D7.1 Sustainability Life Cycle Assessment of the New Product Types

WP 7, T 7.1

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Executive Summary

This document presents the first results of EnDurCrete project WP7, Task 7.1. - Environmental and economic viability of the novel products. Strategic Life Cycle Analysis (SLCA) has been carried out as initial sub-task.

SLCA is a qualitative method analysing social and ecological sustainability at the product system level. It helps to identify major sustainability issues that can be further explored e.g. by standard Life Cycle Analysis or other methods.

The SLCA has been carried out for five EnDurCrete innovative products/technologies (novel cement including sustainable supplementary cementitious materials, novel self-sensing carbon-based green micro fillers, smart corrosion inhibitors based on nano-modified clays, multifunctional coatings and advanced self-sensing concrete monitoring systems), precast concrete elements and complete innovative EnDurCrete system composed of all above listed components.

The work consisted of elaborating modified SLCA questionnaire by Geonardo, providing answers by the partners responsible for particular products/technologies (Heidelberg Cement, Nuova Tesi, UNIVPM, IBOX, AMSolutions, RINA-C) and analysing the collected inputs by Geonardo.

The results of SLCAs of novel cement and precast panels provided by Heidelberg Cement and Nuova Tesi are very reliable because the data provided is based on real industrial scale production and company environmental strategies. These SLCAs allowed identification of number of specific environmental and social challenges that can be further addressed in the subsequent detailed LCA.

The results of SLCAs of other sub-products are influenced by the fact that the data providers usually achieve only laboratory scale production and some of the industrial scale producers are unknown at the moment. In addition, the developments in the frame of the EnDurCrete project have not been completed yet and final compositions or technologies are also unknown. Many answers were therefore based on experience rather than description of the real industrial practice. All of this causes much higher level of uncertainty of the calculated results. However these SLCAs allowed identification of key problematic areas especially in the “raw material” and “production” phase of the life cycle that will be further investigated and reported later in the detailed LCA report.

The end-of-life phase was covered by VITO but the level of uncertainty is also quite high – firstly due to the above mentioned fact that composition of the final product(s) is not yet completely available and secondly because the expected life time of the precast concrete elements is 140 years, which makes predicting of future recycling, reuse or waste treatment technologies very difficult. The answers and results are therefore based on currently available technologies and practices.

Acknowledgement:

Sustainability Life Cycle Assessment is a method developed and promoted by the international sustainability NGO The Natural Step (www.thenaturalstep.org).

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Abbreviations and Acronyms

SLCA – Sustainability Life Cycle Assessment

LCA – Life Cycle Assessment

FSSD - Framework for Strategic Sustainable Development

UNIVPM - Università Politecnica Delle Marche

SC – Sustainability Condition

1 Introduction

This document is the initial output of EnDurCrete project WP7 (Life cycle assessment and economic evaluation, standardization and health and safety aspects), Task 7.1 (Environmental and economic viability of the novel products based on LCA and LCCA).

EnDurCrete concept is based on the following novel technologies:

- Novel cements including sustainable supplementary cementitious materials
- New smart fillers based on nano-modified clays having anti corrosion properties
- New micro carbon-based materials for mechanical and self-sensing properties
- New multifunctional coatings
- Advanced non-destructive monitoring tools (self-sensing concrete systems)

Precast elements for various applications (marine, tunnel, offshore structure, bridge) will be designed and produced in order to demonstrate the properties of the concept in real life conditions.

Strategic Life Cycle Analysis (SLCA) presented in this document should give the initial summary of the major environmental impacts of the new products developed/applied in frame of EnDurCrete project through the whole lifecycle in relation to the main requirements of sustainability. Each of the above listed products/technologies can in fact stand on its own. Therefore all products have been analyzed separately (data provided by the project partners responsible for the particular technology) and subsequently the results have been synthesized in order to provide a general picture of compliance with sustainability principles at final product level.

