Dataset for "*Cement and concrete decarbonisation roadmaps - a meta-analysis within the context of the United Kingdom*"
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Supplementary Information

This Supplementary Information file provides full details of the methods used for the analysis presented in the article Marsh A.T.M. et al. "*Cement and concrete decarbonisation roadmaps – a meta-analysis within the context of the United Kingdom*".

The following sections describe the methods used for:

S1. Assigning material scope to decarbonisation strategies
S2. Determining material scope of the roadmaps
S3. Determining existence of trends between strategies and actor type
S4. Determining Technology and Market Readiness Level (TMRL) range for each strategy
S5. Determining carbon reduction potential for each strategy

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S1. Methodology for assigning material scope to decarbonisation strategies

From roadmaps, 16 distinct strategies were identified. A brief description of each is as follows:

- **Clinker Replacement** = replacement of higher proportions of clinker in blended cements with supplementary cementitious materials.
- **Alternative Binders** = use of cementitious materials with different chemistries in order to lower the embodied carbon of production. Scope is limited to calcium sulfoaluminate clinkers, alkali-activated cements and carbonatable calcium silicate cements, as these are the systems that roadmaps have identified as being capable of making a substantial contribution to decarbonisation by 2050.
- **Decarbonisation of Electricity** = use of low-carbon electricity sources to reduce the emissions of processes requiring electricity (e.g. grinding of cement and fuel).
- **Decarbonisation of Transport** = use of low-carbon transport modes to reduce the emissions of transport processes in production (inc. transport of raw materials and fuels to the cement plant, transport within quarries and cement plants, and delivery of cement to customers).
- **Carbon Capture and Utilisation/Storage (CCUS)** = capture of carbon emissions released from process and/or combustion emissions during production, followed by storage in products or stable reservoirs.
- **Alternative Fuels** = replacement of fossil fuels by biomass.
- **Electrification** = use of alternative kiln technologies to replace current fuels with electricity-powered heating processes (e.g. hydrogen fuel, plasma, and microwave).
- **Thermal Efficiency Improvements** = Upgrading of kiln technologies to reduce heating requirements and hence combustion emissions.
- **Re-carbonation** = capture of process emissions in cement production through carbonation of end-of-life concrete.
- **Recycling of Concrete Fines** = use of concrete fines recovered at end-of-life as a feedstock in clinker production.
- **Concrete Mix Design Optimisation** = reducing the proportion of cement used in concrete by improving particle packing.
- **Reduction of Over-specification** = specifying concrete mixes which are appropriate for given service conditions of loading and exposure, and hence avoiding a higher cement content than is necessary.
- **Improved Design of Structural Elements** = designing concrete structural elements with dimensions that are appropriate for given service conditions of loading and exposure, and hence avoiding redundant material in a structure.
- **Extended Building Lifetime** = maximising the functional life of buildings through flexible design, prioritising refurbishment over demolition and exploiting opportunities for reuse of structural elements.
- **Alternative Construction Materials** = greater use of low-carbon, bio-based construction materials (inc. timber, bamboo) in applications where their use is viable (e.g. housing).
- **Leveraged Thermal Mass** = use of concrete to build high thermal mass elements in buildings, in order to reduce heating and cooling loads and hence reduce operational carbon.

For the most part, this list adopted the strategy naming and categories already used by the roadmaps. These 16 strategies were then divided into two groups, based on material scope (Table S1):

1. **Cement Strategies.** Strategies which reduce the carbon emissions of cement production, either by decreasing direct emissions (i.e. process or combustion emissions) or indirect emissions (i.e. from electricity generation or transport). These strategies decrease the carbon intensity of cement (i.e. embodied carbon per tonne of cement produced), but without necessarily changing the volume of cement produced.

2. **Concrete Strategies.** Strategies which reduce the carbon emissions of concrete in the design, manufacture, use or end-of-use life cycle stages, by decreasing concrete and/or cement consumption and thus clinker production. Also included in this grouping is Leveraged Thermal Mass, which allocates carbon emissions reductions as a result of reducing the operational carbon emissions of buildings. These strategies decrease absolute carbon emissions (i.e. the total amount of carbon released by concrete production), and can also change the overall volume of concrete (and hence also cement) being produced.

Table S1: Classifications of decarbonisation strategies into material scope categories of cement and concrete.

Material scope	Strategy
Cement	Clinker Replacement
	Alternative Binders
	Decarbonisation of Electricity
	Decarbonisation of Transport
	Carbon Capture and Utilisation/Storage
	Alternative Fuels
	Electrification
	Thermal Efficiency Improvements
	Re-carbonation
	Recycling of Concrete Fines
Concrete	Concrete Mix Design Optimisation
	Reduction of Over-specification
	Improved Design of Structural Elements
	Extended Building Lifetime
	Alternative Construction Materials
	Leveraged Thermal Mass

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S2. Methodology for determining material scope of roadmaps

To make a semi-quantitative comparison around the level of detail in which different strategies were considered within the different roadmaps, each strategy was given a weighting from 0-3 depending on its prominence within a roadmap (Table S2). Crucially, the weighting assignment only considered a strategy's prominence within a given roadmap, and not compared to other roadmaps; it was also not intended to assess the quality of a given roadmap.

These results are summarised in Table S3. The mean average weighting for each strategy across the nine roadmaps analysed is an indicator of how much attention a given strategy has been given across the nine roadmaps studied.

Table S2: Criteria for assigning weightings to strategies within roadmaps.

Weighting	Criterion
0	The strategy is not mentioned in the roadmap.
1	The strategy is mentioned, but only briefly and not included in any carbon accounting.
2	The strategy is covered in detail and included in any carbon accounting.
3	The strategy has been covered in substantially more detail than the other strategies.

Table S3: Weightings assigned for the individual strategies, and the average weighting across the nine roadmaps.

