Supplementary Materials

Streamlined Life Cycle Assessment of an Innovative Bio-Based Material in Construction: A Case Study of a Phase Change Material Panel

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Table S1. Midpoint and endpoint impact categories based on IMPACT 2002+ and ReCiPe methods.

Method					
IMPACT 2002+			ReCiPe		
Category		Unit	Category		Unit
Midpoint	Carcinogens	kg C_2H_3Cl-eq	Midpoint	Climate change	kg CO_2-eq
	Non-carcinogens	kg C_2H_3Cl-eq		Ozone depletion	kg CFC-11-eq
	Respiratory inorganics	kg PM2.5-eq		Terrestrial acidification	kg SO_2-eq
	Ionizing radiation	Bq C-14 eq		Freshwater eutrophication	kg P-eq
	Ozone layer depletion	kg CFC-11-eq		Marine eutrophication	kg N-eq
	Respiratory organics	kg C_2H_4-eq		Human toxicity	kg 1,4-DB-eq
	Aquatic ecotoxicity	kg TEG water		Photochemical oxidant formation	kg NMVOC
	Terrestrial ecotoxicity	kg TEG soil		Particulate matter formation	kg PM10-eq
	Terrestrial acid/nutri	kg SO_2-eq		Terrestrial ecotoxicity	kg 1,4-DB-eq
	Land occupation	m^2org.arable		Freshwater ecotoxicity	kg 1,4-DB-eq
	Aquatic acidification	kg SO_2-eq		Marine ecotoxicity	kg 1,4-DB-eq
	Aquatic eutrophication	kg PO_4-P-lim		Ionising radiation	kBq U235-eq
	Global warming	kg CO_2-eq		Agricultural land occupation	m^2a
	Non-renewable energy	MJ primary		Urban land occupation	m^2a
	Mineral extraction	MJ surplus		Natural land transformation	m^2
				Water depletion	m^3
				Metal depletion	kg FE−eq
				Fossil depletion	kg oil-eq
Endpoint	Human health	DALY	Endpoint	Human Health	DALY
	Ecosystem quality	PDF.m^2.yr		Ecosystems	species.yr
	Climate change	kg CO_2-eq		Resources	$
	Resources	MJ primary			

Table S2. The guideline of the environmental performance scoring for the environmental concerns at resource extraction stage in the PCM panel system.

Life Cycle Stage	Environmental Concern	Checklist	Score	Matrix Cell
Resource Extraction	Material Choice	Use of toxic materials (x > 80%)	0	(1,1)
		Few toxic materials (60% < x < 80%)	1	
		Use toxic and virgin materials (40% < x < 60%)	2	
		Mostly virgin materials (20% < x < 40%) *	**3**	
		Use virgin materials (x < 20%)	4	
	Energy Use	Extraction energy use is much more than average (x > 80%)	0	(1,2)
		Extraction energy use is more than average (60% < x < 80%)	1	
		Extraction energy is around average (40% < x < 60%)	**2**	
		Extraction energy use is less than average (20% < x < 40%)	3	
		Extraction energy use is much less than average (x < 20%)	4	
	Solid Residue	Extraction generates much more solid waste than main product (x > 80%)	0	(1,3)
		Extraction generates more solid waste than main product (60% < x < 80%)	1	
		Extraction generates solid waste same amount as main product (40% < x < 60%)	2	
		Extraction generates less solid waste than main product (20% < x < 40%)	**3**	
		Extraction generates much less solid waste than main product (x < 20%)	4	
	Liquid Residue	Extraction generates much more liquid waste than main product (x > 80%)	0	(1,4)
		Extraction generates more liquid waste than main product (60% < x < 80%)	1	
		Extraction generates liquid waste same amount as main product (40% < x < 60%)	2	
		Extraction generates less liquid waste than main product (20% < x < 40%)	**3**	
		Extraction generates much less liquid waste than main product (x < 20%)	4	
	Gaseous Residue	Extraction emits dangerous gaseous emissions, combustion emission and CO_2 without exhaustion system (x > 80%)	0	(1,5)
		Extraction emits dangerous gaseous emissions, combustion emission and CO_2 with exhaustion system (60% < x < 80%)	1	
		Extraction emits small amount of gaseous emissions (40% < x < 60%)	2	
		Extraction emits negligible amount of gaseous emissions (20% < x < 40%)	**3**	
		Extraction does not emit gaseous emissions (x < 20%)	4	

* The bold option and its corresponding score have been selected.

