Prioritizing action perspectives for greening the concrete chain: update 2016

CO_2 abatement potential and CO_2 abatement costs of 17 greening options for concrete

Summary in English

CE Delft

Committed to the Environment

Summary

Background

This study is part of a multi-year trajectory to improve the environmental footprint of the concrete supply chain in the Netherlands. In 2011 the Green Deal on Concrete was signed by the ministries of Economic Affairs and Infrastructure & Environment (I&E) and 24 companies and 7 trade associations representing the concrete chain, cooperating in the Concrete Network, an informal collaboration under the banner of CSR Netherlands, an organization promoting Corporate Social Responsibility. This Green Deal is a statement of intent to render the concrete sector sustainable by the year 2050. Sector-wide negotiations are currently underway to finalize an agreement to this end, encompassing goals relating to CO_2 emissions reduction, the circular economy, biodiversity and social aspects. As a participant in the Concrete Network, the Dutch roads and waterways authority Rijkswaterstaat (an agency of I&E) commissioned CE Delft to elaborate 17 different methods to reduce the carbon footprint of concrete.

Table 1 Synopsis of measures to reduce the carbon footprint of concrete use, by category

Category	Short name	Description of greening option
Changes in concrete composition	Improved aggregate packing	Optimization of aggregate packing
	CEM X	Broadening of permitted raw materials for cement under European standard
	CSA-Belite cements	Alternative binder (sulpho-aluminate belite)
	Supersulphated	Alternative binder (supersulphated cement)
	Alternative CSH	Alternative binder (alternative CSH cement)
	Geopolymers	Alternative binder (alkaline-activated materials)
	Solidia	Alternative binder (CO_2-activated cement)
	Carbstone	Alternative binder (CO_2-activated cement)
Use of recycled materials / components	Design for disassembly	Construction using standard units designed for disassembly
	Mechanical cement recycling	Mechanical cement recycling via C2CA or 'smart crushing'
	Thermal cement recycling	Thermal cement recycling based on 'circular construction' concept
	Incinerator bottom ash	Use of incinerator bottom ash as a filler with binding capacity
Changes to construction process	Construction planning	Longer curing time for poured concrete by adapting construction planning
Extension of building lifetime	Self-healing concrete	Self-healing concrete with calcium carbonate-producing bacteria
Energy consumption in user phase	Concrete core activation	Concrete core activation combined with heat pump and heat/cold storage additional to EPC requirements
Carbon capture in concrete	Mineral CO_2	Use of filler in which CO_2 is sequestered
	Carbon8	Gravel substitute based on fly ash and/or bottom ash and CO_2
	Solidia	CO_2-activated concrete
	Carbstone	CO_2-activated concrete

Greening options

This report presents our findings on these 17 methods, referred to as 'greening options' and briefly characterized in Table 1. These are the updated options described earlier in 'Prioritizing action perspectives for greening the concrete chain: update 2015' (CE Delft, 2015), supplemented by options whereby CO_2 is captured in concrete. As our point of departure we have taken Dutch concrete consumption in 2010, as described in the report 'Environmental impact of concrete use in the Dutch construction industry (2013)' (CE Delft, 2013).

For each of the greening options the CO_2 abatement potential and the CO_2 abatement costs were calculated. The abatement potential and costs are reported in Figure 1 through 4.

This does not mean these are the only options for reducing the carbon footprint of the concrete chain: there are more, but within the limited time available for this study we were unable to research them all, while for the options we did examine it proved impossible to find sufficiently detailed information on them all. Our list of options can therefore best be regarded as a basic source of inspiration for approaches to greening the concrete chain.

