Excellence In Services International Conference EISIC
Formerly Toulon-Verona Conference, founded in 1998

Diagnosing Sustainability Opportunities in Swedish Cement and Concrete

Max Rosvall
Department of Civil and Industrial Engineering
Uppsala University (Sweden)
max.rosvall@angstrom.uu.se
Corresponding Author

Raine Isaksson
Department of Civil and Industrial Engineering
Uppsala University (Sweden)
raine.isaksson@angstrom.uu.se

Abstract

A Sustainability Opportunity Study (SOS) can be used to highlight and make sense of sustainability in any chosen business and in any area of sustainability. In this paper we study sustainability opportunities for Swedish cement and concrete. Emissions from cement, the binder in concrete, play an important role in climate effects for the entire building value chain putting pressure on change. These change challenges have further been accentuated by the recent crisis for the sole Swedish cement producer that has been denied continuing its quarrying operations in its main factory that delivers 75% of the Swedish cement. Even if permission issues could be solved the signal is there that circular solutions not relying on an end of the pipe business model are needed. The international cement industry might also have to rethink the entire business idea. We study both how to understand sustainability opportunities in cement and concrete manufacturing and the theoretical implications of it for the SOS. The paper proposes a further development of the SOS and the matrix that combines Understand-Define-Measure with Diagnosing-Analysing-Solving. We focus on creating a better understanding for the parts of Diagnosing using cement and concrete as examples.

Results indicate that there are alternatives to using virgin limestone as raw material in cement and that we should focus on concrete sustainability performance to reduce the carbon footprint. In Diagnosing Understanding the start should be in the business concept and its sustainability in comparison with the four system principles.

Keywords
climate; concrete; cement; understanding; opportunity; Sweden

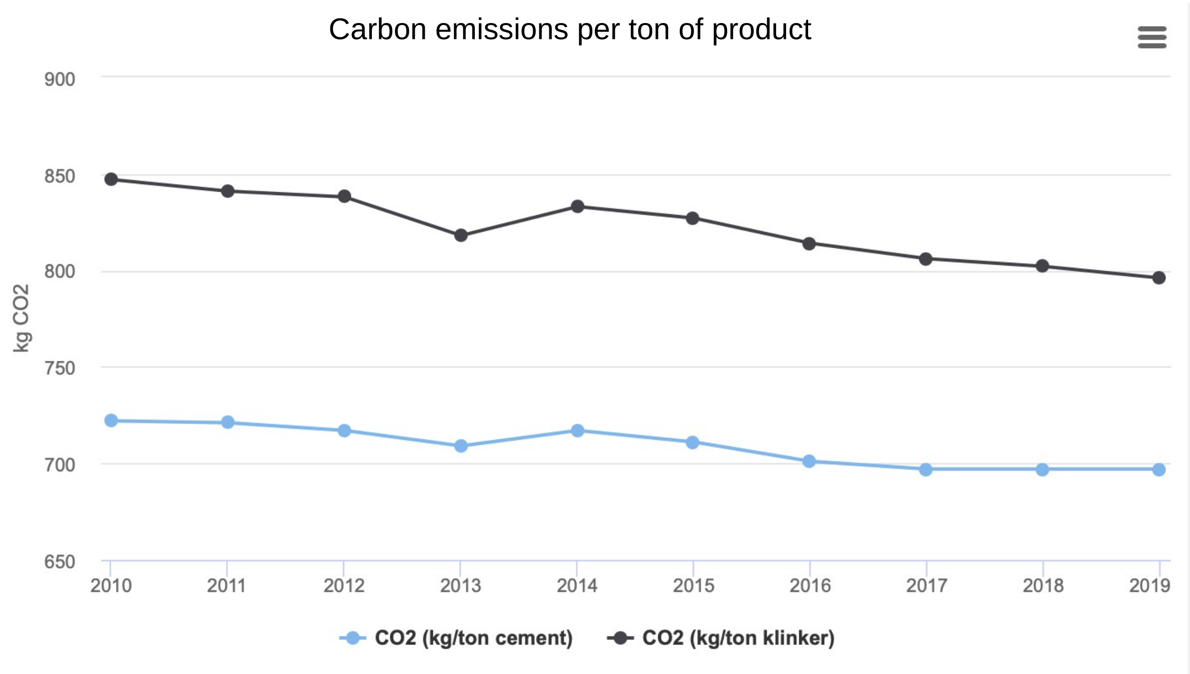
1. Introduction to housing, concrete and cement challenges

Housing is a basic human need and fundamental for the current and future wellbeing of people. Access to acceptable housing conditions contributes to the universal human need of security through the provision of shelter against rough weather, harmful animals, and humans with malicious intent. The lack of housing is a challenge in societies of all income levels. Faced with this challenge, the ancient and most common solution is building, i.e., the process of construction new buildings to accommodate people. With increased understanding of the effects of human activities on the planetary system, the building process is faced with new restrictions and performance measurements. The human activities of the 21st century will be highly affected by pursuit of sustainable development, i.e., meeting the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Sustainable building and housing form an important part of sustainable development.

