedure involving such criteria as *Vehicle fix costs* is not applicable. In these cases the overall potential is evaluated in a more heuristic way.