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Roadmap for Low-Carbon Concrete in Finland

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ABSTRACT
A roadmap for low-carbon concrete was prepared in Finland. The aim of the roadmap was to identify possible options for CO_2-emission reductions in concrete production. The calculations were made to correspond the situations in 2030, 2040 and 2050. The calculations were based on the maximum saving potential and the degree of utilization of the options. The roadmap covers the whole Finnish concrete industry and individual companies in different product segments. It is well known that cement has the largest potential for CO_2 saving, but the roadmap reveals several other potential options as well. The most potential options vary between the product segments. The roadmap also confirms that concrete can reach very low CO_2-emission level in the future.

Key words: Binders, CO_2-emissions, Low Carbon Concrete, Sustainability

1. INTRODUCTION

A roadmap for low-carbon concrete for Finnish concrete industry was made in 2024. The aim of the roadmap was to identify possible options for CO_2-emission reductions in concrete production. Totally 16 different options were analysed. The emissions saving with different options were calculated based on the emission savings of the option as well as on estimated degree of utilization of the option. The calculations were made to correspond to the situation in 2030, 2040 and 2050. The calculations were made for the whole Finnish concrete industry and for individual companies in three product segments (ready-mix concrete, pre-cast concrete and concrete products).

In the analyses, the CO_2-emissions were transparently calculated. To make the calculations comparable, the emission reductions were calculated per m^3 of concrete (kg-$CO_{2\,eq}$/m^3-concrete).

When needed, an average cement content of 350 kg/m^3 was used in the calculations. The total annual concrete production in Finland has been on the average 5 milj. m^3 and that value was used in calculations. The analyses are not sensitive for the total production volume as the saving potentials were calculated per m^3-concrete. The following volume shares of the product segments were used: ready-mix concrete production: 54 %, pre-cast concrete production: 36 % and production of concrete products: 10 %.

Some of the analysed options are partly alternatives to each other and therefore all the options cannot be summed up. However, double counting was tried to avoid as much as possible. Especially, the CO_2-emissions of the cement will be lowering in future, and this affects the saving potentials of several other options. The future CO_2-emission level of cement was taken into account in the calculations of the other options.

In addition to the CO_2-emissions savings, also realization risks and cost effects were estimated for each option. However, as can be easily understood, estimating risks or costs in 2040 or 2050 includes large uncertainties and therefore the presented estimations are just indicative based on the present knowledge.

The roadmap analyses only the CO_2-emissions ($CO_{2\ eq\ total}$) and only the LCA stages A1-A3 have been included. Therefore, the transportation of concrete or elements / concrete products (stage A4) has not been included in the calculations. The transportation has rather significant saving potential, especially in case of pre-cast elements and concrete products. The roadmap focuses on CO_2-emissions, other aspect of the sustainability are not included. For example, recycling of concrete has only limited effects on CO_2-emissions but can be very essential for sustainability. The analyses were made by Aalto University, and the project was supported by a steering group containing members from cement, concrete and construction industries.

2. OPTIONS FOR EMISSION REDUCTION

Totally 16 potential options for CO_2-emission reductions were selected. The options were divided into three groups: Cement production, Concrete production and Structures. The options are presented in Figure 1.

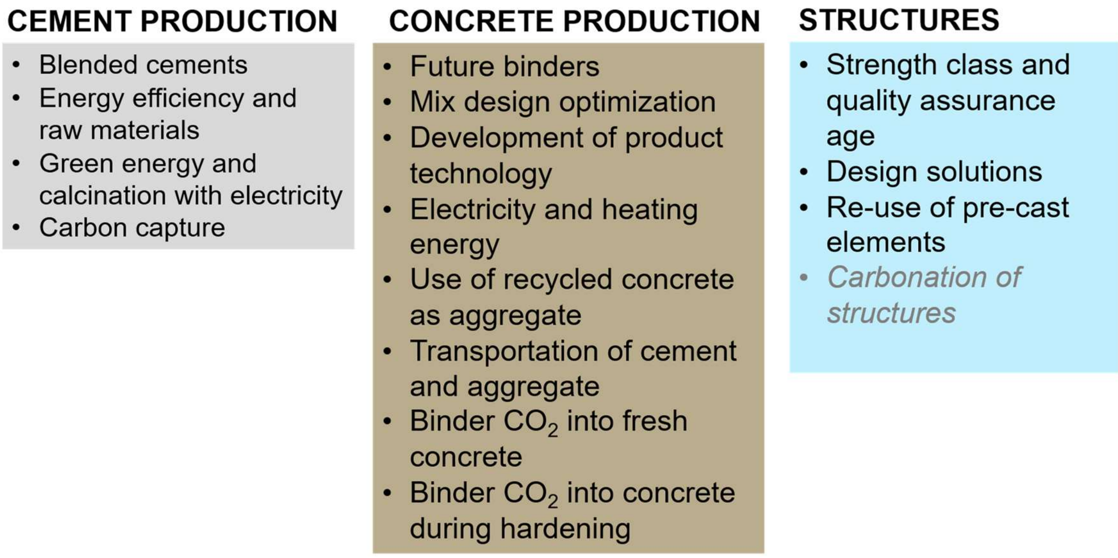

Figure 1 – Selected 16 options for CO_2-emission savings.

The cement production group contains the options which are controlled by the cement industry. Similarly, the concrete production group contains the options which concrete producers can affect. Blended cements could be both in the cement and concrete production groups. Cement companies produce blended cements, but a concrete company selects which cements they want to use. Therefore, the use of blended cements is controlled both by cement and concrete producers. The structures group contains slightly different emission saving options compared to the other two groups. Most of the options in the structures group are controlled by the designer of the structure, but not by the concrete or cement producer. The structures group contains also the carbonation of concrete structures. It is partly different compared to the other options since the carbonation takes place without any actions.

The analyses were made for the whole Finnish concrete industry but also for three different product segments: ready-mix concrete, pre-cast concrete elements and concrete products. Possibilities of an individual company to utilize each option were analysed in the different segments. Some options give only minor emission reductions for the whole concrete industry but can be significant for a single concrete producer. When the reduction potentials of the individual company were estimated, it was assumed that the company puts significant efforts on the emissions savings. Therefore, the values present the maximum saving potentials, not the average level in the product segment.

2.1 Cement production

As expected, cement production has very significant potential for CO_2-emissions reductions. Four different options in the cement production were analysed:

- Use of blended cements
- Improvements in energy efficiency and use of decarbonated raw materials
- Use of low carbon energy and electrical calcination process
- Carbon capture

Use of blended cements
The future use of blended cements was estimated. The basic line was the use of different cement types in 2024 in Finland. The future shares of different cement types were estimated. The clinker content was estimated to be 68% in 2040 and 60% in 2050 as presented in the Cembureau Roadmap 2050 [1]. Table 1 presents the estimated emission reductions achieved with blended cements.

Table 1 - Estimated emission reductions achieved with blended cements.

