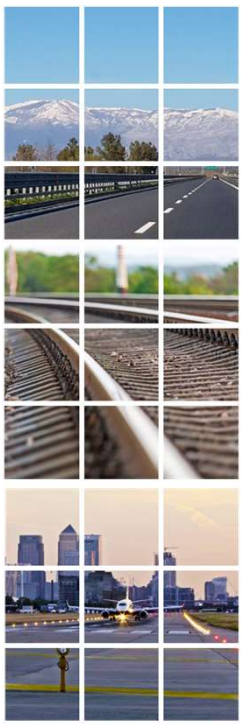
Società Italiana Infrastrutture Viarie
XIX International SIIV Summer School , Perugia 4th - 8th September 2023

Transportation Infrastructures towards Green Transition

Life Cycle Analysis for concrete sleepers: methodology and implementation



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Modes of Transport

Rail sector

"The rail sector can provide substantial benefits for the energy sector as well as for the environment. By diversifying energy sources and providing more efficient mobility, rail can lower transport energy use and reduce carbon dioxide and local pollutant emissions."

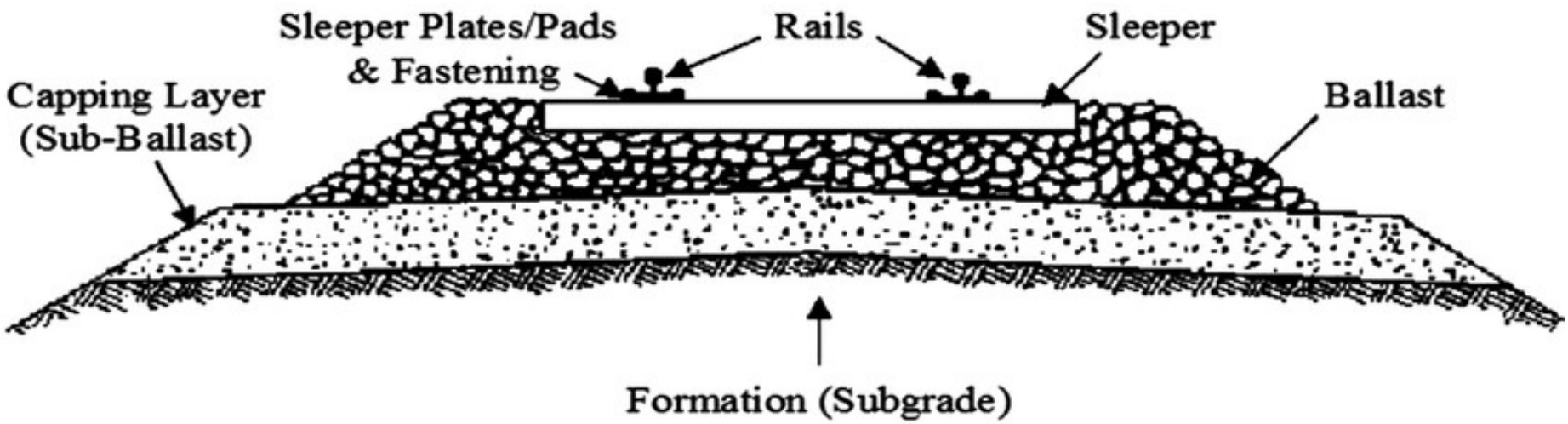
Dr Fatih Birol, International Energy Agency (IEA) Executive Director

The impacts of transport on energy consumption

- Vehicle manufacture, maintenance, and disposal
- Vehicle operation
- Infrastructure construction, maintenance and disposal
- Management of transport operations
- Energy production and trade

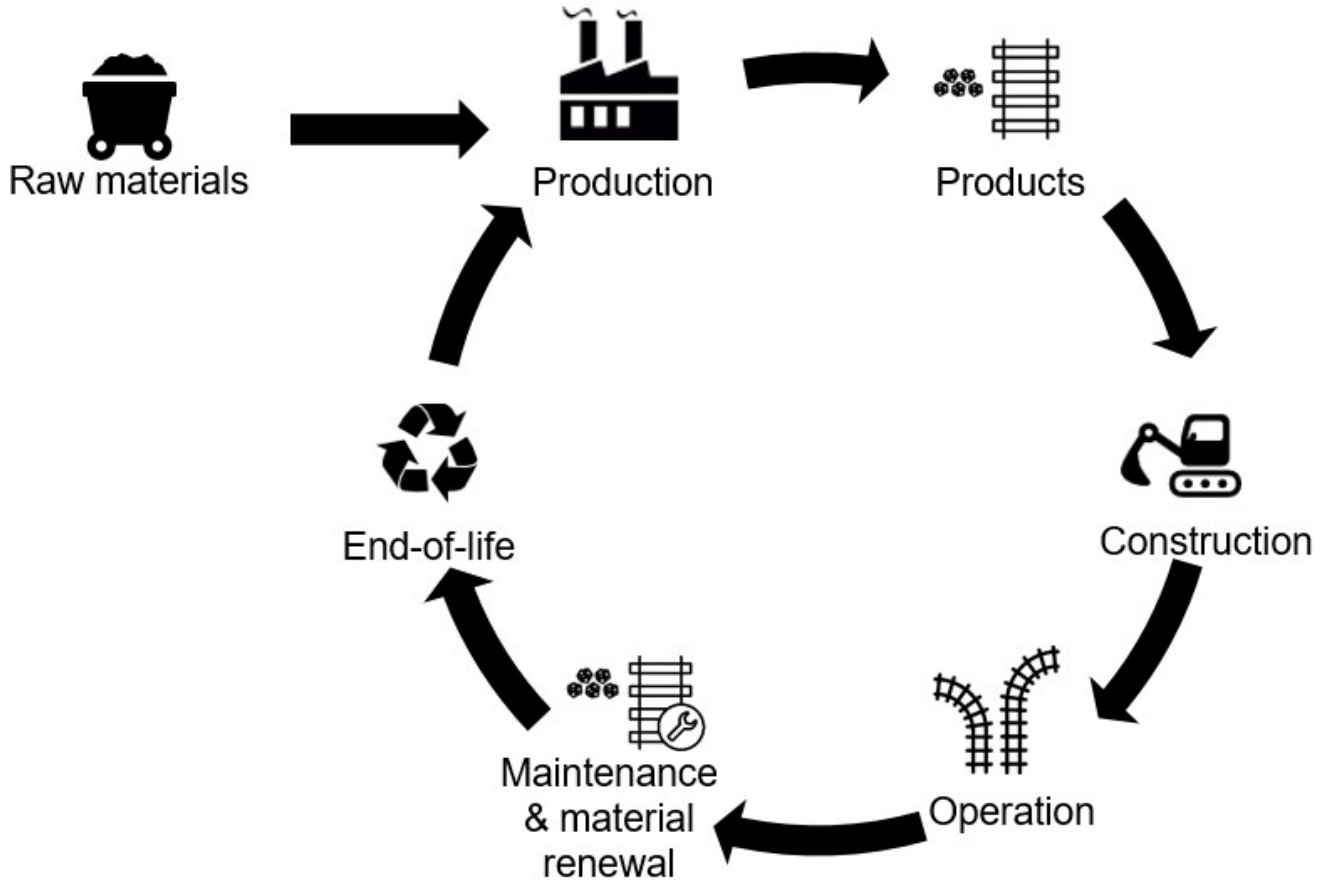
How much does it **cost** to **build** a **railway**?

Railway



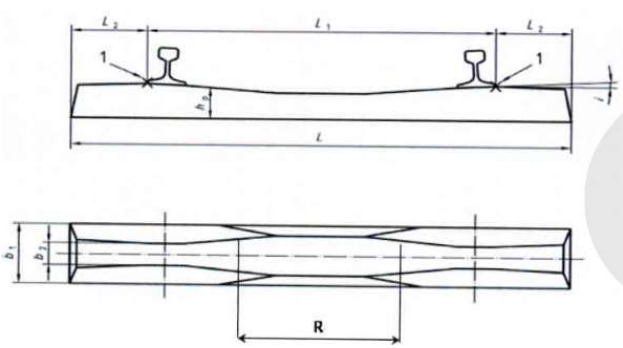
Cross-section of a Typical Railway Track

Environmental impact of rail freight transport



Concrete sleepers

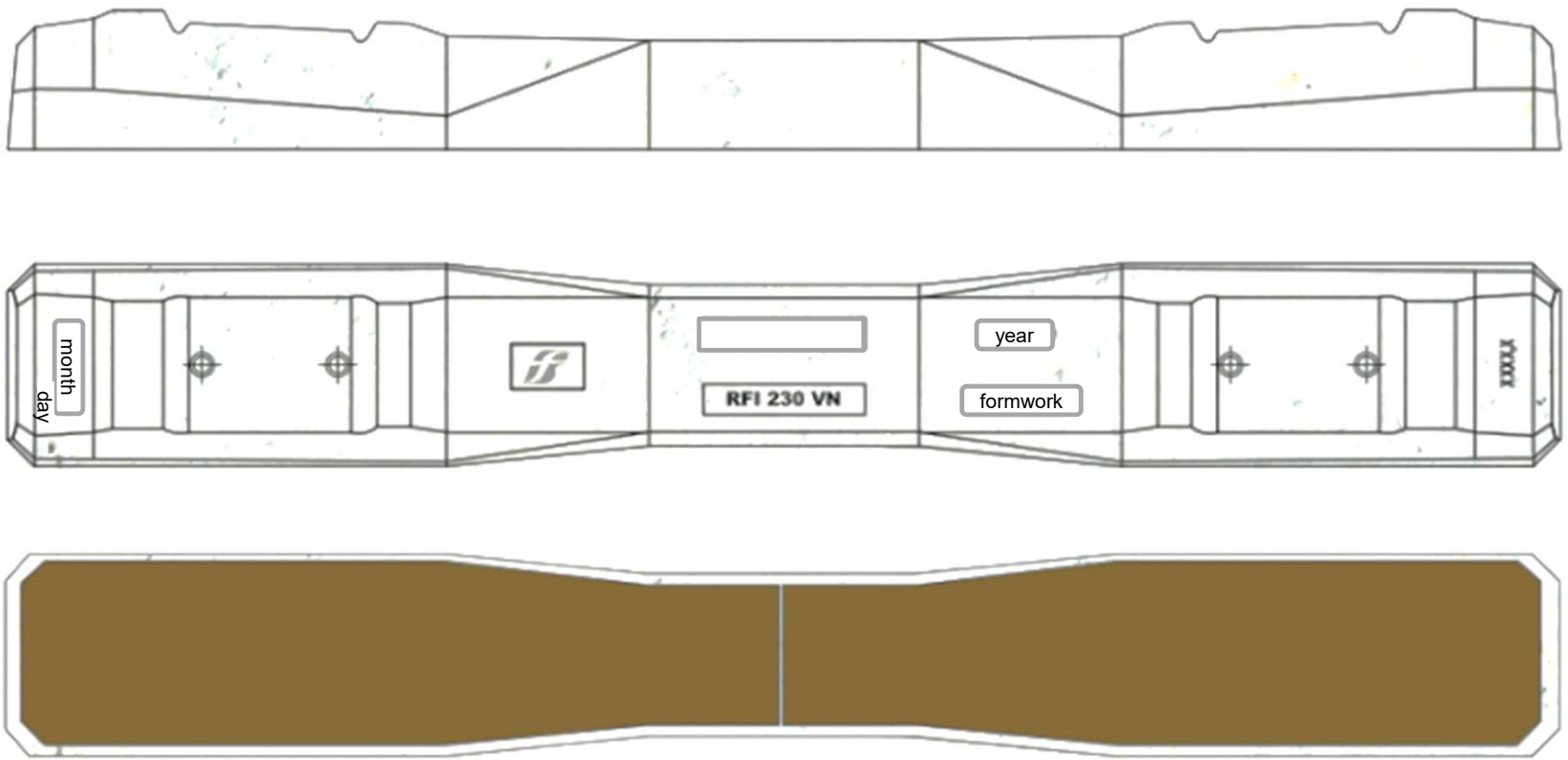
Type of railway sleeper made out of **steel reinforced concrete**



