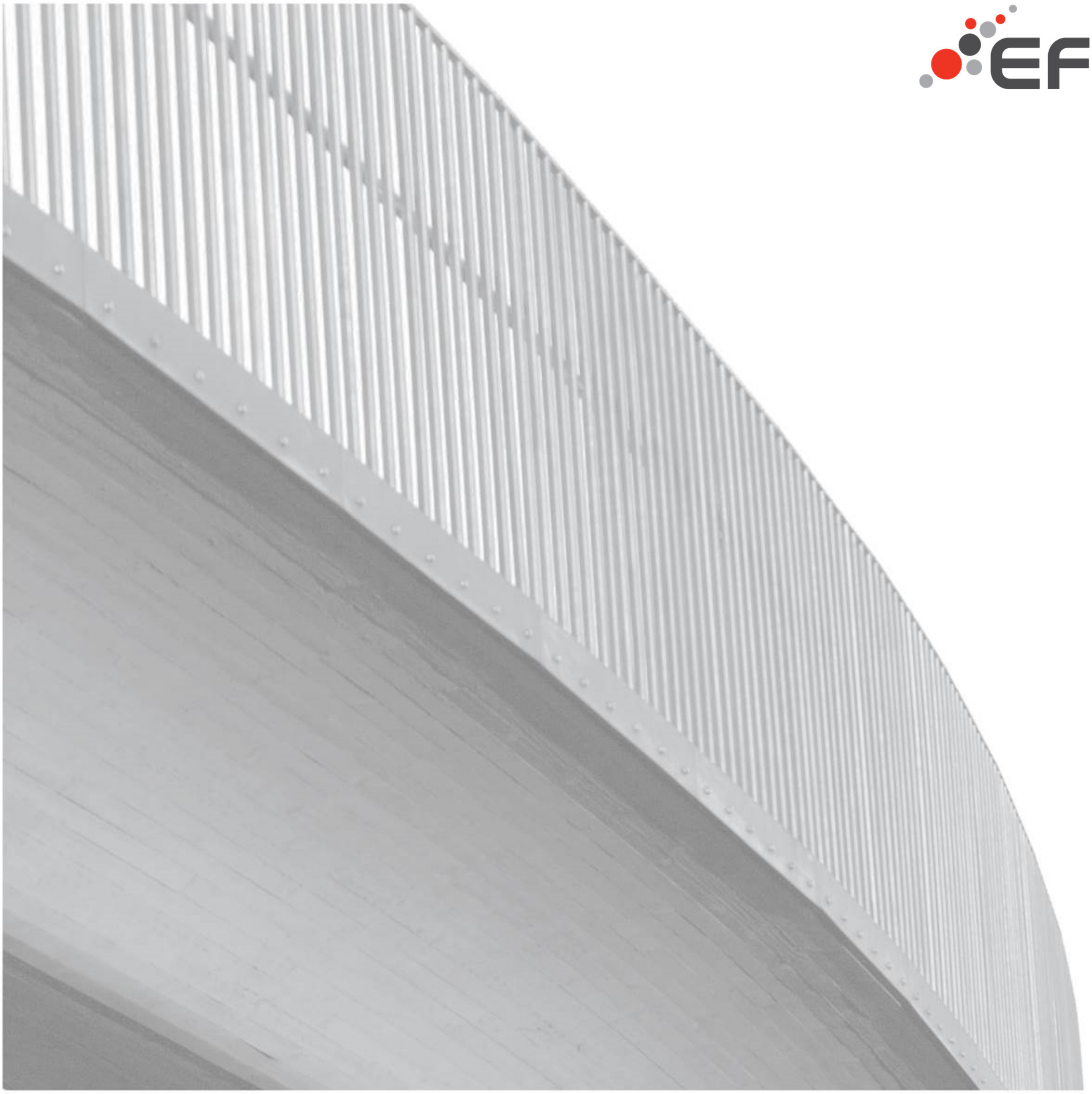
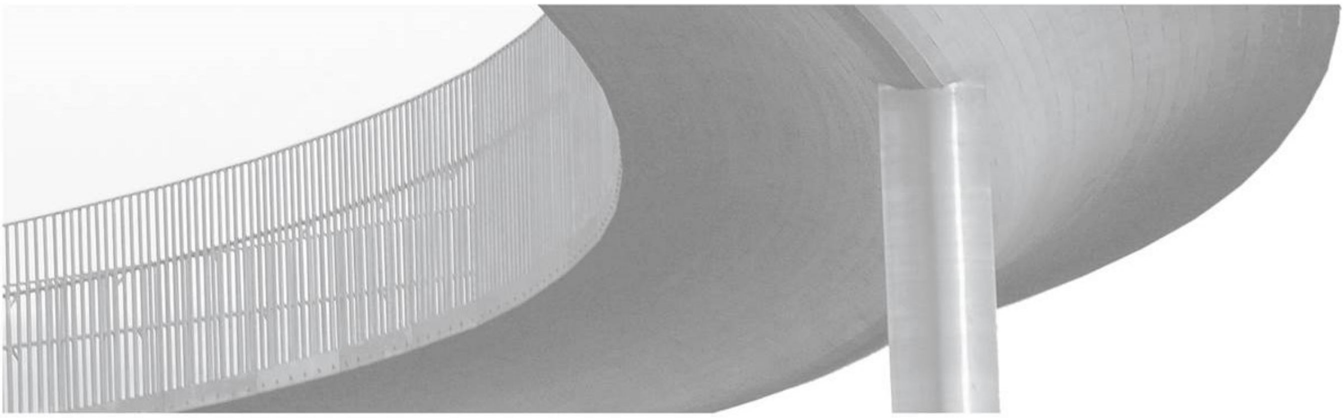


CARBON FOOTPRINT OF ICELANDIC BRIDGES:

Evaluation and future targets

16.08.2024



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EXTRACT

Awareness of bridge carbon footprint in design and construction is critical. This report presents ways to assess carbon footprint and work with the assessment outcome.

A database of 64 Vegagerðin bridges has been set up in the project, of which 35 bridges have been constructed since 2012. Under the assumptions documented in the report, the data has been used to evaluate the current average carbon footprint of bridges in Iceland. A distinction is made between shorter single span bridges on the one hand and longer and multi span bridges on the other.

By analysing the data, a 15% reduction from the average carbon emitted per square meter built is concluded to be achievable with design optimization. Furthermore, the report outlines an evaluation of material producers´ intentions of carbon emission reduction from the material manufacturing processes. Intended technological advances for greener materials and transport are documented.

These two factors couple to define a target development timeline for the carbon emissions of bridges in Iceland, leading to 2050, when the carbon footprint should be within the Net-Zero target of the Paris Agreement.

Vegagerðin‘s dominant role as a bridge stakeholder in Iceland puts the organization in a position to set targets for future trends and emphasis in the field of bridge design. The carbon emission evaluation process can be coordinated by making the carbon footprint per square meter built an obligatory design review variable with an upper limit.

The key finding of the report is the definition of a time-dependent upper limit, currently set at 1,2 tCO_2/m^2 built. In 2025, it should have come down to 0,9 tCO_2/m^2 via design optimization, and onwards with the planned advancements of material production this should come down to 0,15 tCO_2/m^2 in 2050.

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SUMMARY

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1 INTRODUCTION

The proportion of global operational energy and process-related CO_2 emissions for which the global construction industry is responsible for in 2022 is estimated to be 37% [1]. Bridges are included in these 37%. With the aim of respecting the Paris Agreement [2], the carbon footprint of bridges must be evaluated, documented and then reduced. This is obligatory since there is no reason for bridge construction to be excluded from Icelandic national and worldwide targets for carbon emission reduction and carbon neutrality.

Measures such as structural optimisation can contribute to reduce bridges emissions. In Iceland, a database of bridges characteristics has been gathered with data supplied by The Icelandic Road and Coastal Administration, hereafter referred to as Vegagerðin in this report. Since the majority of bridges built in Iceland are owned and operated by this organization, gathering data to represent the national level becomes a feasible task. By analysing this data and setting up a database it is possible to draw up averages that describe bridge design in Iceland, and to calculate their carbon footprint. This analysis forms the baseline from which to target set reduction of bridges carbon footprint in Iceland.

To keep global warming compared to pre-industrial levels to no more than 1.5°C – as called for in the Paris Agreement – emissions need to be reduced by 45% by 2030 and reach net zero by 2050. It is therefore appropriate to draw up plans for bridge carbon emission on national levels to follow this same path to reduction, and to aim for Net-Zero emissions[1] in 2050.

Two main levers seem feasible for reducing emissions from bridge construction in Iceland. In the short term, design optimization can be implemented. The database analysis revealed a range of CO_2 emissions for apparently similar bridge characteristics. The first goal is to aim for the structures with the lowest emissions in this range, since examples show this to be achievable. Vegagerðin can drive an implementation of such a process, by including CO_2 emissions as a key variable in design review.

In the longer term, advances in material production have been predicted to drive down the carbon footprint of construction, for example new compositions and optimization of manufacturing

[1] Net zero means cutting carbon emissions to a small amount of residual emissions that can be absorbed and durably stored by nature and other carbon dioxide removal measures, leaving zero in the atmosphere (cutting emisisons by 90-95%) (https://www.un.org).

processes. The intentions of key concrete and steel manufacturers for the development of material production carbon emissions until 2050 are sourced and referenced in this work.

This report is the outcome of a project sponsored by the Vegagerðin Research Fund, and documents the steps taken to follow the process described above. It defines a scenario for carbon emission from Icelandic bridges based on the current situation and documented plans of material suppliers.

The project was presented at the Via Nordica - UN Global Goals Nordic Road Sector Approaches – Conference in Copenhagen, 11-13 June 2024. The presentation is included as Appendix A to this report.

The authors of the report are responsible for its contents. Its findings shall not be construed as the stated policy of the Icelandic Road and Coastal Administration or the opinions of the institutions or companies that the authors are employed by.

2 ESTIMATION OF ICELANDIC CURRENT BASELINE BRIDGE CO_2 FOOTPRINT

Around 1200 bridges are managed by Vegagerðin across Iceland [3]. In EFLA collaboration with Vegagerðin, a database of Vegagerðin bridges built in Iceland from 1980 to 2023 has been collated, containing bridge characteristics (type of structure, materials, dimensions, material quantities, and normalization to m^2 built). This database is assumed to be representative of bridges in Iceland, since Vegagerðin is the main bridge owner nationally, with only relatively few bridges being operated by municipalities and other stakeholders.

2.1 Synthesis of the database collected

FIGURE 1 shows categorization of Vegagerðin bridges after build year [3].

The dataset set up by EFLA represents 64 road bridges built between 1980 and 2023. The graph presented as FIGURE 2 below shows the square meters built each year in bridges in the dataset. The dataset contains a large portion of Vegagerðin built after 2012, or 35 bridges of about 50 that have been built since 2012.

29 bridges included in the dataset built before 2012 represent about 10% of bridges built by Vegagerðin in the period 1981-2011.

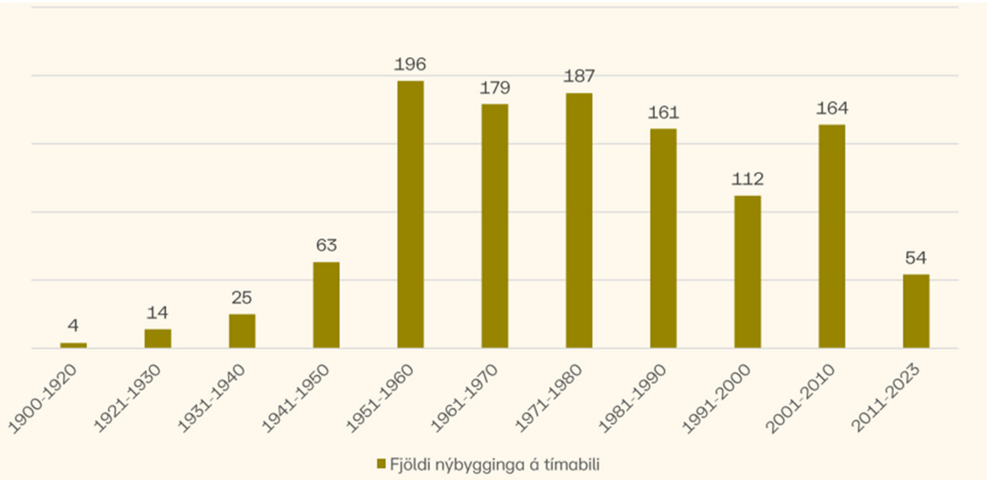

FIGURE 1 –No. of Vegagerðin bridges in operation after build period

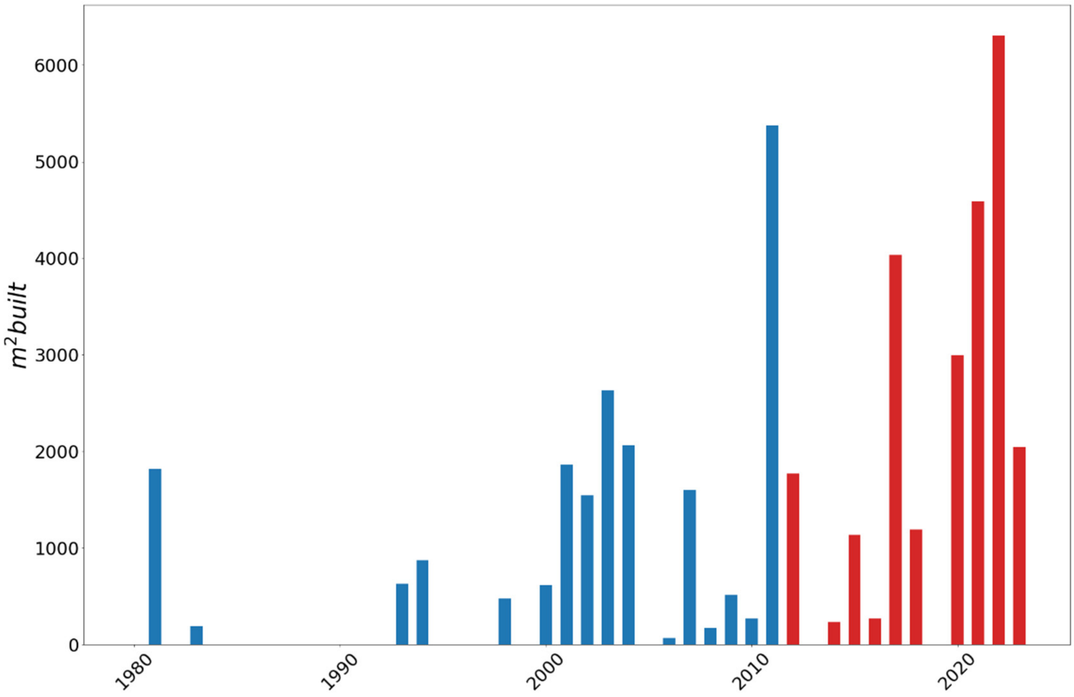

FIGURE 2 - Square meters built per year in bridges which make up the database of this project

The bridges of the database range from 6 to 270 meters long, and from 1 to 8 spans. Most of them are two traffic lane, 10 m wide. More than two thirds are post-tensioned concrete bridges. Girder bridges with post-tensioned concrete are the most common structural type encountered throughout the data (33 bridges), following by slab bridges in steel or post-tensioned concrete (12 bridges of each). The pie charts below illustrate the different types and primary structural materials of the bridge superstructures encountered through the database, with their proportions.