Sweden is often referred to as one of the worlds' most sustainable countries as exemplified in reviews by RobecoSam (2021) and scores high on the SDG index, second out of 193 countries (SDG, 2021). In 2021 Sweden has about 10 million people and consumption-based CO_2 emissions are roughly 70 million tonnes. Industry and energy production in Sweden, included in the EU trading scheme with emissions, contributed with some 19 million tonnes to the production-based emissions. Building and construction industry in Sweden are estimated to contribute with some 7.6 million tonnes of CO_2 emissions, which is about 10% of total consumption-based emissions. The majority, 31% of the building construction emissions are derived from concrete and other cement-based products. Sweden has committed to reducing GHG emissions to net-zero by 2045 and to pursue negative emissions thereafter. The Swedish Mistra Carbon Exit Roadmap writes that the Heidelberg Cement group, owning the two cement plants in Sweden, located in Slite and Skövde, having a capacity of some 3 Mt cement per year, is responsible for around 2.5 Mt CO2 emissions annually, which is equivalent to around 15% of the total Swedish industrial CO2 emissions (Mistra, 2020). This means that the rate of reduction should be rapid and that substantial changes in cement production are needed. Results in Figure 1 indicated that the rate of change is not rapid enough considering the goal of zero net emissions in 2045. The planned solution in the CemZero project is to rely on Cabon Capture and Storage (CCS) (Roadmap, 2018).

Emissions from cement, the binder in concrete, play an important role in climate effects for the entire building value chain putting pressure on change. Concrete as a building material can only be partly substituted even in Sweden. Globally, concrete is the dominating material and has currently no good alternatives whereas there could be alternatives to the ordinary cement, often called Portland Cement (Isaksson and Rosvall, 2021). The carbon footprint from cement is corresponding to about 8% of global emissions. This puts pressure on cement. These change challenges have further been accentuated by the recent crisis for Heidelberg cement that has been denied continuing its quarrying operations in its main factory in Slite that delivers 75-80% of the Swedish cement. Even if permission issues could be temporary solved, the signal is there that circular solutions, not relying on an end of the pipe business model is needed. The current strategy for the Swedish cement industry is mainly "Business As Usual" but preparing for taking care of the carbon emissions by Carbon Capture and Storage (CCS) and continuing quarrying limestone as before. Heidelberg Cement has made a commitment for the Cementa Slite plant to study the building of a full-scale carbon capture and preparing for transport and then storage in old oil wells outside the Norwegian coast. This would enable Cementa to fill its Cemzero project that envisages zero carbon emissions in 2030 (Roadmap, 2018).

Figure 1. Carbon emission reduction from cement and clinker for Cementa Sweden.



Source: Roadmap (2018).

Only taking care of carbon emissions is not future proof since limestone resources are not renewable. The amounts of available limestone in Slite have gradually been reduced by different environmental requirements to the current situation where operations might have to stop already in October 2021. Despite Sweden being a scarcely populated country with some 23 persons per km^2 it is currently practically impossible to quarry limestone, even in Gotland, which is defined as national key area for limestone resources in Sweden. All three companies mining limestone in Gotland have run into problems. This raises the question if Cementa and its owner Heidelberg really have understood what sustainable cement is?

Process orientation for leading and controlling change within organisations is one of the core values in Total Quality Management (TQM). Others are continuous improvement, focus on facts, participation of everybody, committed leadership, and customer focus (Bergman and Klefsjö, 2010). An emerging shift in the field of Quality Management, as a response to cope with the increased pressure of sustainable activities, is an expansion from customer focus to stakeholder focus (Isaksson, 2021). Isaksson et al. (2015) identify People and Planet as the key stakeholders for sustainability and argue that profit has an indirect part in sustainability, interpreted as a means to an end. Profit is needed, but focus should be on People and Planet needs. Isaksson and Rosvall (2020) summarise the process of sustainable building as affordable and carbon neutral. The suggestion is that sustainability needs to include the value-based perspective (Garvin, 1984) that compares stakeholder value with stakeholder harm (Isaksson et al., 2015). For residential housing the most fundamental value is m^2 of living space and the main harm is the price and the carbon footprint. Based on this, value per harm in cement and concrete can be expressed as building value per price and carbon footprint. The building value for cement and concrete can be expressed in strength times weight (cement) and strength times volume. This leads to the value indicators MPa (Mega Pascal) compressive strength times tons and m^3 produced (Isaksson and Buregyeya, 2020). These can be compared with the main harms which are price and carbon footprint.

A Sustainability Opportunity Study (SOS) can be used to highlight and make sense of sustainability in any chosen business and in any area of sustainability including the building value chain (Isaksson and Ramanathan, 2021). Both Isaksson and Rosvall (2021) and Isaksson and Ramathan (2021) elaborate on the generic Opportunity Study (Isaksson et al. 2015) that starts with Diagnosing which leads to an identified improvement potential. The part of Diagnosing has been divided into the steps of Understanding, Defining and Measuring. The reason is that there are problems in agreeing on how sustainability performance should be measured. Without agreed measurements Diagnosing cannot be done properly which means that an Opportunity cannot be defined. Isaksson and Rosvall (2021) study Diagnosing – Understanding-Defining-Measuring of cement and concrete sustainability on a superficial level. The study assumes operations based on the current business concept of the cement industry of maximising sales by producing a commodity product based on quarrying large amount of virgin limestone. It could be that this must be redesigned both in Sweden and globally.

The national roadmap for cement industry, guiding towards a carbon exit by 2045, highlights three areas of improvement in terms of carbon efficiency: cement production processes, alternative binders, and material efficiency (Mistra, 2020). The roadmap identifies opportunities, provides some insights in future technologies and presents four scenarios with different pathways towards a low carbon industry. Cementa, has also produced a roadmap with focus on CCS as the main road to carbon neutrality, which is targeted for 2030 (Roadmap, 2018). This roadmap assumed the continued high use of virgin limestone. Although both roadmaps provide some insights the roads forward look slightly different and there still could be unidentified opportunities for cement and concrete production processes in Sweden, especially in questioning the business concept. Untapped potential is the starting point for an opportunity study. In previous work, Isaksson and Rosvall (2021) and Isaksson and Raminathan (2021) exclude the business concept in Diagnosing-Understanding. This constitutes a research gap. It would be logical to start by reviewing the sustainability of the business concept, the company value proposition and parts of the business plan that indicate planned changed towards sustainability. The research question guiding this Diagnosing of Understanding-Defining-Measuring of cement and concrete sustainability and sustainable development is: How could cement and concrete sustainability be diagnosed based on the business concept?