Table S3. The guideline of the environmental performance scoring for the environmental concerns at manufacturing stage in the PCM panel system

Life Cycle Stage	Environmental Concern	Checklist	Score	Matrix Cell
Product Manufacturing	Material Choice	Use of toxic materials (x > 80%)	0	(2,1)
		Few toxic materials (60% < x < 80%)	1	
		Use toxic and virgin materials (40% < x < 60%)	2	
		Mostly virgin materials (20% < x < 40%)*	**3**	
		Use virgin materials (x < 20%)	4	
	Energy Use	Manufacturing energy use is much more than average (x > 80%)	0	(2,2)
		Manufacturing energy use is more than average (60% < x < 80%)	1	
		Manufacturing energy is around average (40% < x < 60%)	**2**	
		Manufacturing energy use is less than average (20% < x < 40%)	3	
		Manufacturing energy use is much less than average (x < 20%)	4	
	Solid Residue	Manufacturing generates much more solid waste than main product (x > 80%)	0	(2,3)
		Manufacturing generates more solid waste than main product (60% < x < 80%)	1	
		Manufacturing generates solid waste same amount as main product (40% < x < 60%)	**2**	
		Manufacturing generates less solid waste than main product (20% < x < 40%)	3	
		Manufacturing generates much less solid waste than main product (x < 20%)	4	
	Liquid Residue	Manufacturing generates much more liquid waste than main product (x > 80%)	0	(2,4)
		Manufacturing generates more liquid waste than main product (60% < x < 80%)	1	
		Manufacturing generates liquid waste same amount as main product (40% < x < 60%)	2	
		Manufacturing generates less liquid waste than main product (20% < x < 40%)	**3**	
		Manufacturing generates much less liquid waste than main product (x < 20%)	4	
	Gaseous Residue	Manufacturing emits dangerous gaseous emissions, combustion emission and CO_2 without exhaustion system (x > 80%)	0	(2,5)
		Manufacturing emits dangerous gaseous emissions, combustion emission and CO_2 with exhaustion system (60% < x < 80%)	1	
		Manufacturing emits small amount of gaseous emissions (40% < x < 60%)	**2**	
		Manufacturing emits negligible amount of gaseous emissions (20% < x < 40%)	3	
		Manufacturing does not emit gaseous emissions (x < 20%)	4	

* The bold option and its corresponding score have been selected.

Table S4. The guideline of the environmental performance scoring for the environmental concerns at product delivery stage in the PCM panel system.

Life Cycle Stage	Environmental Concern	Checklist	Score	Matrix Cell
Product Delivery	Material Choice	Use of toxic materials (x > 80%)	0	(3,1)
		Few toxic materials (60% < x < 80%)	1	
		Use toxic and virgin materials (40% < x < 60%)	2	
		Mostly virgin materials (20% < x < 40%)	3	
		Use virgin materials (x < 20%)	4	
	Energy Use	Transportation energy use is much more than average (x > 80%)	0	(3,2)
		Transportation energy use is more than average (60% < x < 80%)	1	
		Transportation energy is around average (40% < x < 60%)	2	
		Transportation energy use is less than average (20% < x < 40%)	3	
		Transportation energy use is much less than average (x < 20%)	4	
	Solid Residue	Transportation generates much more solid waste than main product (x > 80%)	0	(3,3)
		Transportation generates more solid waste than main product (60% < x < 80%)	1	
		Transportation generates solid waste same amount as main product (40% < x < 60%)	2	
		Transportation generates less solid waste than main product (20% < x < 40%)	3	
		Transportation generates much less solid waste than main product (x < 20%)	4	
	Liquid Residue	Transportation generates much more liquid waste than main product (x > 80%)	0	(3,4)
		Transportation generates more liquid waste than main product (60% < x < 80%)	1	
		Transportation generates liquid waste same amount as main product (40% < x < 60%)	2	
		Transportation generates less liquid waste than main product (20% < x < 40%)	3	
		Transportation generates much less liquid waste than main product (x < 20%)	4	
	Gaseous Residue	Transportation emits dangerous gaseous emissions, combustion emission and CO_2 without exhaustion system (x > 80%)	0	(3,5)
		Transportation emits dangerous gaseous emissions, combustion emission and CO_2 with exhaustion system (60% < x < 80%)	1	
		Transportation emits small amount of gaseous emissions (40% < x < 60%)	2	
		Transportation emits negligible amount of gaseous emissions (20% < x < 40%)	3	
		Transportation does not emit gaseous emissions (x < 20%)	4	

Table S5. The guideline of the environmental performance scoring for the environmental concerns at use stage in the PCM panel system.