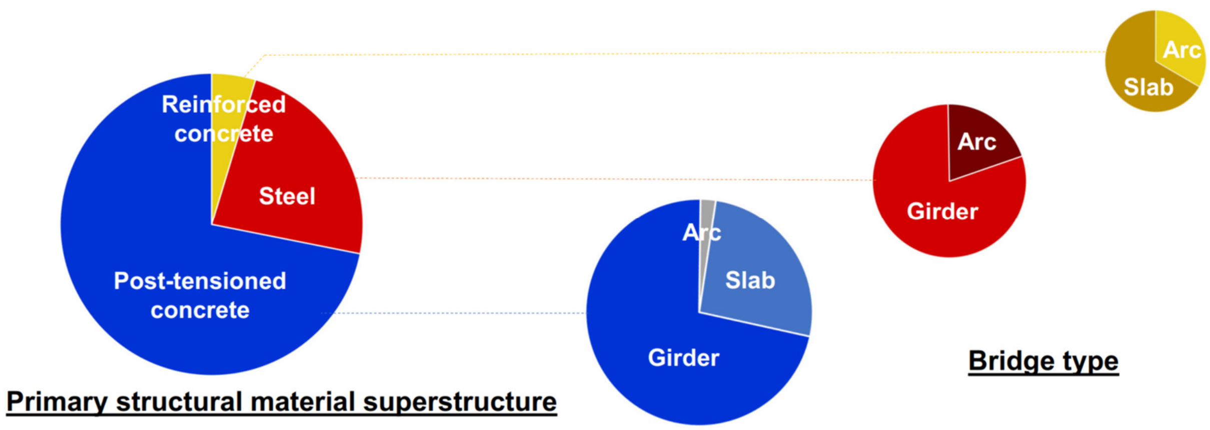

FIGURE 3 - Structure type and primary materials of the bridges from the Icelandic bridges database

2.2 Categorization of the data

The traffic load for the 64 bridges is different. It converges towards the full Eurocode EN1991 traffic load with no application of α-load reduction factor only after 2012 (α = 0,8 often applied previously).

With a view to defining feasible structural optimization, a focus has been set on the 35 bridges built after 2012. In the same spirit, these 35 bridges built after 2012 have been split into two categories: one with single span bridges shorter than 40m (15 bridges), and the other with the multi-span bridges and bridges longer than 40m (20 bridges). These categories are expected to have different CO_2 emissions per square meter built, since abutments are of course required in both cases, but the longer the bridge, the less is the effect of the concrete for the abutments on carbon footprint per m^2.

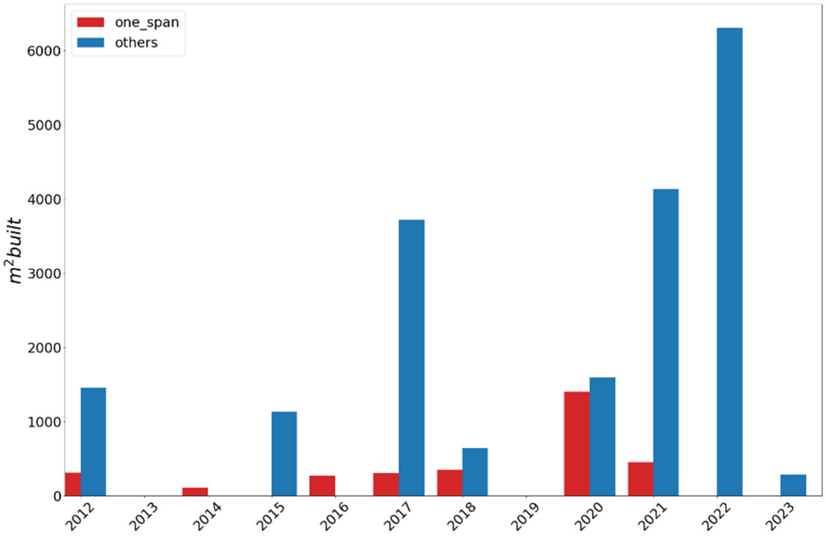

FIGURE 4 - square meters built per year (two categories)

The graph presented in **FIGURE 4** details the bar chart of **FIGURE 2** with a focus on the bridges built after 2012, divided into the two categories mentioned above. In summary, the one span bridges shorter than 40m long represent 13% of square meters built out of the whole set, compared to 87% for the 20 other bridges.

2.3 Estimation of embedded CO_2 in bridges

A simplified estimate of the embedded carbon footprint of the bridges included in the database has been performed based on simplifying assumptions. For every bridge, four main construction materials have been quantified: concrete, reinforcement, construction steel and post-tensioned strands. Relevant Environmental Product Declarations (EPDs) have been used to define the emissions associated with this material and life cycle stages A1 to stage A5 in a Life Cycle Assessment (LCA), also considering the material transport from Europe and within Iceland, and normalizing these emissions to bridge area.

TABLE 1 Carbon footprint calculated for construction materials used in Iceland

		CARBON FOOTPRINT CO_2eq PER UNIT	
	Unit	Material	Transport
Concrete	m^3	426	60
Reinforcement	Ton	818	300
Construction steel	Ton	2500	100
PT-strands	Ton	818	200

The assumption is then made that the sum of the material and transport carbon emissions defined above is accountable for 80% of the whole bridge CO_2 emissions. This assumption draws on previous EFLA experience of "full" LCA of bridges and use of the Norwegian carbon calculator tool VegLCA, where elements additional to those four have been considered.

The formula below therefore synthetizes the method used to compute the bridges CO_2 emissions.

$$80\%\ CO_2e_{\text{total}} = \sum\nolimits_{i \in materials} \left(carbon\ footprint_{material_i} + carbon\ footprint_{transport_i}\right) \times (unit_i)$$

CO_2e_{total} in the formula above is the defining carbon footprint, and then this is normalized to bridge net area.

2.4 Baseline

To estimate what carbon footprint reduction may be realistic, the carbon footprint per square meter built is analysed for each bridge of the built after 2012 dataset.

In each category; the single span bridges and the others, the delta between the bridges with the largest and lowest carbon emission per square meter is an indicator of what is achievable in terms of carbon footprint reduction by optimization. The assumption is that examples showing smallest environmental impact are to be targeted in the design phase of bridges.

The current carbon baseline in Iceland is represented in the graph below. As expected, the longer bridges have, on average, a lower carbon footprint per area (1,1 tCO_2e/m^2) than the single span bridges (1,4 tCO_2e/m^2).

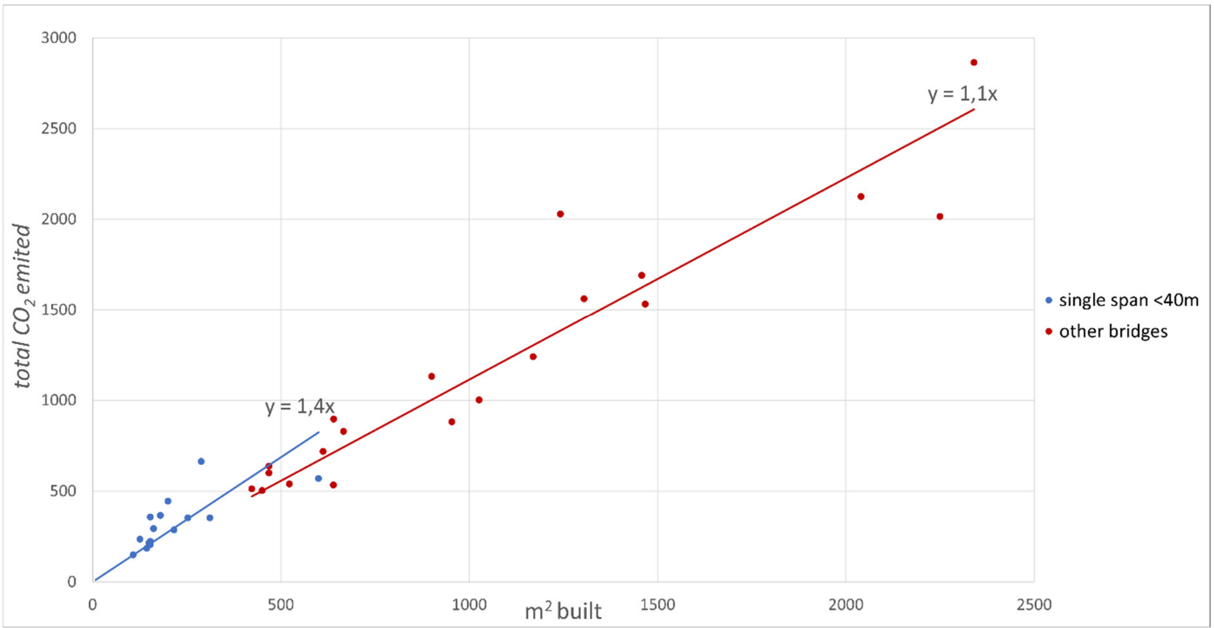

FIGURE 5 - Co_2 emitted per m^2 build today

Each point on this graph represents a bridge built after 2012 from the database. The dispersion of these points around the tendency lines suggests a possible optimization towards less emissive structural solution for bridges in Iceland.

3 TARGET

3.1 Design optimization

As mentioned above, the observed data of carbon emissions per square meter built shows scatter within both categories on the graph in **FIGURE 5**. The bridges with the least emissions per m^2 are realistic targets when it comes to optimization.

A simple line drawn under each dataset is assumed to be a possible target for emission reduction. This reveals a possible 15% decrease of CO_2 emissions:

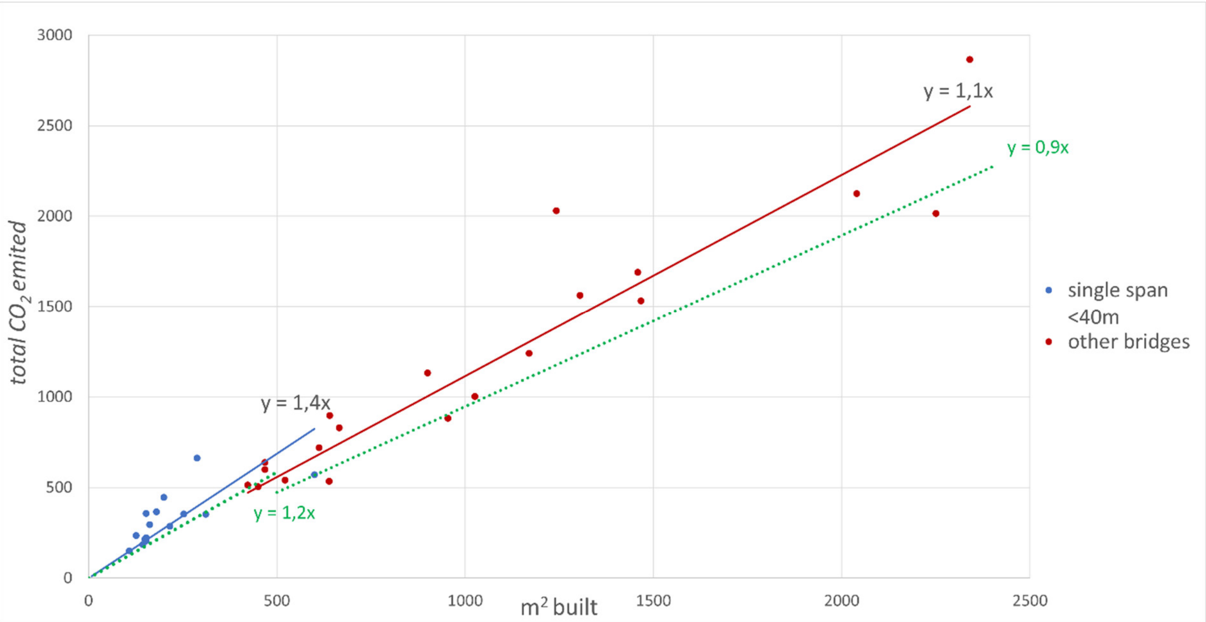

FIGURE 6 - A 15% reduction of CO_2 emission per m^2 built

Hence, it is concluded that a reduction of 15% of the average of carbon footbridge is already achievable for bridges in Iceland. For one span bridges shorter than 40m long, the target should be set to 1,2 tCO_2e/m^2, and for multi-span bridges and single span bridges longer than 40m, the target should be 0,9 tCO_2e/m^2.