Material	Strategy	Non-industry roadmaps				Industry roadmaps					Avg. Weighting
		A	D	E	G	B	C	F	H	I	
Cement	Clinker Replacement	2	2	2	2	2	2	2	2	3	2.1
	Alternative Binders	2	2	2	3	2	2	2	2	2	2.1
	Decarbonisation of Electricity	2	0	2	0	2	0	2	2	2	1.3
	Decarbonisation of Transport	0	0	0	0	2	1	2	0	0	0.6
	Carbon Capture and Utilisation/Storage	2	2	2	2	2	2	2	2	3	2.1
	Alternative Fuels	2	2	2	2	2	1	2	2	3	2.0
	Electrification	0	0	2	0	2	0	2	0	2	0.9
	Thermal Efficiency Improvements	2	2	2	2	2	0	2	2	3	1.9
	Recarbonation	0	0	1	0	2	2	2	1	2	1.1
	Recycling of Concrete: Fines	0	2	2	0	0	0	2	0	3	1.0
Concrete	Concrete Mix Design Optimisation	0	2	2	2	2	2	2	1	2	1.7
	Reduction of overspecification	0	2	3	0	0	2	0	0	0	0.8
	Improved Design of Structural Elements	0	2	2	0	0	2	1	0	2	1.0
	Extended Building Life	0	2	2	1	0	1	1	0	2	1.0
	Alternative Construction Materials	0	0	1	1	0	0	0	0	0	0.2
	Leveraged Thermal Mass	1	0	0	1	2	1	1	1	0	0.8

These weightings were then used to determine the ‘Material Scope’ of individual roadmaps. As described in the main article, the material scope of each roadmap was classified as either a ‘cement oriented’ material scope (i.e. primarily focussed on cement strategies), or a ‘cement and concrete oriented’ material scope (i.e. an approximately even coverage of both cement and concrete strategies).

This classification was done by assessing whether the majority of the overall weightings within a given roadmap was placed upon cement strategies, concrete strategies, or an approximately even mix of both. The following procedure was used to carry out this assessment on each roadmap:

1. Sum the individual weightings of the Concrete Strategies to get Total Concrete Strategy Weighting.
2. Find Average Concrete Strategy Weighting by dividing Total Concrete Strategy Weighting by the number of Concrete Strategies (6).
3. Sum the individual weightings of the Cement Strategies to get Total Cement Strategy Weighting.
4. Find Average Cement Strategy Weighting by dividing Total Cement Strategy Weighting by the number of Cement Strategies (10).
5. Divide Average Concrete Strategy Weighting by Average Cement Strategy Weighting to get a value X. This is indicative of the relative prominence of Concrete Strategies compared to Cement Strategies within each roadmap.

This can be expressed more concisely, through summation notation, in Equation S1:

Equation S1:

$$X = \frac{\left(\frac{\sum_{i=1}^{6} concrete\ strategy\ weighting_i}{6}\right)}{\left(\frac{\sum_{j=1}^{10} cement\ strategy\ weighting_j}{10}\right)}$$

The material scope was then assigned, based on the value of X:

- IF X ≥ 0.75, the material scope of that roadmap was assigned to be cement AND concrete.
- IF X < 0.75, the material scope of that roadmap was assigned to be cement.

A value of X = 0.75 was selected as an appropriate threshold (rather than the ideal value of X = 1 to indicate an equal consideration of both cement and concrete strategies), given that the average weighting of cement strategies when considered altogether (1.5) is much higher than the average weighting of concrete strategies altogether (0.8) (Table S3).

As an example, the calculation procedure for Roadmap A is given below:

1. $\text{Total Concrete Strategy Weighting} = 2 + 2 + 2 + 2 + 0 + 0 = 8$
2. $\text{Average Concrete Strategy Weighting} = \frac{8}{6} = 1.33$
3. $\text{Total Cement Strategy Weighting} = 2 + 2 + 0 + 0 + 2 + 2 + 0 + 2 + 0 + 2 = 12$
4. $\text{Average Cement Strategy Weighting} = \frac{12}{10} = 1.2$
5. $\text{Ratio} = \frac{1.33}{1.2} = 1.11$

6. $1.11 \geq 0.75 \therefore \text{Cement and Concrete Scope}$

The results and intermediate working values for assigning material scope are given in Table S4.

Table S4: Assignments of material scope for the roadmaps, along with intermediate working values.

	Non-industry roadmaps				Industry roadmaps				
	A	**D**	**E**	**G**	**B**	**C**	**F**	**H**	**I**
Total Cement Strategy Weighting	12	12	17	11	18	10	20	13	23
Average Cement Strategy Weighting	1.2	1.2	1.7	1.1	1.8	1	2	1.3	2.3
Total Concrete Strategy Weighting	1	8	10	5	4	8	5	2	6
Average Concrete Strategy Weighting	0.17	1.33	1.67	0.83	0.67	1.33	0.83	0.33	1.00
Cement Scope	X				X		X	X	X
Cement and Concrete Scope		X	X	X		X			

S3. Methodology for determining existence of trends between strategies and actor type

To investigate the existence of any trends between actor type and the promotion of particular decarbonisation strategies, the Average Weighting given by roadmaps of each Actor Type has been calculated for each strategy.

As shown in Table S4, four of the strategies were included in at least moderate detail within all the roadmaps. These were:

- Clinker replacement
- Alternative binders
- Carbon capture and utilisation/storage
- Alternative fuels

For the remaining 12 strategies which were not covered by all the roadmaps, the average weighting was calculated for both industry (Equation S2) and non-industry roadmaps (Equation S3), using the weighting values in Table S3:

Equation S2:

$$\text{Average Industry Weighting} = \frac{\sum \text{Weighting in Industry Roadmaps}}{\text{No. of Industry Roadmaps}}$$

Equation S3:

$$\text{Average Non Industry Weighting} = \frac{\sum \text{Weighting in Non Industry Roadmaps}}{\text{No. of Non Industry Roadmaps}}$$

As an example, the calculation procedure for “Concrete Mix Design Optimisation” is given below, using values from Table S3:

$$\text{Average Industry Weighting} = \frac{2+1+2}{3} = 1.7$$

$$\text{Average Non} - \text{Industry Weighting} = \frac{2+0+2+2}{4} = 1.5$$

The results for the average weighting values by actor type are given in Table S5**Error! Reference source not found.**.