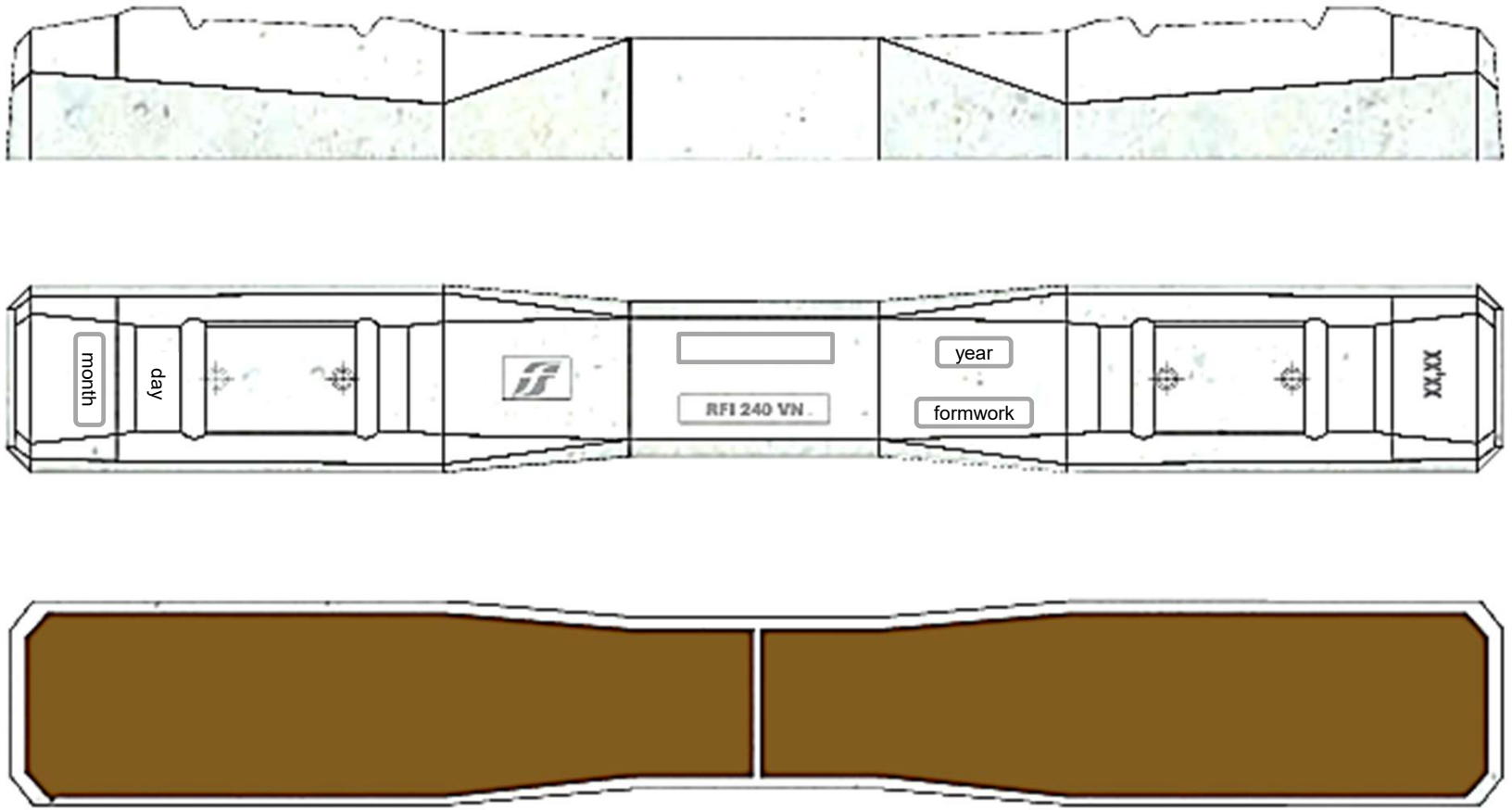
Case study - Concrete sleepers in Italy

	RFI-230 VN	RFI-240 VN	RFI-260 VN
Compliance	Standards EN 13230-1/2 Technical Specifications RFI TCAR AR 03 002 F	Standards EN 13230-1/2 Technical Specifications RFI TCAR AR 03 002 F	Standards EN 13230-1/2 Technical Specifications RFI TCAR AR 03 002 F
Maximum speed	≤ 250 km/h	250 km/h	250 km/h
Lenght L	2.300 mm	2.400 mm	2.600 mm
b1	300 mm	300 mm	300 mm
hp under rails	170 mm	220 mm	220 mm
Depth at centre of rail seat	150 mm	200 mm	200 mm
Rail cant	1/20	1/20	1/20
Rail type	50E5, 60E1	60E1	60E1
Track gauge	1.437 mm, 1.437 – 1.447 mm	1.437 mm, 1.437 – 1.447 mm	1.447 – 1.459,5 mm
Fastening details	Vossloh W14, Pandrol E/1 2039, Pandrol FAST CLIP	Vossloh W14, Pandrol E/1 2039, Pandrol FAST CLIP	Vossloh W14, Pandrol E/1 2039, Pandrol FAST CLIP

Case study - RFI-230 VN

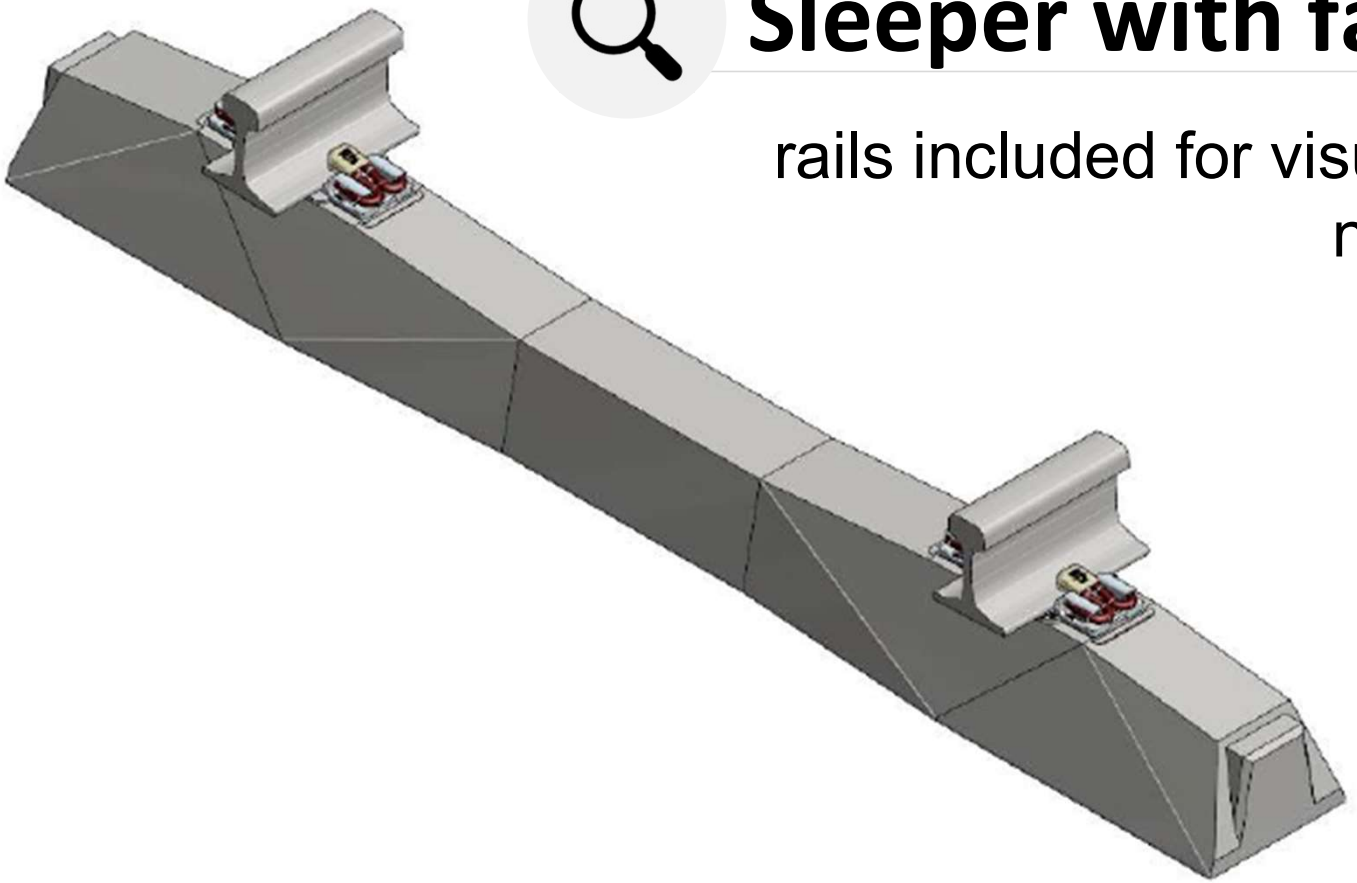


Case study - RFI-240 VN



Case study - RFI-260 VN

Sleeper with fastening systems



rails included for visualization purpose only,
not included in the study

LCA information

Functional unit / declared unit

1 precast concrete sleeper, equipped with fastening system

Time representativeness

The data represents the reference year of 2022

Factories location

Italy

Database and LCA software used

Modelling has been conducted in SimaPro 9.3.0.3.