The carbon footprint calculated per square meter built should become an obligatory design review variable, to allow for each design the comparison of this metric to the aforementioned targets.

3.2 Carbon calculator for infrastructure

In parallel to the project documented in this report, EFLA has been developing LOKI [4], a carbon calculator for infrastructure (development not funded by the Vegagerðin Research fund). Its development draws on other calculator tools that are in use in the other Nordics, and LCA experience, and covers A1-A5 and B4 for roads, bridges, foot- and cycleways and tunnels.

The calculator is an excel file in which it is possible to input the materials quantities associated with a project, for example bridge design. Once these quantities are filled in with the appropriate bridge project variables, the carbon footprint of the project can be directly read and efficiently analysed via a direct output of the carbon footprint per m^2 variable.

Use of the tool, or other means of acquiring normalized carbon footprint, makes it simple at the design stage to see if a project is within the presented targets or not. To recap, this project recommends that for bridges built in Iceland, any new project should respect the target presented **FIGURE 6** of 1,2 tCO_2e/m^2 for single span bridges shorter than 40m long and 0,9 tCO_2e/m^2 for multispan bridges and single span bridges longer than 40m.

4 ADVANCES IN MATERIAL PRODUCTION – SCENARIOS

Currently, raw materials are the primary source of carbon emissions from Icelandic bridges.

From the bridge data introduced in the previous chapter it can be seen that concrete is the material with the highest impact on the carbon footprint of Icelandic bridges (over 70% for all bridges) as presented in the table below:

TABLE 2 - Material impact on Icelandic bridges carbon footprint

	2024	
	single span	more
Concrete	71%	75%
Reinforcement	19%	16%
Construction steel	9%	7%
PT-strands	1%	3%
LCA stages A1-A5		

4.1 Concrete

Concrete consists of aggregates that are bonded together by cement and water. Cement is the second most widely used substance in the world after water, and is responsible for about 90% of the carbon footprint of traditional concrete, and 5-8% of global carbon emissions [5] [6]. Thus, the carbon footprint of concrete is heavily dependent on the environmental impact of cement.

BM Vallá, one of Iceland's leading concrete producers, has its own goals for lowering the carbon footprint of its products. The concrete producer aims to provide near carbon neutral concrete by 2030, decreasing the carbon footprint of their standard concrete products from around 275 kg CO_2/m^3 in 2020 to just 20 kg CO_2/m^3 in 2030, resulting in an average reduction of about 93% across all products. The producer has already been able to reduce the environmental impact of the concrete by approximately 24%, achieved with numerous actions such as replacing a portion of the cement clinker with more environmentally friendly materials such as flyash, utilizing Best Available Technology (BAT) by updating various equipment, reducing water use, and with partial electrification of their fleet.

Furthermore, BM Vallá has developed a new product line, Berglind, that has up to 45% lower carbon footprint than traditional concrete. However, due to the strict standards and regulations that concrete used in bridges must fulfil, this kind of product requires more research before it is implemented, especially in certain parts of bridges.

The most prominent contributor to BM Vallá's goal of achieving concrete carbon neutrality is its cement provider, Heidelberg Materials Brevik in Norway, which aims to become the world's first CO_2-capture facility in the cement industry. The carbon capture plant has been integrated into the existing cement plant, with mechanical depletion scheduled for the end of 2024. This will lead to an additional 50% reduction of the carbon footprint of BM Vallá's concrete products. Furthermore, Heidelberg Materials plans to build a grinding plant in an area west of Þorlákshöfn that processes Icelandic tuff for use in cement production. This project is estimated to reduce the carbon footprint of cement by at least 20-25% if it becomes a reality. Along with the aforementioned goals, BM Vallá states that their goal of achieving near-carbon neutrality by 2030 is realistic.

Another large concrete producer in Iceland is Steypustöðin, which is also concentrating on reducing their products' carbon footprint. Among other actions, the producer is exploring the potential of using recycled concrete in the production of new concrete, as well as setting their focus on increasing its lifetime. Steypustöðin is also working on the electrification of their fleet, which is already well underway. Other plans include supporting the reclamation of land- and wetlands for carbon offsetting and utilising BAT. Just as their competitor, BM Vallá, Steypustöðin has also developed a new more environmentally friendly products, SvanSterk and GrænSterk, that have about 20-30% lower carbon footprint than traditional concrete products by partially replacing cement with flyash and silica dust.

BM Vallá has clear ambitions for the reduction of their concrete products' carbon footprint on a yearly basis which relies heavily on Heidelberg Materials' success in lowering their emissions, whereas Steypustöðin has stated that it will follow the Paris Agreement (30% reduction by 2030, and 90% reduction by 2050). Combining the goals of these concrete producers, assuming an average of the two based on their similar market share, the carbon footprint of concrete is assumed to evolve according to Figure 7. As shown in the figure, the carbon footprint is projected to decrease by more than half by 2030, going as low as 160 kg CO_2/m^3 by 2030, and near carbon-neutral by 2050, or 40 kg CO_2/m^3 concrete.

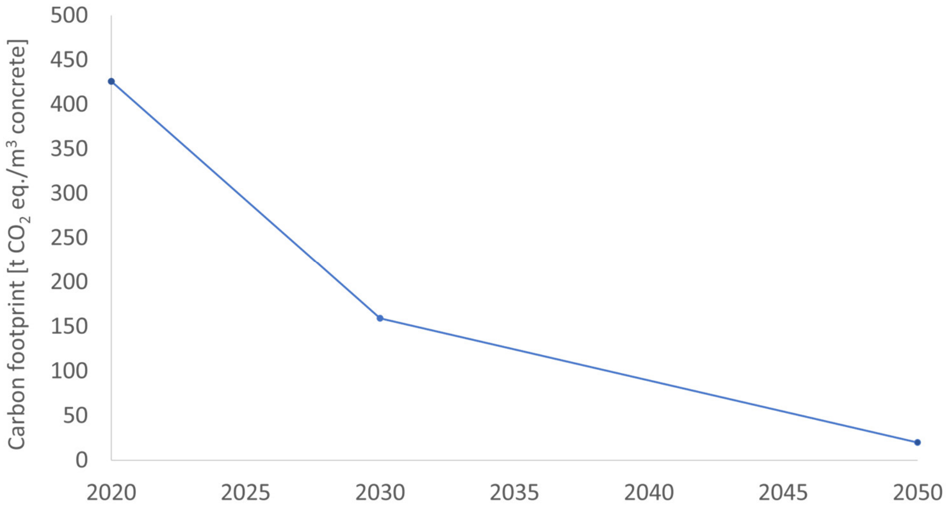

FIGURE 7 The proposed evolution of the carbon footprint of concrete produced in Iceland.

4.2 Steel

4.2.1 Steel production today

The iron- and steel industry is one of the world's largest GHG emitter, directly accounting for 7-9% of global GHG emissions [7] [8]. The environmental impact of steel lies mostly in the production process, i.e. in the acquirement and processing of raw materials, i.e. iron ore, coke and other materials, as well as in the production process itself which can have significant direct emissions. Iron- and steelmaking is particularly energy intensive and requires large amounts of heat, and coal is frequently used as both a source of heat and as part of the production process, providing around 75% of its energy demand [7].

The building sector uses significant amounts of iron and steel and the International Energy Agency (IEA) projects that global steel demand will increase by a third by 2050 [7]. This increase is partly due to iron and steel's critical role in the transition to low carbon sources of energy generation, such as wind turbines, electric vehicles, and solar panels.

In the EU, two crude steel production methods are currently predominant; the blast furnace/basic oxygen furnace (BF/BOF) route and the scrap-based electric arc furnace (EAF), with 58.3% produced via the BF/BOF route and 41.7% produced via the EAF route [9] [8]. BF/BOF requires iron, coal and limestone for the production, and can use up to 35% of scrap material. EAF requires substantially less energy than BOF and can use up to 100% scrap material for the production.

Iron ore is the source of around 70% of the metallic raw materials inputs to steelmaking and the rest is supplied in the form of recycled steel scrap. Using recycled steel has the potential to lower the emissions intensity of steel by 62-90%. However, the availability of steel scrap is not sufficient to meet the demand for steel over the coming years and decades.

China has a large share of overall steel production and is responsible for more than 50% of CO_2 emissions from steelmaking [10]. China, along with India, have the highest CO_2 intensities, due to a predominance of coal as fuel and BF ironmaking. One of the more mature actions to lower emissions from steelmaking is implementing advanced BF technologies, or BAT, which can substantially increase the process efficiency. The EU has successfully reduced emissions by around 50% over the past 50 years by utilizing BOF with BAT, achieving the lowest average CO_2 intensity for BF-based steelmaking.

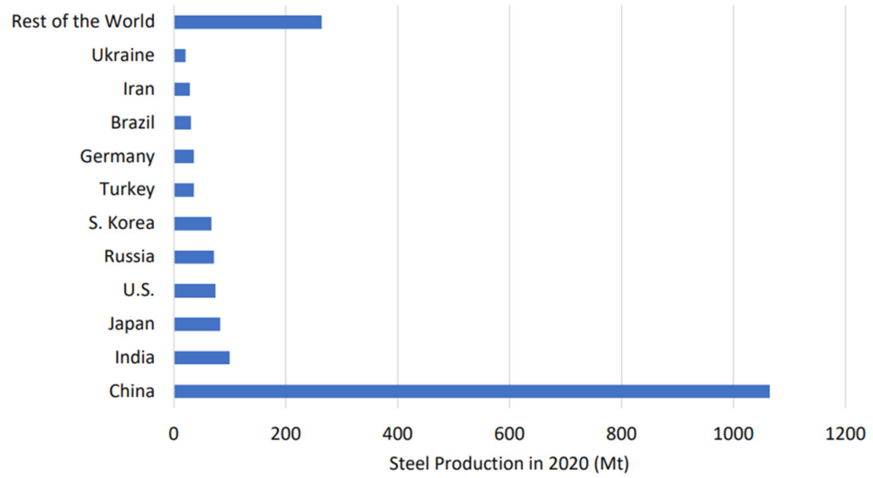

Figure 3. Top 10 steel producing countries in 2020 (Worldsteel 2021)

FIGURE 8 Top 10 steel producing countries in 2020 [11].

4.2.2 Steel decarbonisation

Utilising BAT and switching from BF/BOF to EAF for steelmaking has the potential to significantly reduce emissions from the steel industry. Figure 9 also shows other measures for lowering emissions, though the various decarbonization technologies vary in maturity. The main technologies that are considered to have great potential for steel decarbonisation are the following:

- Hydrogen use,
- Bioenergy use,
- Carbon capture, utilization and storage (CCUS).

The first option refers to the use of hydrogen as a reducing agent instead of coal. However, the carbon intensity of hydrogen varies greatly depending on whether it is produced from natural gas (grey hydrogen) or renewable sources (green hydrogen). Thus, the decarbonisation of the iron and steel industry via hydrogen must be supported by hydrogen produced from a low-carbon route. If used in conjunction with EAF using 100% renewable electricity, there is an opportunity to significantly reduce production emissions.

SSAB, a Swedish company claims that the scope 1 and 2 global warming potential of their upcoming product, SSAB Fossil-free steel™ using their revolutionary HYBRIT technology, replacing coking coal and natural gas with hydrogen, using iron ore pellets that have been mined and processed without fossil fuels, is lower than 0,05 t CO2 eq/steel (referred to in Figure 9) [12]. The company's aim is to deliver their product to the market in 2026. Other similar initiatives by companies in Europe that are currently in the pipeline and will either utilize grey or green hydrogen have been identified [13]:

- SuSteel, VoestAlpine, Austria
- Salcos-Macor, Salzgitter, Germany
- ArcelorMittal Midrex plant, Germany
- Thyssenkrupp Duisburg, Germany

The second option refers to the complete or partial substitution of coal with bioenergy derived from sustainable biomass. This option does not call for a shift away from technologies that are commercially available today; instead, it requires evolving existing BF technology. Another more mature route is using natural gas-based DRI-EAF which typically generates about 20% less direct emissions than coal-based BF-BOF, and can also be used in conjunction with BOF furnaces and bioenergy.

CCUS can help with evolving existing blast furnace technology by capturing the CO_2 from the blast furnace of an integrated steel plant, mitigating carbon emissions and reducing them by 60-70% [13] [14]. However, IEA advises caution when contemplating CCUS in order to prevent steelmakers from investing more in carbon-intensive production, given CCUS alone cannot serve as a comprehensive decarbonization solution [7].