Abatement costs

Abatement costs

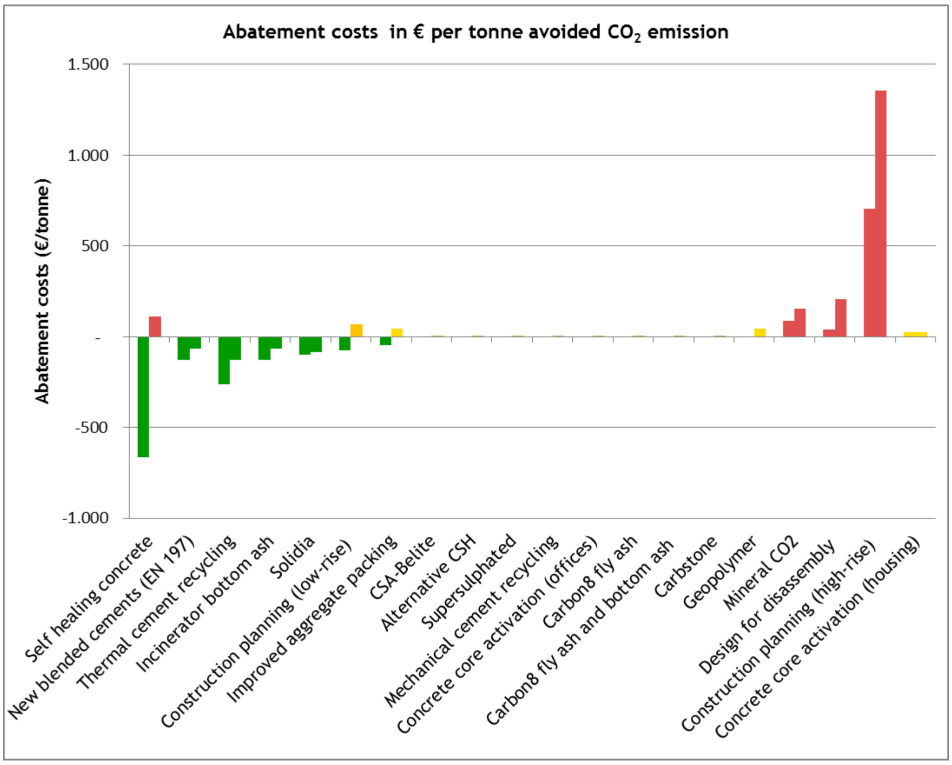
The CO_2 abatement costs are calculated as the cost of avoiding emission of one tonne of CO_2 by using the method in question. These are the costs incurred over the full lifetime of the option divided by the total lifetime CO_2 emission reduction achieved through use of the option. The abatement costs therefore tell us little about the initial additional costs borne by market parties and are therefore not suitable for assessing the business case.

The abatement costs for each of the options are shown in Figure 1 and zoomed in on in Figure 2. For each option the minimum and maximum abatement costs have been calculated. For most options these values are close together, but in some cases there is a substantial spread. The abatement costs have not been corrected for the CO_2 price in the European Emissions Trading Scheme (EU ETS).

If the abatement costs are positive, money needs to be spent to achieve the carbon cuts. If costs are negative, use of the option concerned not only leads to CO_2 cuts but also to a reduction of total lifetime costs.

The data used for these calculations are not specific enough for spot-on Euro calculations. If the costs are around zero, the greening option is approximately cost-neutral.

Figure 1 **Abatement costs for greening options in € per tonne avoided CO_2 emission**