Specific data has been used for the production of sleepers, based on environmental reports for the factories, and the fastening system, based on data provided by the supplier. Specific data has been used for the supply of cement, reinforcement steel and plasticizer, in line with the standard EN 15804. For generic data Ecoinvent v.3.9 was used.

Impact methods used

- *EN 15804+A2 Method V1.00 / EF 3.0 normalization and weighting set,* as implemented in SimaPro
- The indicator GWP is calculated using the method EPD (2018) v.1.01 as implemented in SimaPro

Modules declared

Stage	Product			Construction process		Use							End of life				Potential benefits and loads
	Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction Demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling potential
Module	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
Modules declared	**X**	**X**	**X**	**X**	**X**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**X**	**X**	**X**	**X**	**X**

Description of the system boundary (X=included in LCA; MND=module not declared)

A1-A3 - Product stage

A1 Raw material supply

A2 Transport

A3 Manufacturing






A4-A5 - Construction process stage

A4

Transport

A5

Construction installation process

C1-C4 - End of life stage

C1 De-construction

C2 Transport

C3 Waste Processing

C4 Disposal




D - Potential benefits and loads stage

D

Reuse
Recovery
Recycling
potential

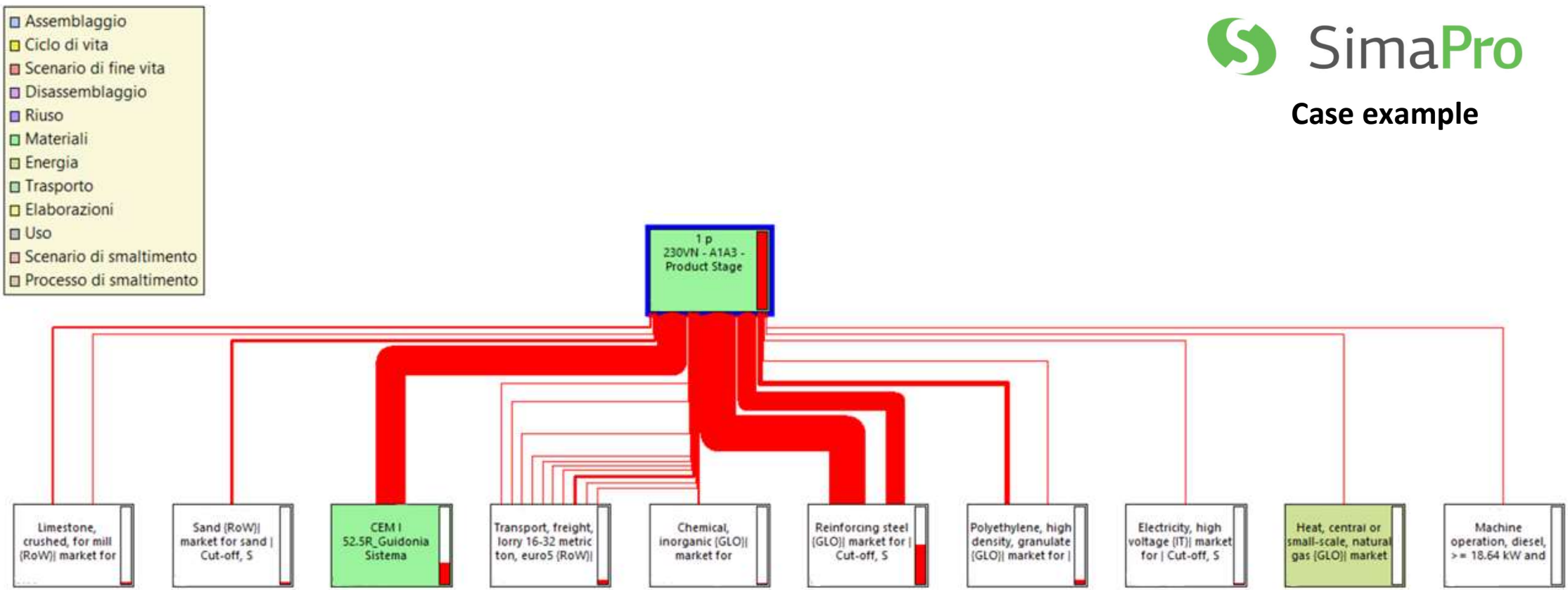
Input data A1-C4

			230	240	260	
		Unit	Quantity			STAGES
Materials/fuels	Sand	% by weight	34.3	34.6	39.3	A1-A3
	Crushed limestone - different grain size	% by weight	32.7	33	37.5	A1-A3
	Portland cement	% by weight	12.6	12.7	14.4	A1-A3
	Reinforcing steel - reinforcement and fastening	% by weight	4.4	4.1	4.2	A1-A3
	Water - tap and well	% by weight	15.4	15.2	17.4	A1-A3 C1-C4
	Granulated polyethylene - sleeper pad and bushing	% by weight	0.5	0.4	0.4	A1-A3
	Inorganic additive	% by weight	0.1	0.1	0.1	A1-A3
	Freight truck, euro 5	tkm	93.5	120.7	137.5	A1-A3 A4-A5 C1-C4
Electricity/heat	Electricity, Italian mix	% by MJ	39.1	42.5	40.7	A1-A3 C1-C4
	Natural gas	% by MJ	20.8	23.4	22.7	A1-A3
	Diesel, machine operation	% by MJ	40.1	34.2	36.5	A1-A3 A4-A5 C1-C4
Emissions to air	Particulates > 10 µm	mg	3.3	4.3	4.9	A1-A3
Final waste flows	Non-hazardous waste, recovery	kg	0.4	0.6	0.6	A1-A3
	Hazardous waste, recovery - landfill	kg	0.03	0.03	0.04	A1-A3 C1-C4

Output data on SimaPro

SimaPro

Case example



Output A1-C4

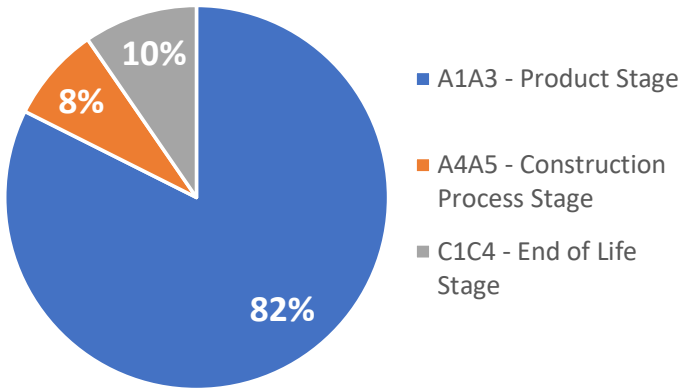
		RFI sleeper		
		230	240	260
Impact category	**Unit**	**Quantity**		
Climate change	kg CO2 eq	87.37	109.67	122.63
Climate change - Fossil	kg CO2 eq	86.99	109.18	122.09
Climate change - Biogenic	kg CO2 eq	0.33	0.43	0.48
Climate change - Land use and LU change	kg CO2 eq	0.04	0.04	0.05
Ozone depletion	kg CFC11 eq	8.88E-06	1.12E-05	1.29E-05
Acidification	mol H+ eq	0.27	0.33	0.37
Eutrophication, freshwater	kg P eq	0.02	0.02	0.02
Eutrophication, marine	kg N eq	0.08	0.10	0.11
Eutrophication, terrestrial	mol N eq	0.77	0.96	1.08
Photochemical ozone formation	kg NMVOC eq	0.29	0.36	0.40
Resource use, minerals and metals	kg Sb eq	2.59E-04	3.17E-04	3.43E-04
Resource use, fossils	MJ	886.66	1086.25	1209.40
Water use	m3 depriv.	22.17	27.56	30.07
Particulate matter	disease inc.	4.47E-06	5.49E-06	6.05E-06
Ionising radiation	kBq U-235 eq	3.70	4.63	5.21
Ecotoxicity, freshwater	CTUe	1467.88	1823.63	1995.26
Human toxicity, cancer	CTUh	1.82E-07	2.19E-07	2.30E-07
Human toxicity, non-cancer	CTUh	9.98E-07	1.22E-06	1.32E-06

Output A1-C4

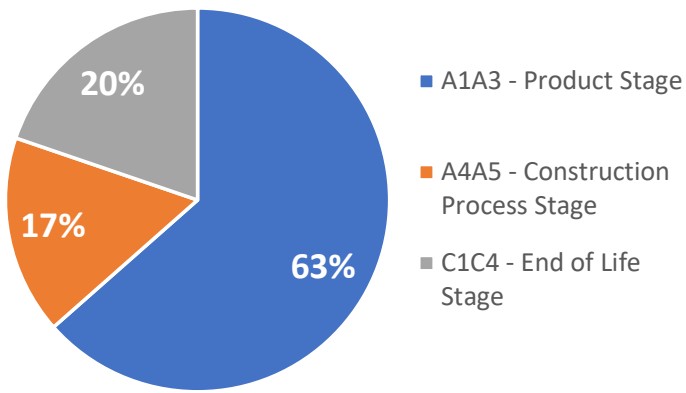
		RFI sleeper		
		230	240	260
Impact category	**Unit**	**Quantity**		
Land use	Pt	387.12	492.94	553.13
Renewable primary energy non as RM	MJ	37.37	46.63	51.03
Renewable primary energy as RM	MJ	0.00	0.00	0.00
Total renewable primary energy	MJ	37.37	46.63	51.03
Non-renewable PE non as RM	MJ	886.75	1086.36	1209.52
Non-renewable PE as RM	MJ	0.00	0.00	0.00
Total non-renewable PE	MJ	886.75	1086.36	1209.52
Secondary raw materials	kg	2.29	3.02	3.43
Renewable secondary fuels	MJ	0.00	0.00	0.00
Non-renewable secondary fuels	MJ	0.00	0.00	0.00
Net use of fresh water	m3	0.58	0.72	0.78
Hazardous waste	kg	0.00	0.00	0.01
Non hazardous waste	kg	0.04	0.05	0.05
Radioactive waste	kg	0.00	0.00	0.00
Components for re-use	kg	0.00	0.00	0.00
Materials for recycling	kg	0.03	0.04	0.05
Materials for energy recovery	kg	0.00	0.00	0.00
Exported energy	kWh	0.00	0.00	0.00