It should be emphasized that SLCA is a qualitative method and therefore it is suitable for an initial overview of the sustainability of production chain and for the identification of critical steps or issues that require increased attention in the subsequent steps. It will be followed by detailed Life Cycle Analysis (LCA) at material and product level.

2 Methodology

Sustainability Life Cycle Assessment (SLCA) is a structured process and assessment method to deliver a strategic overview of the full scope of social and ecological sustainability at the product system level. It results in a strategic analysis – using colours or other qualitative indicators – that allows to see the major impact of the product through the whole lifecycle in relation to principle requirements of sustainability. **The method has been developed by The Natural Step and amended by Geonardo for the purposes of EnDurCrete project.** SLCA helps to identify major sustainability issues in relation to a product or process in a qualitative manner. Once this is clear, the key aspects can be strategically explored and quantified where it is considered necessary (e.g. by standard LCA or other methods). **This means that SLCA is an ideal precursor or strategic filter by which one can look at life cycle assessment, starting with the full scope of sustainability.**

SLCA method is based on **four so called "sustainability system conditions"** as defined by The Natural Step Framework.

Table 2.1 – Sustainability conditions as defined by The Natural Step Framework

Sustainability condition		Explanation
	**SC 1: Nature is not subject to increase of concentrations of substances extracted from the Earth's crust.**	The balance of flows between the ecosphere (living organisms and the physical systems with which they interact) and the lithosphere (the earth's crust) must be such that concentrations of substances from the lithosphere do not systematically increase in the whole ecosphere, or in parts of it.
	**SC 2: Nature is not subject to increase of concentrations of substances produced by society.**	The production and accumulation of human-made substances must not happen faster than they can be reintegrated back into natural cycles, assuming they can be assimilated by nature at all. The focus here is on reducing our dependence on synthetic materials by using safe, biodegradable alternatives which can be reintegrated into natural cycles, as well as decreasing the amount of waste generated by society in general.
	**SC 3: Nature is not subject to degradation by physical means.**	In order for a society to be sustainable, nature's functions and diversity are not systematically impoverished by physical displacement, overharvesting, or other forms of ecosystem manipulation.
	**SC 4: People are not subject to conditions that systematically undermine their capacity to meet their needs.**	In order for a society to be sustainable, resources must be used fairly and efficiently in order to meet basic human needs globally.

The assessment of each of the four sustainability principles is further split into **five lifecycle phases:**

1. **Raw materials.** This covers the extraction of resources, their processing/synthesis and transport to the gates of production where the resources will be used as raw materials to produce the product. This includes material inputs, energy inputs, stakeholders, waste and associated emissions. These

aspects are excluded: the production, maintenance and dismantling of extraction and processing plant/machinery; packaging materials for raw material transportation.

2. **Production.** This covers from the arrival of the raw materials at the factory gate to finished product ready to package. This includes material inputs (processing materials/substances), energy inputs, stakeholders, emissions and waste, but excludes the production, maintenance and dismantling of production plant/machinery. Transports of personnel is also excluded.
3. **Packaging, distribution and retail.** This covers the extraction and production of primary, secondary and tertiary packaging; warehousing; transport and distribution to retail customers and final users. Including key material and energy inputs, but excluding details around the distribution network, such as the building, maintenance and dismantling of roads, vehicles and buildings.
4. **Use and maintenance.** This covers the installation, use and maintenance of the product until the product no longer functions and is removed/discarded. Including material and energy inputs.
5. **Product fate/End of Life.** This covers the recovery, transport, processing and final fate (reuse, recycling, landfilling, treatment, etc.) of the product after its use has ended. Including material and energy inputs, but excluding the production, maintenance and dismantling of vehicles and plant/machinery used throughout the life cycle stage.