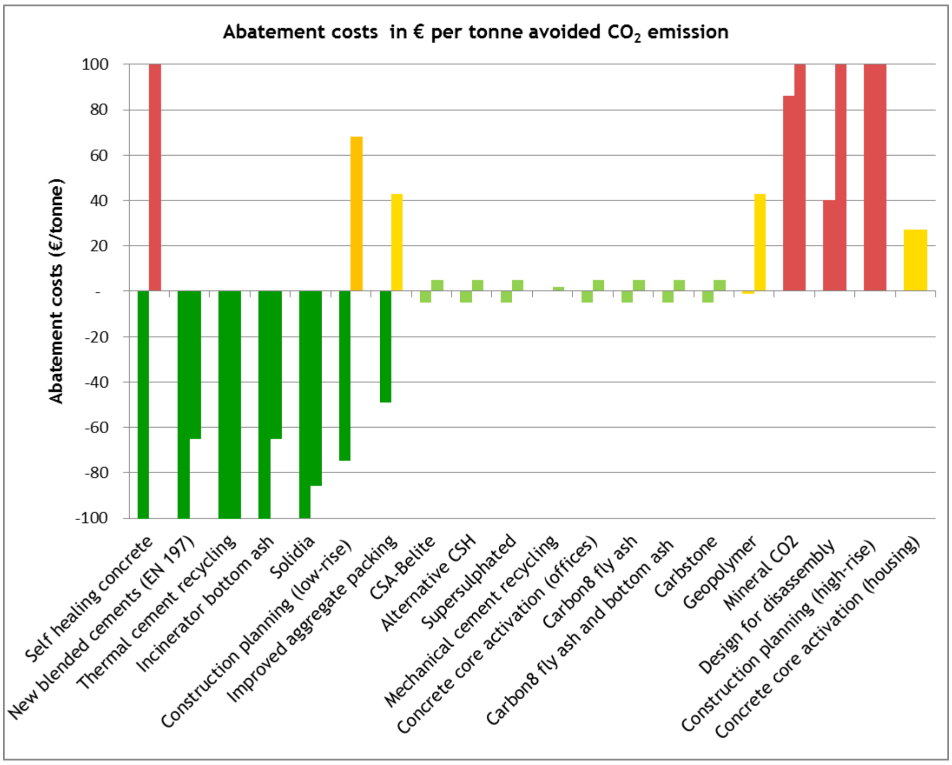


This figure compares the various greening options. In most of the methods the savings are achieved either by saving out on the production of cement or another building material, or by CO_2 capture in the material production phase. These options can be mutually compared. With the options 'self-healing concrete' and 'concrete core activation' the CO_2 reduction occurs (in part) over the lifetime of the concrete. Here, abatement costs were calculated by indexing the lifetime savings to the present using the 'net present value' method.

We use colour codes to indicate the various ranges in abatement costs:

- Dark green for greening options enabling significant cost savings.
- Light green for options that are more or less cost-neutral.
- Yellow for options cost-neutral at a CO_2 price between 10 and 80 €/t.
- Red for options that in their current form lead to a significant cost increase, even with a sharply rising CO_2 price.

Figure 2 Abatement costs per greening option in € per tonne avoided CO_2 emission (detail)



Abatement potential

Abatement potential
The CO_2 abatement potential is the potential of the greening option to reduce the carbon footprint of the concrete. It should be emphasized that this is the *technical* abatement potential, i.e. the potential available if all parties put their full weight behind the option. In reality, market sentiments and commercial considerations will generally play a role, which may mean this potential is not actually secured in practice.

The CO_2 abatement potential was calculated by means of Life Cycle Assessment (LCA), taking 2010 as a reference year and assuming maximum implementation of the option across the Netherlands. The only restriction taken on board was that the option should be technically mature enough and tested for practical application by the year 2020.

This means the following:

Reference year 2010

In assessing the abatement potential it was assumed that national concrete consumption is the same as in 2010, the year for which the CO_2 footprint of concrete use was previously calculated (CE Delft, 2013). This allows the calculated abatement potential for 2020 to be compared with the calculated total footprint of Dutch concrete use in 2010.

Based on LCA

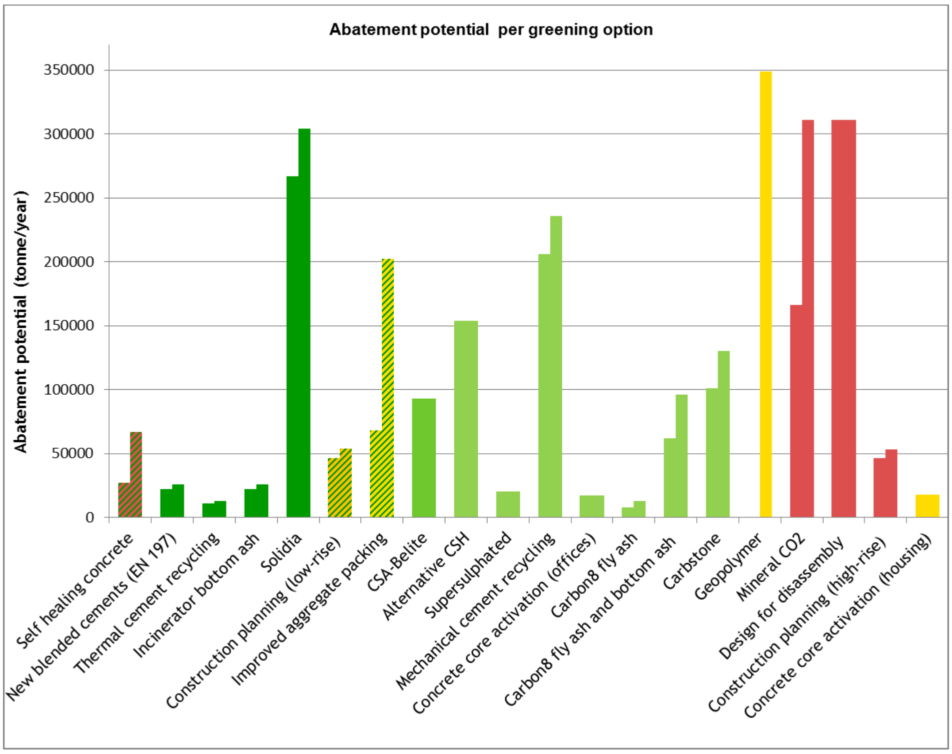
In calculating the CO_2 abatement potential of each greening option it was calculated how much more or less CO_2 is emitted over the entire lifetime of the concrete. The net result of this calculation was multiplied by the amount of concrete to which the greening option is applied per year, giving a figure for annual abatement potential. This is obviously a simplification, but it is the only way to compare the results with the CO_2 footprint for 2010.