Example of output summary plots

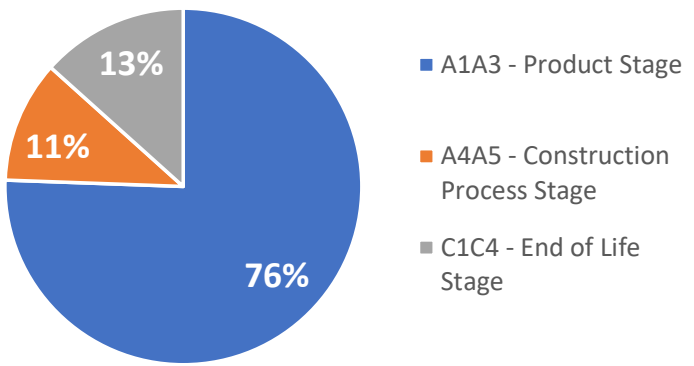
Climate change - kg CO2 eq



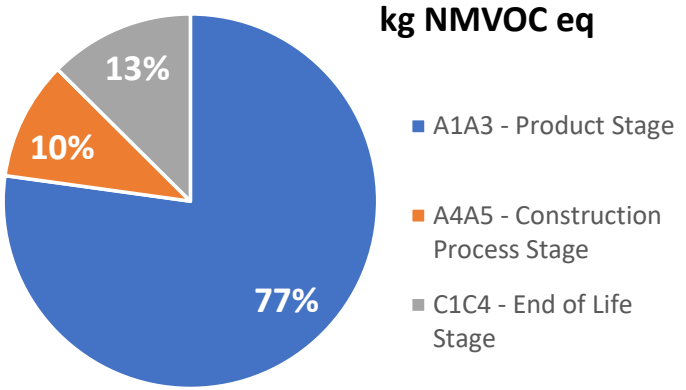
Ozone Depletion - kg CF11 eq



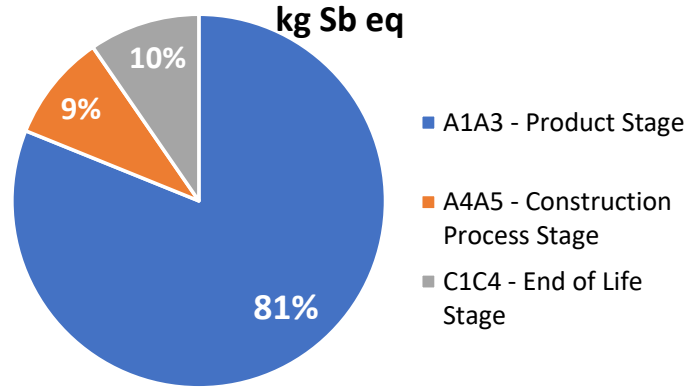
Acidification - mol H+ eq



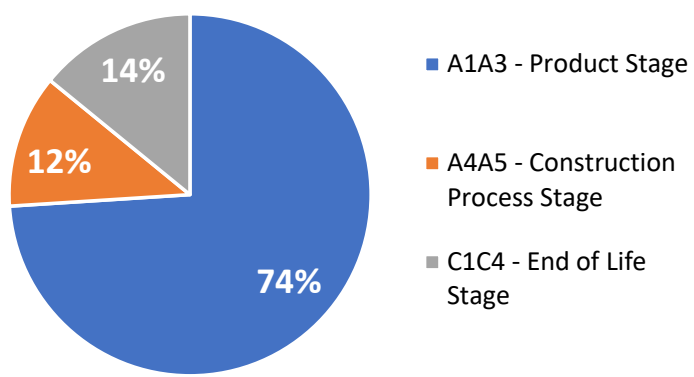
Photochemical Ozone Formation - kg NMVOC eq



Resource use, minerals and metals - kg Sb eq



Resource use, fossils - MJ



Output D

Impact category	Unit	RFI sleeper		
		230	240	260
		Quantity		
Climate change	kg CO2 eq	-26.75	-32.83	-34.25
Climate change - Fossil	kg CO2 eq	-26.73	-32.80	-34.22
Climate change - Biogenic	kg CO2 eq	0.00	0.00	0.00
Climate change - Land use and LU change	kg CO2 eq	-0.02	-0.03	-0.03
Ozone depletion	kg CFC11 eq	-1.46E-06	-1.80E-06	-1.89E-06
Acidification	mol H+ eq	-0.12	-0.15	-0.16
Eutrophication, freshwater	kg P eq	-0.01	-0.01	-0.01
Eutrophication, marine	kg N eq	-0.03	-0.04	-0.04
Eutrophication, terrestrial	mol N eq	-0.33	-0.40	-0.43
Photochemical ozone formation	kg NMVOC eq	-0.14	-0.17	-0.18
Resource use, minerals and metals	kg Sb eq	0.00	0.00	0.00
Resource use, fossils	MJ	-280.58	-344.42	-359.47
Water use	m3 depriv.	-9.96	-12.27	-12.87
Particulate matter	disease inc.	-2.25E-06	-2.77E-06	-2.91E-06
Ionising radiation	kBq U-235 eq	-1.08	-1.33	-1.39
Ecotoxicity, freshwater	CTUe	-1225.26	-1546.69	-1672.68
Human toxicity, cancer	CTUh	-1.65E-07	-2.02E-07	-2.10E-07
Human toxicity, non-cancer	CTUh	-6.48E-07	-7.94E-07	-8.28E-07

Output D

		RFI sleeper		
		230	240	260
Impact category	**Unit**	**Quantity**		
Land use	Pt	-85.25	-104.76	-109.49
Renewable primary energy non as RM	MJ	-15.98	-19.62	-20.47
Renewable primary energy as RM	MJ	0.00	0.00	0.00
Total renewable primary energy	MJ	-15.98	-19.62	-20.47
Non-renewable PE non as RM	MJ	-280.64	-344.50	-359.54
Non-renewable PE as RM	MJ	0.00	0.00	0.00
Total non-renewable PE	MJ	-280.64	-344.50	-359.54
Secondary raw materials	kg	0.00	0.00	0.00
Renewable secondary fuels	MJ	0.00	0.00	0.00
Non-renewable secondary fuels	MJ	0.00	0.00	0.00
Net use of fresh water	m3	-0.28	-0.34	-0.36
Hazardous waste	kg	0.00	0.00	0.00
Non hazardous waste	kg	0.00	0.00	0.00
Radioactive waste	kg	0.00	0.00	0.00
Components for re-use	kg	0.00	0.00	0.00
Materials for recycling	kg	0.00	0.00	0.00
Materials for energy recovery	kg	0.00	0.00	0.00
Exported energy	kWh	0.00	0.00	0.00

Ex. of substances contribution according to the EN 15804+A2 Method

Categoria d'impatto	Unità
Climate change	kg CO2 eq
Climate change - Fossil	kg CO2 eq
Climate change - Biogenic	kg CO2 eq
Climate change - Land use and LU change	kg CO2 eq
Ozone depletion	kg CFC11 eq
Acidification	mol H+ eq
Eutrophication, freshwater	kg P eq
Eutrophication, marine	kg N eq
Eutrophication, terrestrial	mol N eq
Photochemical ozone formation	kg NMVOC eq
Resource use, minerals and metals	kg Sb eq
Resource use, fossils	MJ
Water use	m3 depriv.
Particulate matter	disease inc.
Ionising radiation	kBq U-235 eq
Ecotoxicity, freshwater	CTUe
Human toxicity, cancer	CTUh
Human toxicity, non-cancer	CTUh
Land use	Pt
Renewable primary energy non as RM	MJ
Renewable primary energy as RM	MJ
Total renewable primary energy	MJ
Non-renewable PE non as RM	MJ
Non-renewable PE as RM	MJ
Total non-renewable PE	MJ
Secondary raw materials	kg
Renewable secondary fuels	MJ
Non-renewable secondary fuels	MJ
Net use of fresh water	m3
Hazardous waste	kg
Non hazardous waste	kg
Radioactive waste	kg
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	kWh

Comparto	Sottocomparto	Sostanza	Numero CAS	Fattore	Unità
Aria		(E)-1-Chloro-3,3,3-trifluoroprop-1-ene	102687-65-0	2	kg CO2 eq / kg
Aria		(E)-1,2,3,3,3-Pentafluoroprop-1-ene	005595-10-8	0.0961	kg CO2 eq / kg
Aria		(Perfluorobutyl)ethylene	019430-93-4	1	kg CO2 eq / kg
Aria		(Perfluoroctyl)ethylene	021652-58-4	0.398	kg CO2 eq / kg
Aria		(Perfluorohexyl)ethylene	025291-17-2	0.131	kg CO2 eq / kg
Aria		(Z)-1,1,1,4,4,4-Hexafluorobut-2-ene	000692-49-9	2	kg CO2 eq / kg
Aria		(Z)-1,2,3,3,3-Pentafluoroprop-1-ene	005528-43-8	0.284	kg CO2 eq / kg
Aria		(Z)-1,3,3,3-Tetrafluoroprop-1-ene	029118-25-0	0.347	kg CO2 eq / kg
Aria		1-Propanol, 3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, HFE-71	014117-17-0	509	kg CO2 eq / kg
Aria		1-Propanol, i-3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, i-HFE		492	kg CO2 eq / kg
Aria		1-Propanol, n-3,3,3-trifluoro-2,2-bis(trifluoromethyl)-, n-HF		587	kg CO2 eq / kg
Aria		1-Undecanol, 3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,11,11,11-nonade	087017-97-8	0.113	kg CO2 eq / kg
Aria		1,1,1,3,3,3-Hexafluoropropan-2-ol	000920-66-1	221	kg CO2 eq / kg
Aria		1,2,2-Trichloro-1,1-difluoroethane	000354-21-2	72	kg CO2 eq / kg
Aria		2,3,3,3-Tetrafluoropropene	000754-12-1	0.429	kg CO2 eq / kg
Aria		Acetate, 1,1-difluoroethyl 2,2,2-trifluoro-		38	kg CO2 eq / kg
Aria		Acetate, 2,2,2-trifluoroethyl 2,2,2-trifluoro-	000407-38-5	8	kg CO2 eq / kg
Aria		Acetate, difluoromethyl 2,2,2-trifluoro-	002024-86-4	33	kg CO2 eq / kg
Aria		Acetate, methyl 2,2-difluoro-	000433-53-4	4	kg CO2 eq / kg
Aria		Acetate, methyl 2,2,2-trifluoro-	000431-47-0	64	kg CO2 eq / kg
Aria		Acetate, perfluorobutyl-	209597-28-4	2	kg CO2 eq / kg
Aria		Acetate, perfluoroethyl-	343269-97-6	3	kg CO2 eq / kg
Aria		Acetate, perfluoropropyl-		2	kg CO2 eq / kg
Aria		Butane, 1,1,1,2,2,3,3,4,4-nonafluoro-, HFC-329p	00375-17-7	2740	kg CO2 eq / kg
Aria		Butane, 1,1,1,3,3-pentafluoro-, HFC-365mfc	000406-58-6	966	kg CO2 eq / kg
Aria		Butane, perfluoro-	000355-25-9	10200	kg CO2 eq / kg
Aria		Butane, perfluorocyclo-, PFC-318	000115-25-3	10600	kg CO2 eq / kg
Aria		Butanol, 2,2,3,3,4,4,4-heptafluoro-	000375-01-9	41	kg CO2 eq / kg
Aria		Butanol, 2,2,3,3,4,4,4-heptafluoro-1-	000375-01-9	20	kg CO2 eq / kg
Aria		Butanol, 2,2,3,4,4,4-hexafluoro-1-	000382-31-0	21	kg CO2 eq / kg
Aria		Carbon dioxide	000124-38-9	1	kg CO2 eq / kg
Aria		Carbon dioxide, biogenic	000124-38-9	1	kg CO2 eq / kg
Aria		Carbon dioxide, fossil	000124-38-9	1	kg CO2 eq / kg
Prima		Carbon dioxide, in air	000124-38-9	-1	kg CO2 eq / kg
Aria		Carbon dioxide, land transformation	000124-38-9	1	kg CO2 eq / kg
Prima		Carbon dioxide, non-fossil, resource correction	000124-38-9	-1	kg CO2 eq / kg