The paper is structured as follows. In chapter 2 we describe the theoretical background for Opportunity Studies and how to understand Diagnosing as part of the Opportunity study. In chapter 3 our mainly conceptual method of work is described. Results from the study are presented in chapter 4 and these are discussed and concluded in chapter 5.

2. Theory background for Opportunity Studies

Opportunity within an organisation is defined as having an improvement potential that the organisation is not currently working with (Isaksson, 2015). An opportunity study is based on three distinctive sub-processes: Diagnosing, analysing and solving. Diagnosing highlights the improvement potential as a difference between what can be done and what is done. This requires an agreed performance indicator. Analysing identifies the causes for the existing improvement potential and Solving creates proposed solutions. Diagnosing in more detail is about setting the process interfaces and identifying the key improvement indicators within the delimitation.

Isaksson and Rosvall (2021) use the logic of understanding-defining-measuring-communicating-leading sustainable development in combination with the Opportunity Study steps of Diagnosing, Analysing, Solving to form the matrix in Table 1.

Table 1. Matrix for combining the Opportunity logic DAS with the first three steps of UDMCL

	Understanding	Defining	Measuring
Diagnosing			
Analysing			
Solving			

Source: Isaksson and Rosvall (2021).

The reason for splitting up Diagnosing in several parts is that for many businesses and processes it has proved difficult to identify agreed indicators for sustainability performance. The Opportunity Study originates from process improvement where the KPI to be improved is accepted and relevant such as in cases with cost reduction, capacity increase, emission reduction or quality improvement. Reporting quality could at occasions also be a challenge, but it seems that reporting sustainability performance is considerably more difficult to agree upon. Isaksson and Rosvall (2021) study the parts of Diagnosing - Understanding, Defining and Measuring in more detail as visualised in Table 2.

Diagnosing requires a process chart describing the delimitation of the studied process, but also a more detailed description using the Process Based System Model (PBSM) (Isaksson, 2015). See also Figure 2 that presents a PBSM for the cement manufacturing process. The first part for understanding is realising that the scope for the main sustainability impacts needs to be the entire value chain from cradle to grave. When having established the value chain as a basis for identifying main stakeholders and main impacts there is some assurance of that the right thing is reported (Cöster et al., 2020). The value chain can be a presented as a process from first input to last output to describe the interfaces and it can further be clarified using the PBSM as in Figure 2. The main impacts should be based on the main effects on the final stakeholders which Isaksson et al., (2015) suggest as People and Planet. E.g., Planet (human needs for eco-system services) needs can be broken down into having a protected atmosphere, a living biosphere and having a lithosphere (the Earth's crust) including water resources (Isaksson, 2021).

There is a challenge for every organisation to identify the vital key impacts that the value chain has on globally important sustainability issues such as climate, biodiversity and poverty (Isaksson, 2021). The suggestion is to use input for the analysis from the UN SDGs, from the Planetary Boundaries Framework (Steffen et al. 2015) and from the System Principles in the FSSD (2017). Applying these for the value chain should enable the organisation to identify and understand the main sustainability impacts. The understanding is then formulated into a definition which is good enough to interpret into measurements and KPIs. Future organisations and businesses are expected to take part of a circular economy, which is based on three core principles: (1) Design out waste and emissions, (2) keep products and materials in use, and (3) regenerate natural systems (McDonough and Braungart, 2009). Following the suggested frameworks for the understanding, defining and identification of KPIs ensures a compatibility with a circular economy (Korhonen et.al., 2018).

In Table 3 results from Isaksson and Ramanathan (2021), who have done Understanding-Measuring for the process of providing residential buildings, is presented. This is a test done based on Table 2 – Measuring. To understand Opportunities in Cement and Concrete manufacturing Table 1 needs to be applied. In this study focus is on Diagnosing cement and concrete sustainability, where some partial work has been done by Isaksson and Rosvall (2021), see Table 4.

Table 2. Diagnosing with Understanding-Defining-Measuring

	Understanding	Defining	Measuring
D	Setting scope for value chain and parts of it by using the PBSM Identifying main sustainability stakeholders and main impacts on them by referring to the UN SDGs, the Planetary Boundaries Framework and the system principles from the Framework for Strategic Sustainable Development (FSSD) Defining the qualitative improvement potential as the difference between possible and/or required performance and current performance	Based on the Pareto principle define the vital few stakeholders and impacts on them in terms of stakeholder needs that can measured Focus on People and Planet needs and convert this to a proposed definition that can be operationalised	Measure sustainability as a state and sustainable development as change Identify value and harm indicators – the KPIs (y-values) that can be used to describe current sustainability and the sustainability performance over time Value and harm are expressed in terms of impacts on People, Planet and Profit KPIs should be expressed in absolute and relative terms Assess the quantitative improvement potential for chosen y-values in terms of level and rate of change

Source: Isaksson and Rosvall (2021).