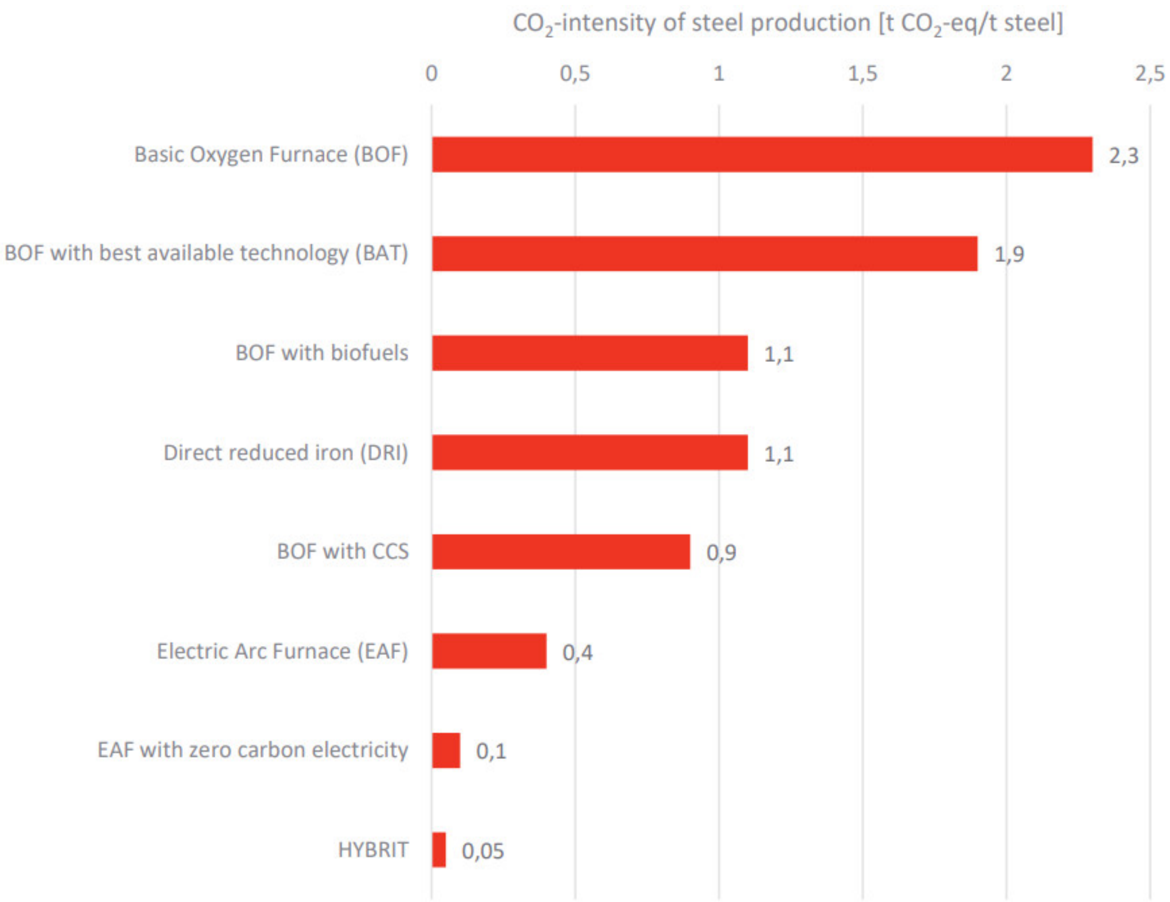

FIGURE 9 The CO_2 intensity of methods for emission cuts, compared to the baseline scenario of the BOF route [14].

4.2.3 Scenario analysis and challenges on the pathway to net-zero steel

The IEA and the Mission Possible Partnership (MPP) have published carbon mitigation options, suggesting scenarios for the iron and steel industry's decarbonization to comply with a 1.5° C target, highlighting what this transition may look like [7] [15]. The IEA's Sustainable Development Scenario (SDS) sets out an ambitious pathway compatible with the goals of the Paris Agreement, outlining a pathway which leads to a 58% reduction in the emission intensity of crude steel production by 2050, and 90% reduction by 2090. In this scenario, 90% of the emission reductions in 2030 are projected to be due to technology performance improvements and material efficiency, i.e. the utilisation of BAT. In the longer term, the innovative technologies that integrate various hydrogen and CCUS technologies are required for further emission reductions by 2050. Additionally, the energy consumption of steelmaking must decrease by 14%, along with necessary changes in the use of various fuels changes, with coal use declining by 40% due to the transitioning to 100% hydrogen DRI in order to follow the pathway laid out by IEA.

MPP's Carbon Cost Scenario illustrates how the sector might decarbonise if coordinate action to support low-CO_2 steelmaking takes hold in this decade, reaching net-zero by 2050. Just as in the SDS of IEA, the decarbonisation will have to consist of a combination of solutions, with about 25% of emission reductions expected to be achieved from two technologies alone, hydrogen-based DRI and CCUS.

MPP's scenario assumes a faster technology development and ambitious decarbonisation efforts, whereas IEA is more conservative and realistic in their estimations of the pace and scale of technological advancements. MPP also assumes more favourable conditions concerning policies and market that support rapid decarbonisation, whereas IEA considers a wider range of variables and uncertainties. Both scenarios presented by IEA and MPP are useful in their own right, highlighting that the path to decarbonizing the iron and steel sector will require a combination of the solutions described in Chapter 4.2.2, as well as other strategies such as lowering global steel demand by increasing infrastructure lifetime. Both IEA and MPP clearly state that there are multiple obstacles that the iron and steel sector must overcome, with the main ones summarised in Figure 10. Some notable challenges include the varying maturity of certain technologies and their slow implementation, as well as uncertainty regarding the market demand for green steel and its connection to regulations and policies in different regions and countries.

Steel decarbonization is technically feasible, but it will be challenging as demonstrated by the IEA and MPP scenarios. The projected evolution of the materials' carbon footprint is based on specific scenarios and is highly dependent on the assumptions underlying their predictions concerning future outcomes. Forecasting a specific potential future is impossible because it involves a high level of uncertainty. Thus, to estimate the development of the carbon footprint of steel supplied to Iceland, an average of these two models is assumed, resulting in the evolution shown in Figure 11.

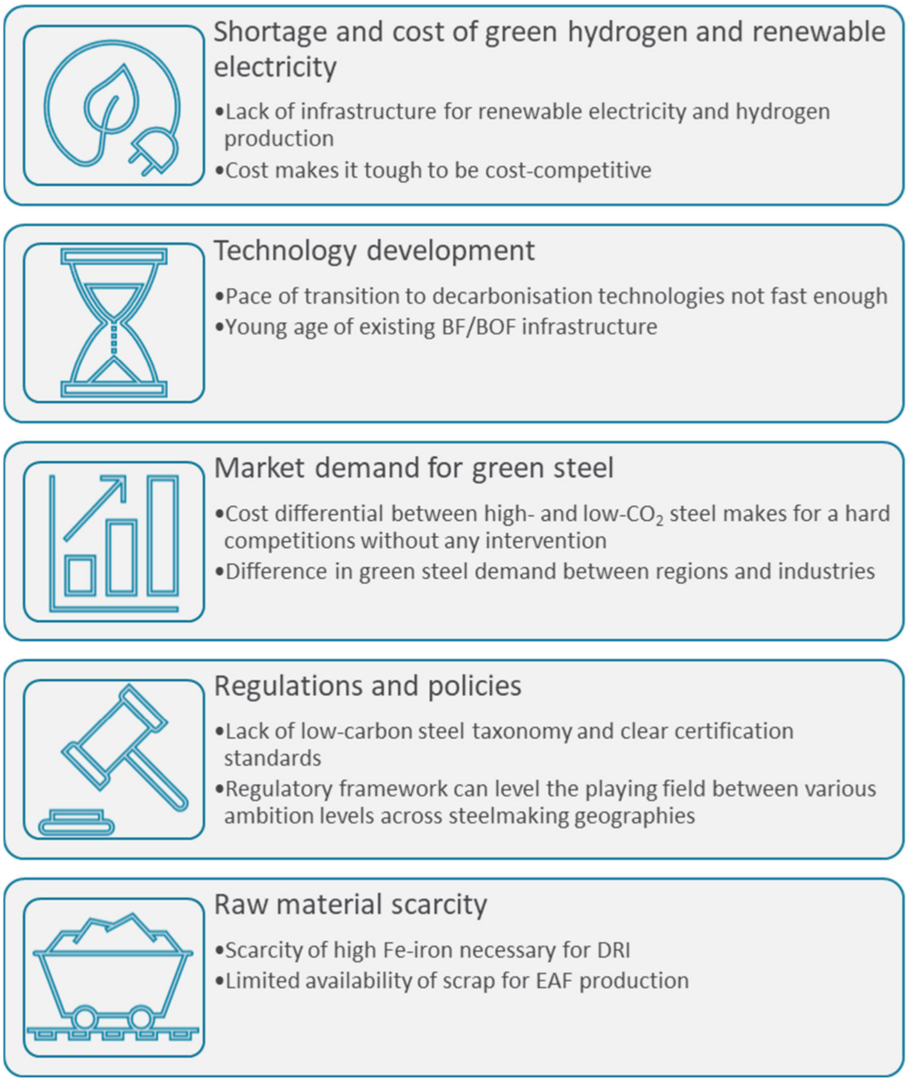

FIGURE 10 Current challenges that the steel industry faces in achieving carbon neutrality. Figure adapted from Deloitte's report on pathways to steel decarbonisation [10].

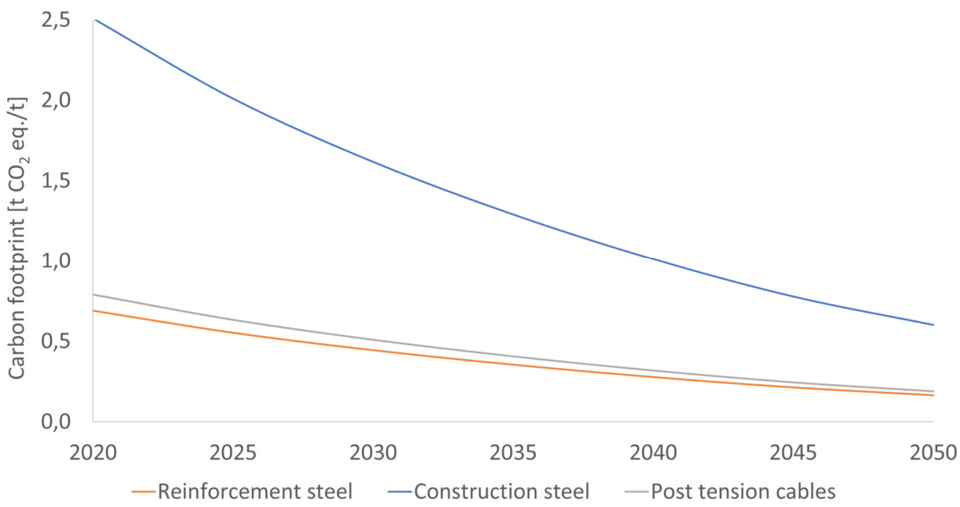

FIGURE 11 Proposed evolution of steel carbon footprint considering the two scenarios proposed by IEA and MPP.

4.3 Transport

The Paris Agreement sets the carbon goal for this research. To stay in line with the objectives of the agreement, the evolution of emissions from the transport sector is here assumed to follow the IPCC forecasts for shipping. Emission remains constant until 2030, in 2040 a 40% reduction in the carbon footprint of transport has been assumed, with the reduction rising to 60% in 2050.

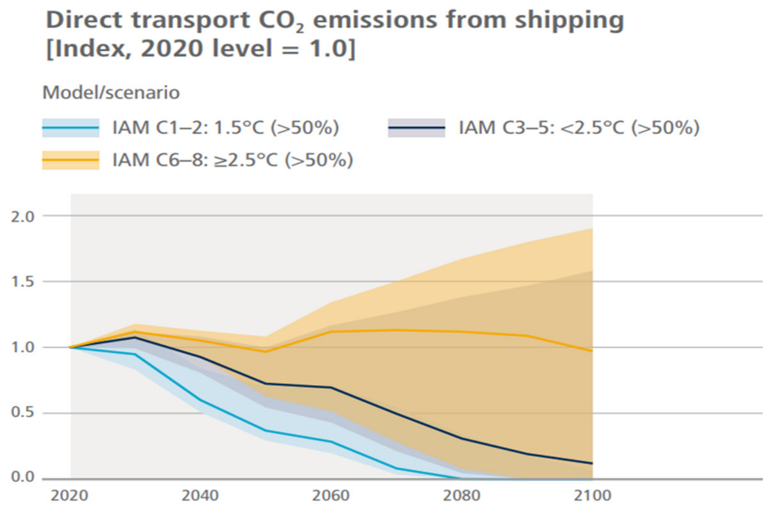

FIGURE 12 Evolution of Shipping carbon footprint expected by IPCC

4.4 Synthesis

Combining the assumed averages in the evolution of concrete and steel carbon footprint with the decrease of transport environmental impact, the timelapse detailed in the table below is obtained :

TABLE 3 Carbon footprint estimated per year for transport and primary materials for bridges in Iceland

	2024		2030		2040		2050	
	Material	Transport	Material	Transport	Material	Transport	Material	Transport
Concrete	430	60	160	60	90	40	20	20
Reinforcement	820	300	450	300	280	180	170	120
Construction steel	2500	100	1620	100	1010	60	600	40
PT-strands	820	200	510	200	320	120	190	80

5 FUTURE SCENARIO FOR CARBON FOOTPRINT OF ICELANDIC BRIDGES

By combining the structural optimization (see Chapter 3) with the reduction of materials emissions (see Chapter 4), a target development timeline for the carbon emissions of bridges in Iceland can be drawn up.

As mentioned in section 2.2, the one span bridges shorter than 40m represent 13% of the total square meters built since 2012, and multi-span bridges and bridges over 40m account for the rest, 87%. To weight the average of carbon equivalent emitted per square meter built, this ratio (15-85) is used.