Total amount of **215** substances

Ex. of substances contribution according to the EN 15804+A2 Method

Categoria d'impatto	Unità
Climate change	kg CO2 eq
Climate change - Fossil	kg CO2 eq
Climate change - Biogenic	kg CO2 eq
Climate change - Land use and LU change	kg CO2 eq
Ozone depletion	kg CFC11 eq
Acidification	mol H+ eq
Eutrophication, freshwater	kg P eq
Eutrophication, marine	kg N eq
Eutrophication, terrestrial	mol N eq
Photochemical ozone formation	kg NMVOC eq
Resource use, minerals and metals	kg Sb eq
Resource use, fossils	MJ
Water use	m3 depriv.
Particulate matter	disease inc.
Ionising radiation	kBq U-235 eq
Ecotoxicity, freshwater	CTUe
Human toxicity, cancer	CTUh
Human toxicity, non-cancer	CTUh
Land use	Pt
Renewable primary energy non as RM	MJ
Renewable primary energy as RM	MJ
Total renewable primary energy	MJ
Non-renewable PE non as RM	MJ
Non-renewable PE as RM	MJ
Total non-renewable PE	MJ
Secondary raw materials	kg
Renewable secondary fuels	MJ
Non-renewable secondary fuels	MJ
Net use of fresh water	m3
Hazardous waste	kg
Non hazardous waste	kg
Radioactive waste	kg
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	kWh

Comparto	Sottocomparto	Sostanza	Numero CAS	Fattore	Unità
Aria		1-Butanol	000071-36-3	1.05	kg NMVOC eq / kg
Aria		1-Butene	000106-98-9	1.82	kg NMVOC eq / kg
Aria		1-Butene, 2-methyl-	000563-46-2	1.3	kg NMVOC eq / kg
Aria		1-Butene, 3-methyl-	000563-45-1	1.13	kg NMVOC eq / kg
Aria		1-Hexene	000592-41-6	1.48	kg NMVOC eq / kg
Aria		1-Pentene	000109-67-1	1.65	kg NMVOC eq / kg
Aria		1-Propanol	000071-23-8	0.948	kg NMVOC eq / kg
Aria		2-Butanol	000078-92-2	0.676	kg NMVOC eq / kg
Aria		2-Butanone, 3-methyl-	000563-80-4	0.615	kg NMVOC eq / kg
Aria		2-Butene (cis)	000590-18-1	1.94	kg NMVOC eq / kg
Aria		2-Butene (trans)	000624-64-6	1.91	kg NMVOC eq / kg
Aria		2-Butene, 2-methyl-	000513-35-9	1.42	kg NMVOC eq / kg
Aria		2-Hexanone	000591-78-6	0.966	kg NMVOC eq / kg
Aria		2-Hexene (cis)	007688-21-3	1.81	kg NMVOC eq / kg
Aria		2-Hexene (trans)	004050-45-7	1.81	kg NMVOC eq / kg
Aria		2-Methyl-1-propanol	000078-83-1	0.608	kg NMVOC eq / kg
Aria		2-Methyl-2-butanol	000075-85-4	0.385	kg NMVOC eq / kg
Aria		2-Pentanone	000107-87-9	0.926	kg NMVOC eq / kg
Aria		2-Pentene (cis)	000627-20-3	1.89	kg NMVOC eq / kg
Aria		2-Pentene (trans)	000646-04-8	1.89	kg NMVOC eq / kg
Aria		2-Propanol	000067-63-0	0.318	kg NMVOC eq / kg
Aria		3-Hexanone	000589-38-8	1.01	kg NMVOC eq / kg
Aria		3-Methyl-1-butanol	000123-51-3	0.731	kg NMVOC eq / kg
Aria		3-Pentanol	000584-02-1	1.01	kg NMVOC eq / kg
Aria		3-Pentanone	000096-22-0	0.699	kg NMVOC eq / kg
Aria		3,3-Dimethyl-2-butanone	000075-97-8	0.546	kg NMVOC eq / kg
Aria		4-Hydroxy-4-methyl-2-pentanone	000123-42-2	0.519	kg NMVOC eq / kg
Aria		4-Methyl-2-pentanone	000108-10-1	0.828	kg NMVOC eq / kg
Aria		Acetaldehyde	000075-07-0	1.08	kg NMVOC eq / kg
Aria		Acetic acid	000064-19-7	0.164	kg NMVOC eq / kg
Aria		Acetone	000067-64-1	0.159	kg NMVOC eq / kg
Aria		Benzaldehyde	000100-52-7	-0.155	kg NMVOC eq / kg
Aria		Benzene	000071-43-2	0.368	kg NMVOC eq / kg
Aria		Benzene, 1,2,3-trimethyl-	000526-73-8	2.14	kg NMVOC eq / kg
Aria		Benzene, 1,2,4-trimethyl-	000095-63-6	2.16	kg NMVOC eq / kg
Aria		Benzene, 1,3,5-trimethyl-	000108-67-8	2.33	kg NMVOC eq / kg

Total amount of **3239** substances

Ex. of substances contribution according to the EN 15804+A2 Method

Categoria d'impatto	Unità
Climate change	kg CO2 eq
Climate change - Fossil	kg CO2 eq
Climate change - Biogenic	kg CO2 eq
Climate change - Land use and LU change	kg CO2 eq
Ozone depletion	kg CFC11 eq
Acidification	mol H+ eq
Eutrophication, freshwater	kg P eq
Eutrophication, marine	kg N eq
Eutrophication, terrestrial	mol N eq
Photochemical ozone formation	kg NMVOC eq
Resource use, minerals and metals	kg Sb eq
Resource use, fossils	MJ
Water use	m3 depriv.
Particulate matter	disease inc.
Ionising radiation	kBq U-235 eq
Ecotoxicity, freshwater	CTUe
Human toxicity, cancer	CTUh
Human toxicity, non-cancer	CTUh
Land use	Pt
Renewable primary energy non as RM	MJ
Renewable primary energy as RM	MJ
Total renewable primary energy	MJ
Non-renewable PE non as RM	MJ
Non-renewable PE as RM	MJ
Total non-renewable PE	MJ
Secondary raw materials	kg
Renewable secondary fuels	MJ
Non-renewable secondary fuels	MJ
Net use of fresh water	m3
Hazardous waste	kg
Non hazardous waste	kg
Radioactive waste	kg
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	kWh

Comparto	Sottocomparto	Sostanza	Numero CAS	Fattore	Unità
Aria		Ammonia	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AD	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AE	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AF	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AG	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AI	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AL	007664-41-7	0.021	mol H+ eq / kg
Aria		Ammonia, AM	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AO	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AQ	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AR	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AS	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AT	007664-41-7	1.72	mol H+ eq / kg
Aria		Ammonia, AU	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AW	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, AZ	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BA	007664-41-7	0.088	mol H+ eq / kg
Aria		Ammonia, BB	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BD	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BE	007664-41-7	2.658	mol H+ eq / kg
Aria		Ammonia, BF	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BG	007664-41-7	0.04	mol H+ eq / kg
Aria		Ammonia, BH	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BI	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BJ	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BM	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BN	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BO	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BR	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BS	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BT	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BV	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BW	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, BY	007664-41-7	1.593	mol H+ eq / kg
Aria		Ammonia, BZ	007664-41-7	3.02	mol H+ eq / kg
Aria		Ammonia, CA	007664-41-7	3.02	mol H+ eq / kg

Total amount of **1750** substances

Example of input data contribution to…

Some examples

Climate change	%
Portland cement	48.01
Reinforcing steel - reinforcement and fastening	37.13
Freight truck, 16-32 tons, euro 5	5.21
High-density granulated polyethylene - sleeper pad and bushing	4.30
Sand	1.57
Electricity, high voltage	1.37
Inorganic additive	0.87
Natural gas	0.69
Diesel, machine operation	0.43
Crushed limestone - different grain size	0.35
Electricit, low voltage, photovoltaic	0.05
Freight truck, 3.5-7.5 tons, euro 5	0.01
Tap water	0.01

Ozone depletion	%
Portland cement	47.83
Reinforcing steel - reinforcement and fastening	25.26
Freight truck, 16-32 tons, euro 5	14.99
Sand	3.64
Electricity, high voltage	2.28
High-density granulated polyethylene - sleeper pad and bushing	1.37
Natural gas	1.30
Inorganic additive	1.27
Diesel, machine operation	1.20
Crushed limestone - different grain size	0.75
Electricit, low voltage, photovoltaic	0.07
Freight truck, 3.5-7.5 tons, euro 5	0.03
Tap water	0.01

Acidification	%
Reinforcing steel - reinforcement and fastening	53.84
Portland cement	20.19
Freight truck, 16-32 tons, euro 5	7.53
High-density granulated polyethylene - sleeper pad and bushing	6.08
Sand	4.20
Inorganic additive	2.55
Crushed limestone - different grain size	2.54
Electricit, low voltage, photovoltaic	2.02
Diesel, machine operation	0.66
Natural gas	0.26
Electricit, low voltage, photovoltaic	0.10
Freight truck, 3.5-7.5 tons, euro 5	0.01
Tap water	0.01