On the basis of the ratio between the average weighting by actor type, each strategy was assigned into a category:

1. IF “industry average weighting : non-industry average weighting” > 2 – assign as “*favoured by industry roadmaps*”
2. IF “industry average weighting : non-industry average weighting” < 0.5 – assign as “*favoured by non-industry roadmaps*”
3. IF neither of the above conditions are met – assign as “*not favoured by either actor type*”

A threshold ratio of > 2:1 between the two average weightings was selected as being appropriately high for the purpose of this analysis, to identify any obvious trends between actor type and the strategies favoured for consideration within the roadmaps. The assigned categories for each strategy are given in Table S5**Error! Reference source not found.**.

Table S5: Calculated values for average weighting by actor type, for each strategy.

Strategy	Average Weighting		Average weighting ratio of industry to non-industry	Category
	Industry	Non-industry		
Decarbonisation of Electricity	1.6	1.0	1.6	Not favoured by either actor type
Decarbonisation of Transport	1.0	0.0	-	Favoured by industry roadmaps
Electrification	1.2	0.5	2.4	Favoured by industry roadmaps
Thermal Efficiency Improvements	1.8	2.0	0.9	Not favoured by either actor type
Recarbonation	1.8	0.3	7.2	Favoured by industry roadmaps
Recycling of Concrete Fines	1.0	1.0	1.0	Not favoured by either actor type
Concrete Mix Design Optimisation	1.8	1.5	1.2	Not favoured by either actor type
Reduction of overspecification	0.4	1.3	0.3	Favoured by non-industry roadmaps
Improved Design of Structural Elements	1.0	1.0	1.0	Not favoured by either actor type
Extended Building Life	0.8	1.3	0.6	Not favoured by either actor type
Alternative Construction Materials	0.0	0.5	0.0	Favoured by non-industry roadmaps
Leveraged Thermal Mass	1.0	0.5	2.0	Favoured by industry roadmaps

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S4. Methodology for determining Technology and Market Readiness Level (TMRL) ranges of decarbonisation strategies

To make a comparison between the decarbonisation strategies, Technology and Market Readiness Level (TMRL) was used as a semi-quantitative measure of technological and market maturity. The TMRL titles and descriptions have been used from the International Energy Agency ETP Clean Technology Guide (IEA, 2021) (Table S6**Error! Reference source not found.**).

Table S6: The International Energy Agency's Readiness Level (RL) scale used to assess decarbonisation strategies for the cement and concrete industry.

Readiness Level	Title	Description
1	Initial idea	Basic principles have been defined
2	Application formulated	Concept and application of solution have been formulated
3	Concept needs validation	Solution needs to be prototypes and applied
4	Early prototype	Prototype proven in test conditions
5	Large prototype	Components proven in conditions to be deployed
6	Full prototype at scale	Prototype proven at scale in conditions to be deployed
7	Pre-commercial demonstration	Prototype working in expected conditions
8	First of a kind commercial	Commercial demonstration, full-scale deployment in final conditions
9	Commercial operation in relevant environment	Solution is commercially available, needs evolutionary improvement to stay competitive.
10	Integration needed at scale	Solution is commercial and competitive but needs further integration efforts
11	Proof of stability reached	Predictable growth

The TMRL of several strategies are included within the International Energy Agency ETP Clean Technology Guide, and these values were used where available. For strategies which were not included within the ETP Clean Technology Guide, TMRL values were determined using information collated from the ten roadmaps, and supplemented with data from other sources. These values are based on the best available information that is publicly accessible – due to the nuances between neighbouring levels, these values should be considered as indicative, rather than definitive. Some strategies were assigned a range of TMRLs, reflecting the diversity of technological maturity for different technologies in development within that strategy. The assigned values are presented in Table S7**Error! Reference source not found.**, along with comments to explain why these values were selected.

Table S7: TMRL values and explanatory comments for each decarbonisation strategy.

Material	Strategy	TMRL	Comments
Cement	Clinker Replacement	11	Blended cements are commercially available and included within EN 197-1
	Alternative Binders	3 – 9	IEA rates alkali-activated binders to be TMRL = 9, and magnesia based cements to be TMRL = 3. Calcium Sulphoaluminate clinkers are commercially available (TMRL = 9). Carbonatable Calcium Silicate cements are at pilot phase (TMRL = 6). Calcium sulfo-aluminate cements have been used at an industrial scale in China for several decades (TMRL = 11).
	Decarbonisation of Electricity	11	Decarbonised electricity is proven and commercially available
	Decarbonisation of Transport	6	Electric industrial vehicles are currently being tested
	Carbon Capture and Utilisation/Storage	4 – 8	IEA rates CCUS technologies to span a TMRL range of 4 - 8. TMRL 4: membrane separation; TMRL 6: oxy-fuelling, direct separation, novel physical adsorption (silica or organic-based): TMRL 7: calcium looping, chemical absorption; TMRL 8: chemical absorption, partial capture rates (less than 20%).
	Alternative Fuels	11	Biomass is commercially available for use as an alternative fuel
	Electrification	5 – 6	IEA rates direct electrification of kilns to be TMRL = 4.
	Thermal Efficiency Improvements	11	Technology to improve thermal efficiency is commercially available
	Re-carbonation	6	Fastcarb have demonstrated pilot schemes of this strategy
	Recycling of Concrete Fines	6	IEA rates recycling of concrete fines to be TMRL = 6. In addition, Roadmap D cites several studies which have demonstrated feasibility
Concrete	Concrete Mix Design Optimisation	11	The technology required to optimise concrete mix design is commercially available
	Reduction of Over-specification	11	Over-specification can be reduced within the current design codes
	Improved Design of Structural Elements	7 - 10	Prefabrication and efficient design of elements within the codes are commercially available (TMRL = 10). Prototypes of elements with efficient geometry are being optimised (TMRL = 7).
	Extended Building Lifetime	11	Designing with a ‘long life, loose fit’ approach focussing on versatility and reusing concrete frames are both achievable using mature technology

