FROM LAB TO RAIL:
A COMBINED MECHANICAL-LCA MATRIX FOR FIBER-REINFORCED POLYMERS

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Background

The DLR Rolling Stock (RoSto) project is developing innovative technologies for the design of next-generation railway vehicles. The development process for such vehicles is subject to complex requirements, particularly in the areas of aerodynamics, fire safety, mechanics, and environmental sustainability. To ensure an optimized selection of materials as early as the initial design phase, it is necessary to develop an integrated selection matrix that systematically takes ecological and mechanical criteria into account.

Analysis of the individual components

To explain the structure of the mechanical-LCA matrix, the mechanical properties of the selected materials are first considered separately from their potential environmental impacts.

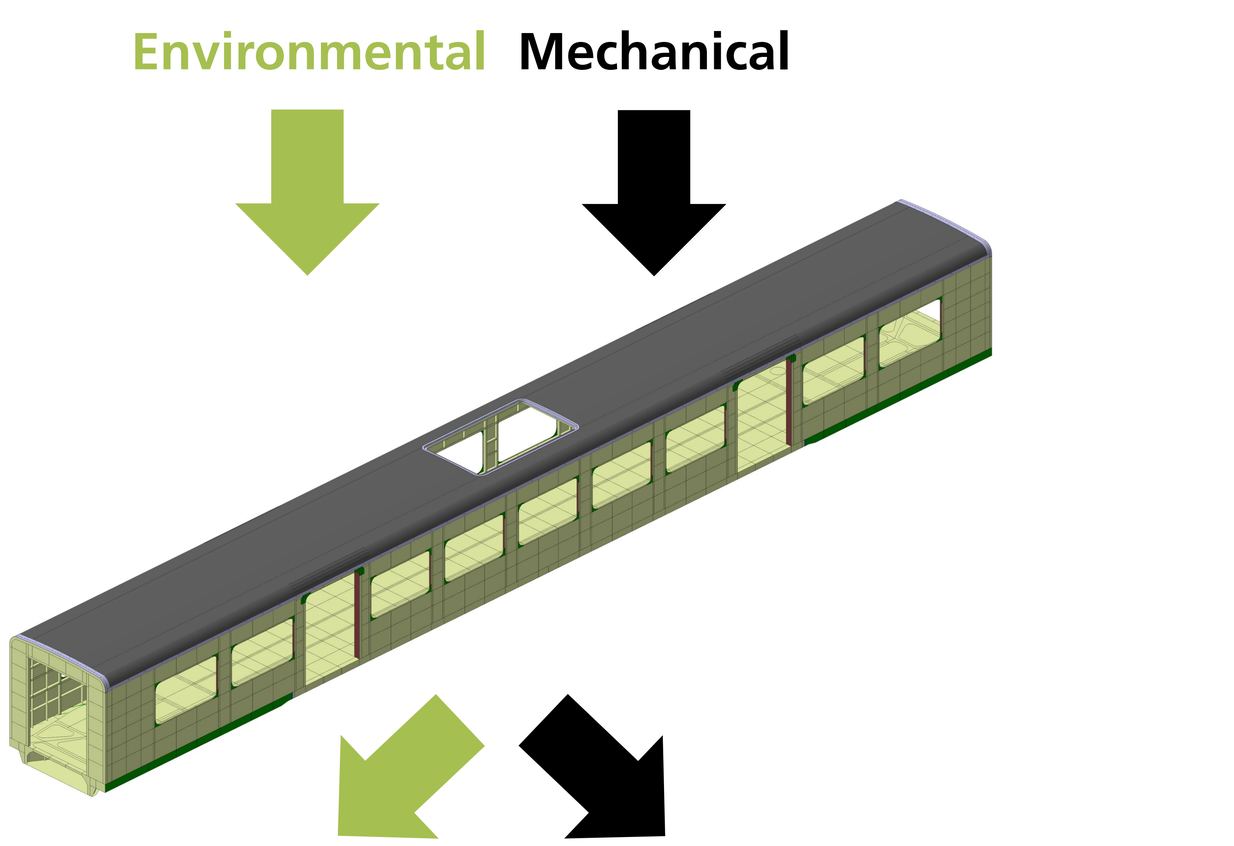
- In fiber-reinforced composites, the fibers typically determine the strength. Therefore, the tensile strength of fibers and resins is examined as an example.
- Although no direct composite properties are available, this data can enable a preliminary selection of suitable materials
- In this early decision-making phase, a screening LCA provides additional value. Materials with unfavorable impact indicator results can already be excluded.