Most influent input data on the impact categories

Raw material

- Portland cement
- Reinforcing steel
- Crushed limestone
- Sand

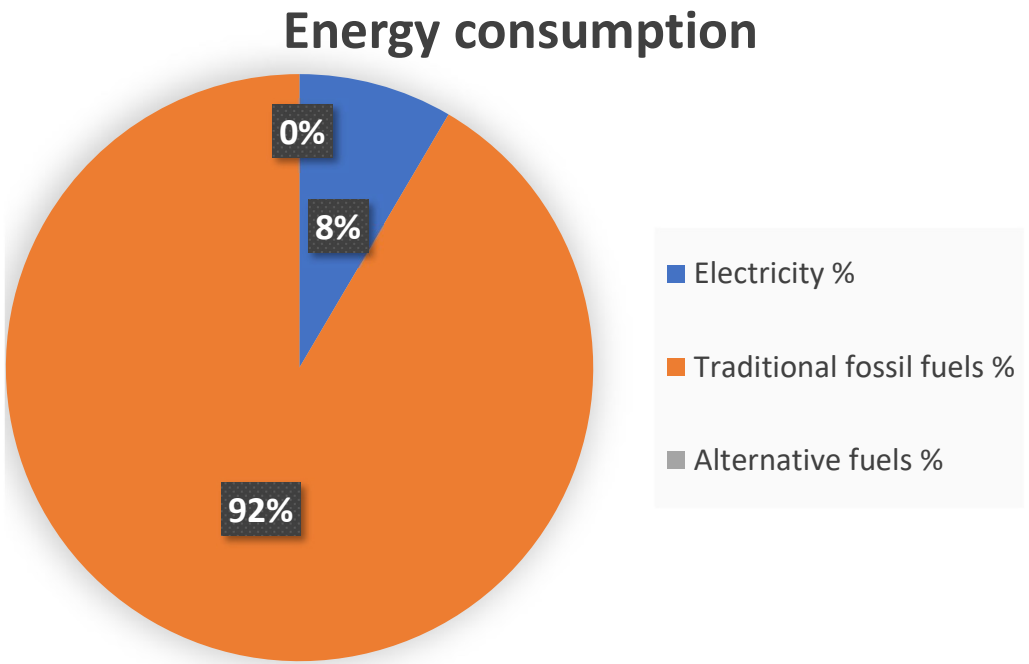
Energy Consumption

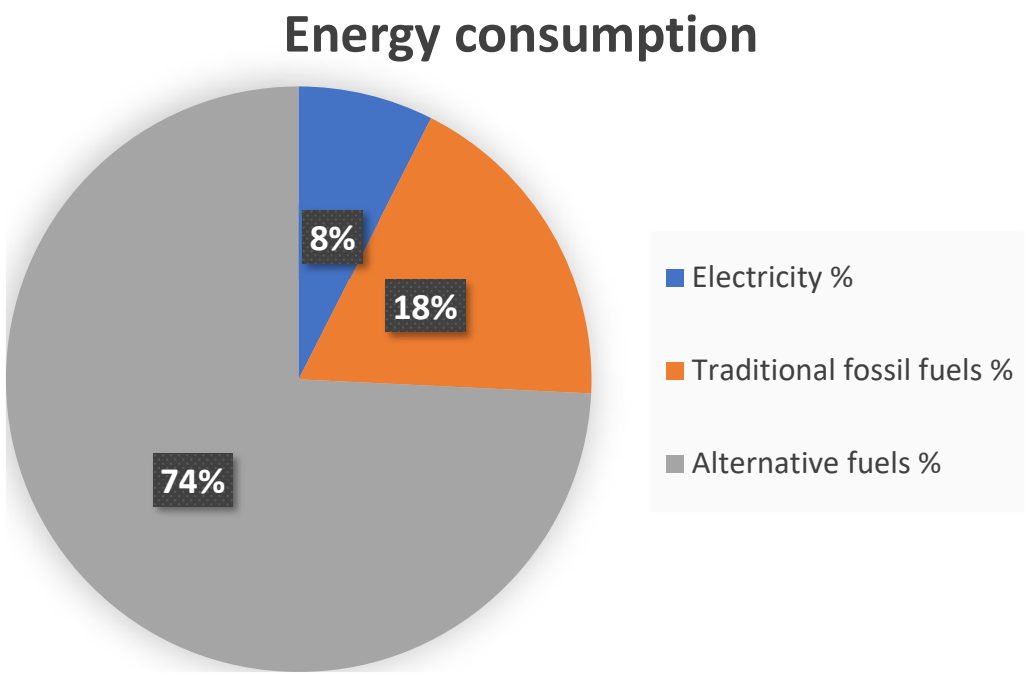
- Electricity, high voltage

Transportation

- Freight truck, euro 5

Portland cement – clinker production





Different Portland cement production

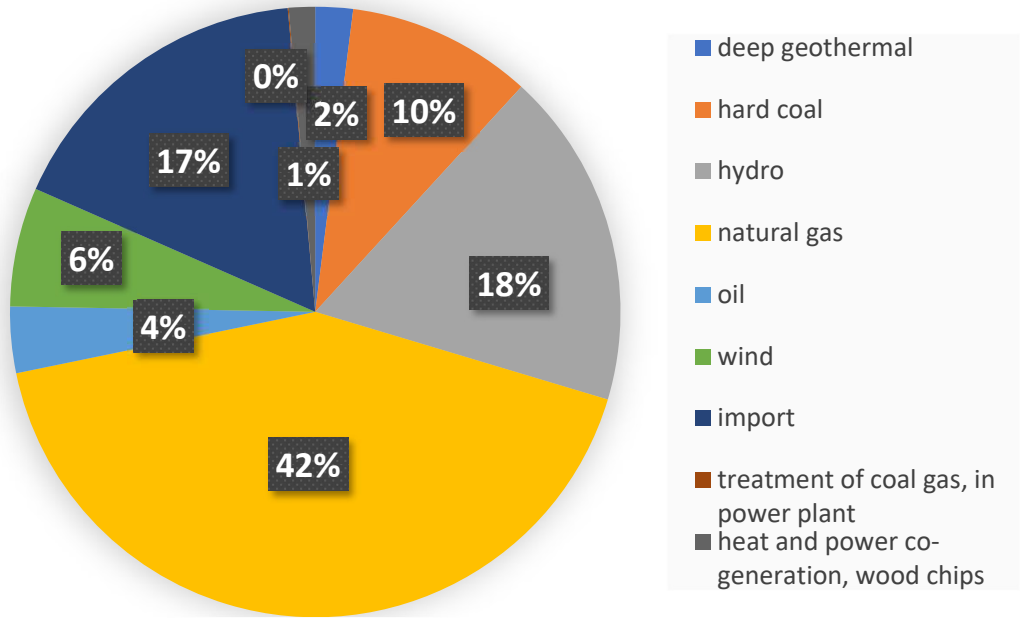
		CEM I current	CEM I green	PP
Impact category	**Unit**	**Quantity**		
Climate change	kg CO2 eq	989.23	816.92	-17%
Climate change - Fossil	kg CO2 eq	983.03	811.58	-17%
Climate change - Biogenic	kg CO2 eq	6.01	5.20	-13%
Climate change - Land use and LU change	kg CO2 eq	0.09	0.05	-47%
Ozone depletion	kg CFC11 eq	7.54E-05	2.98E-05	-61%
Acidification	mol H+ eq	1.19	0.71	-40%
Eutrophication, freshwater	kg P eq	0.02	0.02	-14%
Eutrophication, marine	kg N eq	0.53	0.51	-4%
Eutrophication, terrestrial	mol N eq	3.67	3.40	-7%
Photochemical ozone formation	kg NMVOC eq	1.55	1.41	-9%
Resource use, minerals and metals	kg Sb eq	0.00	0.00	13%
Resource use, fossils	MJ	5174.69	2347.20	-55%
Water use	m3 depriv.	73.84	62.10	-16%
Particulate matter	disease inc.	9.30E-06	9.97E-06	7%
Ionising radiation	kBq U-235 eq	27.19	14.26	-48%
Ecotoxicity, freshwater	CTUe	5764.34	4396.42	-24%
Human toxicity, cancer	CTUh	5.42E-08	6.27E-08	16%
Human toxicity, non-cancer	CTUh	1.65E-06	3.54E-06	114%

Different Portland cement production

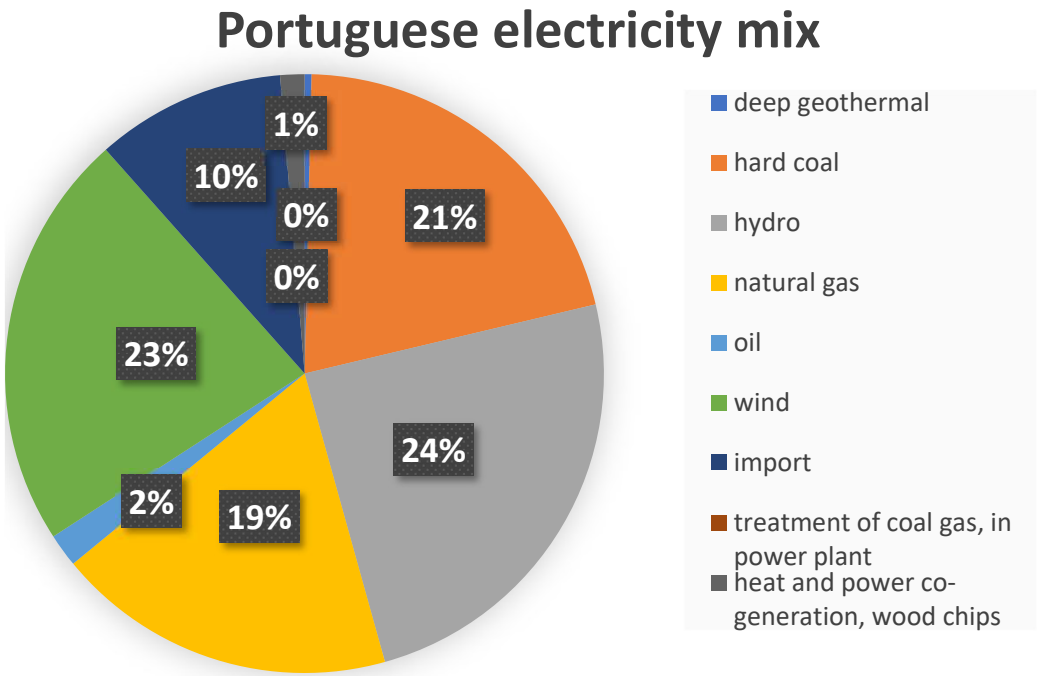
		CEM I current	CEM I green	PP
Impact category	**Unit**	**Quantity**		
Land use	Pt	1109.18	727.99	-34%
Renewable primary energy non as RM	MJ	280.66	243.26	-13%
Renewable primary energy as RM	MJ	0.00	0.00	
Total renewable primary energy	MJ	280.66	243.26	-13%
Non-renewable PE non as RM	MJ	5175.13	2347.39	-55%
Non-renewable PE as RM	MJ	0.00	0.00	
Total non-renewable PE	MJ	5175.13	2347.39	-55%
Secondary raw materials	kg	65.72	97.75	49%
Renewable secondary fuels	MJ	0.00	2281.56	
Non-renewable secondary fuels	MJ	0.00	939.09	
Net use of fresh water	m3	1.91	1.63	-15%
Hazardous waste	kg	0.10	0.76	660%
Non hazardous waste	kg	1.01	0.64	-37%
Radioactive waste	kg	0.00	0.00	
Components for re-use	kg	0.00	0.17	
Materials for recycling	kg	0.94	0.66	-31%
Materials for energy recovery	kg	0.00	0.00	
Exported energy	kWh	0.00	1.11	