	Alternative Construction Materials	8 - 11	Elements made using engineered wood products such as CLT are commercially available (TMRL = 11). Hybrid structures using steel and timber are available for niche applications (TMRL = 8).
	Leveraged Thermal Mass	11	Leveraged Thermal Mass is an established method to reduce operational energy

S5. Methodology for determining carbon reduction potential for each strategy, for each roadmap

In order to make semi-quantitative evaluations between the roadmaps, it was intended to achieve a balance between:

- Relevance of regional scope to the UK context
- Fair comparison between roadmaps of the same regional scope
- Number of roadmaps to compare

To balance these criteria, it was decided to make a detailed comparison between the roadmaps whose scope covered the UK or the European region:

A. Industrial Decarbonisation and Energy Efficiency Roadmaps to 2050: Cement
B. UK Concrete and Cement Industry Roadmap to Beyond Net Zero
D. A sustainable future for the European Cement and Concrete Industry: Technology assessment for full decarbonisation of the industry by 2050
E. Industrial Transformation 2050 – Pathways to Net-Zero Emissions from EU Heavy Industry
F. Cementing the European New Deal: Reaching Climate Neutrality Along the Cement and Concrete Value Chain

The other UK-specific roadmap (Roadmap C) was not used as it did not model contributions for individual strategies.

From the values given and arguments stated in each roadmap, estimates have been made for the anticipated carbon reduction to concrete production in 2050 from each strategy. These estimates are indicative – due to the differences in approach and presentation of data between different roadmaps, these estimates are not intended to be used for an exact comparison.

The following assumptions were made to calculate the estimates:

- Process emissions account for 65% of clinker production emissions (Favier et al., 2018, Material Economics, 2019).
- Combustion emissions account for 35% of clinker production emissions (Favier et al., 2018, Material Economics, 2019).
- Clinker production accounts for 94% of the embodied carbon of cement (Material Economics, 2019).
- Cement production accounts for 95% of the embodied carbon of concrete (Material Economics, 2019).
- Clinker production accounts for 90% of the embodied carbon of concrete (Material Economics, 2019).

Several limitations were identified around making a comparative analysis between different roadmaps, based on the decisions used in their modelling:

- **Baseline year**. There is some variation in the baseline year which is used, from which emissions reductions to 2050 are calculated (a range between 2012 to 2018). This was deemed to be an acceptable source of error, given the overall nature of the estimates is to give semi-quantitative, relative comparisons between strategies and roadmaps, rather than precise figures. Roadmap D (pg.49) observed that whilst it is common to use 1990 as a baseline year for modelling decarbonisation (as the European Commission does), the majority of the carbon reduction in concrete emissions over the period of 1990-2015 was in fact due to reduction in demand following the financial crisis of 2008.

- **Modelled production volumes**. The expected level of market demand for cement and concrete can have a significant impact on what impact reductions in carbon emissions per tonne of material can have on absolute levels of emissions, depending on what is happening to the overall production volume. For Europe, there is consensus that demand for cement and concrete is relatively stable, and will be unlikely to undergo either dramatic increases or decreases to 2050. Nonetheless, there is some degree of difference between roadmaps around the modelled production volumes in 2050:
    - Roadmap A modelled three different scenarios for changes in production volumes (in the UK). Values were taken for the "Current Trends" scenario, as these were described in most detail. In this scenario, cement production was modelled to stay constant from 2015 – 2050.
    - Roadmap B did not explicitly state a reference scenario. A slightly ambiguous statement (pg.7) suggested 2050 production levels in the UK were predicted to be the same as 2018 quantities (i.e. 11.8 million tonnes of cementitious materials, and 90 million tonnes of concrete).
    - Roadmap D modelled a reference scenario on the IEA Reference Technology Scenario, but didn't explicitly state the direct implications in terms of levels of cement and concrete demand in 2050.
    - Roadmap E (pg.162) projected a 10% increase in cement production volume from 167 Mt/year at present to 184 Mt/year in 2050, with a very slight drop in overall emissions from 109 Mt.CO_2/year at present to 108 Mt.CO_2/year in 2050.
    - Roadmap F made no explicit statement about what was considered to be the projected baseline scenario for 2050.

A summary of estimated values is provided (Table S8), followed by a detailed explanation for how those values were estimated for each of the strategies based on the data in each roadmap. Page references are included to describe exactly where the source data is taken from within each roadmap. In some cases, a roadmap included different scenarios for how a strategy could be used, with different carbon reduction values. In this case, the value was chosen which gave the biggest difference compared to the values from other roadmaps, in order to capture the range of values.

Table S8: Summary table for expected carbon reduction values by 2050, from the five roadmaps used for this analysis.