Original SLCA methodology consists of ten steps that combine the requirements of the ISO standard for Life Cycle Assessment with strategic planning methodology of the Framework for Strategic Sustainable Development (FSSD). Complete SLCA includes suggestions for solutions and creating sustainable innovation road map. Because the SLCA performed in frame of EnDurCrete project will be followed by detailed LCA at material and product level, these steps will be covered in later stage of the project and therefore this simplified SLCA ends with analysis and synthesis of results and simple recommendations based on the information available already in this initial phase of the project.

The questionnaire consisting of carefully selected questions covering all above listed sustainability conditions and life cycle phases has been developed by ThinkStep, slightly amended by Geonardo and distributed among EnDurCrete partners responsible for following parts of the production chain.

Table 2.2 – Overview of composite cement inventory – number of answers

Product	Responsible partner
Novel Portland composite cement	HeidelbergCement
Pre-cast concrete elements	NTS
Novel self-sensing micro-fillers	UNIVPM
Smart corrosion inhibitors	IBOX
New multi-functional protective coatings	AM-Solutions
Multifunctional self-monitoring reinforcing system	RINA-C

The questions first assess the impact of the product based on four sustainability principles. Alongside impacts, the questions also try to identify if there are any targets of the responsible company/institute in making sustainable changes within the life cycle of the product, again based on sustainability principles. Thus, the questions are divided into **impact** and **progress** categories.

The answers covering end-of-life and recyclability of the complete product (innovative concrete precast element) were provided by VITO.

Once the answers were collected, the score for each sustainability condition and product life cycle phase was calculated based on very simple principle: positive answer ("yes") = +1; negative answer ("no") = -1; neutral answer („do not know" or „not applicable") = 0.

3 Sustainability Life Cycle Analysis

3.1 SLCA of Novel Portland composite cement

Product system

The products analyzed are novel Portland Composite Cements (PCC) including sustainable, high-quality supplementary cementitious materials that are valorised industrial by-products (i.e. classified coal combustion fly ashes and ground granulated blast furnace slag). These are CEM II/C-M (S-V) and CEM VI (S-V) cement binders, i.e. novel classes of Portland-composite cements where reduction of the Portland cement clinker content down to 35-64% is achieved by replacement of Portland cement clinker by blend of mainly size-graded fly ash (symbol V in the cement code) and blast furnace slag (S). The novel cements are produced by HeidelbergCement.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is omitted because cement becomes integral part of the reinforced concrete construction and cannot be treated separately at the end of life of the final product.

Inventory analysis

The answers to the first three phases of the entire life cycle (Raw materials, Production, Packaging and distribution) were provided by the binder producer, HeidelbergCement. These answers are based on the actual cement production processes and sustainability policies of the company and are therefore highly reliable and representative.

The answers to the fourth phase (Use and maintenance) were elaborated by Geonardo and harmonized with the answers related to the complete product (concrete pre cast element) provided by Nuova Tesi. It is clear that cement itself can be used in many different ways that would significantly affect for example the answer to the question: "*Does the intended use of the product avoid systematically undermining the user's or surrounding community's capacity to meet their basic human needs*?" Both answers "yes" and "no" are apparently possible according to type and use of the construction made of the concrete based on the novel binders. The answers therefore reflect uncertainty caused by this versatile use of the novel material (typically "do not know" option was selected).

The questionnaire covering initial four phases of the life cycle consists of 112 questions. Overview of number of particular answers is provided in Table 3.1.