	2024	2030	2040	2050
Average clinker content	82 %	73 %	68 %	60 %
Average emissions of cement [kg-CO_2/tn-cem]	0,609	0,555	0,530	0,484
Average emissions of cement in concrete [kg-CO_2/m^3-con]	213	194	186	169
Emission saving vs 2024 [kg-CO_2/m^3-con]	-	-19	-28	-44

In addition to the blended cements, secondary cementitious materials (SCM) can be added also in concrete mixing stations. It is assumed that it has the same effects on CO_2-emissions as the blended cements. The secondary cementitious materials used in blended cements may change in the future, but it is assumed that the CO_2-emission level of future SCMs are on the same level as the present ones.

In case of individual companies clearly higher usage of blended cements can take place. Table 2 shows the estimated maximum emission savings in different product segments achieved with intensive use of blended cements.

Table 2 - Estimated emission reductions achieved with blended cements in different product segments. The values present the maximum potential for emissions savings in individual companies.

Product segment	Emission savings vs. 2024 [kg-CO_2/m^3-con]			
	2024	2030	2040	2050
Ready-mix concrete production	-	-29	-38	-46
Pre-cast concrete production	-	-50	-65	-68
Concrete products	-	-68	-87	-108

Improvements in energy efficiency and use of decarbonated raw materials
The emission reductions due to improvements in energy efficiency and use of decarbonated raw materials in cement production were estimated based on the Cembureau Roadmap 2050 [1]. The following emission savings were estimated:

- Improvements in energy efficiency: - 22 kg-CO_2/tn-cem
- Decarbonated raw materials: -25 kg-CO_2/tn-cem

The total saving potential in concrete is -16 kg-CO_2/m^3-con. It was estimated that 50 % of the saving potential can be achieved in 2030, 75 % in 2040 and 100 % in 2050.

Use of low carbon energy and electrical calcination process

In case of low carbon energy, fossil energy is expected to be replaced by alternative fuels and bio-based fuels. The following emission values were used in the calculations: fossil fuels: 335 g-CO_2/kWh, alternative fuels: 115 g-CO_2/kWh and bio-based fuels: 27 g-CO_2/kWh. It was also estimated that the electrical calcination process will be partly in use (75 %) in 2040 and fully in use in 2050. The use of fossil fuels decreases quickly and already in 2030 its share was estimated to be only 10 %. In 2050 the major energy sources (90 %) are bio-based fuels and alternative fuels. Low emission electricity will be used in the calcination process. Also, the emissions related to other uses of electricity in the cement manufacturing (e.g. grinding of clinker) will be reduced due to lower CO_2-emissions of the electricity. The calculated savings are connected only to the clinker manufacturing and therefore reducing clinker content will lower the savings of the cement and concrete. The estimated total emission savings are presented in Table 3.

Table 3 - Estimated emission reductions achieved with low carbon energy and electrical calcination. The changes in the clinker content (Table 1) have been taken into account.

	2024	2030	2040	2050
Emission saving in cement [kg-CO_2/tn-cem]	-	-63	-110	-117
Emission saving in concrete [kg-CO_2/m^3-con]	-	-22	-38	-41

Carbon capture CCU/S

Carbon capture is the most significant option for the emission reductions in the cement production. It was estimated that in Finland carbon capture will be partly (50 %) in use in 2040 and fully in use in 2050. In the calculations, only the effects of the carbon capture were analysed, possible utilization or storage of the captured CO_2 were not included in the analyses. The decreasing clinker content in cement reduces the CO_2 savings of carbon capture. Also, the reductions presented in Table 3 as well as improvements in energy efficiency and use of decarbonated raw materials have been taken into account in the calculations.

Table 4 - Estimated emission reductions achieved with carbon capture.

	2024	2030	2040	2050
CO_2-emissions of clinker production in cement [kg-CO_2/tn-cem]	741	542	506	444
Utilization rate of CCS/U	0 %	0 %	50 %	100 %
Emission savings in cement [kg-CO_2/tn-cem]	0	0	-113	-285
Emission savings in concrete [kg-CO_2/m^3-con]	-	0	-39	-100

The different emission reduction potentials of the cement production have been collected in Figure 2. The savings achieved with blended cements depend on the product segment, here the average values of the Finnish concrete industry have been presented. In the short term (2030), the biggest reductions will be achieved by more extensive use of blended cements. In the longer term (2050), the carbon capture will be clearly the most significant option. The figure shows that CO_2-emissons of cement manufacturing can be significantly reduced and close to zero-level emissions are possible.

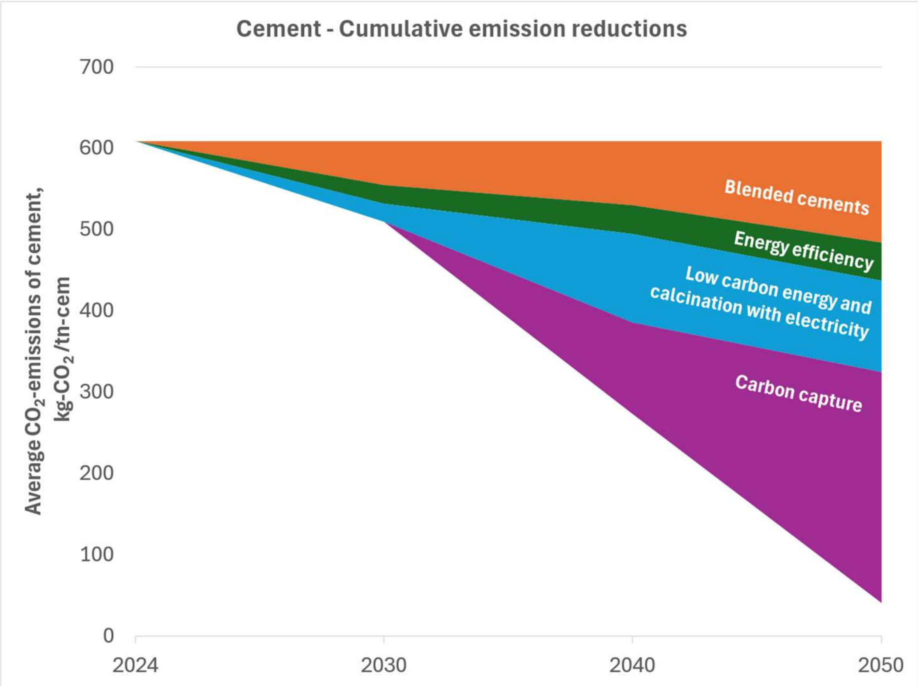

Figure 2 – Cumulated CO_2-emission saving potentials in cement production in 2024, 2030, 2040 and 2050.