Life Cycle Stage	Environmental Concern	Checklist	Score	Matrix Cell
Product use	Material Choice	Use of toxic materials (x > 80%)	0	(5,1)
		Few toxic materials (60% < x < 80%)	1	
		Use toxic and virgin materials (40% < x < 60%)	2	
		Mostly virgin materials (20% < x < 40%)	3	
		Use virgin materials (x < 20%)	4	
	Energy Use	Product usage energy use is much more than average (x > 80%)	0	(5,2)
		Product usage energy use is more than average (60% < x < 80%)	1	
		Product usage energy is around average (40% < x < 60%)	2	
		Product usage energy use is less than average (20% < x < 40%)	3	
		Product usage energy use is much less than average (x < 20%)	4	
	Solid Residue	Product usage generates much more solid waste than main product (x > 80%)	0	(5,3)
		Product usage generates more solid waste than main product (60% < x < 80%)	1	
		Product usage generates solid waste same amount as main product (40% < x < 60%)	2	
		Product usage generates less solid waste than main product (20% < x < 40%)	3	
		Product usage generates much less solid waste than main product (x < 20%)	4	
	Liquid Residue	Product usage generates much more liquid waste than main product (x > 80%)	0	(5,4)
		Product usage generates more liquid waste than main product (60% < x < 80%)	1	
		Product usage generates liquid waste same amount as main product (40% < x < 60%)	2	
		Product usage generates less liquid waste than main product (20% < x < 40%)	3	
		Product usage generates much less liquid waste than main product (x < 20%)	4	
	Gaseous Residue	Product usage emits dangerous gaseous emissions, combustion emission and CO_2 without exhaustion system (x > 80%)	0	(5,5)
		Product usage emits dangerous gaseous emissions, combustion emission and CO_2 with exhaustion system (60% < x < 80%)	1	
		Product usage emits small amount of gaseous emissions (40% < x < 60%)	2	
		Product usage emits negligible amount of gaseous emissions (20% < x < 40%)	3	
		Product usage does not emit gaseous emissions (x < 20%)	4	

Table S6. The guideline of the environmental performance scoring for the environmental concerns at end of life stage in the PCM panel system.

Life Cycle Stage	Environmental Concern	Checklist	Score	Matrix Cell
Refurbishment Recycling, Disposal	Material Choice	Use of toxic materials (x > 80%)	0	(5,1)
		Few toxic materials (60% < x < 80%)	1	
		Use toxic and virgin materials (40% < x < 60%)	2	
		Mostly virgin materials (20% < x < 40%)*	**3**	
		Use virgin materials (x < 20%)	4	

Energy Use	End of life energy use is much more than average (x > 80%)	0	(5,2)
	End of life energy use is more than average (60% < x < 80%)	1	
	End of life energy is around average (40% < x < 60%)	2	
	End of life energy use is less than average (20% < x < 40%)	**3**	
	End of life energy use is much less than average (x < 20%)	4	
Solid Residue	End of life generates much more solid waste than main product (x > 80%)	0	(5,3)
	End of life generates more solid waste than main product (60% < x < 80%)	**1**	
	End of life generates solid waste same amount as main product (40% < x < 60%)	2	
	End of life generates less solid waste than main product (20% < x < 40%)	3	
	End of life generates much less solid waste than main product (x < 20%)	4	
Liquid Residue	End of life generates much more liquid waste than main product (x > 80%)	0	(5,4)
	End of life generates more liquid waste than main product (60% < x < 80%)	1	
	End of life generates liquid waste same amount as main product (40% < x < 60%)	2	
	End of life generates less liquid waste than main product (20% < x < 40%)	**3**	
	End of life generates much less liquid waste than main product (x < 20%)	4	
Gaseous Residue	End of life emits dangerous gaseous emissions, combustion emission and CO_2 without exhaustion system (x > 80%)	0	(5,5)
	End of life emits dangerous gaseous emissions, combustion emission and CO_2 with exhaustion system (60% < x < 80%)	1	
	End of life emits small amount of gaseous emissions (40% < x < 60%)	2	
	End of life emits negligible amount of gaseous emissions (20% < x < 40%)	**3**	
	End of life does not emit gaseous emissions (x < 20%)	4	