Table 3.1 – Overview of composite cement inventory – number of answers

Answer	Nr.
Yes	45
No	25
Do not know	13
Not applicable	29

Results

After the questions were answered, the result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.1 – SLCA results – novel composite cement

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	-1	2	-2	2
	-1	2	1	3
	-2	4	0	0
	3	3	3	1

The results clearly indicate that the major impacts according to Framework for Strategic Sustainable Development can be found in the "Raw material" production phase. This is caused mainly by three factors:

- Part of the raw materials are provided by the sub-contractors and the cement producer cannot directly influence the way the raw materials are extracted; however, company codes of conduct covering sustainability and sustainability audits for suppliers are under development.
- The raw materials are transported by the means of transport using fossil fuels. Diesel consumption cannot be avoided at this moment but the use of more sustainable means of transport should be encouraged once these are commonly available.
- Avoiding physical degradation of nature caused by raw material extraction is not possible unless all virgin raw materials used along the process of making cement are replaced by secondary ones. This is currently not feasible but HeidelbergCement is actively increasing the share of secondary materials which can be demonstrated by the use of fly ash and slag in EnDurCrete cements.

Another negative result was achieved in SC1, Packaging and distribution life cycle phase. This is again caused by the fact that cement is usually transported by state-of-the-art trucks driven by diesel. The company is well aware of this fact and optimization of logistics in terms of sustainability has high priority.

3.2 SLCA of precast concrete elements

Product system

The product assessed in this chapter is precast concrete panel/column/segment based on the novel materials produced in frame of EnDurCrete project. Because the project-specific elements are covered in other sub-chapters of this SLCA, SLCA of precast panels focuses mainly on the production of the typical precast concrete panel as commercially produced by Nuova Tesi.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is omitted because it is treated separately for the complete construction in chapter 3.7.

Inventory analysis

The answers to questionnaire were provided by Nuova Tesi, company that will be responsible for production of precast concrete elements in frame of EnDurCrete project. Production of precast concrete elements is the main business of the company and the answers are based on the current practice. This means that the answers are highly reliable, describing the actual situation. The questionnaire covering initial four phases of the life cycle consists of 112 questions. Overview of number of particular answers is provided in Table 3.2.

Table 3.2 – Overview of precast concrete elements inventory – number of answers

Answer	Nr.
Yes	34
No	61
Do not know	2
Not applicable	15

Relatively high number of negative answers is caused mainly by the big number of answers „no“ in the sections of the questionnaire dedicated to „progress“ in each sustainability condition and life cycle phase. This means that the company does not have any formalized sustainability policies and strategies and there is a large space for improvement in this area (which is of course limited by economic factors and size of the company).

Results

After the questions were answered, the result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.2 – SLCA results – precast concrete elements

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	-3	-3	-3	2
	-7	-5	-1	3
	-5	-3	-5	0
	-5	-1	-1	1

The results show huge potential for improvement in production phases “raw materials”, “production” and “packaging and distribution”. The main reasons for rather negative results of SLCA are following:

Raw materials

- The raw materials are extracted and transported by the machines using fossil fuels. This way of sourcing raw materials has no feasible alternative at the moment.
- Extraction of raw materials (especially aggregate) is typical physical degradation of nature. It can be partially reduced by the use of alternative fillers (for example secondary aggregate from crushed recycled concrete) but their availability is still very limited and such alternative fillers also have certain technological limitations.
- Aggregate extraction also typically causes accompanying negative phenomena for society such as increased transport, noise, dust, destruction of roads etc.
- Nuova Tesi does not have any strategies and policies towards better sustainability.

Production

- Production of precast panels uses fossil energy. Replacement by green energy sources is therefore recommended when possible.
- Oil used for demolding can cause nature pollution (but only in case of accident or improper treatment).
- Nuova Tesi does not have any strategies and policies towards better sustainability in this area.

Packaging and distribution

- Precast concrete elements are usually transported by trucks burning diesel.
- Nuova Tesi needs to develop strategies and policies towards better sustainability in this area.

3.3 SLCA of self-sensing carbon-based micro fillers

Product system

This SLCA deals with **self-sensing carbon-based green micro fillers** that will be added to EnDurCrete concrete mixes derived from industrial by-products. In this specific char obtained by biomass gasification (average diameter = 50 µm) is considered. The new fillers will not only increase the concrete mechanical performance thanks to microstructure refinement and durability, but also further implement structure monitoring solutions, giving concrete a "self-monitoring" capability, based on the electrical resistivity variation taking place when cracks appear, especially in presence of water.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is omitted because it is treated separately for the complete construction in chapter 3.7.