Particularly with the alternative binders (CSA-belite, geopolymers, alternative CSH and CO_2-activated (Solidia) cement), there are strict protocols to be adhered to before market entry is permitted. In our calculations we have therefore assumed limited use in non-structural concrete applications.

The calculated CO_2 abatement potentials are shown in Figure 3, using the same colour codes as for the abatement costs in Figure 1 and 2.

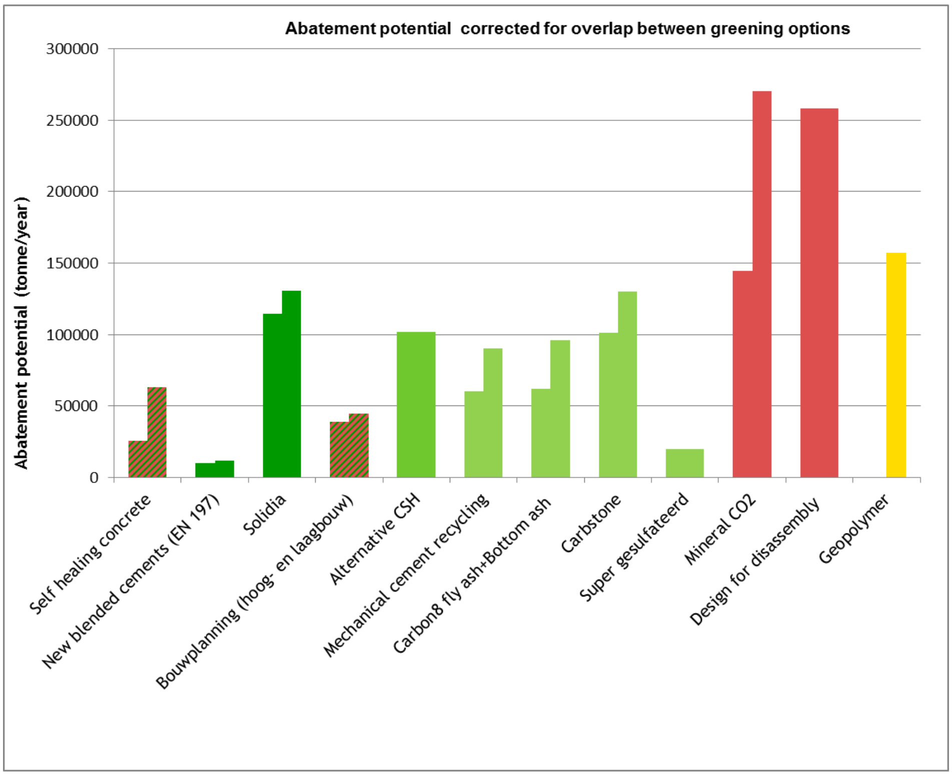
The greening options cannot all achieve their full abatement potential at the same time. If the CO_2 emissions of certain concrete products are reduced by using Solidia cement rather than Portland clinker, geopolymers cannot also be used in those products. In Appendix F the overlap between the options is therefore reported. The overlap has been corrected for, as shown in Figure 4.