* The bold option and its corresponding score have been selected.

Table S7. Midpoint assessment of a PCM panel, considering IMPACT 2002+ method.

	Unit	Wood [a]	PCM	Energy [b]	Other [c]
Carcinogens	kg C_2H_3Cl-eq	3.6E−02	2.8E−02	6.9E−03	7.3E−03
Non-carcinogens	kg C_2H_3Cl-eq	2.1E−02	9.9E−02	1.3E−02	5.6E−04
Respiratory inorganics	kg PM2.5-eq	1.3E−03	2.2E−03	1.6E−03	6.3E−05
Ionizing radiation	Bq C-14-eq	4.9E+00	4.8E+00	3.3E+01	3.7E−01
Ozone layer depletion	kg CFC-11-eq	7.3E−08	5.6E−08	4.3E−08	4.4E−09
Respiratory organics	kg C_2H_4-eq	7.0E−04	1.2E−03	1.8E−04	8.2E−05
Aquatic ecotoxicity	kg TEG water	1.2E+02	2.8E+02	1.1E+02	3.3E+00
Terrestrial ecotoxicity	kg TEG soil	4.0E+01	2.0E+02	3.2E+01	5.6E−01
Terrestrial acid/nutri	kg SO_2-eq	1.9E−02	5.8E−02	2.5E−02	9.1E−04
Land occupation	m^2org.arable	1.9E−01	2.2E+00	2.8E−02	4.6E−04
Aquatic acidification	kg SO_2-eq	4.6E−03	9.8E−03	1.0E−02	2.9E−04
Aquatic eutrophication	kg PO_4 P-lim	1.7E−04	6.6E−04	2.8E−04	1.0E−05
Global warming	kg CO_2 eq	6.8E−01	1.1E+00	1.5E+00	6.6E−02
Non-renewable energy	MJ primary	1.2E+01	1.0E+01	1.8E+01	2.3E+00
Mineral extraction	MJ surplus	4.3E−02	7.6E−02	7.2E−03	1.7E−03

a. including MDF and HDF panels; b. including heating and electricity energies; c. including plastic bag, glue and waste scenarios.

Table S8. Midpoint assessment of a PCM panel, considering ReCiPe H, method.

	Unit	Wood [a]	PCM	Energy [b]	Other [c]
Climate change	kg CO_2-eq	7.1E−01	1.2E+00	1.6E+00	7.3E−02
Ozone depletion	kg CFC-11-eq	7.3E−08	5.6E−08	4.3E−08	4.4E−09
Terrestrial acidification	kg SO_2-eq	4.4E−03	1.1E−02	9.3E−03	2.6E−04
Freshwater eutrophication	kg P-eq	2.2E−04	4.3E−04	7.4E−04	1.2E−05
Marine eutrophication	kg N-eq	1.9E−04	1.2E−02	3.0E−04	3.0E−05
Human toxicity	kg 1,4-DB-eq	3.1E−01	6.3E−01	5.3E−01	2.1E−02
Photochemical oxidant formation	kg NMVOC	3.7E−03	5.4E−03	4.2E−03	3.0E−04
Particulate matter formation	kg PM_{10}-eq	2.2E−03	4.1E−03	3.1E−03	1.1E−04
Terrestrial ecotoxicity	kg 1,4-DB-eq	1.2E−04	1.4E+00	4.9E−05	6.2E−06
Freshwater ecotoxicity	kg 1,4-DB-eq	7.3E−03	2.5E−01	1.4E−02	1.8E−03
Marine ecotoxicity	kg 1,4-DB-eq	7.0E−03	3.9E−02	1.4E−02	1.7E−03
Ionising radiation	kBq U235-eq	4.8E−02	4.7E−02	3.1E−01	3.6E−03
Agricultural land occupation	m^2a	1.7E+00	2.3E+00	1.9E−01	1.5E−03
Urban land occupation	m^2a	2.4E−02	2.2E−02	1.1E−02	3.8E−04
Natural land transformation	m^2	2.3E−04	2.9E−03	3.4E−04	8.8E−06
Water depletion	m^3	1.6E−02	2.5E−01	2.9E−02	1.0E−03
Metal depletion	kg FE−eq	5.7E−02	1.1E−01	1.1E−02	1.8E−03
Fossil depletion	kg oil-eq	2.5E−01	2.2E−01	3.3E−01	4.8E−02