Inventory analysis

The answers to questionnaire related to self-sensing carbon-based micro fillers were provided by Università Politecnica Delle Marche (UNIVPM). This is a major limitation of this SLCA. UNIVPM is a research organization and will for sure not become commercial producer of developed material(s). In addition, the development of the new fillers in frame of EnDurCrete project has not been completed yet (the final deliverable of the related task is due in M15), therefore the answers are mainly based on the experience of the UNIVPM experts rather than description of existing or expected production cycle. Relatively high number of questions was therefore answered "do not know" because such information is not yet available. This causes higher uncertainty of this particular SLCA. Overview of number of answers is provided in Table 3.2.

Table 3.3 – Overview of self-sensing carbon-based micro fillers – number of answers

Answer	Nr.
Yes	31
No	2
Do not know	79
Not applicable	0

Only two questions were answered "No" although it is almost sure that there would be much higher number of these answers if the real production would be described – at least the questions related to fossil energy sources and means of transportation of materials and products.

Results

After the questions were answered, the result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.3 – SLCA results – self-sensing micro fillers

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	1	2	2	2
	1	2	3	3
	2	2	2	3
	1	0	1	2

As explained above, the results of this SLCA have only limited predictive value because they do not describe any real industrial production and majority of questions was answered “do not know”. It can therefore be only generally stated that there are several positive findings (the material is basically secondary, therefore there are only very limited negative impacts caused during raw material production phase; the production itself is also supposed to cause no or very limited emissions of pollutants).

These results should therefore be understood as very preliminary. Detailed Life Cycle Analysis to be performed later in the project should bring deeper insight in sustainability of production and use of self-sensing concrete fillers.

3.4 SLCA of smart corrosion inhibitors

Product system

This SLCA deals with **smart corrosion inhibitors** for concrete formulation - laminar clays modified with alkoxysilane groups and anionic corrosion inhibitors. These additives will respond intelligently since the inhibitor compound will be only released from the clay when the corrosion probability increases, as a result of a pH decrease, determined by water and carbon dioxide, or chlorides concentration increase.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is omitted because it is treated separately for the complete construction based on novel materials and products as discussed in chapter 3.7

Inventory analysis

Inventory analysis questionnaire for smart corrosion inhibitors was elaborated by IBOX, engineering company responsible for development and assessment of the innovative material. It has to be noted that the company will probably not become the industrial scale producer of the new fillers (it is expected that concrete admixture company such as SIKA may commercialize the final product). Therefore the answers also do not represent the real industrial production and are rather based on IBOX staff expertise and experience. In addition, the development of the new anti-corrosion fillers has not yet been completed in frame of EnDurCrete project (the related Task 3.1. should end at M16). This also leads to relatively high number of answers “do not know” and ”not applicable” (almost half of all answers). Therefore the results presented below have to be understood as preliminary analysis of overall sustainability.

Overview of number of answers is provided in Table 3.4.

Table 3.4 – Overview of smart corrosion inhibitors inventory – number of answers

Answer	Nr.
Yes	43
No	13
Do not know	15
Not applicable	41

Results

The result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.4 – SLCA results – smart corrosion inhibitors

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	-2	7	0	2
	-2	4	0	3
	-1	7	0	3
	0	4	0	4

Figure 3.4. demonstrates that the main negative environmental impacts can be expected during the "**Raw material**" life cycle phase. The main reasons are:

- Clays used as basic materials have to be extracted as virgin materials, which leads to physical degradation of nature. It could be possible to prepare similar materials synthetically, but the impacts of such alternative are highly questionable.
- Extraction and transport of raw materials is done by machinery using fossil fuels (diesel); this way of acquiring raw materials has no real industrial scale alternative at the moment.
- No clear purchasing guidelines or codes of conduct are reported by IBOX (but the situation can be different for the future commercial producer of the final product).