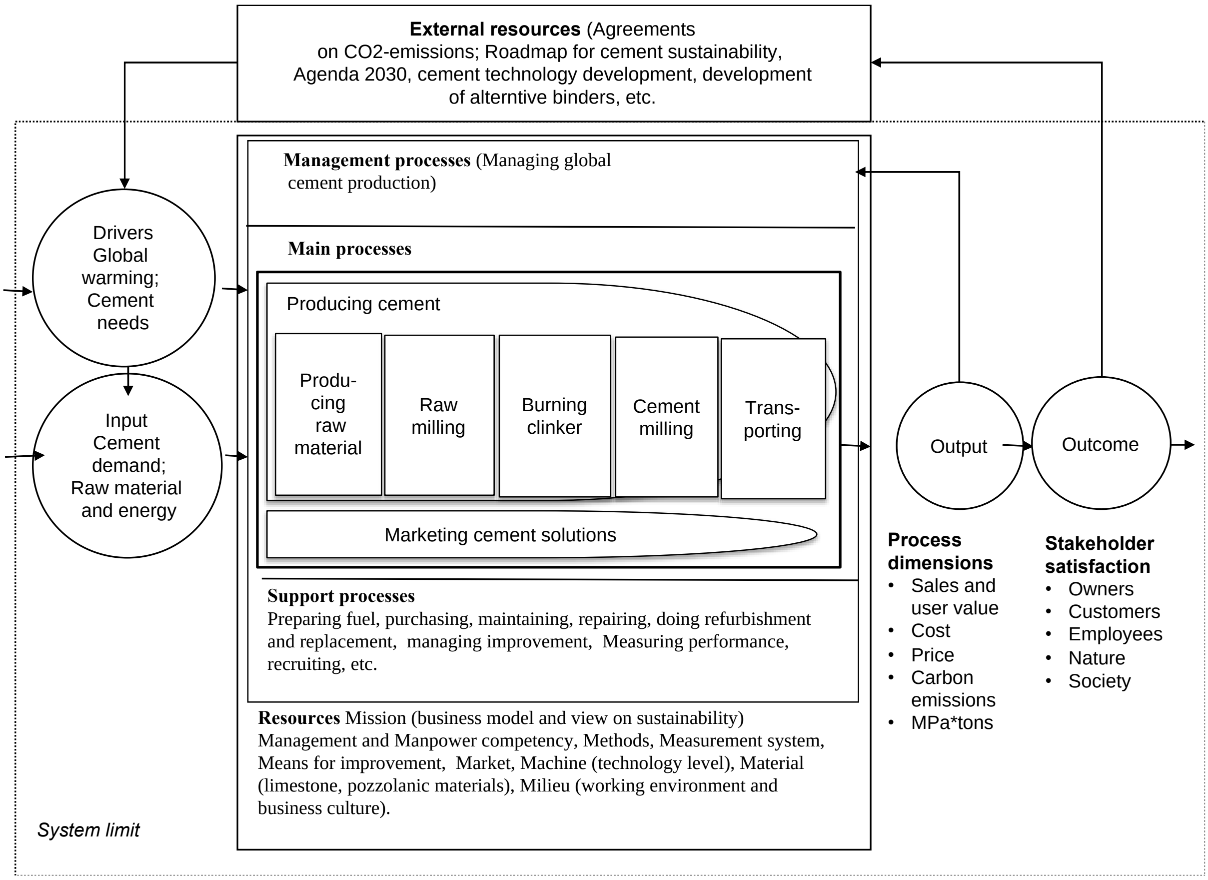
Table 3. Proposed targets and indicators for sustainability and sustainable development.

	Sustainability		Sustainable development	
Indicators	"Absolute"	Relative	"Absolute"	Relative
Target affordability	A USD/m^2	100% of populations' basic housing needs met	B USD/m^2 reduction per year	% population increase with affordable housing
Target climate neutrality	0 kg CO_2 net emissions in value chain	0 kg CO_2/m^2 building and year	C ton CO_2 reduction per year from buildings	D% reduction of kg CO_2/m^2 per year
Performance over time for different indicators	y=f(time)			
Performance variation – standard deviation of process over year (s)	s_y			

Source: Isaksson and Raminathan (2021).

The purpose of the opportunity study is still to highlight overlooked improvement potential and result in an actionable project to realise the identified potential. The outcome however, being a project plan in the previous opportunity study, will vary based on the identified key actor/actors in the described system. The diagnosing processes are still relevant in their presented form but need to be further elaborated.

Figure 2. A Process Based System Model (PBSM) adapted for cement manufacturing.



Source: Isaksson and Rosvall (2021).

When assessing sustainability opportunities, here defined as the improvement potential in system processes related to the key stakeholders People and Planet and their needs, the opportunity study needs some modification.

A key issue is to review the current business concept, value proposition and business plan to study if they are compatible with the system principles (Broman and Robèrt, 2017), with the Planetary Boundaries framework (Steffen et al. 2015) and the UN SDGs. The complex concept of sustainability is in this context defined through the system principles from the framework for strategic sustainable development (Broman and Robèrt, 2017):

In a sustainable society, nature is not subject to systematically increasing …

1. … concentrations of substances extracted from the Earth's crust.
2. … concentrations of substances produced by society.
3. … degradation by physical means.

and people are not subject to structural obstacles to …

4. … health.
5. … influence.
6. … competence.

7. … impartiality.
8. … meaning-making.

Table 4. A matrix for understanding, defining and measuring cement sustainability and cement sustainable development.