Strategy	**Expected CO_2 Reduction by 2050 (%)**							
	A	**B**	**D**	**E**	**F**	**Average**	**Min.**	**Max.**
Clinker Replacement	1.9	-	14.3	8.9	10.3	8.8	1.9	14.3
Alternative Binders	-	-	9.0	0.3	2.4	3.9	0.3	9.0
Decarbonisation of Electricity	-	4.0	-	5.7	5.0	4.9	4.0	5.7
Decarbonisation of Transport	-	7.0	-	-	1.4	4.2	1.4	7.0
Carbon Capture and Utilisation/Storage	31.5	61.0	31.7	74.1	39.9	47.6	31.5	74.1
Alternative Fuels	14.2	16.0	12.7	-	10.1	13.3	10.1	16.0
Electrification	-	-	-	30.7	2.7	16.7	2.7	30.7
Thermal Efficiency Improvements	-	-	3.3	3.3	3.7	3.4	3.3	3.7
Recarbonation	-	12.0	-	-	7.3	9.7	7.3	12.0
Recycling of Concrete Fines	-		12.4	12.1	3.8	9.4	3.8	12.4
Concrete Mix Design Optimisation	-	-	8.9	24.3	-	16.6	8.9	24.3
Reduction of Overspecification	-	-	1.2	10.8	-	6.0	1.2	10.8
Improved Design of Structural Elements	-	-	12.0	19.1	20.0	17.0	12.0	20.0
Extended Building Lifetime	-	-	6.0	6.7	-	6.4	6.0	6.7
Alternative Construction Materials	-	-	-	-	-	-	-	-
Leveraged Thermal Mass	-	44.0	-	-	-	44.0	44.0	44.0

5.1 Clinker replacement

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Clinker replacement modelled as maximal under "Max Tech with CCS pathway" (pg.60).

Expected reduction in cement production emissions = 2.0% (compared to 2012 baseline) (pg.60).

Expected reduction in concrete production emissions = $\underline{0.95 \times 2.0 = 1.9\%}$

Roadmap B – Mineral Products Association (MPA, 2020)

Does not report specific values for this individual strategy – emissions reductions are aggregated within a "low carbon cements and concretes" category.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Assumptions:

- SCMs have no embodied carbon (excepting calcined pozzolans). (pg.89, Favier et al.)

2015 emissions:

Current clinker to cement ratio = 0.73 (p. 26)

Carbon intensity of clinker $= 0.875\ \mathrm{tCO_2/t\ clinker}$ (p. 23)

Cement embodied carbon $= 0.73 \times 0.875 = 0.639\ \mathrm{tCO_2/t\ cement}$

2050 emissions:

Expected clinker to cement ratio by 2050 = 0.6 (p. 62)

Embodied carbon $= 0.6 \times 0.875 = 0.525\ \mathrm{tCO_2/t\ cement}$

Carbon intensity of calcined pozzolans $= 0.25\ \mathrm{tCO_2/t\ pozzolan}$ (p. 89)

Carbon intensity of calcined pozzolans in cements, based on an estimated market share of 18% of supplementary cementitious materials = $0.18 \times 0.25 \times 0.4 = 0.0180\ \mathrm{tCO_2/t\ cement}$ (p. 89)

Embodied carbon $= 0.525 + 0.018 = 0.543\ \mathrm{tCO_2/t\ cement}$

Reduction in emissions:

Reduction in cement production emissions = $1 - \frac{0.543}{0.639} = 15.0\%$

Reduction in concrete production emissions = $\underline{0.95 \times 15.0 = 14.3\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

2015 emissions:

Current clinker to cement ratio = 0.74 (p. 160)

Carbon intensity of clinker $= 0.82\ \mathrm{tCO_2/t\ clinker}$ (pg.175)

Carbon intensity of cement = $\frac{109\ (t.CO2/year)}{167\ (t.cement/year)} = 0.653\ \mathrm{tCO_2/t\ cement}$ (p. 162)

2050 emissions:

Expected clinker to cement ratio by 2050 = 0.6 (p. 172)

Embodied carbon $= 0.6 \times 0.82 = 0.492\ \mathrm{tCO_2/t\ cement}$

Assume same embodied carbon per tonne of clinker, and full market share of calcined clays (pg. 32)

Embodied carbon of calcined pozzolans $= 0.25 \frac{\mathrm{t.CO_2}}{\mathrm{t.pozzolan}} \times 0.4\ \frac{t.pozzolan}{t.cement} = 0.1\ \frac{\mathrm{t.CO_2}(pozz.)}{\mathrm{t.cement}}$

Therefore, embodied carbon $= 0.492 + 0.1 = 0.592\ \mathrm{tCO_2/t\ cement}$

Reduction in emissions:

Reduction in cement production emissions $= 1 - \frac{0.592}{0.653} = 9.34\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 9.34 = 8.87\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (p. 15)

Reduction by 2050 due to lower clinker factor = $72\ \mathrm{kgCO_2/t\ cement}$ (p. 12)

Reduction in cement production emissions = $\frac{72\ (kg.CO_2/t.cement)}{667\ (kg.CO_2/t.cement)} = 10.8\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 11 = 10.3\%}$

5.2 Alternative Binders

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Insufficient details were included to report specific values for this strategy in the "Max Tech with CCS" pathway.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not report specific values for this individual strategy – emissions reductions are aggregated within a "low carbon cements and concretes" category.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Assumptions:

- Due to lower TMRL and specific technical issues, hydrothermal reactive belite cements and magnesium cements were not deemed to be viable within the period to 2050 (pg.33-34)

Calcium Sulfoaluminate Clinkers (CSAs)

Market Penetration = 10% (p. 89)

Reduction Potential Compared to PC clinker = 20% (p. 89)

Expected Reduction = 0.1 x 0.2 = 2%

Carbonatable Calcium Silicate Clinkers (CCSCs)

Market Penetration = 10% (p. 89)

Reduction Potential Compared to PC clinker = 70% (p. 89)

Expected Reduction = 0.1 x 0.7 = 7%

Alkali Activated Binders (AABs)

Market Penetration = 2% (p. 89)

Reduction Potential Compared to PC clinker = 50% (p. 89)

Expected Reduction = 0.02 x 0.5 = 1%

Total Expected Reduction

= 2% + 7% + 1% = 10% compared to PC clinker

Expected reduction in concrete production emissions = $\underline{0.9 \times 10 = 9.0\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

2015 emissions:

Carbon intensity of cement $= \frac{109\ (t.CO2/year)}{167\ (t.cement/year)} = 0.653\ \mathrm{tCO_2/t\ cement}$ (p. 162)

Reduction by 2050:

5% of Portland cement production replaced by alternative cement chemistries by 2050 (p. 173)

Average carbon intensity of alternative binders $0.77\ \mathrm{t.CO_2/t.clinker}$ (p.175)

Carbon intensity of current clinker production $0.82\ \mathrm{t.CO_2/t.clinker}$ (p.175)

Reduction in process emissions per tonne of clinker $= 1 - \frac{0.77}{0.82} = 6.10\%$

Reduction in clinker production emissions = 6.10% x 5% = 0.305%

Expected reduction in concrete production emissions = $\underline{0.9 \times 0.305\% = 0.275\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (p. 15)

Reduction by 2050 due to alternative binders = $17\ \mathrm{kgCO_2/t\ cement}$ (p.12)

Reduction in cement production emissions $= \frac{17}{667} = 2.55\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 2.55 = 2.42\%}$

5.3 Decarbonisation of electricity

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Insufficient details were included to report specific values for this strategy in the "Max Tech with CCS" pathway.

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 4% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

Expected reductions (by 2050 cf. 2015 levels) in embodied carbon of cement from electricity decarbonisation = 6% (p.162)

Expected reduction in concrete production emissions = $0.95 \times 6\% = 5.70\%$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (pg.15)

Reduction by 2050 due to decarbonisation of electricity = $35\ \mathrm{kgCO_2/t\ cement}$ (p.12)

Reduction in cement production emissions = $\frac{35}{667} = 5.25\%$

Expected reduction in concrete production emissions = $0.95 \times 5.25\% = 4.99\%$

5.4 Decarbonisation of transport

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not include values for this strategy

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 7% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

Does not include values for this strategy.

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (pg.15)

Reduction by 2050 due to decarbonisation of transport = $10\ \mathrm{kgCO_2/t\ cement}$ (p.12)

Reduction in cement production emissions $= \frac{10}{667} = 1.50\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 1.50\% = 1.42\%}$

5.5 Carbon capture and utilisation/storage

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

CCUS modelled as 100% deployment in 2050 under "Max Tech with CCS pathway" (pg.60).

Expected reduction in cement production emissions = 33.2% (compared to 2012 baseline) (pg.60).

Expected reduction in concrete production emissions = $\underline{0.95 \times 33.2 = 31.5\%}$

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 61% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

This roadmap estimates cement production emissions by 2050 can be reduced by 75% (c.f. 1990 levels) using other, non-CCUS strategies. In one scenario, this roadmap proposes that 80% of remaining emissions are abated by CCUS (pg.66)

For 80% of 25% remaining cement emissions:

0.8 x 0.25 = 20% of overall cement emissions

Expected reduction in concrete production emissions (c.f. 1990 level) = $\underline{0.95 \times 20\% = 19.0\%}$

Adjust for the fact that 2015 emissions were 40% lower than 1990 levels (pg. 49):

$$\frac{1.0}{0.6} \times 19.0\% = 31.7\%$$

N.B. Due to the approach used in this roadmap and how the scenarios are presented, the values stated here for CCUS potential represent one option for the authors' opinion on how much carbon reduction *should* be achieved with CCUS, rather than how much *could* be achieved considering its technological potential..

Roadmap E - European Climate Foundation (Material Economics, 2019)

Total cement production CO_2 emissions (2015) = 109 Mt CO_2 per year (p. 181)

In "Carbon Capture" pathway:

Reduction due to CCUS = 85 Mt CO_2 per year (p. 181)

Reduction in cement production emissions $= \frac{85}{109} = 78.0\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 78.0\% = 74.1\%}$

In "New Processes" pathway:

Reduction in cement emissions due to CCUS = 35 Mt CO_2 per year (p. 181)

Reduction in cement production emissions = $\frac{35}{109} = 32.1\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 32.1\% = 30.5\%}$

In “Circular Economy” pathway:

Reduction in cement emissions due to CCUS = 31 Mt CO_2 per year (p. 181)

Reduction in cement production emissions = $\frac{31}{109} = 28.4\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 28.4\% = 27.0\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (pg.15)

Reduction by 2050 due to CCUS = $280\ \mathrm{kgCO_2/t\ cement}$ (p.12)

Reduction in cement production emissions = $\frac{280}{667} = 42.0\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 42.0\% = 39.9\%}$

https://doi.org/10.5518/1430

5.6 Alternative fuels

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Fuel switching to biomass modelled as maximal in 2050 under "Max Tech with CCS" pathway, with all additional biomass above 2015 levels to be virgin biomass, rather than further volumes of waste biomass (pg.60).

Expected reduction in cement production emissions = 14.9% (compared to 2012 baseline) (pg.60).

Expected reduction in concrete production emissions = $\underline{0.95 \times 14.9 = 14.2\%}$

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 16% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

2015 replacement levels of alternative fuels = 33% waste and biomass (alternative fuels; p. 58)

Average emissions per unit energy of fuel in 2015 = $7.6 \times 10^{-5} \mathrm{tCO_2/MJ}$ (p. 88)

Emissions per unit energy of waste and biomass fuel = $3.5 \times 10^{-5} \mathrm{tCO_2/MJ}$ (p. 88)

Therefore, deducing the carbon emissions per unit energy from combined, conventional fuel sources:

$$= \frac{7.6\times10^{-5} - 0.33\times3.5\times10^{-5}}{1-0.33} = 9.6 \times 10^{-5} \mathrm{tCO_2/MJ}$$

Anticipated 2050 replacement levels of alternative fuels = 80% waste and biomass (alternative fuels; p. 58)