Italian vs Portuguese energy mix

Italian electricity mix



Portuguese electricity mix



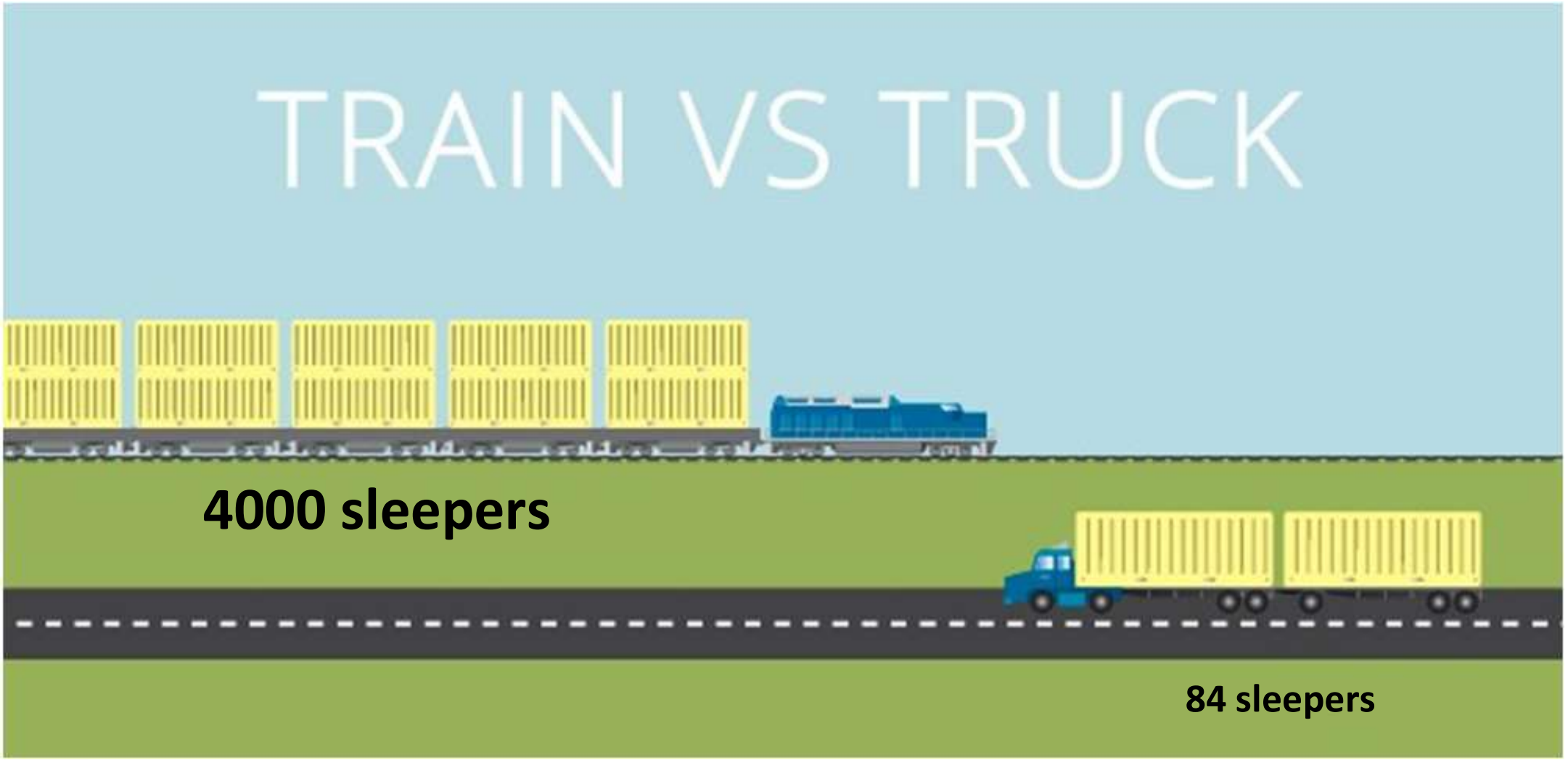
Italian vs Portuguese energy mix

		Electricity, high voltage		
		Italian	Portuguese	PP
Impact category	**Unit**	**Quantity**		
Climate change	kg CO2 eq	1.21E-01	1.09E-01	-10%
Climate change - Fossil	kg CO2 eq	1.11E-01	1.07E-01	-3%
Climate change - Biogenic	kg CO2 eq	1.00E-02	8.88E-05	-99%
Climate change - Land use and LU change	kg CO2 eq	1.42E-05	1.22E-03	8525%
Ozone depletion	kg CFC11 eq	1.54E-08	5.80E-09	-62%
Acidification	mol H+ eq	5.10E-04	8.34E-04	63%
Eutrophication, freshwater	kg P eq	2.53E-05	3.80E-05	50%
Eutrophication, marine	kg N eq	7.83E-05	1.19E-04	53%
Eutrophication, terrestrial	mol N eq	8.71E-04	1.26E-03	45%
Photochemical ozone formation	kg NMVOC eq	2.44E-04	3.45E-04	41%
Resource use, minerals and metals	kg Sb eq	9.64E-08	9.90E-08	3%
Resource use, fossils	MJ	1.71E+00	1.41E+00	-18%
Water use	m3 depriv.	7.54E-02	4.74E-02	-37%
Particulate matter	disease inc.	1.95E-09	2.06E-09	6%
Ionising radiation	kBq U-235 eq	1.56E-02	7.98E-03	-49%
Ecotoxicity, freshwater	CTUe	1.03E+00	1.49E+00	44%
Human toxicity, cancer	CTUh	2.25E-11	2.42E-11	8%
Human toxicity, non-cancer	CTUh	5.62E-10	8.19E-10	46%

Italian vs Portuguese energy mix

		Electricity, high voltage		
		Italian	Portuguese	PP
Impact category	**Unit**	**Quantity**		
Land use	Pt	2.95E-01	3.07E-01	4%
Renewable primary energy non as RM	MJ	4.45E-01	6.19E-01	39%
Renewable primary energy as RM	MJ	0.00E+00	0.00E+00	
Total renewable primary energy	MJ	4.45E-01	6.19E-01	39%
Non-renewable PE non as RM	MJ	1.71E+00	1.41E+00	-18%
Non-renewable PE as RM	MJ	0.00E+00	0.00E+00	
Total non-renewable PE	MJ	1.71E+00	1.41E+00	-18%
Secondary raw materials	kg	0.00E+00	0.00E+00	
Renewable secondary fuels	MJ	0.00E+00	0.00E+00	
Non-renewable secondary fuels	MJ	0.00E+00	0.00E+00	
Net use of fresh water	m3	2.01E-03	9.75E-04	-52%
Hazardous waste	kg	0.00E+00	0.00E+00	
Non hazardous waste	kg	0.00E+00	0.00E+00	
Radioactive waste	kg	0.00E+00	0.00E+00	
Components for re-use	kg	0.00E+00	0.00E+00	
Materials for recycling	kg	0.00E+00	0.00E+00	
Materials for energy recovery	kg	0.00E+00	0.00E+00	
Exported energy	kWh	0.00E+00	0.00E+00	

Transportation



Truck vs Train

		Transportation		
		Truck	Train	PP
Impact category	**Unit**	**Quantity**		
Climate change	kg CO2 eq	1.74E-01	4.86E-02	-72%
Climate change - Fossil	kg CO2 eq	1.74E-01	4.84E-02	-72%
Climate change - Biogenic	kg CO2 eq	9.21E-05	1.36E-04	48%
Climate change - Land use and LU change	kg CO2 eq	7.08E-05	7.68E-05	8%
Ozone depletion	kg CFC11 eq	3.83E-08	3.61E-09	-91%
Acidification	mol H+ eq	7.19E-04	4.58E-04	-36%
Eutrophication, freshwater	kg P eq	1.31E-05	9.90E-06	-24%
Eutrophication, marine	kg N eq	2.12E-04	1.82E-04	-14%
Eutrophication, terrestrial	mol N eq	2.31E-03	1.98E-03	-14%
Photochemical ozone formation	kg NMVOC eq	7.04E-04	5.41E-04	-23%
Resource use, minerals and metals	kg Sb eq	5.92E-07	2.22E-07	-63%
Resource use, fossils	MJ	2.56E+00	6.28E-01	-75%
Water use	m3 depriv.	8.86E-03	5.21E-03	-41%
Particulate matter	disease inc.	1.48E-08	6.83E-09	-54%
Ionising radiation	kBq U-235 eq	1.17E-02	4.43E-03	-62%
Ecotoxicity, freshwater	CTUe	2.23E+00	6.15E-01	-72%
Human toxicity, cancer	CTUh	6.54E-11	4.86E-11	-26%
Human toxicity, non-cancer	CTUh	2.14E-09	5.97E-10	-72%

Truck vs Train

		Transportation		
		Truck	Train	PP
Impact category	**Unit**	**Quantity**		
Land use	Pt	1.74E+00	4.19E-01	-76%
Renewable primary energy non as RM	MJ	2.95E-02	3.24E-02	10%
Renewable primary energy as RM	MJ	0.00E+00	0.00E+00	
Total renewable primary energy	MJ	2.95E-02	3.24E-02	10%
Non-renewable PE non as RM	MJ	2.56E+00	6.28E-01	-75%
Non-renewable PE as RM	MJ	0.00E+00	0.00E+00	
Total non-renewable PE	MJ	2.56E+00	6.28E-01	-75%
Secondary raw materials	kg	0.00E+00	0.00E+00	
Renewable secondary fuels	MJ	0.00E+00	0.00E+00	
Non-renewable secondary fuels	MJ	0.00E+00	0.00E+00	
Net use of fresh water	m3	2.85E-04	2.38E-04	-17%
Hazardous waste	kg	0.00E+00	0.00E+00	
Non hazardous waste	kg	0.00E+00	0.00E+00	
Radioactive waste	kg	0.00E+00	0.00E+00	
Components for re-use	kg	0.00E+00	0.00E+00	
Materials for recycling	kg	0.00E+00	0.00E+00	
Materials for energy recovery	kg	0.00E+00	0.00E+00	
Exported energy	kWh	0.00E+00	0.00E+00	

Current scenario VS “Green scenario”