	Understanding	Defining	Measuring
D	The Process Based System Model (PBSM) for the building value chain can be presented as in Figure 1. The main stakeholder needs identified are similar to those for the entire building value chain, cement affordability and zero or low climate impact. Defining the qualitative improvement potential as the difference between possible and/or required performance and current performance. This should be done for cement strength performance, price and carbon footprint New cements could have a potential in higher substitution with calcined clays (LC3) and with higher use of different slags	Based on the Pareto principle define the vital few stakeholders and impacts Focus on People and Planet needs and convert this to a proposed definition that can be operationalised. Cement sustainability is defined as producing affordable user building value (cement strength generating capacity) with zero climate impact. Sustainable cement development is that zero climate impact is achieved latest 2045. Strategy could be CCS and new or alternative cements	Measure sustainability as a state and sustainable development as change (chosen y-values as average, variation and a trend) Identify value and harm indicators – the KPIs (y-values) that can be used to describe current sustainability and the sustainability performance over time Cement MPa*tons Carbon emissions per ton of cement Price per ton of cement MPa*tons/carbon emissions MPa*tons/price
A	A qualitative review of main causes by using the 10 M checklist (Isaksson, 2015)	The main Ms identified for cement industry generally are: Mission – 1; Management – 2; Measurement – 3; Machine – 4; Manpower (5); Milieu	A quantitative review could consist of calculating how many MPa*tons that could be substituted by using available slag as raw material and as SCM Similarly, the potential of calcine clays could be assessed
S	Product innovation could consist of developing and producing LC3 and slag-based binders	Defining solutions and strategies for these	Setting targets for level of sustainability and rate of change that corresponds to sustainable development

Source: Adapted from Isaksson and Rosvall (2021).

Here, sustainability is defined using the system principles. These imply that we are in a state such as nature was before humans, but with humans. This could be interpreted as the circular economy where people needs, as defined by requirements 4-8, are fulfilled while respecting the three first principles. The Agenda 2030 goals should be seen as milestones which help us in specifying what to focus on. The Planetary Boundaries framework provides tolerance limits that should not be exceeded - the limits for a safe development for humanity.

For the housing value chain, the key planet harm indicator is identified as effects on the atmosphere by CO_2 emissions, people harm indicator is identified as price, and people value indicator is square meters of housing space (Isaksson and Rosvall, 2020). The fact that there are more indicators that are of importance for a sustainable housing is acknowledged, but the indication that the industry in Sweden is lacking sufficient reporting on the identified principal key indicators (see Isaksson and Rosvall 2020; 2021), which motivates the use of Pareto principle as a starting point.

Focus, in this paper, is studying Diagnosing with Understanding-Defining-Measuring in more detail and including optional value propositions for cement manufacturing. Isaksson and Rosvall (2021) conclude that there are globally no substitutes to concrete as the main building material, but there are substitutes for cement. The purpose is to see if sustainability has been thoroughly understood for Cement and Concrete.

3. Method

The paper is mainly conceptual where the model for the Sustainability Opportunity Study is developed in what could be seen as Innovation Action Research (Kaplan, 1998). The Opportunity Study (Isaksson, 2015) is tested in new contexts and results lead to both improvements of the model and to results that are intended to improve the process studied. Results are published and presented for criticism and then further improved. Cement and concrete sustainability have been discussed based on Diagnosing-Understanding in Table 4 with focus on the Swedish context of cement manufacturing and by interpreting the current business concept, value proposition and business plan. There has been some theory development where the FSSD system principles are used to analyse the current cement and concrete business concepts both locally and globally to pinpoint the main gaps. Here, one of the authors uses a preunderstanding based on a 20-year experience within cement manufacturing.

4. Results for Understanding the Diagnosing and Analysing of Cement and Concrete Sustainability and Sustainable Development

4.1. Understanding Diagnosing of Cement and Concrete Sustainability

The FSSD system principles are summarised into four principles with the five People related businesses mentioned in Broman and Robért (2017) simplified into the original form in Robért (2000). The principles are named based on suggestions from the FSSD expert Claes Kollberg and translated from Swedish. The proposed framework is presented in Table 5.

The business idea locally in Gotland is a very temporary one, since limestone resources, even in the best of cases are limited. With increased focus on nature, tourism and people on the island the maximum amount of limestone that can be used has successively been reduced thereby shortening the life span of the plant with current production. During periods the plan has exported up to half its production abroad mainly competing with price, partly since quarrying the limestone has been cheap with a horizontally structured quarry with homogeneous and easily accessible limestone. With an earlier and better understanding of sustainability and with focus on maximising building value addition over time the strategy would have been different. The strategy would have focused on minimising the use of limestone partly to reduce carbon emissions and partly to extend the life span of the quarry.

The current business idea for Heidelberg Cement and the global cement industry is selling Portland Cement (PC) dealing with it as a commodity. This is reflected by the fact that footprints are related to tons of cement not to the performance of cement (see Figure 1). In cement standards as in the European EN Cement standard 197 there are three different strength classes indicating the minimum range of compressive strength performance from 32.5 to 52.5 MPa indicating a considerable performance difference. The binding ability could be taken as an important performance indicator and cement and concrete value could be expressed in Strength*tons (Isaksson, 2015). However, in different reduction schemes only tons are considered, and the performance is largely ignored. This means that the business idea is maximising sales in tons. There is an option of maximising building value as strength-volume concrete with minimised cement content. This would require a system of payment for concrete performance, which should be feasible to put up, but which is not there. The current business idea leads to reduced focus on improving cement performance since better cement would lead to reduced sales. In Europe the cement production, and overall construction industry is mature with no or little growth. Also, large companies dominate in a consolidated market, which means that there is a type of oligopoly. This means that making cement better would only lead to lost sales. Still, it is surprising that the main proposal forward is to study the construction of CCS. This would lead to a solution, at a cost of about 100€/ton CO_2. It would however do nothing for the problem with limestone availability.

Table 5. System principles as harm compared to value and harm locally and globally for cement and concrete. Effects on system principles assessed as NEG, neg, zero, pos, and POS, where capital letters indicate stronger effects.