Assessment of the composite structure

Once the material screening has been completed, the mechanical and environmental properties of the composite are examined in detail. In this example, laboratory-scale flexural tests were used to provide representative measurements of the flexural strength, whilst a specifically tailored LCA was carried out for each of the resin systems used. The results can be compared graphically, allowing mechanical and environmental parameters to be visualized simultaneously and their interdependencies to be analyzed.

Provision of the selection matrix

To enable a holistic assessment of mechanical and environmental performance indicators, the two-dimensional selection matrix is expanded. First, the mean values of the mechanical performance indicators are calculated. A high value indicates better mechanical performance. Environmental impact indicators are presented as the relative deviations from the maximum value. The resulting negative deviation is converted into a positive benefit, which increases the material's final score. To increase the flexibility of material selection, the user can weight each parameter group individually and thus specifically prioritize certain aspects (e.g. strength versus carbon footprint). Finally, an overall score is calculated, where a higher value indicates a better overall rating of both categories. This approach enables a transparent and customizable decision-making process for sustainable composite materials.



	Mechanical Properties	Epoxy Resin A + Flax Fiber	Epoxy Resin A + Glass Fiber	Epoxy Resin B + Flax Fiber	Epoxy Resin B + Glass Fiber	Unit
Mechanical	*Flexural Modulus*	*59%*	*100%*	*49%*	*86%*	*MPa*
	Specific Flexural Modulus	90%	100%	75%	86%	GPa
	Flexural Strength	*21%*	*78%*	*19%*	*100%*	*MPa*
	Specific Flexural Strength	33%	78%	29%	100%	MPa
Environmental	**Environmental Indicators**					**Reference unit**
	Acidification	100,0%	71,6%	68,7%	54,3%	mol H+-Eq
	Climate change	95,0%	100,0%	67,8%	84,2%	kg CO2-Eq
	Ecotoxicity: freshwater	86,6%	58,9%	100,0%	65,4%	CTUe
	Energy resources: non-renewable	98,7%	100,0%	69,7%	82,8%	MJ, net calorific value
	Eutrophication: freshwater	100,0%	93,2%	56,3%	68,2%	kg P-Eq
	Eutrophication: marine	100,0%	34,7%	93,5%	31,9%	kg N-Eq
	Eutrophication: terrestrial	100,0%	47,2%	90,6%	42,7%	mol N-Eq
	Human toxicity: carcinogenic	99,2%	100,0%	69,9%	82,4%	CTUh
	Human toxicity: non-carcinogenic	17,3%	100,0%	2,6%	92,2%	CTUh
	Ionising radiation: human health	70,7%	100,0%	47,5%	86,6%	kBq U235-Eq
	Land use	100,0%	54,3%	50,0%	26,0%	dimensionless
	Material resources: metals/minerals	87,3%	100,0%	36,0%	70,9%	kg Sb-Eq
	Ozone depletion	65,2%	100,0%	42,2%	86,8%	kg CFC-11-Eq
	Particulate matter formation	100,0%	62,9%	79,7%	52,0%	disease incidence
	Photochemical oxidant formation	89,3%	100,0%	62,3%	84,8%	kg NMVOC-Eq
	Water use	100,0%	13,0%	88,5%	7,2%	m3 world Eq deprived
Calculated Average	*Mechanical Properties*	*61,7%*	*89,0%*	*51,8%*	*92,8%*	*positive*
	Environmental Indicators	*88,1%*	*77,2%*	*64,1%*	*63,6%*	*negative*
Weighting	Mechanical Properties	61,7%	89,0%	51,8%	92,8%	**50,0%**
	Environmental Indicators	11,9%	22,8%	35,9%	36,4%	**50,0%**
Scoring	**Total Score**	**36,8%**	**55,9%**	**43,9%**	**64,6%**	