Very positive results achieved for **"Production"** phase actually do not refer to industrial production but rather to laboratory scale production at IBOX. Therefore the results for industrial scale production can be different.

3.5 SLCA of protective coatings

Product system

Product considered in this SLCA is an innovative multi-functional concrete element coating material (paint) with self-healing properties and improved resistance to aggressive agent, with focus on deep sea exposure. This material is being developed by AMSolutions.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is omitted because it is treated separately for the complete construction in chapter 3.7

Inventory analysis

The inventory was elaborated by AMSolutions. Similarly to IBOX, also AMSolutions is a small innovation/research oriented company providing state-of-the-art technical services, here in the field of development and optimization of innovative protective concrete coatings. The company has a certain experience with scale-up of the innovative solutions but it is not likely that it would be the industrial scale producer of the final product. The final way of commercialization and industrial production is therefore not known at the moment (the most likely would be some kind of licensing to established producer of similar products having necessary infrastructure). Therefore also the answers in this SLCA questionnaire are mostly based on the information related to laboratory scale production and experience of the company with upscaling of similar products. This fact leads to relatively higher number of answers “do not know” or “not applicable”. It should also be noted that AMS considers as raw materials the commercial chemicals that are used either directly in the coating formulation or for the synthesis of the ingredients of the coating formulation (ITO, Ag ions, microcapsules etc.).

Summary of number of answers is provided in Table 3.5.

Table 3.5 – Overview of protective coatings inventory – number of answers

Answer	Nr.
Yes	52
No	18
Do not know	29
Not applicable	13

Results

After the questions were answered, the result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.5 – SLCA results – protective coatings

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	-2	1	0	4
	-1	3	0	3
	2	3	0	4
	0	5	6	6

Similarly to previous SLCAs the major negative impacts have been identified in the "Raw material" product life cycle phase. As mentioned above, many of the final product precursors are chemicals produced by third parties and therefore the access to necessary information is limited. Therefore the predictive value of the analysis is rather limited.

The negative results in "Raw materials" phase is mainly caused by two reasons:

- The raw materials and products are certainly transported using fossil fuels. As already discussed, the replacement of traditional means of transport at industrial level is very difficult at the moment.
- The raw materials can contain substances that are scarce in nature, such as Ag, Sn or In. It is theoretically possible to seek for precursors not containing these substances but their functional parameters would have to be properly tested and economic consequences should also be considered.

The result in phase "Production" is generally positive but the questionnaire includes relatively high number of answers "No" (but number of answers "Yes" is higher resulting in overall positive result). Each answer "no" represents potential sustainability problem, but at the same time opportunity for improvement. The main negative factors during production phase are related to the following aspects:

- Production uses materials that may contains substances scarce in nature.
- Waste containing some of the scarce substances (around 100 ppm) and also substances that risk accumulating in nature is produced in limited amounts.
- Electric energy is not completely purchased from sustainable resources.
- The production uses chemicals that cannot be considered safe materials.

The results in life cycle phases "Packaging and distribution" and "Use" are generally positive, but it should be repeated that the answers are based on expert estimation rather than real industrial practice and real life answers will highly depend on future producers and users of the product. The production will be probably performed by other company or companies whose environmental strategies and policies are unknown at the moment.

3.6 SLCA of self-monitoring reinforcing system

Product system

This SLCA deals with multifunctional self-monitoring concrete reinforcing system developed by RINA-C. The main focus of this SLCA is the fiberglass grid as it is by far the main material of the reinforcing system.