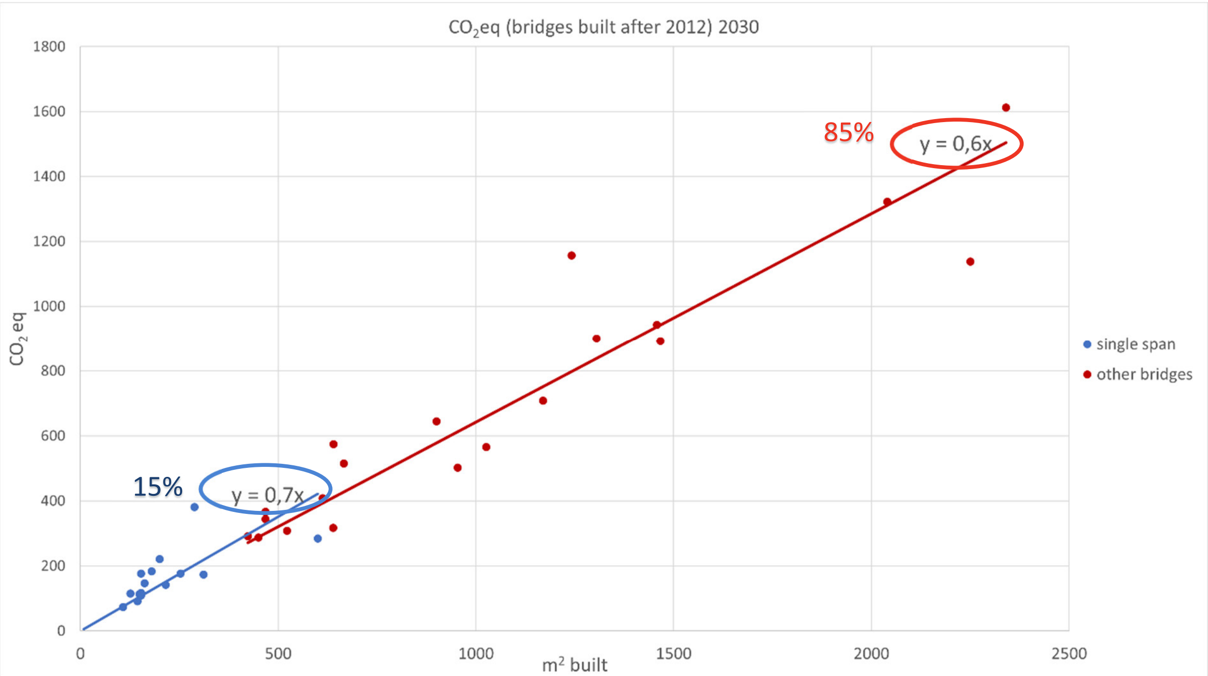

FIGURE 13 - Weight between the two categories, shown for 2030

Certain assumptions need to be made regarding the chronology of developments. Firstly, it is assumed that the optimization of bridge design can be realised straight away in collaboration between bridge designers and stakeholders. If a carbon footprint per square meter becomes an obligatory design review variable, optimizing structures can in principle take effect within a year and from then onwards. Therefore, the 15% carbon footprint decrease is depicted in the target set up through this research from 2025.

Since the evolution of materials towards greener technologies involves a wide range of actors, starting with manufacturers and transporters, it will happen more gradually. The evolution presented in **TABLE 3** is retained to set the carbon target.

The combination of structural optimization and materials and transport evolution finally leads to the following target for carbon footbridge in Icelandic bridges:

TABLE 3 - Proposed evolution of Icelandic bridges carbon footprint

YEAR	CO_2/m^2
2024	1150
2030	550
2040	325
2050	150

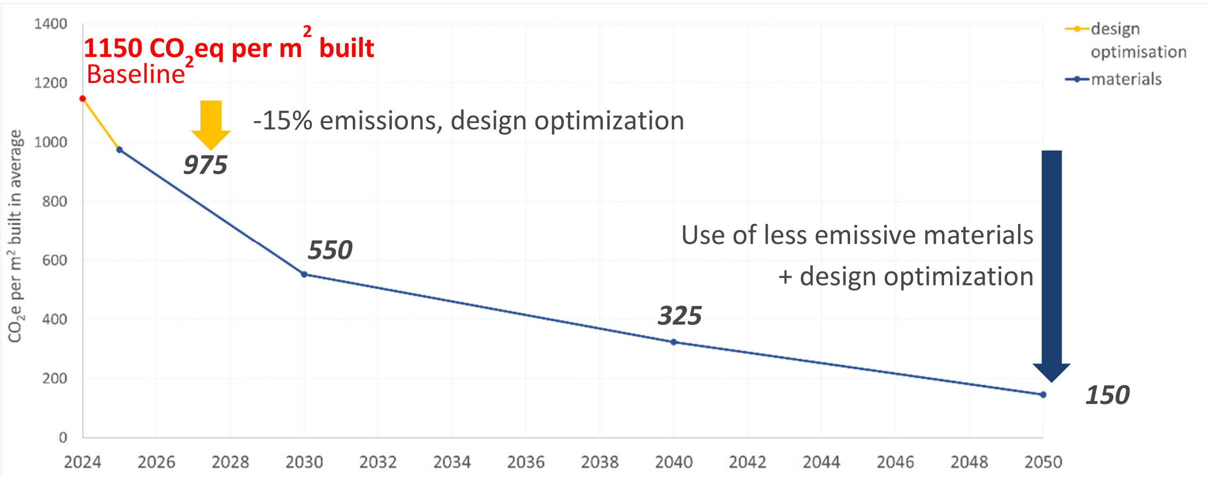

FIGURE 14 - Future scenario for Carbon footprint of icelandic bridge

Today, the average carbon footprint of bridges in Iceland is evaluated as 1150 CO_2eq per square meter built. Considering structural optimization in place in 2025, a drop of 15% of this carbon footprint leads to 975 CO_2eq per square meter built. Then, the combination of this design efficiency, the evolution of materials towards greener technology, plus the reduction of transport emissions decrease the carbon variable target to 150 CO_2eq/m^2 in 2050, a value that is almost inscribing this trajectory in the Net-Zero target recommended by IPCC (87% emissions decrease).

6 ALIGNING WITH UN SUSTAINABLE DEVELOPMENT GOALS

https://sdgs.un.org/goals

In 2015, the United Nations adopted the *2030 Agenda for Sustainable Development* with 17 mains goals: the Sustainable Development Goals (SDGs). This research project is directly linked to two of these goals. The SDG number 9 aims to "build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". The sub-target 9.4 of this SDG mentions the indicator in use throughout this research: CO_2 emission per unit of value added.

To set a carbon footprint target for bridges in Iceland directly echoes what all United Nations Member States put in their agenda.

Firstly, as underlined with the target 9.4, "By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities".

Secondly, in accordance with the main statement of this research, as highlighted in the target 12.2 of the SDGs, "By 2030, achieve the sustainable management and efficient use of natural resources".

Going for greener construction technologies and efficient structural design are among the goals being pursued by the United Nations. Setting the carbon footprint per square meter of Icelandic bridges as an obligatory design review parameter would be in line with this pursuit.

7 CONCLUSIONS

Awareness of bridge carbon footprint in design and construction is critical. The project has presented ways to assess carbon footprint and work with the assessment outcome.

A database of 64 bridges has been set up in the project, of which 35 bridges have been constructed since 2012. Under the assumptions documented in Chapter 2, the data has been used to evaluate the current average carbon footprint of bridges in Iceland. A distinction is made between shorter single span bridges on the one hand and longer and multi span bridges on the other.

By analysing the data, a 15% reduction from the average carbon emitted per square meter built is concluded to be achievable with design optimization. This decrease coupled to technological advances for greener materials and transport would lead to an average emission of 150 CO_2eq/m^2 in 2050, a value that almost inscribes this future carbon footprint within the Net-Zero target of the Paris Agreement.

Since the models used to predict the evolution of materials footprint are projections of producers' intentions in the future, they are subject to uncertainties. The role of the structural engineer in managing these uncertainties is to constantly challenge best practices for bridge projects and keep the optimization of bridge environmental impact at the forefront of the design and construction process.

Vegagerðin's dominant role as a bridge stakeholder in Iceland puts the organization in a position to set targets for future trends and emphasis in the field of bridge design. The carbon emission evaluation process can be coordinated by making the carbon footprint per square meter built an obligatory design review variable with an upper limit.

This research concludes that at the time of writing, this upper limit should be set as 1,2 tCO_2/m^2 built, and in 2025, it should have come down to 0,9 tCO_2/m^2 via design optimization.

The intention of the authors is to continue to support Vegagerðin on its journey in implementation of carbon emission targets for bridge construction via Vegagerðin Research Fund sponsorship. The next steps have been defined as:

- An input to Vegagerðin adoption of the carbon footprint per square meter variable as a primary metric of the bridge design process. It is anticipated that results from the carbon calculator tool LOKI would be used, and the foresight is for a process that would run similarly to the way traffic safety associated with road design is reviewed today.

- Identification of areas where there may be scope for systematic carbon savings in bridge construction compared to current practice.
- Definition of material requirements to include in bridge construction tenders, specifying upper acceptable limits to embedded carbon.

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APPENDIX A CARBON FOOTPRINT OF ICELANDIC BRIDGES: EVALUATION AND FUTURE TARGETS – PRESENTATION AT VIA NORDICA JUNE 12TH 2024

Via Nordica 2024

COPENHAGEN 11-12 (13) JUNE

UN Global Goals · Nordic Road Sector Approaches

Magnús ARASON, *EFLA Consulting Engineers*

Carbon footprint of Icelandic bridges: Evaluation and future targets

INTRODUCTION

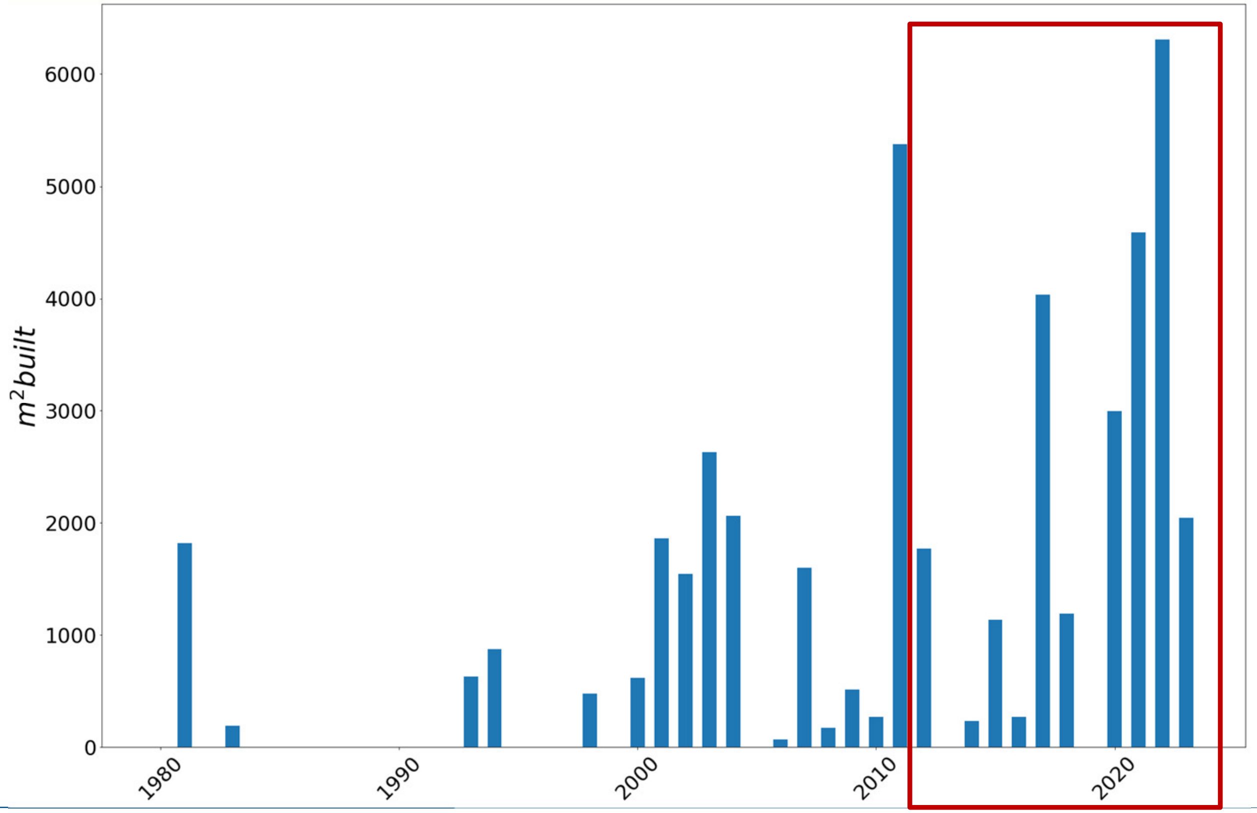
- **Bridges have a carbon footprint**
- **Evaluation in design and construction**
- **Knowledge within the industry is key**
- **The Icelandic Road and Coastal Administration is ambitious to map and reduce its carbon footprint**
- **Research and development initiatives**
- **EFLA providing consultancy**

INTRODUCTION – PRESENTATION CONTENT

- **Estimation of baseline bridge carbon footprint**
  - Database setup
- **Consistent design and construction evaluation**
  - Carbon calculator for infrastructure
- **Target setting**
- **Future footprint prediction (with caveat)**

DATABASE

- **64 road bridges built between 1980 and 2023**
  - 1 to 8 spans, 6m to 270m long
  - Most are 10m wide, two traffic lanes
- **35 bridges built after 2012**
  - Full EN1991 traffic load for this set
  - Vast majority of Vegagerðin bridges included
  - Representative of today´s design basis
  - Focus on this data