Expected fuel emissions per unit energy in 2050 (assuming constant emissions intensity from other fuel sources):

$$(0.8 \times 3.5 \times 10^{-5} \mathrm{tCO_2/MJ}) + \left((1-0.8) \times 9.6 \times 10^{-5} \mathrm{tCO_2/MJ}\right) = 4.7 \times 10^{-5} \mathrm{tCO_2/MJ}$$

Combustion emissions reduction (from 2015 to 2050):

$$1 - \frac{4.7 \times 10^{-5}}{7.6 \times 10^{-5}} = 38.2\%$$

Clinker emissions reduction (assuming that combustion emissions account for 35% of cement production emissions):

$$= 0.35 \times 38.2\% = 13.4\%$$

Concrete emissions reduction = $\underline{0.95 \times 13.4\% = 12.7\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

This roadmap focusses on electrification as a means to eliminate combustion emissions and so none of the pathways prescribe high levels of fuel replacement – in fact all suggest lower levels of biomass fuel replacement than are currently used.

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (pg.15)

Reduction by 2050 due to biomass fuels = $71\ \mathrm{kgCO_2/t\ cement}$ (p. 12)

Reduction in cement production emissions = $\frac{71}{667} = 10.6\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 10.6 = 10.1\%}$

5.7 Electrification

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

No values included for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

No values stated.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

In "New Processes" pathway:

Anticipates 100% of cement kilns are electrified by 2050 (pg.182).

Current clinker carbon emissions per unit mass = $0.82\ \mathrm{tCO_2/t\ clinker}$ (pg.175)

Kiln electrification reduces carbon emissions of clinker by $0.28\ \mathrm{tCO_2/t\ clinker}$ (pg.175)

Clinker emissions reduction from electrification = $\frac{0.28}{0.82} = 34.1\%$

Expected reduction in concrete production emissions = $\underline{0.9 \times 34.1\% = 30.7\%}$

In "Circular Economy" pathway:

Anticipates 55% of cement kilns are electrified by 2050 (pg.182).

Using values from above – expected reduction in concrete production emissions:

$$\underline{0.55 \times 30.7\% = 16.9\%}$$

In "Carbon Capture" pathway:

Anticipates 10% of cement kilns are electrified by 2050 (pg.182).

Using values from above – expected reduction in concrete production emissions:

$$\underline{0.10 \times 30.7\% = 3.7\%}$$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (pg.15)

Reduction by 2050 due to Electrification = $19\ \mathrm{kgCO_2/t\ cement}$ (p. 12)

Reduction in cement production emissions = $\frac{19}{667} = 2.8\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 2.8\% = 2.7\%}$

5.8 Thermal efficiency improvements

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Insufficient details were included to report specific values for this strategy in the "Max Tech with CCS" pathway.

Roadmap B - Mineral Products Association (MPA, 2020)

No values stated.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Approximate energy efficiency for EU cement plants currently: 3300 MJ/t clinker (p. 24)

Energy input for cement plants with best available current technologies: 3000 MJ/t clinker (p.24)

Potential improvement in energy efficiency (MJ/t clinker):

$$= \frac{3300 - 3000}{3300} = 10\%$$

From a 10% improvement in energy efficiency, assume a 10% reduction in combustion emissions.

Contribution of combustion emissions to cement emissions = 35%

Expected contribution of improved thermal efficiency to reduction to cement emissions reductions:

0.35 x 10% = 3.5%

Expected reduction in concrete production emissions:

$\underline{0.95 \times 3.5 = 3.3\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Current carbon intensity of clinker production = $0.82\ \mathrm{tCO_2/t\ clinker}$ (p.175)

Carbon intensity of clinker production with an anticipated 10% improvement in energy efficiency = $0.79\ \mathrm{tCO_2/t\ clinker}$ (p. 175)

Resulting reduction in CO_2 intensity of clinker production (p. 175):

$$\frac{0.82 - 0.79}{0.82} = 3.7\%$$

Expected reduction in concrete production emissions = $\underline{0.9 \times 3.7 = 3.3\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (p.15)

Reduction by 2050 due to Thermal Efficiency Improvements = $26\ \mathrm{kgCO_2/t\ cement}$ (p.12)

Reduction in cement production emissions = $\frac{26}{667} = 3.9\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 3.9\% = 3.7\%}$

5.9 Re-carbonation

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not include values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 12% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

Does not include values for this strategy.

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

2017 emissions = $667\ \mathrm{kgCO_2/t\ cement}$ (p.15)

Reduction by 2050 due to Recarbonation = $51\ \mathrm{kgCO_2/t\ cement}$ (p. 12)

Reduction in cement production emissions $= \frac{51}{667} = 7.6\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 7.6 = 7.3\%}$

5.10 Recycling of concrete fines

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not include values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

No values stated.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Recycled fines provide a source of calcium that does not require calcination, therefore assumes no process emissions.

The "Structural optimisation and circular economy principles" scenario anticipates 20% deployment by 2050 (p.62).

Assuming that process emissions make up 65% of cement production emissions:

Expected reduction cement production emissions = $\underline{0.2 \times 0.65 = 13.0\%}$

Expected reduction in concrete production emissions = $\underline{0.95 \times 13 = 12.4\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Use of recycled fines instead of limestone can eliminate process emissions.

Current carbon intensity of clinker production = $0.82\ \mathrm{tCO_2/t\ clinker}$ (p.175)

Carbon intensity of clinker production with an anticipated 20% reduction in process emissions through use of recycled fines = $0.71\ \mathrm{tCO_2/t\ clinker}$ (p. 175)

Resulting reduction in CO_2 intensity of clinker production:

$$\frac{0.82 - 0.71}{0.82} = 13.4\%$$

Expected reduction in concrete production emissions = $\underline{0.9 \times 13.4\% = 12.1\%}$

Roadmap F - European Climate Foundation (CEMBUREAU, 2020)

2017 emissions = $0.667\ \mathrm{kgCO_2/t\ cement}$ (p.15)

Reduction by 2050 due to Recycling of Concrete Fines = $27\ \mathrm{kgCO_2/t\ cement}$ (p. 12)

Reduction in cement production emissions = $\frac{27}{667} = 4.0\%$

Expected reduction in concrete production emissions = $\underline{0.95 \times 4.0 = 3.8\%}$

5.11 Concrete Mix Design Optimisation

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not report specific values for this individual strategy – emissions reductions are aggregated within a "low carbon cements and concretes" category.