2.2 Concrete production

Seven different options were recognised related to the concrete production. The potentials of the options vary rather strongly between the product segments. The CO_2-reduction potentials of the concrete production are clearly lower level compared with the cement production and none of the options has clearly higher potential compared to others. The analysed options are:

- Future binders
- Mix design optimization
- Development of production technology
- Use of electricity and heating energy
- Use of recycled concrete as aggregate
- Transportation of cement and aggregate
- Binding of CO_2 into fresh concrete
- Binding of CO_2 into concrete during hardening

Future binders
Future binders cover here new binders which are outside the scope of the present cement and concrete standards. They can be new types of cements or new types of secondary cementitious materials. Probably the best-known of such binders are alkali activated slag and geopolymers, but there are many other alternatives as well. The analysis was not focusing on certain specific type of binder or raw materials but was based on the CO_2-emission levels and estimated use of the binders. A more common use of future binders in concrete will be challenging as the cement and

concrete standards set strict requirements for the materials which can be used in concrete. The future use of such binders was estimated to be:

- 2030: 1 % from the total use of binders
- 2040: 3 % from the total use of binders
- 2050: 8 % from the total use of binders

The lower CO_2-emission level of conventional cements in the future strongly affects the compatibility of the future binders. For example, a new binder having the emission level of 400 CO_2-kg/tn is not very competitive with the conventional cements. On the other hand, new binders with very low emission level are not realistic either. In the calculations, the emissions level of 200 CO_2-kg/tn was considered as most realistic. Table 5 presents the emission savings in binder and concrete with different emissions level of future binders.

Table 5 - Estimated total emission reductions achieved with future binder. The use of future binder is assumed to 1 % in 2030, 3 % in 2040 and 8 % in 2050. The development of CO_2-emission level of cement has been taken into account in the calculations.

CO_2-emissions of future binder [kg-CO_2/tn]	CO_2-reduction in binder [kg-CO_2/tn-cem]			CO_2-reduction in concrete [kg-CO_2/m^3-con]		
	2030	2040	2050	2030	2040	2050
50	-5	-14	-35	-1,9	-5,0	-12,2
100	-5	-13	-31	-1,6	-4,5	-10,8
200	**-4**	**-10**	**-23**	**-1,2**	**-3,5**	**-8,0**
400	-2	-4	-7	-0,5	-1,4	-2,4

In case of individual companies, the use of future binders can be significantly higher as presented above. It was estimated that for example in the production of concrete products, the use could up be 5 % in 2030, 15 % in 2040 and 30 % in 2050. The respective emissions savings in concrete would be -6 kg-CO_2/m^3-con in 2030, -17 kg/m^3 and -30 kg/m^3 in 2050. Also in these calculations, the emissions level of future binders was assumed to be 200 kg-CO_2/tn.

Mix design optimization

Mix design optimization normally aims at lower cement content which leads to lower CO_2-emissons of concrete. Earlier the mix design optimization was made mainly due to cost effects, but nowadays also CO_2-emissions may play an important role. In practice the mix design optimization could be made for example in the following ways:

- Grading of aggregate could be optimized, or the quality of aggregate could be improved so that water demand of the aggregate decreases and cement content could be reduced.
- Use of admixtures could be optimized so that the cement content could be reduced.
- If the variation / strength margin of compressive strength could be reduced, also the cement content could be reduced.

On the other hand, the use of crushed fine aggregates will be increasing in future in Finland and that may cause increase of the water demand of aggregate. The analyses were based on the changes in the cement content without analysing specific reasons for the cement reduction. It was assumed that in 2050 50 % of the concrete production could decrease cement content by 20 kg/m^3, 40 %

of the production by 10 kg/m^3 and 10 % cannot change the cement content. The calculated emission savings in concrete have been presented in Table 6.

Table 6 - Estimated emission reductions achieved with mix design optimization.

	Adjusted average cement content [kg/m^3]	Emissions of concrete from cement [kg-CO_2/m^3-con]	Emissions savings vs. 2024 [kg-CO_2/m^3-con]
2024	350	213	-
2030	341	208	-5,5
2040	339	206	-6,7
2050	336	205	-8,5

In case of individual companies clearly higher cement saving could be achieved. It was estimated that up to 70 % of the companies could achieve cement content reduction of 20 kg/m^3 and 30 % 10 kg/m^3 already in 2040. In such a case the CO_2-emission saving in concrete could be -10,4 kg-CO_2/m^3-con compared to 2024.

Development of production technology

In the roadmap, the development of production technology analyses two main possibilities for emissions savings: more effective heat treatment of concrete and lower consistency class of concrete. In both cases the maximum saving in the cement content was assumed to be 20 kg/m^3. Possibilities to utilize those technologies depend strongly on the product segment. The utilization of more effective heat treatment is valid only for production of pre-cast concrete and concrete products and the change of consistency class is practically possible only in ready-mix concrete production. According to the estimations, in 2050 up to 75 % from pre-cast concrete production and concrete products could achieve 20 kg/m^3 reduction in cement content with help of more effective heat treatment. Similarly, 60 % of ready-mix concrete production could save 20 kg/m^3 cement with optimizing the consistency class.

It should be noted that more effective heat treatment increases energy consumption, but it is assumed that the low carbon energy will be used. The consistency class is decided by subscriber of the concrete (construction company) and therefore the concrete producer has only limited possibilities to affect the consistency class. The estimated emissions savings are given in Table 7.

Table 7 - Estimated emission reductions achieved with development of production technology.

	CO_2-reduction in concrete [kg-CO_2/m^3-con]		
	2030	2040	2050
Heat treatment	-2,6	-3,0	-3,8
Change of consistency class	-3,8	-5,1	-5,1
TOTALLY	**-6,4**	**-8,1**	**-8,9**

Individual companies have slightly bigger possibilities to utilize heat treatment or change consistency class of concrete. It was estimated that from pre-cast concrete and concrete product companies up to 85 % could utilize more extensive heat treatment in 2050. Similarly, 50 % of ready-mix companies could utilize the change of consistency class. The total emission savings in 2050 would be -9 kg-CO_2/m^3-con for ready-mix concrete producer, 15 kg-CO_2/m^3-con for pre-cast concrete producer and -13 kg-CO_2/m^3-con for a producer of concrete products. In certain cases, higher cement savings than 20 kg/m^3 could be achieved, especially with heat curing.

Use of electricity and heating energy

The production of concrete consumes rather little energy, but in the production of pre-cast concrete elements and concrete products energy consumption is a significant source of CO_2-emissions. In the analysis, the average energy consumptions of the Finnish Low Carbon Concrete Classification [2] were used:

- Ready-mix concrete production:
  - Electricity: 7 kWh/m^3-con
  - Heating energy: 11 kWh/m^3-con
- Production of pre-cast concrete elements and concrete products:
  - Electricity: 50 kWh/m^3-con
  - Heating energy: 100 kWh/m^3-con

Two types of changes are expected to take place in future: the energy consumption slightly decreases, and the future energy has lower CO_2-emissions. Fossil fuels will be replaced with bio-based fuels. In 2024 app. 80 % from heating energy in the concrete production was fossil energy. The use is estimated to decrease so that in 2030 it would be 60 %, in 2040 30 % and in 2050 all the heating energy would be bio-based energy.