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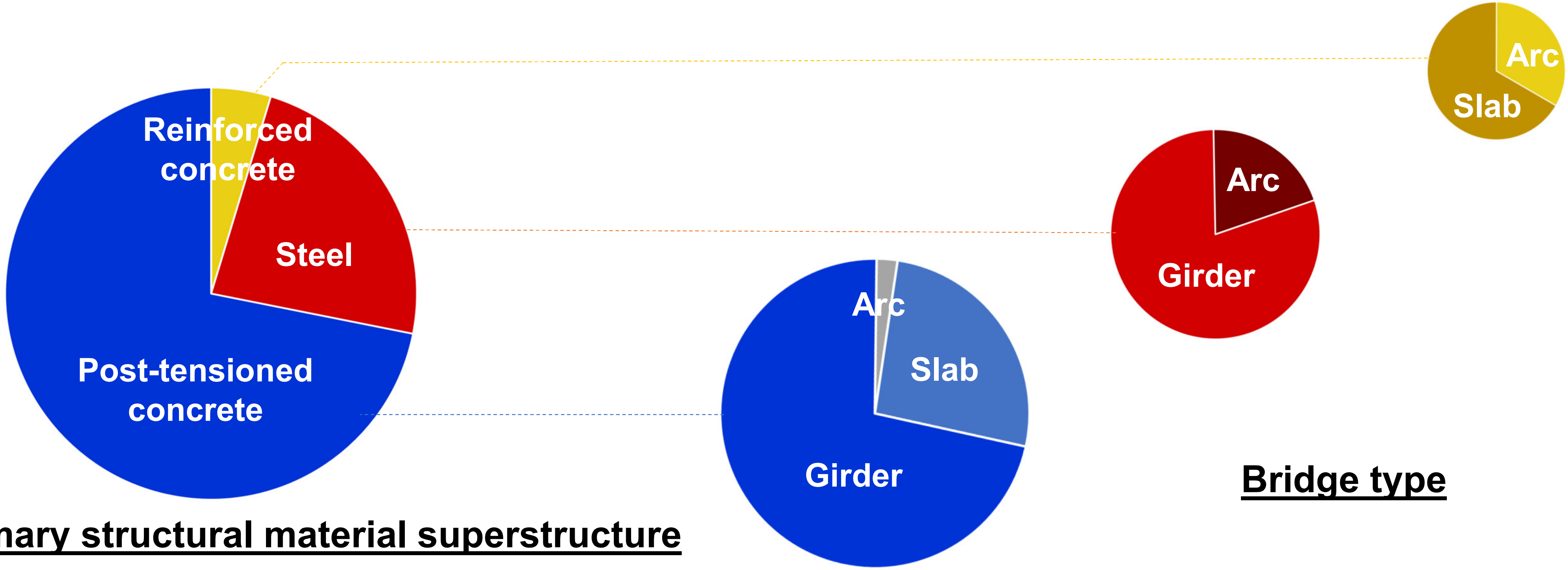
DATABASE



Primary structural material superstructure

Bridge type

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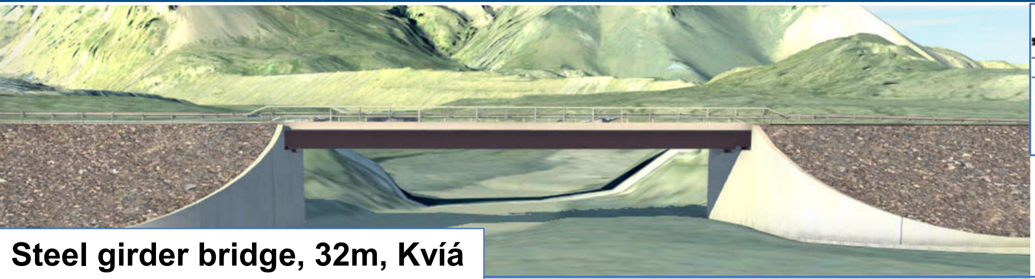
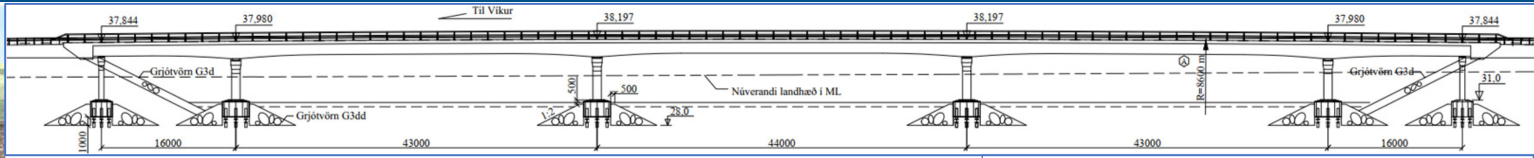
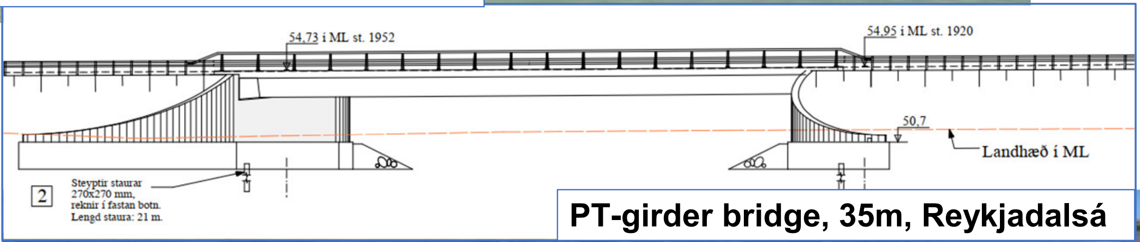
DATABASE – BRIDGE EXAMPLES



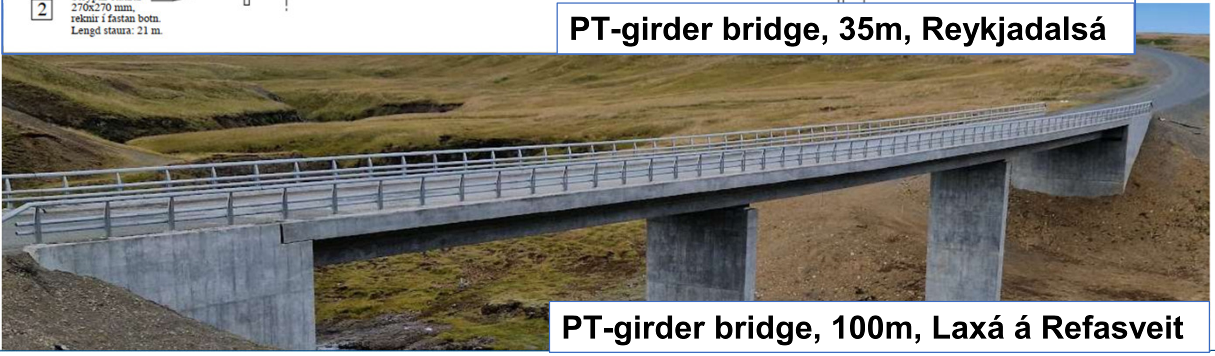
Steel girder bridge, 32m, Kvíá



PT-girder bridge, 162m, Múlakvísl

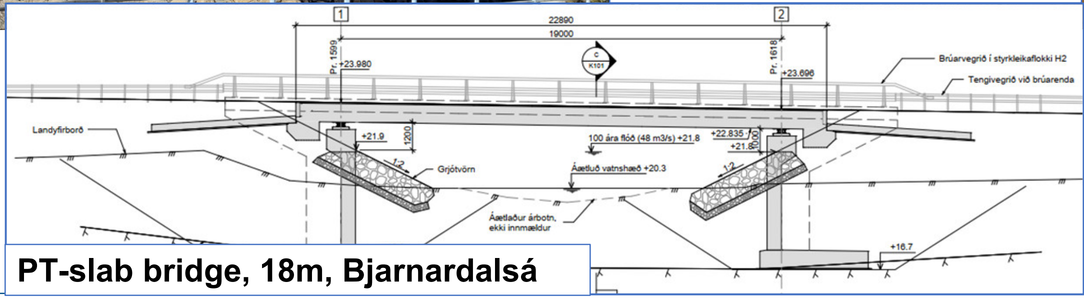


PT-girder bridge, 35m, Reykjadalsá



PT-girder bridge, 100m, Laxá á Refasveit

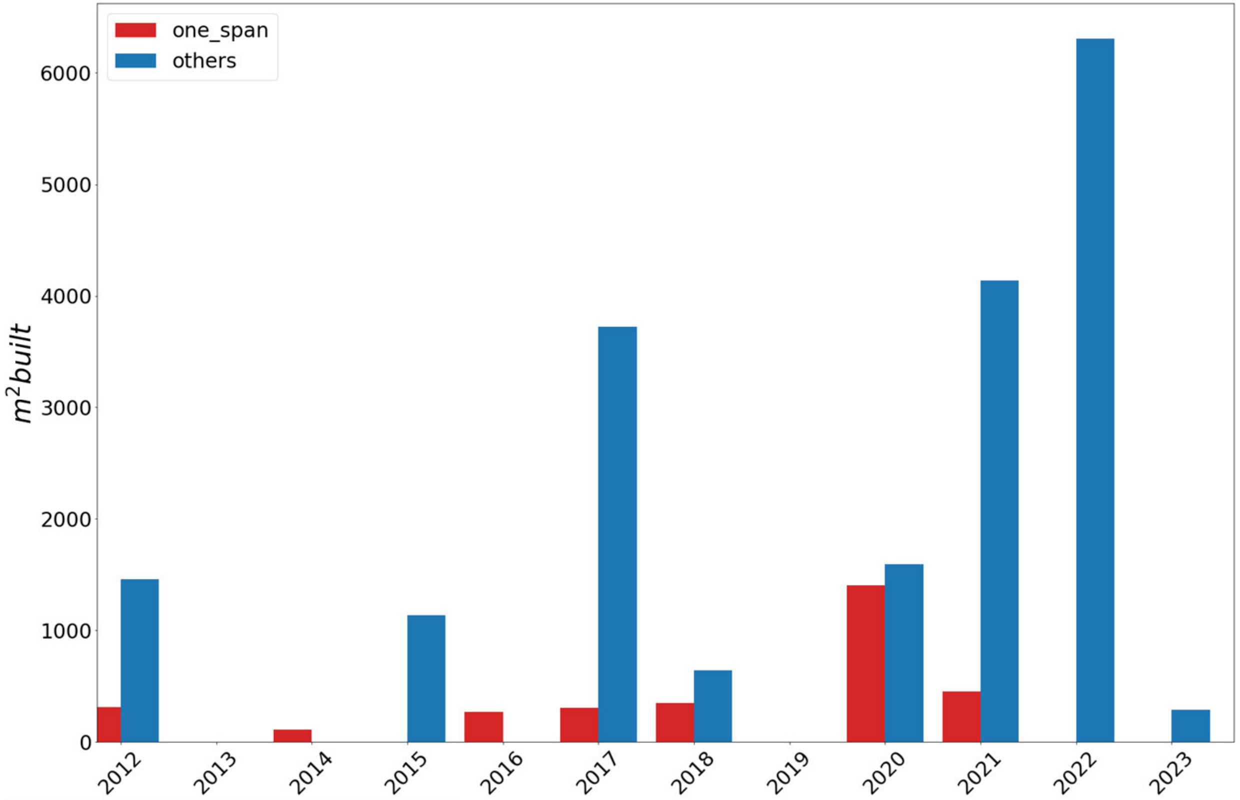
PT-slab bridge, 47m, Varmá



PT-slab bridge, 18m, Bjarnardalsá

DATABASE

- **Database of bridges built after 2012 split in two:**
  1. Single span bridges shorter than 40m
     - 15 bridges
  2. Multi-span bridges and bridges longer than 40m
     - 20 bridges