Figure 3 CO_2 abatement potential per greening option in tonne avoided CO_2 emission per year



From Figure 4 it follows that the total cumulative abatement potential is 0.9-1.4 million tonnes of CO_2 per year. **Of this, 0.6 to 0.7 million tonnes of CO_2 per year can be secured at no net cost.** It should again be emphasized that this is the *technical* abatement potential. As stated in Box 2, this means this potential can only be achieved if all parties put their full weight behind the option. In reality, market sentiments and commercial considerations will generally play a role, which may mean this potential is not actually secured in practice.

Figure 4 Net CO_2 abatement potential per greening option in tonne avoided CO_2 emission per year



Maturity of the required technology (TRL levels)

While many of the cited greening options are still under development, there are major differences in the degree to which the technology is already proven. The further a technology is developed, the more certainty can be attributed to the assessed abatement costs and abatement potential. Conversely, the less far advanced a technology is, the greater the variation that can feasibly occur in the abatement potential and costs.

This is a recurrent problem when assessing technological innovation. At the end of the 1980s NASA therefore developed a method for scoring the maturity of new technologies using a scale of so-called Technology Readiness Levels (TRL). These range from TRL 1, the least developed level: an idea based on fundamental, scientifically proven principles, to TRL 9, the most advanced: a system whose effectiveness has been proven in an operational environment over a longer period of time.

This method of assessing innovation enjoys wide acceptance. We have here used the generalized definitions employed by the European Commission (Horizon, 2014):

TRL 1 – basic principles observed
TRL 2 – technology concept formulated
TRL 3 – experimental proof of concept
TRL 4 – technology validated in lab
TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7 – system prototype demonstrated in operational environment
TRL 8 – system complete and qualified

TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

TRL 1 to 3 inclusive relate to the kind of research often carried out at universities, TRL 3 to 6 relate to the kind of research focused on in the Netherlands by ECN and TNO. Industrial R&D departments are usually involved once TRL 4 has been successfully completed, i.e. from TRL 5 onwards. When TRL 9 has been reached the only obstacle to implementation is the degree of market acceptance.

Besides the abatement potential and abatement costs, Appendix A also reports the TRL of each greening option. These results are summarized in **Figure 5** and 6, giving a compact depiction of the fraction of the abatement potential associated with a low TRL and consequently still very uncertain, and the fraction with a high TRL and thus fairly certain. Given the spread in the calculated values of both the abatement costs and the abatement potential as well as the TRL levels, the most unfavourable as well as the most favourable situation are depicted.

Figure 5 shows the most unfavourable scenario: the lowest abatement potential, the highest abatement costs and the lowest TRL per greening option. **Figure 6** shows the most favourable scenario: the highest abatement potential, the lowest abatement costs and the highest TRL per greening option. The size of the circles indicates the abatement potential: the bigger the circle, the greater the potential.

The TRL levels mean we can also pronounce on the certainty of the abatement potential:
- the abatement potential of options with TRL 9 is certain;
- the abatement potential of options with TRL 6-8 is probable;
- the abatement potential of options with TRL 1-5 is uncertain.

In the most unfavourable scenario (Figure 5) a number of greening options have a TRL of 1-5 (see Table 2). Their potential can therefore be deemed (partially[1]) uncertain. Proceeding from the TRL level in the most unfavourable scenario, between 0.3 and 0.5 million tonnes of the 0.9-1.4 million tonnes CO_2 corrected abatement potential is uncertain.

Table 2 **Greening options with TRL 1-5 in the most unfavourable scenario**

Greening option	TRL, most unfavourable scenario	TRL, most favourable scenario
Mineral CO_2	4	4
Alternative CSH	4	5
Carbon8 fly ash + bottom ash	5	5
Thermal cement recycling	4	8
CSA-Belite	5	8
Improved aggregate packing	4	9

[1] If the TRL is below 6 in both scenarios, the potential is uncertain. If the TRL is below 6 only in the most unfavourable scenario, then the potential is only partly uncertain. This is because the fraction of the abatement potential for which a higher TRL holds is also more certain in terms of abatement potential.