System principles	Local Gotland	Global	Comments
Earth Crust (I)	neg (hole in the ground and possible effects on groundwater) **NEG** Limited resource with limited time of use	**NEG** (climate effects of CO_2)	CCS could in the long run solve the global problem and to some extent respect the Earth Crust principle. But this is not the case locally. Also, the CCS solution globally does not seem viable. Virgin limestone is not a renewable resource and makes the business concept unsustainable.
Chemical (II)	zero	neg	Building waste is considerable both in Sweden and globally, but it is not dangerous or poisonous.
Natural Capital (NC) (III)	zero	zero	Some local effects on biodiversity. Buildings generally reduce the NC but could also be neutral or even beneficial (e.g., avoiding erosion). The placement of buildings is not a cement or concrete issue.
Trust (IV-VIII)	zero/neg	zero/pos	The cement business has both local opposition (Not in my backyard - NIMBY) and support (employment) but has not a clear sustainability focus, which reduces trust. Satisfying global building and infrastructure needs with a footprint is a possible needed and positive contribution.

In understanding sustainability one important part could be understanding if the business concept and the main products in the value proposition are feasible in the long run or not. The cement industry as like the coal and oil industry a problem in that the current business model is lucrative. For the cement industry new products often threaten the existing business concept. For an organisation it becomes almost impossible to create the sense of urgency for change when money is pouring in. In some cases, the low carbon solutions have been more expensive than consuming externalities for free. The cement industry has in many cases not had to pay for quarrying limestone, making holes in the ground and emitting billions of tons of CO_2. Only recently have some carbon taxes been introduced with Sweden as one of the forerunners. Still, in Sweden there are basically no mining fees making the use of limestone cheap. There is a requirement for funding some money for the restauration of the quarry like filling it with water and rounding of the edges after finishing operations. The cap-and-trade system still makes most emissions free of taxes. However, with reduced quotas and increasing prices, the ton of CO_2-emission on the European carbon trade market has started climbing from some few Euros some years ago to some 50 Euros in 2021. Would this cost be put on all cement produced the production costs would more than double. Change needs have suddenly manifested themselves clearly, which should lead to intensified work with alternative binders. In comparison with other products the cement sales value compared to its carbon footprint is extremely low. Isaksson et al. (2015) estimate that global average value generation compared to the carbon footprint is about 2500 US$/ton of CO_2. Cement only generates about 200 US$/ton of CO_2. Isaksson (2016) speculates in that a higher cement prices would have improved its performance in concrete considerably. If cement would have cost 1500 US$ per ton instead of 150 US$ per ton then several alternatives with lower carbon footprint would have been feasible.

Table 6. Summary of Diagnosing Understanding based on cement and concrete.

Understanding Diagnosing based on Table 2 and 4	Proposed UD – Business Concept proofing	Comments

• Setting scope for value chain
• PBSM (figure 2)
• Main stakeholder needs: Cement affordability and zero or low climate impact
• Main sustainability stakeholders and main impacts on them by referring to the UN SDGs, the Planetary Boundaries Framework and the four system principles
• Defining the qualitative improvement potential as the difference between possible and/or required performance and current performance
	• Raw materials to concrete in structure (input and output)
	• Low virgin limestone content in cement and low concrete carbon footprint
	• Stakeholders and needs
	    o Gotland – Earth Crust principle (EC) (limestone and water)
	    o Planet – EC (CO_2)
	    o Planet – Natural Capital (some loss of biodiversity)
	    o People – concrete blocks and structures
	• Business concept sustainability? NO!
	    o EC limestone – No – PC not compatible locally
	    o EC water – No – could be solved
	    o Planet – EC – CCS could solve this
	• Business plan. Reducing use of virgin limestone in cement and concrete with 90% - reduced pressure on quarry, no need of CCS and reduced pressure on climate – Important resource reduction potential which can extend factory life time
		In Understanding it is enough to define input and output of value chain. The PBSM could be used to clarify visualising but could also be seen as a part of analysing.
		
		When using the Earth Crust principle locally the business concept based on using virgin limestone is not sustainable.
		
		The business plan should be with focus on finding alternative low carbon footprint cements, but here there seems to be an important gap.

Mistra (2020) writes about Swedish construction using more cement than needed in concrete mixes – “Regarding optimisation of concrete recipes, there is often 20-30% more cement in the concrete mix today than what is required by standards, which occurs for two reasons: over-specification of cement by concrete producers, and higher exposure classes for the concrete than the situation demands”. Additionally, Mistra (2020) notes that faster construction processes require quicker setting and drying. The cement is cheap because it does not pay for several externalities. Since the critical task of cement is binding the concrete together this indicates that its use for other purposes, such as quicker drying, is because it is the cheapest solution. Quicker drying and higher strength could be achieved with additives such as water reducers and with other types of cement if they would have been a cheaper solution. Since cement is cheap it is overused in concrete. The cement industry has a business concept that is based on maximising tons of a commodity product in a mature market. This can be done since there has been a de facto Swedish monopoly based on an informal European and partly global oligopoly. Prices and earnings can be kept high, which increases the threshold to change the business concept. With politicians and the press having a limited understanding of cement and concrete sustainability and with research closely linked to the current business concept there is a limited understanding of sustainability opportunities. It is likely that the cement industry business concept of maximising tons of cement used has taken away focus on the necessity of increasing cement performance and reducing concrete carbon footprint.

A key component of any business plan is the business concept and value proposition. These should explain why customers should choose your solution. With customer needs expanding from price to the sustainability of a solution it is important to understand how sustainable a business concept is. The business concept for producing concrete using cement based on extensive limestone quarrying and limestone calcination is not sustainable and cannot become that even with CCS. This does not seem to have been understood by the global cement industry.