DATABASE – ESTIMATION OF EMBEDDED CO_2 IN BRIDGES

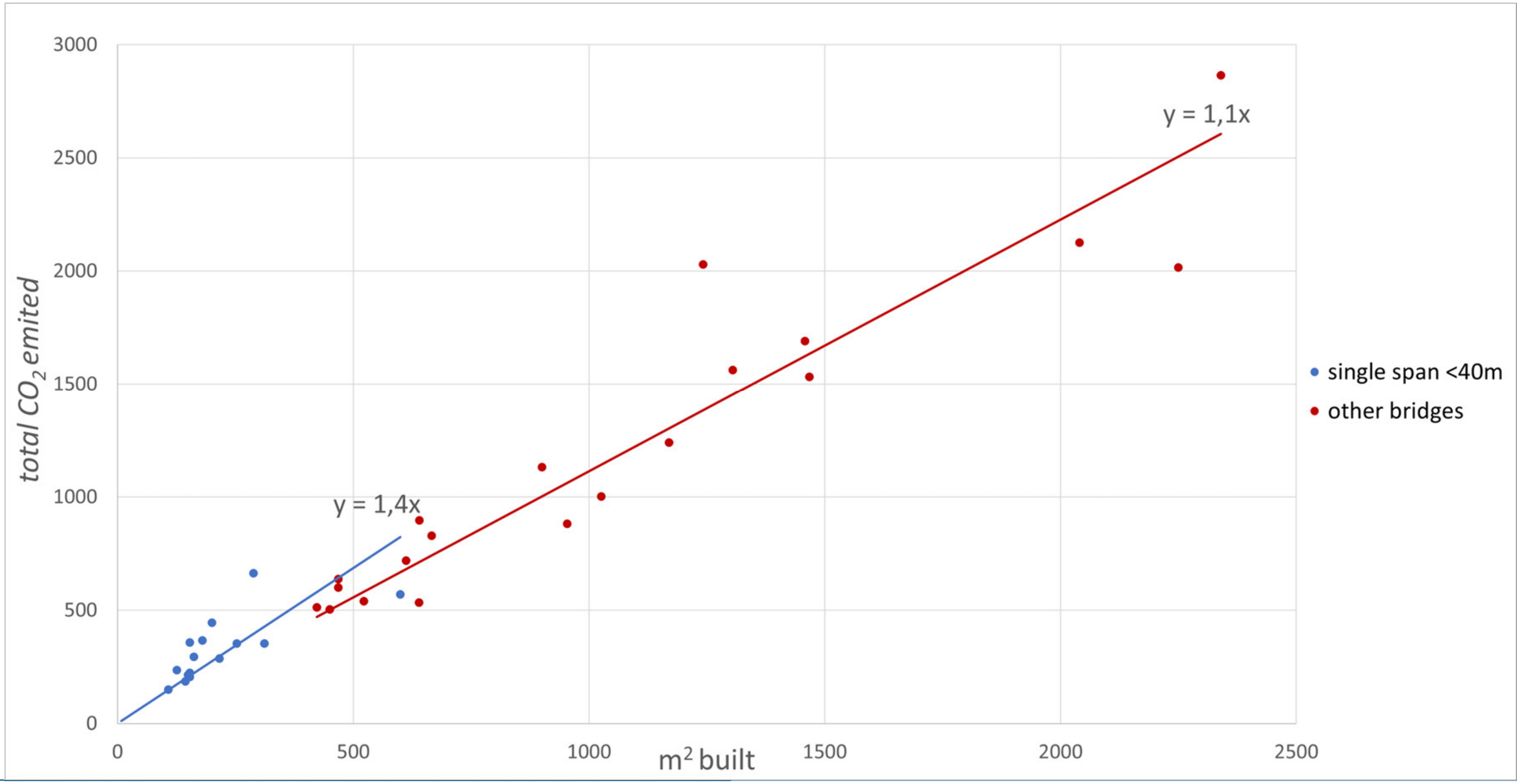
- **Simplified estimate of bridge carbon footprint:**
  - Quantification of 4 main construction materials only
  - EPDs
  - Material transport from Europe and within Iceland
  - Assumption: These are accountable for 80% of bridge CO_2
  - LCA stages A1-A5 CO_2 estimates normalized to bridge area

		Carbon footprint CO_2eq per unit	
	Unit	Material	Transport
Concrete	m^3	426	60
Reinforcement	ton	818	300
Contruction steel	ton	2500	100
PT-strands	ton	818	200

$$80\%\ CO_2e_{\mathrm{total}} = \sum_{i \in materials} \left(carbon\ footprint_{material_i} + carbon\ footprint_{transport_i}\right) \times (unit_i)$$

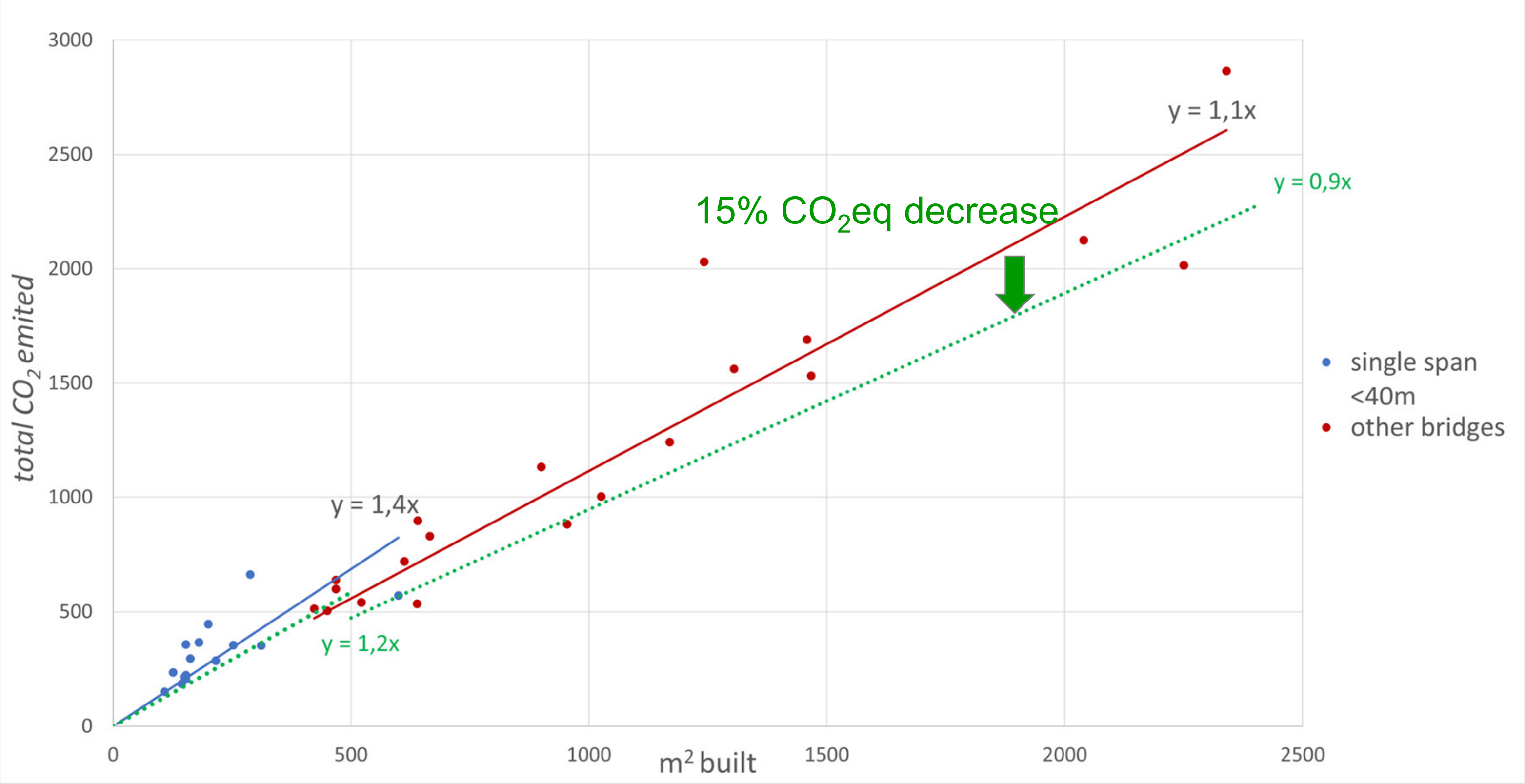
BASELINE

- **Average estimated carbon footprint of bridges in Iceland built after 2012:**
  - Single span <40m = 1,4 tCO_2e/m^2
  - Other bridges = 1,1 tCO_2e/m^2



TARGET: DESIGN OPTIMIZATION

- **Optimization is achievable**
- **Reduction target 15% from baseline:**
  - Single span <40m ≈ 1,2 tCO_2e/m^2
  - Other bridges ≈ 0,9 tCO_2e/m^2
- **Carbon footprint per m^2 to become an obligatory design review variable**
- **Induction of a design tool / calculator**



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CARBON CALCULATOR FOR INFRASTRUCTURE – LOKI

- **Requirement to evaluate carbon footprint of Icelandic infrastructure**
- **Calculator tools are in use in the other Nordics**
- **LOKI based on experience of LCA and the Nordic tools, covers A1-A5 and B4 for**
    - Roads
    - Bridges
    - Foot- and cycleways
    - Tunnels

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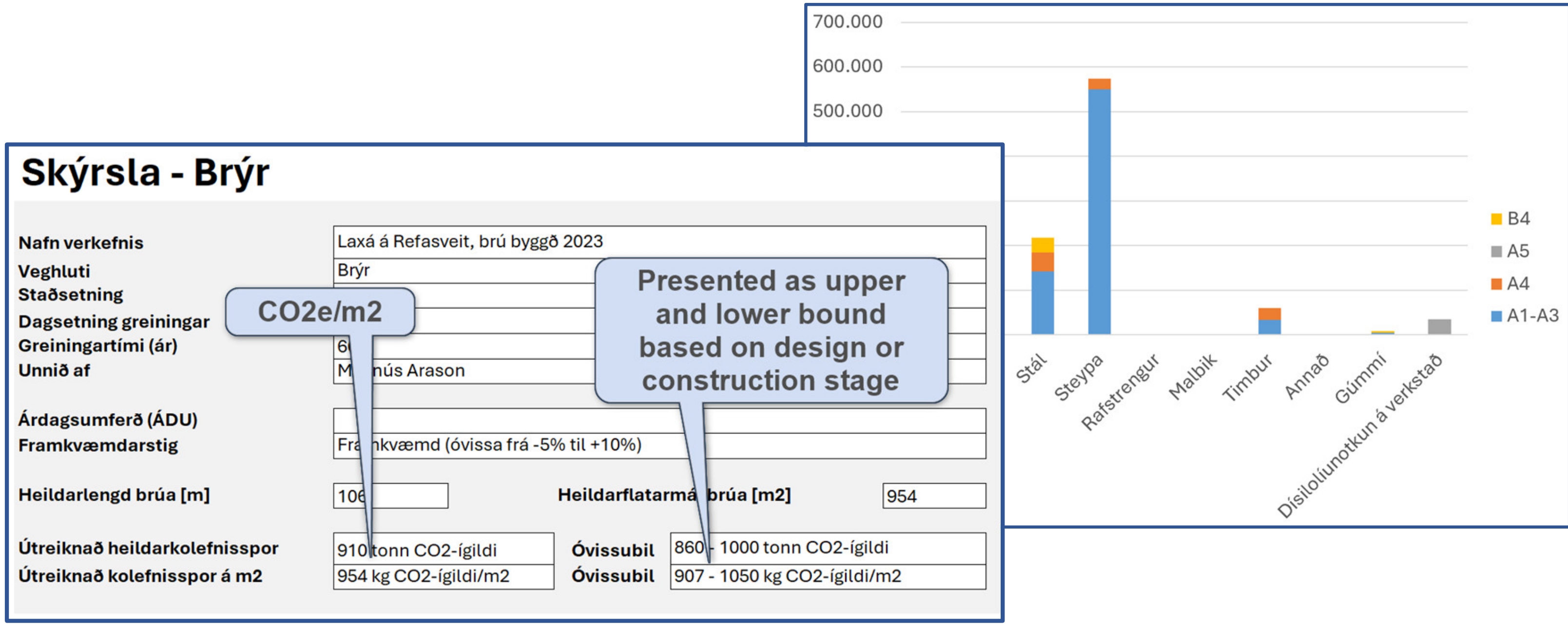
CARBON CALCULATOR FOR INFRASTRUCTURE – LOKI

- Breakdown of CO_2 sources from bridges
- LOKI normalizes results
- Upper and lower bound
- Direct application in CO_2e/m^2 evaluation for bridge designs
- For use at all design and construction stages



ADVANCES IN MATERIAL PRODUCTION – SCENARIOS

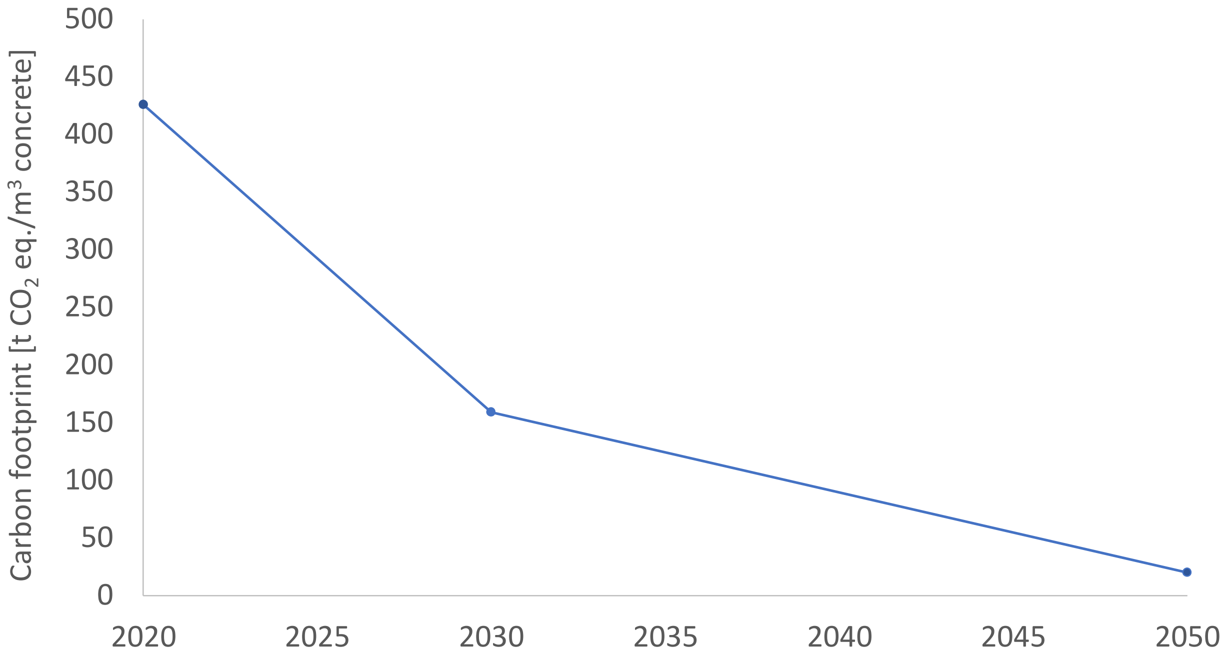
- **Materials the primary source of CO_2 emissions from Icelandic bridges currently**
- **Possible to draw up scenarios for bridges based on published targets from key sources:**
  - Insights to plans from concrete suppliers
  - Review of planned evolvement of steel production
  - IPCC scenarios for future transport emissions

		Carbon footprint CO_2eq per unit	
	Unit	Material	Transport
Concrete	m^3	426	60
Reinforcement	ton	818	300
Contruction steel	ton	2500	100
PT-strands	ton	818	200

How will these numbers develop???