Raw material

Portland cement scenario zero

VS

Portland cement scenario green

Energy Consumption

Electricity, high voltage IT

VS

Electricity, high voltage PT

Transportation

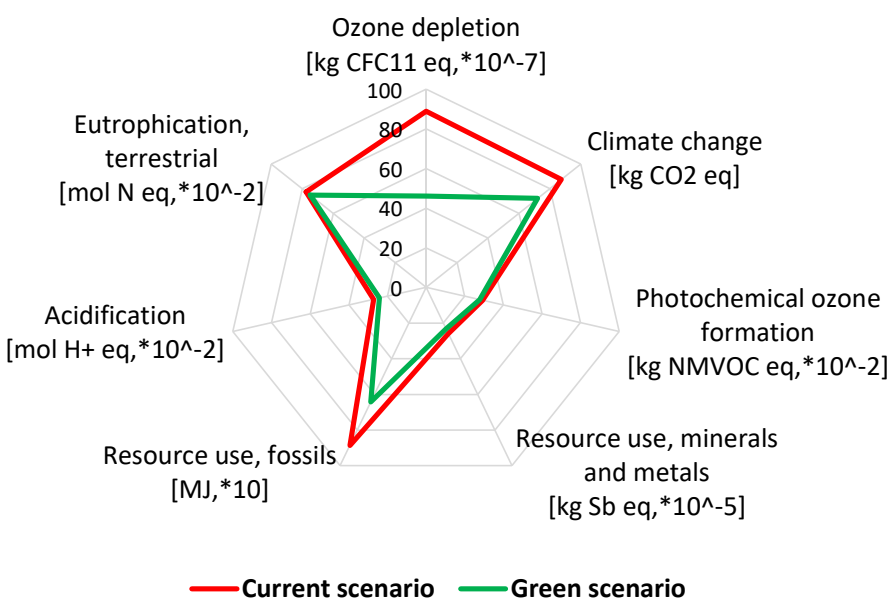
Freight truck, euro 5

VS

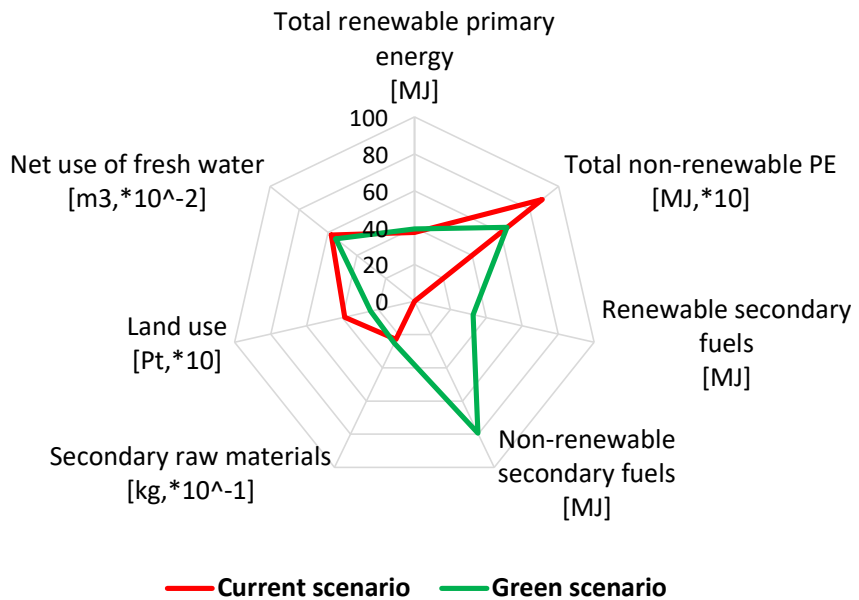
Train

Output comparison - RFI 230 VN

ENVIRONMENTAL IMPACT CATEGORIES

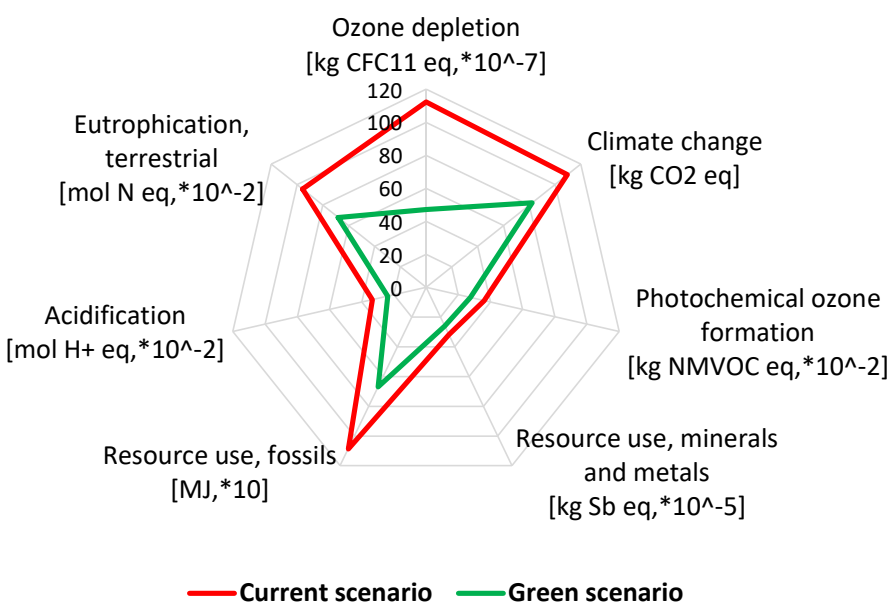


RESOURCE USE



Output comparison - RFI 240 VN

ENVIRONMENTAL IMPACT CATEGORIES



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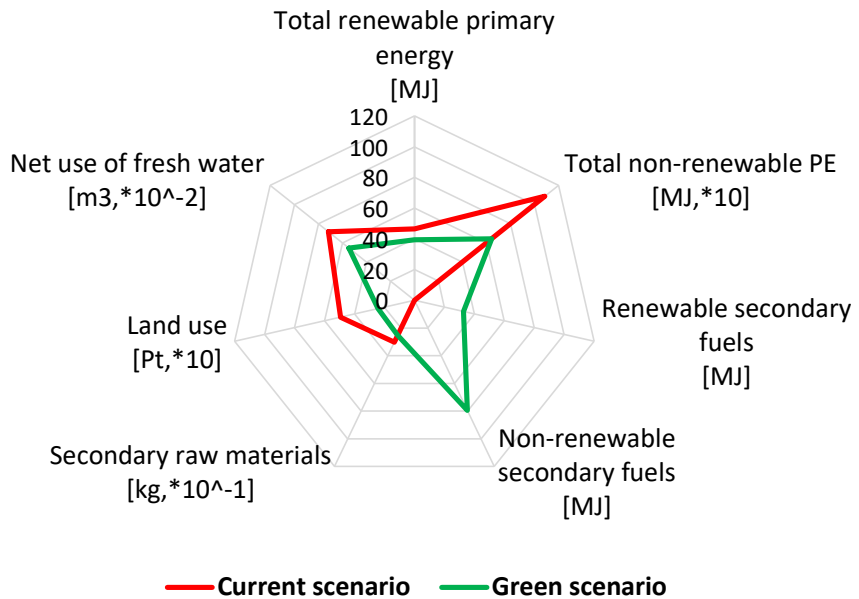
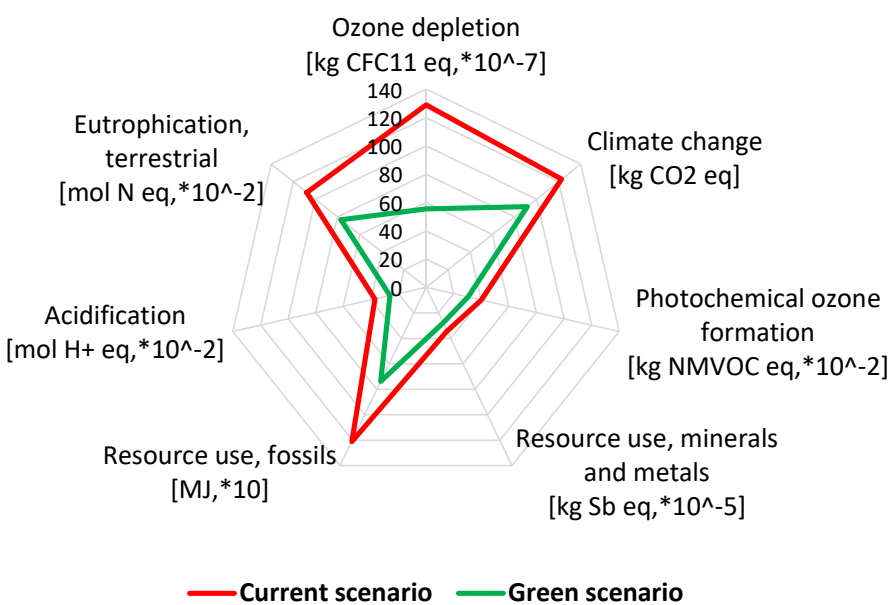


Output comparison - RFI 260 VN

ENVIRONMENTAL IMPACT CATEGORIES



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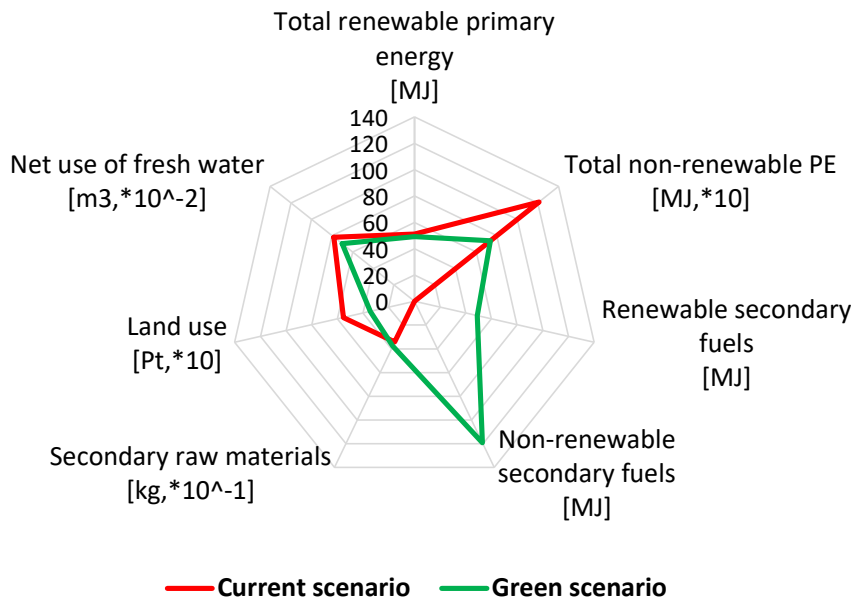

Conclusions

- LCA gives an unbiased set of data useful to examine and improve the environmental performance of railway sleepers
- The interpretation of the results identifies cement, steel, energy mix, and transportation as the most impacting variables
- Alternative approaches to the current scenario return not univocal effects on the investigated impact categories
- It is important to develop a comprehensive method to synthetize the LCA results because the “greenest” solution depends on the surroundings

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