In a rich country like Sweden, where cement costs constitute only about 3% of the total building costs it would not have been too difficult to introduce a binder system in concrete with ten times the cost and effect, but with 10% of the footprint, provided the externalities would have been taxed and provided the cement industry would have been paid for the concrete performance. In Table 6 Diagnosing Understanding has been summarised.

4.2. Understanding Defining of Cement and Concrete Sustainability

With an extension of Understanding sustainability to include business concept, value proposition and business plan there could be some changes to how Defining is presented in Table 2 and 4. A detail here is that we should look at the matrix with a Diagnosing in focus. This means that what we primarily study here is how cement and concrete sustainability have been understood, defined and measured. Doing this in more detail is part of future research. What we present here could be seen as working hypotheses. The main difference in Table 7 compared to previous proposals in Table 2 and 4 is that Diagnosing consists of an assessment of the current definition followed by proposed definition for sustainable cement and concrete and sustainable development for cement and concrete. Cement and concrete should be seen jointly. There is no functional value in cement itself. It is only when it becomes part of a building or a structure where we have a functional value that we can compare the footprints with. The value proposition with focus on performance in concrete needs to be accepted in a producer and customer agreement between cement and concrete producers.

4.3. Understanding Measuring of Cement and Concrete Sustainability and Sustainable Development

The proposed measurements of cement and concrete sustainability and sustainable development are presented in Table 8 based on Table 3 proposals. The two harm components used are virgin limestone and carbon emissions. The value has here been translated from m^2 space to strength times volume ($MPa*m^3$) of concrete. The assumption is that this corresponds building value that can be translated to the required building strength.

Table 7. Diagnosing Defining of cement and concrete sustainability and sustainable development.

Defining based on Table 2 and 4	Proposed Diagnosing of Defining
Cement sustainability is defined as producing affordable user building value (cement strength generating capacity) with zero climate impact. Sustainable cement development is that zero climate impact is achieved latest 2045. Strategy could be CCS and new or alternative cements.	There seems to be no clear definition in the building value chain of what cement and concrete sustainability and sustainable development are. Cement manufacturing has focused on reduction of the carbon footprint. Proposed business concept for sustainable cement in industrialised countries: Producing and selling a cement binder with zero use of virgin limestone and net zero carbon footprint. Value proposition: Selling binding effect in concrete as strength times volume compared to carbon footprint. Price related to concrete performance. Business plan. Going from cement based on calcined limestone to low limestone and low climate effect binders. Cement and concrete sustainability in Sweden is defined as: High compressive strength binder solution in concrete with zero use of virgin limestone and zero carbon footprint. Cement and concrete sustainability in Sweden going from current level to a level of sustainability until 2045.

Table 8. Diagnosing Measuring of cement and concrete sustainability and sustainable development based on Table 3.

	Sustainability		Sustainable development	
Indicators	Absolute	Relative	Absolute	Relative
Limestone (L) and carbon emissions (C)	Tons of L and C	Kg of L/MPa*m^3 concrete	Reduction of tons of L used per year	% reduction of L/m3 concrete
Targets L and C	0 tons of L and C in concrete production	0 tons of L and C/MPa*m^3 concrete	A/B tons of reduction of L and C per year in concrete building value production	C/D % reduction of L and C/MPa*m3 concrete and year
Performance over time for different indicators	y=f(time) (Eg., MPa*m^3 /ton CO_2 and MPa*m^3 /ton L over time)			
Performance variation – standard deviation of process over year (s)	s_y			

4.4. Summarising Diagnosing Sustainability and Sustainable Development

Diagnosing means interpreting the current performance compared to possible or required performance. When there are agreed KPIs and a known Best Demonstrated Practice or agreed target this is a relatively simple exercise. The detected gap can be an opportunity for improvement or a threat of the current business concept or both. Detecting a threat early and becoming a first mover could increase market shares and profitability. When it is unclear what sustainability is, how it could be defined correctly and how it then could be measured we need to diagnose understanding, defining, and measuring to be able to assess an improvement potential. We do not have figures for the current sustainability performance of Swedish concrete in terms of kg limestone and CO_2/MPa*ton of concrete or how it has developed over years. Based on Figure 1 the carbon footprint is about 700 kg/ton of cement. Mistra (2020) notes that cement addition in Swedish concrete has increased and is at least 420 kg per m^3 concrete. This means about 300 kg CO_2/m^3 of concrete. About 60% of the carbon emissions are from the raw material or about 180 kg. The amount of limestone used can be calculated based on a clinker kiln feed with about 35% of Loss on Ignition at 1000°C. Most of this is from the CO_2. This makes it 280 kg of limestone/m^3 of concrete from cement raw materials only. Both the level of limestone used in concrete and the carbon footprint indicate a low level of sustainability. The rate of change does not correspond to sustainable development. Based on Figure 1 the reduction in the cement carbon footprint is about 25 kg compared to 750 kg over ten years or about 3% in ten years or 0.3% per year. The required reduction for reaching zero emissions in 2045 from the 2019 level could be assessed as at least 7% per year. This halves the emissions in ten years and results in 2045 to remaining emission of about 100 kg ton cement. This means that the current rate should increase with a factor 20 to cope with the carbon emissions. There is no plan and no data for how to reduce the use of limestone. Here, the sustainable rate of reduction could be similar. The quarrying permission applied for in the Cementa Slite plant, which has been rejected, is for 20 years. The potential for continued business is considerable. It is based on avoiding the threats posed by governmental targets of zero carbon emissions and difficulties in having access to limestone.