In case of ready-mix concrete production, the emission savings remain low, in 2050 -2,9 kg-CO_2/m^3-con. However, in pre-casting and in the production of concrete products the emission savings are significant:

- 2030: -8,5 kg-CO_2/m^3-con
- 2040: -17,7 kg-CO_2/m^3-con
- 2030: -25,7 kg-CO_2/m^3-con

In case of individual companies, the values can be even higher, especially in short term. Already in 2030 a saving of 24,8 kg-CO_2/m^3-con could be achieved. However, the most active companies have already done actions related to energy consumption and therefore the existing saving potentials can be smaller. On the other hand, if geothermal or solar energy is effectively utilized at the factory, the energy savings can be even higher as estimated. Only the purchased energy consumption is taken into account in the calculations.

Use of recycled concrete as aggregate

Crushed concrete can be effectively recycled in the road and land construction but also in the concrete production. However, when used in the concrete production, crushed concrete replaces natural aggregates, and the natural aggregate has very low CO_2-emissions. In Finland, emissions of 6 kg-CO_2/tn are used for the crushed aggregate and for the natural sand it is even lower [2]. Therefore, use of recycled concrete as aggregate cannot give significant savings in CO_2-emissions. Also, the maximum share of recycled concrete aggregate in the concrete production is rather low. The CO_2-emission savings were assumed to come from two sources:

- Reduced CO_2-emission of crushed concrete aggregate
    - Emissions of crushed concrete assumed to be 0
    - Amount of crushed concrete aggregate: 20 % from the total volume of aggregate (= 380 kg/m^3)
- Shorter transportation of crushed concrete aggregate
    - Amount of crushed concrete aggregate: 20 % from the total volume of aggregate (= 380 kg/m^3)
    - Transportation distance of normal aggregate: 70 km. Transportation distance of crushed concrete aggregate: 0 km.
    - Emissions of transportation: 0,085 kg-CO_2/tn*km

The emission savings in 2050 would be 6,8 kg-CO_2/m^3-con, from which 4,5 kg-CO_2/m^3-con is due to the shorter transportation distance. In case of an individual company, the CO_2-emission will not be much higher, but the savings can take place faster, already in 2030.

Transportation of cement and aggregate
CO_2-emissions of transportation of cement or aggregate are not included into the emissions of cement or aggregate, but the concrete producer must include them in the CO_2-emissions calculations of concrete. The level of emission is strongly dependent on the transportation distance and especially with aggregate, the average distance is increasing all the time. Finnish Low Carbon Classification gives the following emissions for the transportation using fossil fuels /2/:

- Cement: 0,079 kg-CO_2/tn*km
- Aggregate: 0,085 kg-CO_2/tn*km

If bio diesel is used, the emissions are assumed to 30 % of the present values. The respective value with electrical trucks would be 10 %. The transportation distance is estimated to be 200 km for cement and 70 km for aggregate. In case of aggregates, the increasing transportation distances have not been considered. The emission savings have been presented in Table 8.

Table 8 - Estimated emission reductions achieved with transportation of cement and aggregate.

	CO_2-reduction in concrete [kg-CO_2/m^3-con]	
	Cement	Aggregate
Bio diesel	-7,7	-15,8
Electrical truck	-10,5	-21,5

It was further estimated that bio diesel is more probable alternative as it does not require any renewal of the trucks. It was estimated that in 2030 bio diesel could be used 50 % of the transportations and 100 % in 2040. Individual companies could use bio diesel 100 % already in 2030. The electrical trucks would give even higher saving potentials.

Binding of CO_2 into fresh concrete or concrete during hardening
Two developing technologies related to binding CO_2 into concrete were analysed. The use of both technologies is connected to the situation when CO_2 is available in larger amounts, e.g. when carbon capture is already in use. Based on the on-going project in Finland, fresh concrete could bind CO_2 up to 7 % from the amount of cement. The clinker content of cement is reducing in future and that affects the binding capacity. Also, the use of the technology will be rather limited.

It was assumed that from the concrete industry 1% could utilize the technology in 2030, the respective values for 2040 and 2050 are 5 % and 10 %. In individual companies, the use could clearly higher: 25 % in 2030, 40 % in 2040 and 50 % in 2050. Table 9 presents the estimated emission savings in concrete.

Table 9 - Estimated emission reductions achieved with binding of CO_2 into fresh concrete.

	CO_2-reduction in concrete [kg-CO_2/m^3-con]	
	Concrete industry	Individual company
2030	-0,2	-5,3
2040	-1,0	-8,0
2050	-1,7	-8,7

Binding of CO_2 into concrete during hardening is done by a Finnish start-up company According to the knowledge of the company, app. 200 kg-CO_2/tn-cem can be bound into concrete. This means 70 kg-CO_2/m^3-con, but the value decreases as the clinker content is decreasing in future. The calculation assumes that only clinker is binding CO_2, although the binding will take place also with secondary cementitious materials. In addition to the binding effect, CO_2 treatment also increases early strength of concrete. In the calculations, 15 % saving in the cement content was assumed. The total effects of the CO_2-binding into concrete during hardening are high:

- 2030: 83,0 kg-CO_2/m^3-con
- 2040: 78,1 kg-CO_2/m^3-con
- 2050: 69,6 kg-CO_2/m^3-con

The lowering tendency is due to the lower clinker content in future. The major challenge is the utilization rate of the technology. For the concrete industry, the following values were used: in 2030: 1 %, in 2040: 3 % and in 2050: 6 %. For individual companies the values can be clearly higher: in 2030: 50 %, in 2040 and 2050: 100 %. The technology is suitable mainly for a company producing concrete products. The technology requires CO_2-chambers and that limits the use with larger products or cast-in-situ structures. The estimated emission savings are presented in Table 10.

Table 10 - Estimated emission reductions achieved with binding of CO_2 into concrete during hardening.

	CO_2-reduction in concrete [kg-CO_2/m^3-con]	
	Concrete industry	Individual company
2030	-0,5	-41,5
2040	-2,0	-78,1
2050	-3,5	-69,6

2.3 Structures

The analyses of the concrete structures are more complicated compared to the ones for the cement and concrete production presented earlier. Reduction potentials vary significantly between individual projects or cases and therefore general estimations for CO_2-savings are very difficult to give. The following options were analysed:

- Strength class and quality assurance age
- Design solutions
- Re-use of pre-cast concrete elements
- Carbonation of structures

Strength class and quality assurance age

The effects of optimization of strength class and quality assurance age were estimated. Principally, the use of unnecessary high strength class should be avoided, and the classification age of 91 days could be used more. Both are giving possibilities to reduce cement content and thereby reduce CO_2-emissions.

The effect of a strength class on the CO_2-emissions was estimated with help of Finnish Low Carbon Classification [2]. Average differences of two consecutive strength classes were calculated. In 2030 it was 18 kg-CO_2/m^3-con and 14 kg-CO_2/m^3-con in 2040 and 2050. The emission savings achieved with changing the quality assurance age from 28 days to 91 days were estimated to be 30 kg-CO_2/m^3-con in 2030, 25 kg-CO_2/m^3 in 2040 and 20 kg-CO_2/m^3 in 2050. The emission savings have been presented in Tables 11 and 12.