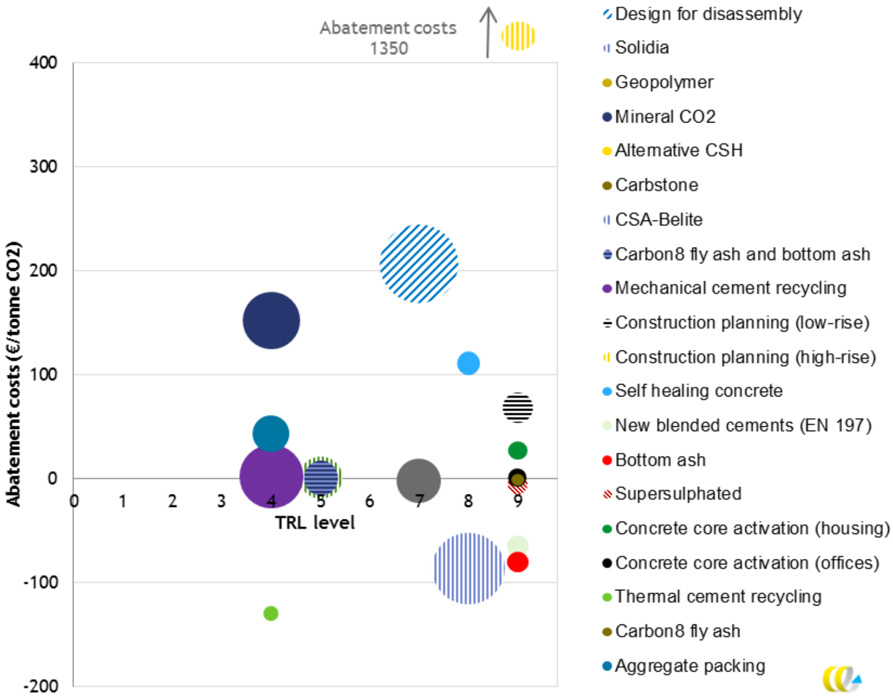
In the most unfavourable scenario (Figure 5) a number of greening options have a TRL of 6-8 (see Table 3).

Table 3 Greening options with TRL 6-8 in the most unfavourable scenario

Greening option	TRL, most unfavourable scenario	TRL, most favourable scenario
Mechanical cement recycling	6	8
Design for disassembly	7	7
Carbstone	7	8
Geopolymers	8	8
Self-healing concrete	8	8
Solidia	8	9

The potential of these options can therefore be deemed probable. Proceeding from the TRL in the most unfavourable scenario, between 0.6 and 0.9 million tonnes of the 0.9-1.4 million tonnes CO_2 corrected abatement potential is uncertain.

Figure 5 Most unfavourable scenario



The most unfavourable scenario has the lowest abatement potential, the highest abatement costs and the lowest TRL level per greening option. To provide a clear picture of how the various greening options differ, the abatement-cost axis has been truncated at +400. This means 'Construction planning (high-rise)' lies off the scale, so this circle has been placed at the right TRL level, with an arrow pointing to the value of the abatement costs.