System boundaries

This SLCA covers only four of five life cycle phases as defined by SLCA methodology. End of life and recycling is treated separately for the complete construction in chapter 3.7

Inventory analysis

The inventory has been elaborated by RINA-C, engineering company responsible for development of multi-functional self-monitoring reinforcing system to be used in EnDurCrete precast elements. The system will be composed of commercially available materials and products, therefore the answers are based on publicly available information about the products and engineering experience of RINA-C experts. The way of commercialization of the system is still to be developed and this leads to very high number of answers “do not know” and “not applicable” (more than 70 %). Level of uncertainty of the results is therefore relatively high.

Overview of number of answers is provided in Table 3.6.

Table 3.6 – Overview of self-monitoring reinforcing system – number of answers

Answer	Nr.
Yes	18
No	13
Do not know	60
Not applicable	21

Results

After the questions were answered, the result has been calculated and presented in the form of colorized matrix for each sustainability principle and life cycle phase covered. Green for the most sustainable and red for the least sustainable.

Figure 3.6 – SLCA results – self-monitoring reinforcing system

Sustainability condition	Raw material	Production	Packaging and distribution	Use
	-2	-1	0	2
	-3	-3	-2	3
	1	0	1	0
	1	2	3	3

The main reasons for negative result in "Raw material" phase are following:

- AR-glass scrims are made of alkali-resistant sodium zirconium silicate glass with a zirconium oxide concentration ≥ 16%). ZrO_2 can be considered scarce substance. The replacement of such material is technologically questionable and goes far beyond the scope of the project.
- Raw materials are transported by the means of transport using fossil fuels.
- The chemical additives can be sourced in the way causing some risk of accumulating harmful substances in nature. Use of such chemicals should be limited to lowest possible extent.

The main negative aspects of "Production" phase are as follows:

- The production process includes special materials (additives) that may contain materials scarce in nature; minor part of these materials can also become production waste. Use of these materials should be limited to lowest possible extent.
- Some of the materials used during the production risk accumulating in nature. Proper waste treatment/recycling is therefore strongly recommended.
- Production probably uses electric energy from grid, which is not fully sustainable.

The negative result in SC2/Packaging and distribution life cycle phase is caused by the fact that the product is usually packed in plastic materials that can potentially cause risk when accumulated in nature. In addition, the distribution uses traditional means of transport using fossil fuels.

3.7 End-of-life

Product system

As already mentioned, the end-of-life phase was not analyzed for each sub-product separately but for the whole expected EnDurCrete system – concrete precast elements including novel Portland composite cement, self-sensing micro-fillers, smart corrosion inhibitors, protective coatings and self-monitoring reinforcing system.

Inventory

End-of-life questionnaire consisted of 28 questions answered by VITO according to current knowledge of EnDurCrete product system characteristics and state-of-the-art technologies for treatment of construction waste. It has to be noted that expected durability of the final products is 140 years and it is therefore very difficult to predict future technologies and ways of treatment of similar waste types.

Table 3.7 – End-of-life – number of answers

Answer	Nr.
Yes	12
No	10
Do not know	2
Not applicable	4

Results

The results are presented in the form of colorized matrix, green for the most sustainable and red for the least sustainable.

Figure 3.7 – SLCA results – end-of-life

Sustainability condition	End of life
	2
	1
	0
	-1

Main negative findings related to end-of-life phase are as follows:

- According to current status, the transport of waste to treatment would use fossil fuels. Situation after 140 years can however be different.
- Also the sources of energy used in current recycling are usually not fully sustainable. However it is difficult to predict electricity mix in 140 years.
- There is possibility of release of substances that risk accumulating in nature coming from innovative product components especially when the construction wastes are landfilled. This will need to be verified later in the project (task 7.4).
- Dust from crushing or leaching of substances when re-used as road base can cause certain health risks related to end-of-life treatment and reuse. Proper safety standards (contemporary at time of product end-of-life) have to be applied.

3.8 EnDurCrete complete product

Product system

Whole EnDurCrete system – concrete precast elements including novel Portland composite cement, self-sensing micro-fillers, smart corrosion inhibitors, protective coatings and self-monitoring reinforcing system.