Table 11 - Estimated emission reductions achieved with changes in strength class (one strength class lower). Effects in the production of concrete products was considered minimal.

	Effect of change of strength class on emissions [kg-CO_2/m^3-con]	Share in the production			Emission savings in concrete industry [kg-CO_2/m^3-con]
		Ready-mix concrete	Pre-cast concrete	Concrete industry	
2030	-18	10 %	10 %	9,0 %	-1,8
2040	-14	20 %	20 %	18,0 %	-2,5
2050	-14	20 %	20 %	18,0 %	-2,5

Table 12 - Estimated emission reductions achieved with changes in quality assurance age (from 28 d to 91 d). Effects in the production of concrete products was considered minimal.

	Effect of change of quality assurance age on emissions [kg-CO_2/m^3-con]	Share in the production			Emission savings in concrete industry [kg-CO_2/m^3-con]
		Ready-mix concrete	Pre-cast concrete	Concrete industry	
2030	-30	15 %	0 %	8,1 %	-2,4
2040	-25	20 %	0 %	10,8 %	-2,7
2050	-20	20 %	0 %	10,8 %	-2,2

Individual companies can have higher shares than those presented in Tables 11 and 12. Strength class could be modified up to 50 % in production of ready-mix concrete and pre-casting. Similarly, the change of quality assurance age could take place up to 30 % in production of ready-mix concrete and pre-casting. In such cases, the emissions savings would be up to -9,0 kg-CO_2/m^3-con both in ready-mix and pre-cast concrete production.

Design solutions

The effects of the design solutions on the CO_2-emissions are difficult to estimate. There are several options which can be made to reduce volume of concrete, strength class of the structure and amount of reinforcement in the structure. However, cross effects exist, for example lowering the strength class may easily increase the need of reinforcement. Here, rather general values were used for slabs and wall structures. In individual cases, probably much higher reductions could be achieved.

It was estimated that the emissions saving potential of design solutions is 30 - 45 kg-CO_2/m^3-con, however this will be slightly lower in future as the emissions of cement are decreasing. The following values for emission savings were used in the calculations:

- 2030: Average: 34 kg-CO_2/m^3-con, range: 27 - 41 kg-CO_2/m^3-con
- 2040: Average: 33 kg-CO_2/m^3-con, range: 26 - 39 kg-CO_2/m^3-con
- 2050: Average: 30 kg-CO_2/m^3-con, range: 24 - 36 kg-CO_2/m^3-con

It was estimated that the concrete industry can achieve 20 % from the minimum values. An individual ready-mix concrete can achieve 30 % from the average value and pre-cast concrete producer 40 % from the average values. The emission savings have been presented in Table 13.

Table 13 - Estimated emission reductions achieved with design solutions.

	CO_2-emissions savings [kg-CO_2/m^3-con]		
	Ready-mix concrete	Pre-cast concrete	Concrete industry
2030	-10,3	-13,7	-5,5
2040	-9,8	-13,1	-5,2
2050	-8,9	-11,9	-4,8

Re-use of pre-cast concrete elements

Re-use of pre-cast elements can give high emission savings as the production of a new element can be totally avoided. However, the possibilities for re-using of concrete elements are rather limited. Hollow-core slabs have clearly the highest potential for re-using. It was estimated that up to 50 % of the hollow-slabs in a new apartment building could be replaced with re-used hollow-core slabs. The CO_2-emission of the re-used slab was estimated to be 10 % from the values of the new slabs. The CO_2-emissions of new hollow-core slabs will be decreasing with time, and this was taken into account as shown in Table 14.

Table 14 – CO_2-emissions of hollow-core slabs and the emission reduction achieved with re-used slabs.

	Low carbon classification class [2]	CO_2-emissions of hollow-core slab [2] [kg-CO_2/m^3-con]	Emission savings with re-used slabs [kg-CO_2/m^3-con]
2024	GWP.REF	295	-132,8
2030	GWP.70	205	-92,3
2040	GWP.70	205	-92,3
2050	GWP.55	160	-72,3

The total use of the re-used hollow-core slabs will be relatively low, it was estimated to be 1 % in 2030, 2 % in 2040 and 3 % in 2050 from the total use. In case of individual pre-cast companies, the respective values were estimated to be: 10 % in 2030, 15 % in 2040 and 25 % in 2050. The emission savings are presented in Table 15.

Table 15 – Estimated CO_2-emissions reductions achieved with re-used hollow-core slabs.

	CO_2-emission savings [kg-CO_2/m^3-con]	
	Pre-cast concrete producer	Concrete industry
2030	-9,2	-0,9
2040	-13,8	-1,8
2050	-18,0	-2,2

Carbonation of structures

Carbonation of existing structures is slightly different option compared with the 15 other options in the roadmap. Carbonation of existing concrete structures is included in the roadmap more as a reference value as the carbonation does not require any actions. To some extent the carbonation of crushed concrete can be accelerated.

A Finnish national project estimated that the annual carbon sink of the existing concrete structures is app. 56 000 tn [3]. The average annual concrete production in Finland has been app. 5 million m^3 and the same average level is believed to continue. Thus, the carbon sink due to carbonation is 11,2 kg-CO_2/m^3-con for produced concrete. The calculation method is not perfectly correct as the carbonation takes place in old, existing structures. However, this kind of calculation gives comparable values with the other options. The carbon sink was estimated to increase slightly with time as crushed concrete will be carbonated more effectively in future. The emission savings due to carbonations are estimated to as follows. The values are assumed to same for all the product segments.

- 2030: 11,2 kg-CO_2/m^3-con
- 2040: 12,0 kg-CO_2/m^3-con
- 2050: 15,0 kg-CO_2/m^3-con

3. CO_2-EMISSION REDUCTIONS

The CO_2-emission reductions of 16 options for the Finnish concrete industry have been collected in Figure 3. The figure presents the average situation of Finnish concrete industry, individual companies can have much larger saving potentials as presented in Figure 4 - 6.

Cement production has clearly the biggest potential for emission savings. This is obvious as cement is causing a major part of the CO_2-emissions of concrete. From cement production carbon capture has the highest potential, but in Finland it will be realised earliest in 2040. In short term (in 2030) blended cement and low carbon energy have the highest potentials. The other significant options for emissions savings are transportation of cement and aggregate, design solutions and carbonation of concrete.

The analysis of the average concrete industry does not reveal all the possibilities for emission reductions. There are clearly some options which are not significant for the whole industry but can be very important for individual companies. Therefore, the CO_2-emission potentials of individual companies were calculated, and the values are presented in Figure 4 - 6. The analyses assume, that a company puts significant efforts on the emission savings. Therefore, the values are rather maximum values than average values.