a. including MDF and HDF panels; b. including heating and electricity energies; c. including plastic bag, glue and waste scenarios.

Table S9. Environmental Responsible Product Assessment for PCM panel.

		Environmental Concern					Total
		Material Choice	Energy Use	Solid Residue	Liquid Residue	Gaseous Residue	
Life Stage	Resource Extraction	3	2	3	3	3	14
	Product Manufacturing	3	1	2	3	2	11
	Product Delivery *	-	-	-	-	-	0
	Product Use *	-	-	-	-	-	0
	Refurbishment Recycling, Disposal	3	3	2	3	3	14
	Total (max: 12)	9	6	7	9	8	39

* The use and delivery stages were not considered at this study.

Table S10. The comparison of results of the full LCA and simplified LCA tool (BilanProduit) for a PCM panel.

ReCiPE– Midpoint- H			**IMPACT 2002+**			**BilanProduit**		
Impact category	Unit	**Total**	Impact category	Unit	**Total**	Impact category	Unit	**Total**
Climate change	kg CO_2 eq	3.54	Global warming	kg CO_2 eq	3.31	GWP, 100 years	kg CO_2-eq	1.73
Terrestrial acidification	kg SO_2 eq	0.02	Terrestrial acid/nutri	kg SO_2 eq	0.10	Acidification	kg SO_2 eq	0.00
-	-	-	Aquatic acidification	kg SO_2 eq	0.02	-	-	-
Freshwater eutrophication	kg P eq	0.00	Aquatic eutrophication	kg PO_4 P-lim	0.00	Eutrophication (air, water, soil)	kg PO_4-eq	0.00
Marine eutrophication	kg N eq	0.01	Carcinogens	kg C_2H_3Cl eq	0.08	-	-	-
Freshwater ecotoxicity	kg 1,4-DB eq	0.27	Non-carcinogens	kg C_2H_3Cl eq	0.13	-	-	-
Marine ecotoxicity	kg 1,4-DB eq	0.06	Aquatic ecotoxicity	kg TEG water	500.41	Aquatic ecotoxicity	kg 1,4-DB eq	0.28
Terrestrial ecotoxicity	kg 1,4-DB eq	1.44	Terrestrial ecotoxicity	kg TEG soil	269.79	-	-	-
Ozone depletion	kg CFC-11 eq	0.00	Ozone layer depletion	kg CFC-11 eq	-	-	-	-
Human toxicity	kg 1,4-DB eq	1.31		-	-	Human Toxicity	kg 1,4-DB eq	0.83
Photochemical oxidant formation	kg NMVOC	0.01	Respiratory organics	kg C_2H_4 eq	0.00	Photochemical pollution	kg C_2H_4	0.00
Particulate matter formation	kg PM10 eq	0.01	Respiratory inorganics	kg PM2.5 eq	0.01	-	-	-
Ionising radiation	kBq U235 eq	0.14	Ionizing radiation	Bq C-14 eq	14.44	-	-	-
Agricultural land occupation	m^2a	4.92	Land occupation	m^2org.arable	2.48	-	-	-
Urban land occupation	m^2a	0.06	Non-renewable energy	MJ primary	37.47	Non-Renewable Energy	MJ eq	47.65
Natural land transformation	m^2	0.00	Mineral extraction	MJ surplus	0.12	Resource consumption	kg Sb eq	0.02
Water depletion	m^3	0.29						
Metal depletion	kg Fe eq	0.17						
Fossil depletion	kg oil eq	0.80						