Inventory

There was no separate inventory carried out for the whole system. The results are based on the inventories of all sub-products provided by HeidelbergCement, Nuova Tesi, UNIVPM, IBOX, AMSolutions, RINA-C and VITO.

Results

The results have been achieved as the average of the results of all sub-components as presented in chapters 3.1 – 3.7. It should be emphasized that these results are not related to any real life product available at the moment. Because there is no actual producer of such product, there are also no company strategies and policies towards sustainability. However even these preliminary averaged results can serve as a baseline for a more detailed Life Cycle Analysis that will be subsequently carried out in frame of EnDurCrete project.

Figure 3.8 – SLCA results – EnDurCrete products average

Sustainability condition	Raw material	Production	Packaging and distribution	Use	End-of-life
	-2	1	-1	2	2
	-2	1	0	3	1
	-1	2	0	2	0
	0	2	2	3	-1

The main sustainability challenges are related to "Raw materials" product life cycle phase. This is partially caused by the fact that the raw materials are almost always purchased from third parties and the possibility to apply sustainability principles directly by the project partners or future product producer(s) is limited. It is highly recommended to always consider environmental (and social) aspects of use of all raw materials and select the most sustainable ones when possible. This will be analyzed in detail in LCA at material level.

All raw materials and products are at the moment transported by means of transport using fossil fuels. Although the possibility to replace them is currently very limited, it should be encouraged to seek for at least means of transport causing lower emissions of green-house gases and other adverse environmental impacts.

4 Conclusions

Sustainability Life Cycle Analysis has been performed for the five EnDurCrete innovative sub-products (novel cement including sustainable supplementary cementitious materials, new smart corrosion inhibitors based on nano-modified clays, novel self-sensing carbon-based green micro fillers, multifunctional coatings and advanced self-sensing concrete monitoring systems), as well as for the precast concrete elements and complete innovative EnDurCrete system composed of all above listed components.

The SLCAs results of novel cement and precast elements are considered as the most reliable since the questionnaires related to these products contained the smallest number of answers “do not know” and “not applicable”.

SLCA of **novel cement** identified the following opportunities for improvement in terms of sustainability:

- Company code of conduct covering sustainability and sustainability audits for suppliers of raw materials should be developed and applied (already ongoing).
- The use of the most environmentally friendly means of transports and sources of energy should be encouraged.
- Share of secondary materials in cement should be increased in order to reduce degradation of nature (topic of EnDurCrete cement development).

SLCA of **precast concrete elements** was carried out by Nuova Tesi. The main findings and recommendations are as follows:

- Negative impacts of raw material extraction should be limited when possible although it is technically complicated at the moment. These negative impacts can be partially reduced by the use of alternative fillers (for example secondary aggregate from crushed recycled concrete) and the use of environmentally friendly technologies and means of transport.
- Green energy should be used when possible during production.
- The company should develop strategies and policies towards better sustainability identifying possible improvements in all production phases.

The results of SLCAs of the remaining EnDurCrete system components (self-sensing carbon-based micro fillers, smart corrosion inhibitors based on nano-modified clays, multifunctional coatings and advanced self-sensing concrete monitoring systems) suffer from substantial uncertainty caused by a significantly high number of answers “do not know” and “not applicable”. The development of innovative products in frame of EnDurCrete project has not been fully completed and upscaling strategies have not yet been concluded. Relatively high number of the answers “do not know” is therefore (but not only) caused by the fact that it is not sure who will be the final product industrial scale producers and what will be their sustainability standards, policies and strategies.

The general findings of this preliminary SLCA analysis are that the main negative impacts can be observed in “Raw materials” phase for all sub-products and quite often also in “Production” phase, especially when the production process requires the use of chemicals or can cause emissions of potentially harmful substances. These issues will be further investigated in frame of subsequent detailed Life Cycle Analysis on material and product level.