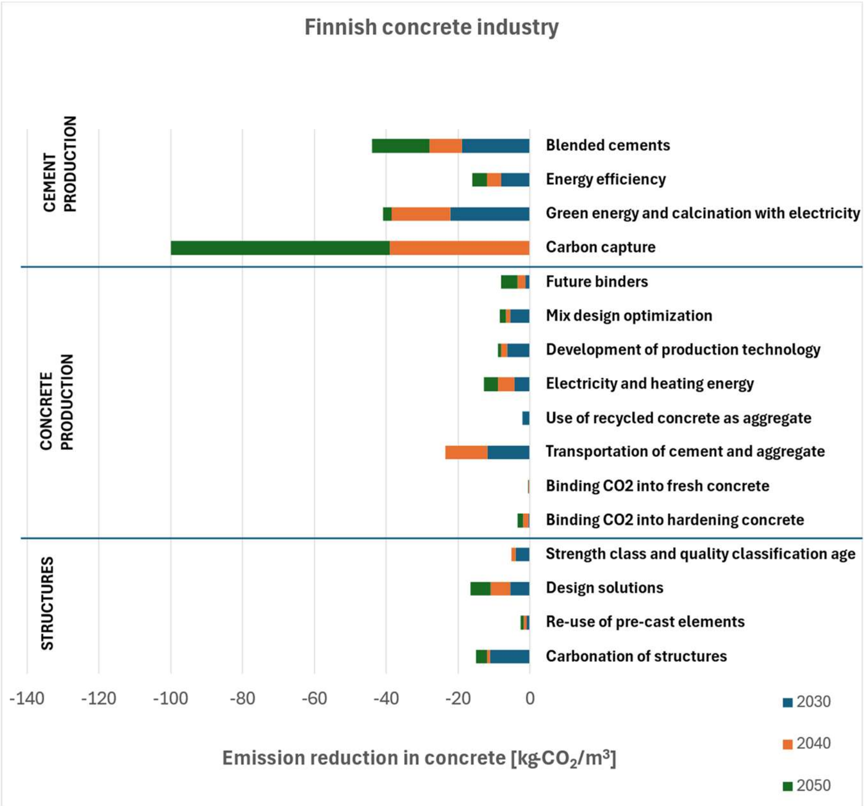

Figure 3 – CO_2-emission saving potentials of concrete in 2030, 2040 and 2050. The figure presents the average emission reductions of Finnish concrete industry.

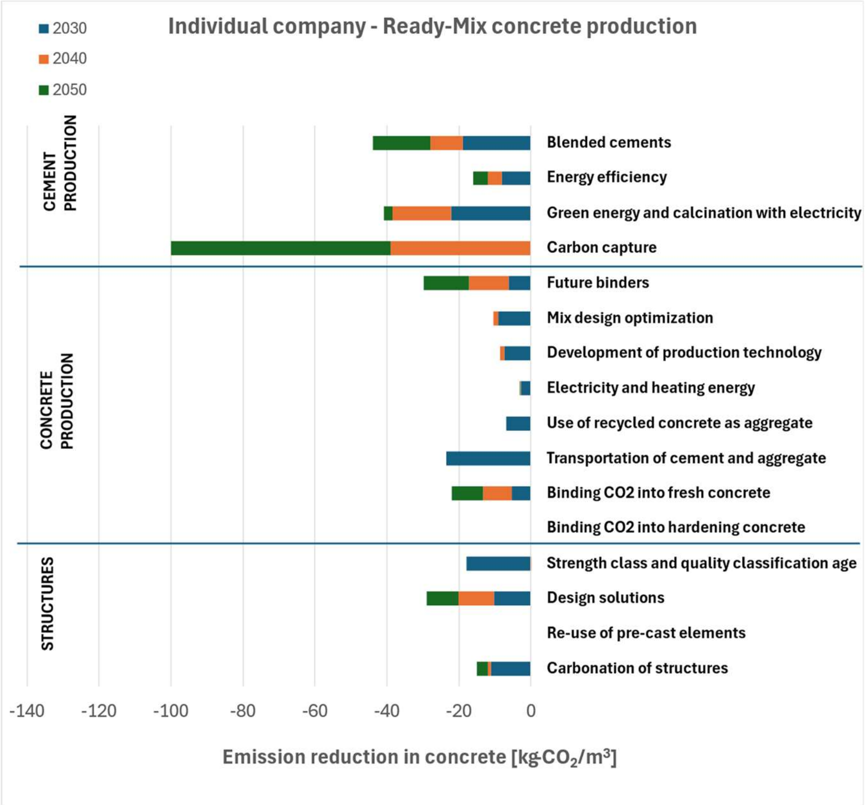

Figure 4 – CO_2-emission saving potentials of concrete in 2030, 2040 and 2050. The figure presents the potential of an individual company producing ready-mix concrete.

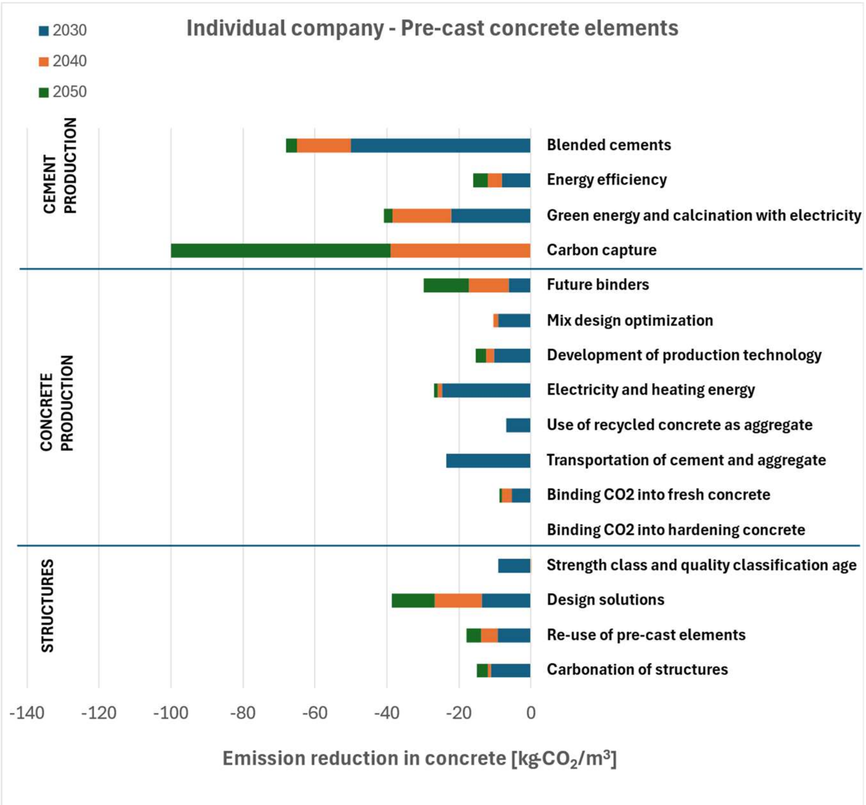

Figure 5 – CO_2-emission saving potentials of concrete in 2030, 2040 and 2050. The figure presents the potential of an individual company producing pre-cast concrete elements.