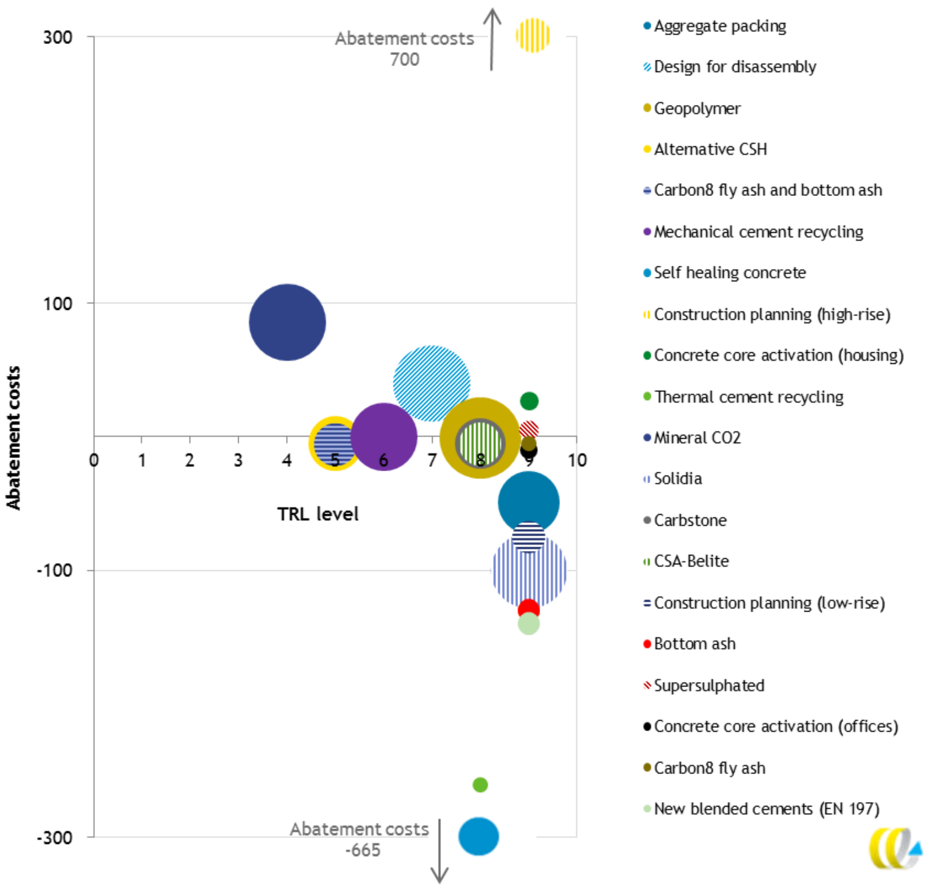
In the most unfavourable scenario (Figure 5) a number of greening options have a TRL of 9 (see Table 4). Their potential can thus be regarded as certain.

Translating back to the corrected abatement potential, it can therefore be concluded that:
– 0.1 million tonnes annual CO_2 reduction is certain;
– 0.6-0.8 million tonnes annual CO_2 reduction is probable;
– 0.3-0.5 million tonnes annual CO_2 reduction is uncertain.

Table 4 Greening options with TRL 9 in the most unfavourable scenario

Greening option	TRL level in most unfavourable scenario	TRL level in most favourable scenario
Construction planning (low-rise)	9	9
Construction planning (high-rise)	9	9
CEM X	9	9
Bottom ash	9	9
Supersulphated	9	9
Concrete core activation (housing)	9	9
Concrete core activation (offices)	9	9
Carbon8 fly ash	9	9

Figure 6 Most favourable scenario



The most favourable scenario has the highest abatement potential, the lowest abatement costs and the highest TRL level per greening option. To provide a clear picture of how the various greening options differ, the abatement-cost axis has been truncated at -300 and +300. This means 'Construction planning (high-rise)' (+700) and 'Self-healing concrete' (-665) are off the scale, so these circles have been placed at the right TRL level, with an arrow pointing to the value of the abatement costs.

This is assuming the same cement and concrete consumption as in 2010 and calculating using the lowest estimated TRL levels. When using the estimated TRL in the most favourable scenario, the fraction of the abatement potential that is uncertain is smaller and the fraction that is probable or certain is bigger. Comparison of Figures 5 and 6 gives an indication of the magnitude of the changes.

References in the summary

CE Delft, 2013
Marijn Bijleveld, Geert Bergsma & Marit van Lieshout
Milieu-impact van betongebruik in de Nederlandse bouw [Environmental impact of concrete use in the Dutch construction industry]
Delft: CE Delft, 2013

CE Delft, 2015
Marit van Lieshout
Update Prioritering handelingsperspectieven verduurzaming betonketen 2015 [Prioritizing action perspectives for greening the concrete chain: update 2015]
Delft: CE Delft, 2015

Horizon, 2014
HORIZON 2020 – WORK PROGRAMME 2014-2015, General Annexes, Page 1
Available online:
http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

For the calculations on the individual greening options we refer to the report in Dutch: Update prioritering handelings-perspectieven verduurzaming betonketen 2016 [Prioritizing action perspectives for greening the concrete chain: update 2016].
Available online: www.ce.nl/ce/verduurzaming_beton/901