5. Conclusions and discussion on diagnosing sustainability opportunities for cement and concrete

The main conclusion from the study is that it is important to start the process of Understanding in the business concept. Understanding the business concept is a prerequisite for identifying value and harm correctly in the value chain. The business concept should be confronted with the four system principles of Earth Crust, Chemicals, Strong Sustainability and Trust as described in Table 5. The use of limestone could on the global level be seen as respecting the Earth Crust principle provided conversion of it via CCS to new stone. However, when the principles are applied locally, quarrying of limestone is not in accordance with the Earth Crust principle. This could be seen as a Not In My Back Yard (NIMBY) issue that must be supported for the common good. However, there is no other place on the island of Gotland for quarrying the limestone and neither is there in Sweden. Limestone is a non-renewable resource like coal or oil and its quarrying causes problems wherever it is done, and it has a high carbon footprint. One ton of 90% pure limestone emits 400 kg of CO_2. So far there seems to be no cement plant that captures all its carbon emissions. HeidelbergCement states 2021 that with 400,000 tonnes of CO_2 to be captured annually in the Brevik plant the company will build the first industrial-scale CCS project at a cement factory in the world.

It is unlikely that the complicated and expensive technology can work on a global level. It is an end of the pipe solution. The simple conclusion is that quarrying limestone generally and for burning cement clinker specifically is not compatible with the system principles or with a circular economy. Here, it seems to have been of help for the understanding to divide the review with the system principles in a local and global situation.

The Swedish cement business concept consists of producing a commodity with mainly limestone as raw material for the cement clinker and on maximising tons of sales. This is like in international cement production. The business concept is not sustainable. Proposed cement and concrete sustainability in Sweden is defined as: “High compressive strength binder solution in concrete with zero use of virgin limestone and zero carbon footprint”, see Table 7. The user value in concrete structures should be maximised in comparison with the footprints of use of limestone and the carbon emissions.

The concrete building value is expressed in strength times volume or MPa*m^3. This follows earlier logic in Isaksson (2015; 2016). Measurements are proposed as absolute for value and for harm and as relative with main value compared to main harm MPa*m^3/ton CO_2 and ton limestone, see Table 8. Values are not ordinary recorded in terms of using these value and harm indicators. The industry deals with clinker and cement as bulk as visualised in Figure 1. This ignores performance differences and reduces focus on improving cement performance.

Future research will focus on understanding analysing of the causes for the indicated improvement potential.

References

Bergman B., Klefsjö B. (2010). *Quality from Customer Needs to Customer Satisfaction.* Studentlitteratur, Stockholm.

Broman, G.I., Robèrt, K.H. (2017). "A framework for strategic sustainable development", *Journal of Cleaner Production,* 140,17-31.

Cöster, M., Dahlin, G. and Isaksson, R., 2020. "Are They Reporting the Right Thing and Are They Doing It Right?—A Measurement Maturity Grid for Evaluation of Sustainability Reports", *Sustainability*, 12(24), 10393.

Garvin, D.A. (1984). "What does Product Quality really mean", *Sloan management review*, 25, 25-43.

Isaksson, R. (2015). "Making sense of opportunities in building material production", *The TQM Journal*.

Isaksson, R. (2016). "Process based system models for detecting opportunities and threats–the case of World Cement Production", *International Journal of Quality and Service Sciences*.

Isaksson, R., 2021. "Excellence for sustainability–maintaining the license to operate", *Total Quality Management & Business Excellence*, 32(5-6), 489-500.

Isaksson, R. and Buregyeya, A., 2020. "Understanding sustainability–the case of building blocks in Tanzania and Uganda", *The TQM Journal.*

Isaksson, R.B., Garvare, R. and Johnson, M., 2015. "The crippled bottom line–measuring and managing sustainability", *International Journal of Productivity and Performance Management*.

Isaksson, R., Ramanathan, S. (2021). "Sustainability Opportunity Study - Diagnosing", *EISIC 2021 paper*.

Isaksson, R., Rosvall, M. (2021). "Cement and Concrete - Quality and Sustainability Understanding, defining and measuring opportunities", *ISDRS Conference July 13-15, Östersund.*

Kaplan, R.S. (1998). "Innovation action research: creating new management theory and practice", *Journal of management accounting research*, 10, 89.

Korhonen, J., Honkasalo, A., Seppälä, J., (2018). "Circular Economy: The Concept and its Limitations", *Ecological Economies*, 143, 37-46.

McDonough, W., & Braungart, M. (2009). Cradle to cradle: Remaking the way we make things. London: Vintage.

Mistra (2020). Technical roadmap - Cement Industry, Available at: https://www.mistracarbonexit.com/news/2020/5/19/technical-roadmap-cement-industry ; downloaded August 2, 2021.

Robèrt, K.H. (2000). "Tools and concepts for sustainable development, how do they relate to a general framework for sustainable development, and to each other?", *Journal of cleaner production*, 8(3), 243-254.

Roadmap (2018). Roadmap for fossil free cement, Available at: https://fossilfrittsverige.se/wp-content/uploads/2020/10/ffs_cementbranschen.pdf ; downloaded August 2, 2021.

RobecoSam (2021). Country Sustainability Ranking: peripheral progress stalling. Available at: https://www.robeco.com/en/insights/2017/06/country-sustainability-ranking-peripheral-progress-staling.html ; downloaded August 2, 2021.

SDG (2021). Rankings - The overall performance of all 193 UN Member States. Available at: https://dashboards.sdgindex.org/rankings ; downloaded August 2, 2021.WCED (1987). World Commission on Environment and Development. Our Common Future. Oxford: Oxford University Press.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., De Vries, W., De Wit, C.A., Folke, C. (2015). "Planetary boundaries: Guiding human development on a changing planet". *Science*, 347, 6223.