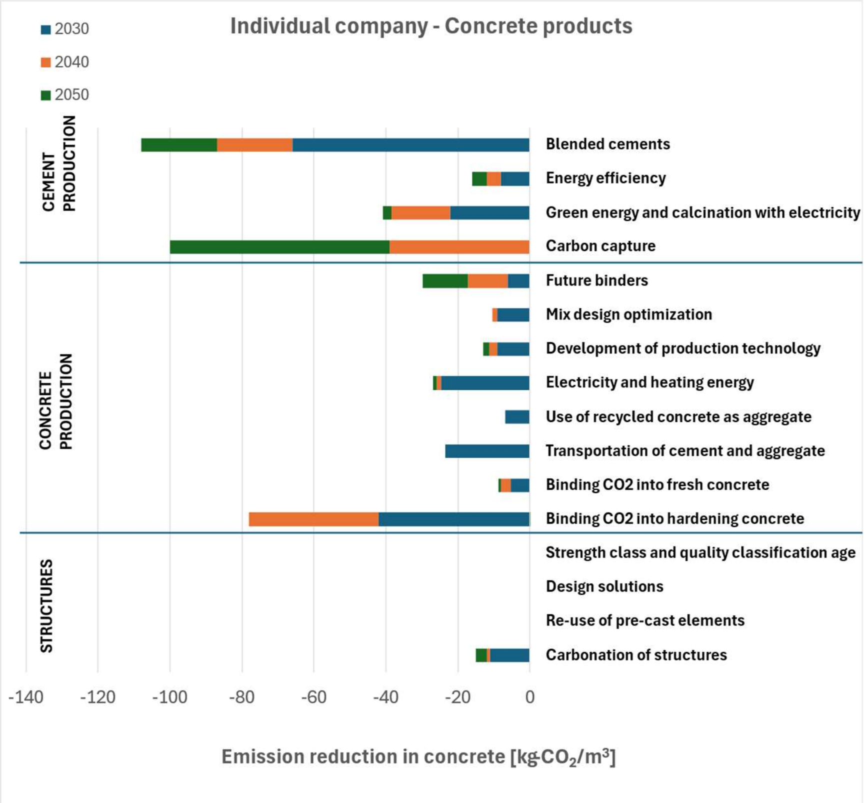

Figure 6 – CO_2-emission saving potentials of concrete in 2030, 2040 and 2050. The figure presents the potential of an individual company producing concrete products.

For an individual company producing ready-mix concrete, the cement production has clearly the largest potential for CO_2-emission savings. Future binders have the largest potential outside the cement production. Also, transportation of cement and aggregate, binding CO_2-emissions into fresh concrete and design solutions have saving potential bigger than 20 kg-CO_2/m^3-con.

For a pre-cast concrete producer, blended cements have a high potential, especially in short term. In longer term, the carbon capture has clearly the highest potential. Use of blended cement in pre-casting is somewhat contradictory as early strength is critical in pre-casting. On the other hand, the conditions for hardening can be adjusted. For example, heat curing in the pre-cast concrete production is much easier compared to cast-in-situ structures. The other options giving over 20 kg-CO_2/m^3-con reductions in pre-casting are future binders, energy consumption in concrete production, transportation of cement and aggregate as well as design solutions. Re-use of pre-cast elements is close to 20 kg- CO_2/m^3-con and can increase in future.

Production of concrete products has rather similar CO_2-saving potentials as pre-casting except that blended cements and binding CO_2 into hardening concrete have even higher potential. However, both are feasible only in certain types of production. Therefore, the potential varies between the companies. Also, future binders, energy consumption in production and transportation of cement and aggregate have rather high reduction potential in the production of concrete products.

Future binders have relatively high CO_2-reduction potential in all three product segments. However, there are several uncertainties related to future binders. Which raw materials will be available in future, especially in larger amounts, what will be the CO_2-emissions level of future binders, are they accepted to use in load-bearing structures etc. In the road map, it was assumed that future binders can be used on rather high amounts, e.g. in 2050 up to 8 % from the total use of binders.

All the 16 options for CO_2-emission reductions cannot be used simultaneously and some of them are limited only to a certain product segment. However, quite many of them can be combined and CO_2-emission level of concrete can be lowered to a very low level. CO_2-emissions of concrete below 50 kg-CO_2/m^3 are not unrealistic in future. Carbon capture plays a very important role, but in Finland the introduction takes time. It was estimated that the carbon capture is 50 % in use in 2040 and fully in use in 2050.

4. RISKS AND COST EFFECTS

In addition to CO_2-emission savings, also risks and cost effects of each option were estimated. The estimations were based on the analyses of the expected future development of each option. As can be expected, estimations of risks and costs in future include lot of uncertainties. Therefore, the presented estimations are only indicative and can be very different in different markets. Figure 7 presents the estimated risks and Figure 8 cost effects.