Roadmap D - European Climate Foundation (Favier et al., 2018)

2015 cement content = 8 $kg_{cement}/m^3/MPa$ (p. 62)

2050 expected cement content = 5 $kg_{cement}/m^3/MPa$ (p. 62)

Reduction in cement consumption (per m^3/MPa):

$$\frac{8-5}{8} = 37.5\%$$

Anticipate this can be applied to 50% of the total volume of concrete in a building, and reach 50% market penetration (p. 90).

Reduction in cement production emissions:

$$0.5 \times 0.5 \times 37.5\% = 9.4\%$$

Expected reduction in concrete production emissions = $\underline{0.95 \times 9.4 = 8.9\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Assumes 184 Mt/year of cementitious material in Europe by 2050 assuming current practice (p. 162)

Reduction due to reduced binder intensity = 47 Mt/year (p. 166)

Reduction in cement production emissions:

$$\frac{47}{184} = 25.5\%$$

Expected reduction in concrete production emissions = $\underline{0.95 \times 25.5\% = 24.3\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Does not include values for this strategy.

5.12 Reduction of Over-specification

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not include values for this strategy.

Roadmap D - European Climate Foundation (Favier et al., 2018)

2015 cement content of concrete = 300 kg/m^3 (p. 62)

2050 anticipated cement content of concrete under "Structural optimisation and circular economy principles" scenario = 285 kg/m^3 (p. 62)

Reduction in cement content of concrete (per unit volume):

$$\frac{300 - 285}{300} = 5.0\%$$

Anticipate this can be applied to 50% of the total volume of concrete in a building, and reach 50% market penetration (p. 90).

Expected reduction in cement production emissions:

$$0.5 \times 0.5 \times 5.0\% = 1.3\%$$

Expected reduction in concrete production emissions = $\underline{0.95 \times 1.25 = 1.2\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Assumes 184 Mt/year of cementitious material in Europe by 2050 assuming current practice (p.162).

Anticipated deduction in cement consumption due to reduced binder intensity = 21 Mt/year (p. 166)

Expected reduction in cement production emissions:

$$\frac{21}{184} = 11.4\%$$

Expected reduction in concrete production emissions = $\underline{0.95 \times 11.4 = 10.8\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Does not include values for this strategy.

5.13 Improved design of structural elements

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not include values for this strategy.

Roadmap D - European Climate Foundation (Favier et al., 2018)

In the “Structural optimisation and circular economy principles” scenario, anticipate reduction of concrete use of 20-40% for precast concrete (p. 62)

Assume midrange value of 30% reduction of concrete use (and hence cement use), in the precast concrete sector.

In this scenario, precast concrete is anticipated to have a market share of 35-45% of cement use in 2050 (p.61).

Assume midrange value of 40% market share of precast concrete in 2050.

Expected reduction in concrete production emissions = $\underline{0.3 \times 0.4 = 12.0\%}$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Assumes 184 Mt/year of cementitious material in Europe by 2050 assuming current practice (p.175).

Reduction in cement production due to optimisation of elements (24 Mt/year), reduced overspecification (13 Mt/year) = 24 + 13 = 37 Mt/year (p. 166)

Expected reduction in cement production emissions:

$$\frac{37}{184} = 20.1\%$$

Expected reduction in concrete production emissions = $\underline{0.95 \times 20.1\% = 19.1\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Anticipate reduction of concrete use of 10-30% (p. 31)

Assume midrange value of 20% reduction of concrete use in 2050.

Expected reduction in concrete production emissions = $\underline{20.0\%}$

5.14 Extended Building Lifetime

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not include values for this strategy.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Anticipate 10-20% reduction in concrete use for precast concrete in 2050 due to reuse (p. 62)

Assume midrange value of 15% reduction of concrete use (and hence cement use), in the precast concrete sector.

In this scenario, precast concrete is anticipated to have a market share of 35-45% of cement use in 2050 (p.61).

Assume midrange value of 40% market share of precast concrete in 2050.

Expected reduction in concrete production emissions = $0.4 \times 15\% = 6.0\%$

Roadmap E - European Climate Foundation (Material Economics, 2019)

Assumes 184 Mt/year of cementitious material in Europe by 2050 assuming current practice (p. 166).

Reduction due to reuse and reconstruction (7 Mt/year), and space sharing (6 Mt/year) (p.166):

$$7 + 6 = 13\ Mt/year$$

Expected reduction in cement production volume:

$$\frac{13}{184} = 7.1\%$$

Assume that this results in the same reduction in cement production emissions

Expected reduction in concrete production emissions = $\underline{7.1 \times 0.95 = 6.7\%}$

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Does not include values for this strategy.

5.15 Alternative Construction Materials

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Does not include values for this strategy.

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

Does not include values for this strategy.

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Does not include values for this strategy.

5.16 Leveraged Thermal Mass

Roadmap A - Department for Business, Energy & Industrial Strategy (WSP and DNV-GL, 2015)

Does not report values for this strategy.

Roadmap B - Mineral Products Association (MPA, 2020)

Expected reduction in concrete production emissions = 44% (pg.9)

Roadmap D - European Climate Foundation (Favier et al., 2018)

Does not include values for this strategy.

Roadmap E - European Climate Foundation (Material Economics, 2019)

Does not include values for this strategy.

Roadmap F - The European Cement Association (CEMBUREAU, 2020)

Does not include values for this strategy.

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