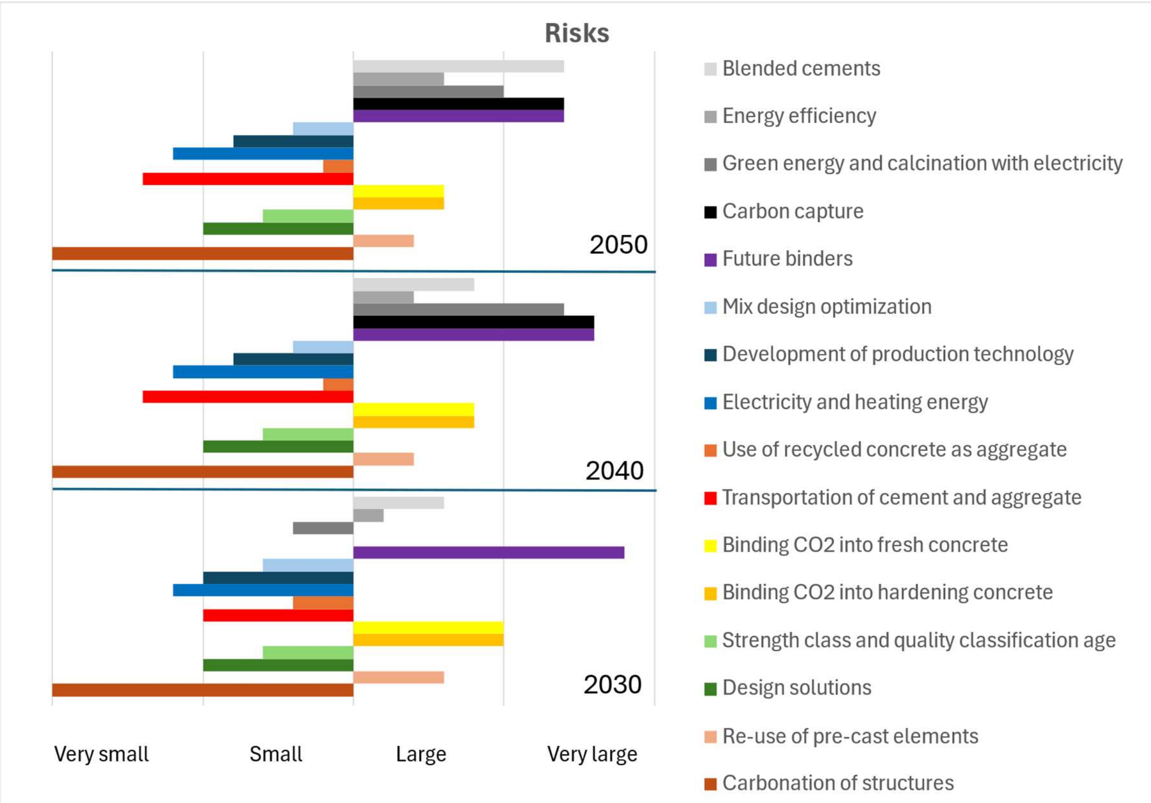

Figure 7 – Estimated risks of 16 options for CO_2-emission savings. The estimations are only indicative. The length of the beam represents the estimated risk level.

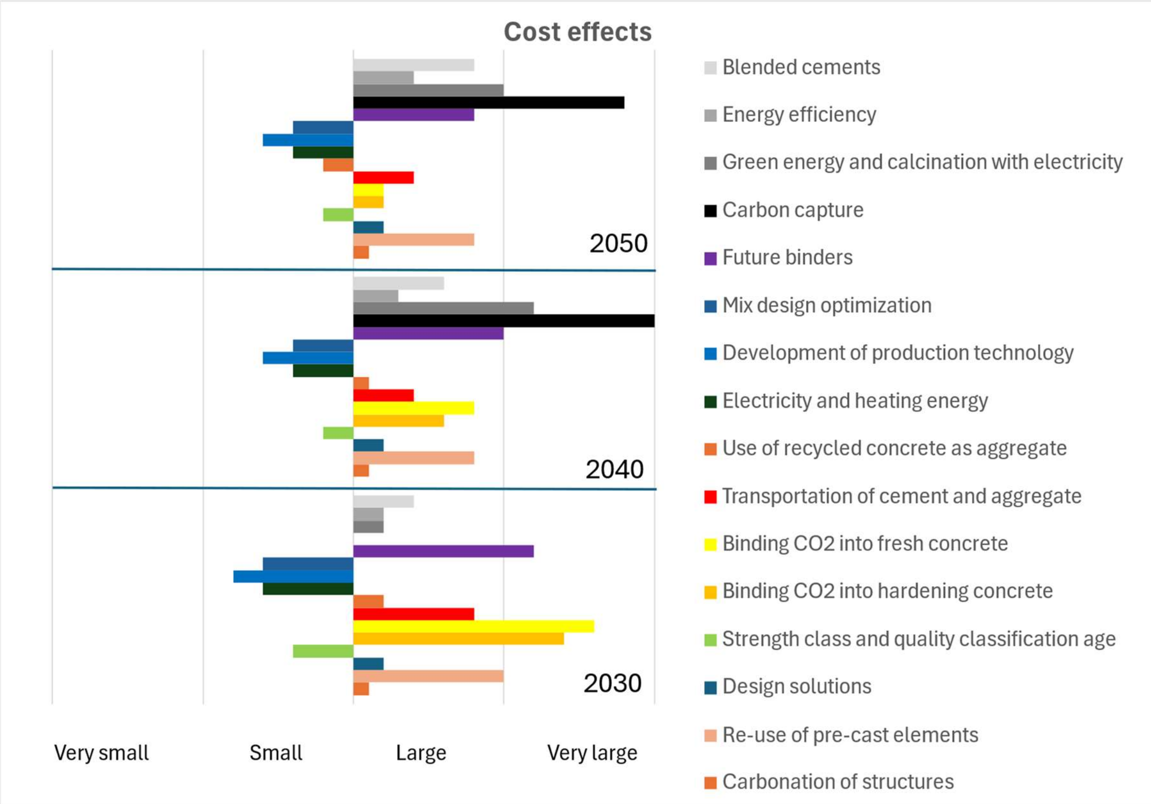

Figure 8 – Estimated cost effects of 16 options for CO_2-emission savings. The estimations are only indicative. The length of the beam represents the estimated level of cost effect.

From the estimated risks, the largest risks are related to carbon capture and future binders. Also, risks related to blended cements will be increasing with time as the availability of suitable secondary cementitious materials can be challenging. Some of the options have rather small risks, for example energy use in concrete production as well as transportation of cement and aggregate have relative low risks. Carbonation of existing concrete structures is considered riskless.

Similarly, the estimated cost effects vary between the analysed options. Carbon capture is estimated to have the highest costs. Also, future binders can have rather high costs. Binding CO_2 into concrete is seen as relatively expensive technology, but it is assumed that with time the costs will be lower. Also, re-use of pre-cast concrete elements is estimated to have quite high cost effects. There are also some options with smaller costs effects. For example, if the cement content or energy consumption can be reduced, the costs effects are often low or even positive especially in a longer period.

5. CONCLUSIONS

A roadmap for low-carbon concrete was made in Finland to identify the most potential options for CO_2-emission reductions in concrete production. The road map estimates the situation in 2030, 2040 and 2050. The calculations were made for the whole Finnish concrete industry but also for individual companies in three different product segments. The calculations required many assumptions of the future situation and therefore the values in the roadmap are only indicative. However, the roadmap allows comparisons of the different options for emissions savings and reveals some new, less-known possibilities for CO_2-emission savings in concrete production.

As expected, the largest emission reductions can be achieved in the cement production. Carbon capture will give the biggest reductions followed by the use of blended cements and low carbon energy & electrical calcination in cement production. However, the introduction of the carbon capture will take time and therefore it is very important to utilize other possibilities to reduce CO_2-emissions of concrete in shorter term. Potential options for a concrete producer are for example more extensive use of blended cements, transportation of cement and aggregate, improvements in the energy use as well as mix design optimization. Depending on the production type, an individual producer has several additional options for emission savings.

The different options include risks on different levels, and the cost effects vary between the options. Both risk and cost effects were analysed, but the estimations include lot of uncertainties.

The roadmap also reveals that concrete can be low-carbon or even zero-emission material in future. As the emissions of the cement can be reduced close to zero, it will be possible to produce concrete with very low CO_2-emissions. However, this will take time and there will be significant cost effects.

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REFERENCES

1. Cembureau 2050 Roadmap. 2024. Link: https://cembureau.eu/media/ulxj5lyh/cembureau-net-zero-roadmap.pdf
2. Low Carbon Classification of Concrete in Finland. Link: https://vahahiilinenbetoni.fi/in-english/
3. CO_2NCRETE SOLUTION – Carbon sink of concrete structures (in Finnish). Project report. Link: https://betoni.com/wp-content/uploads/2024/11/CO2NCRETE-SOLUTION-Betonikanta-analyysi.pdf