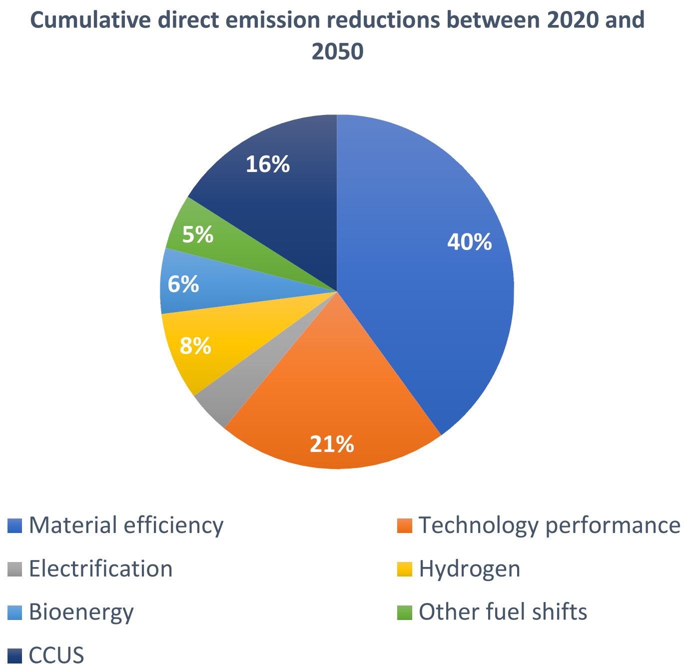
ADVANCES IN MATERIAL PRODUCTION – CONCRETE

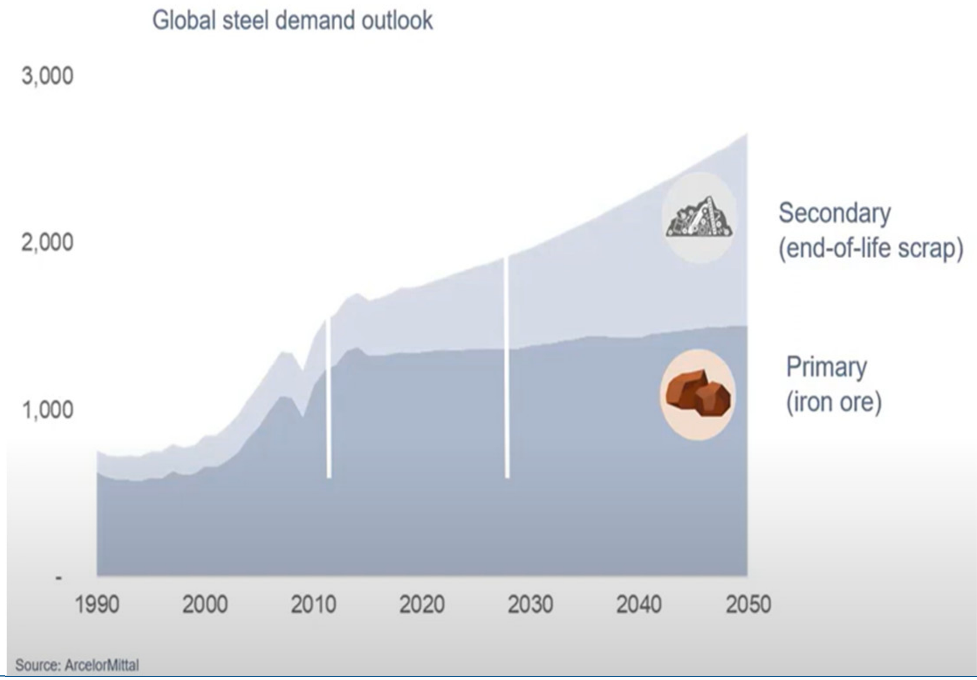
- **Cement responsible for ≈ 90% of concrete carbon footprint**
- **Two main producers of cement used in Iceland**
  - Heidelberg
  - Aalborg
- **Production emissions lowered by additives, new technologies, and carbon capture and storage**
- **Assume average of the two producers**



ADVANCES IN MATERIAL PRODUCTION – STEEL

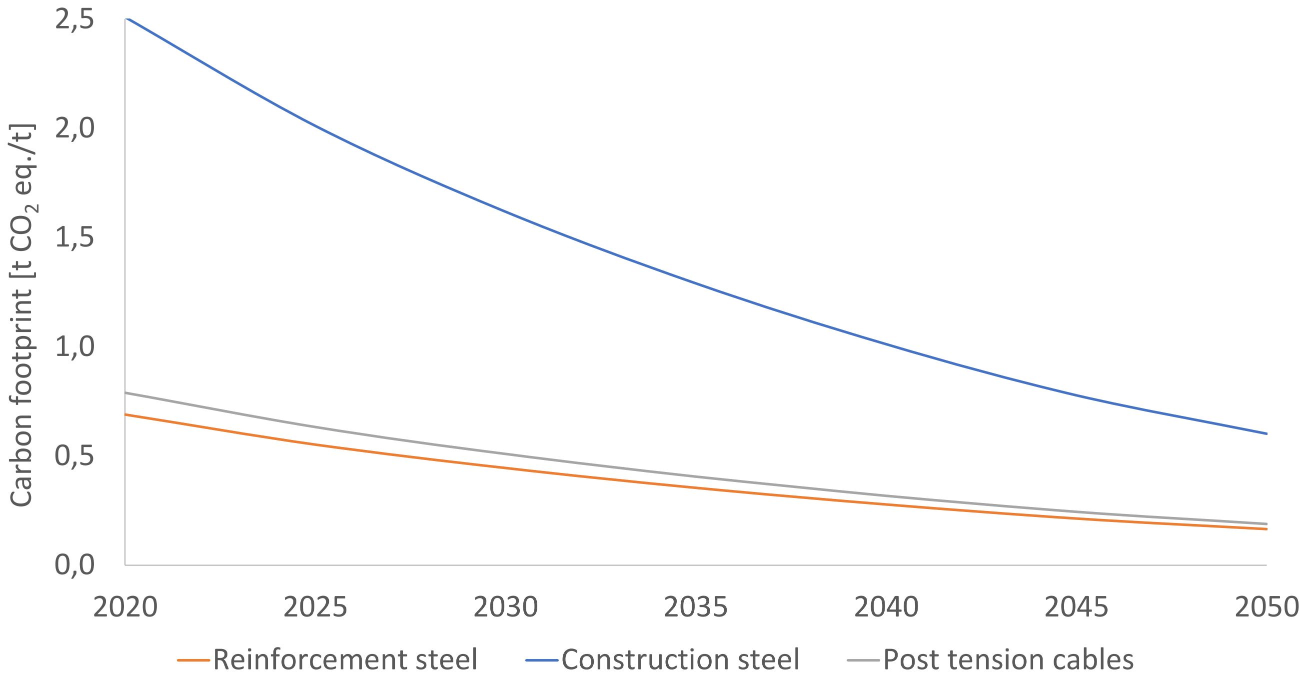
- **Switch from Basic Oxygen Furnace (BOF) to Electric Arc Furnace (EAF)**
- **Material efficiency and technology advancements**
- **Recycling of steel is increasing**
- **All reduce CO_2 footprint from steel production**





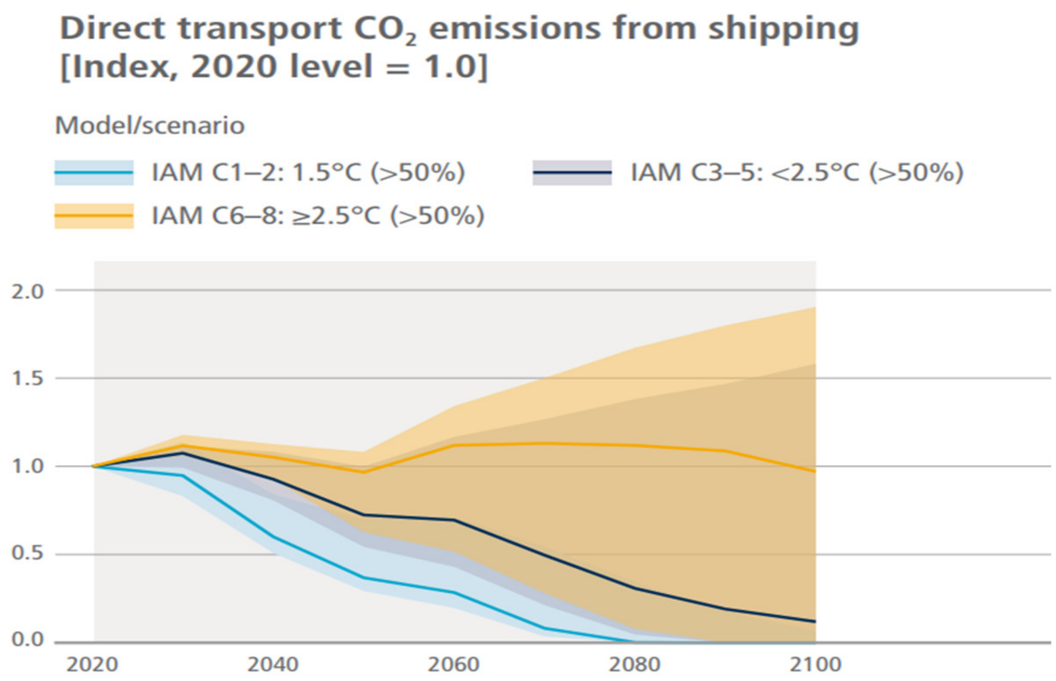
ADVANCES IN MATERIAL PRODUCTION – STEEL

- **Two models:**
  - International Energy Agency (IEA)
    - 58% CO_2 emission reduction by 2050
  - Mission Possible Partnership (MPP)
    - Net-zero emissions by 2050
    - Needs weighty carbon costing legislation
- **Assume an average of these two models**



ADVANCES IN TRANSPORT EMISSIONS

- **Scenario for shipping defined by IPCC:**
  - Constant emission until 2030
  - 40% drop in emissions until 2040
  - 60% drop in emissions until 2050
- **Assume for all transport in predictions**

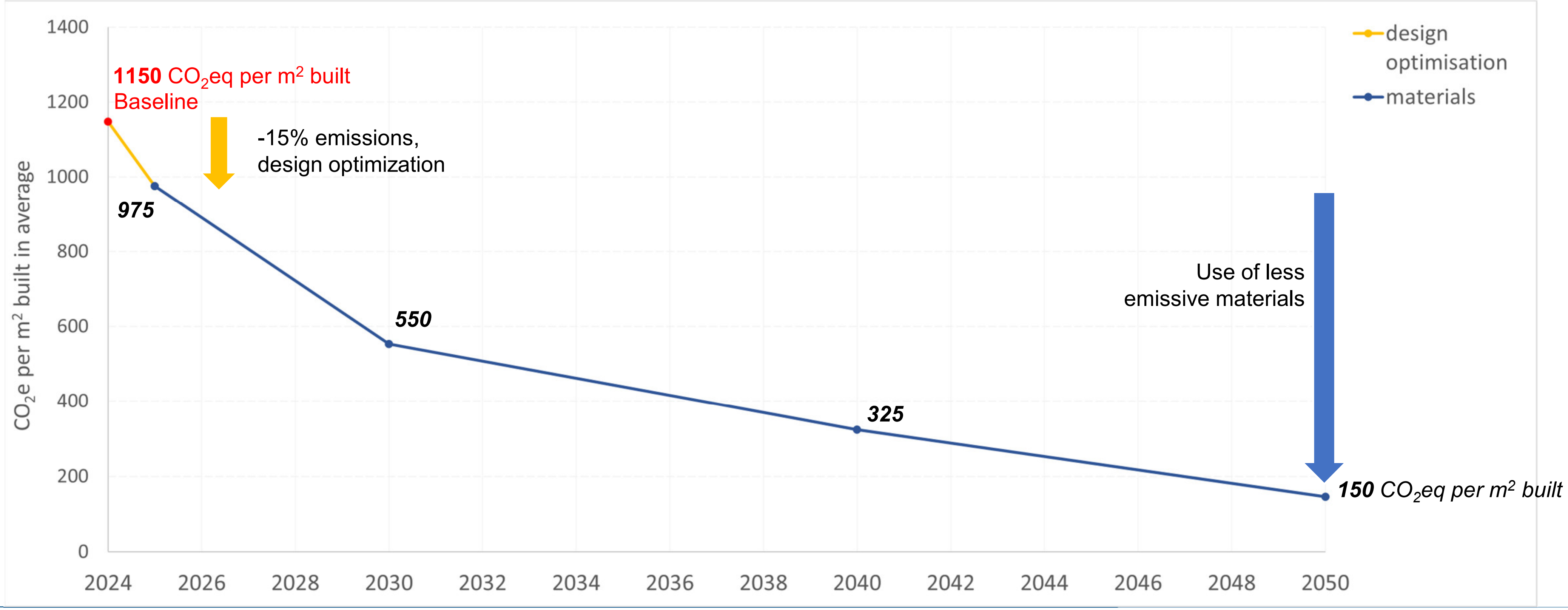


LOWER CARBON EMISSION – SNAPSHOTS

- **Above models consistent with "Science Based Targets Initiative" aimed at <1,5°C rise from pre-industrial levels**
- **Models tabulated:**
  - Current emissions
  - 2030
  - 2040
  - 2050

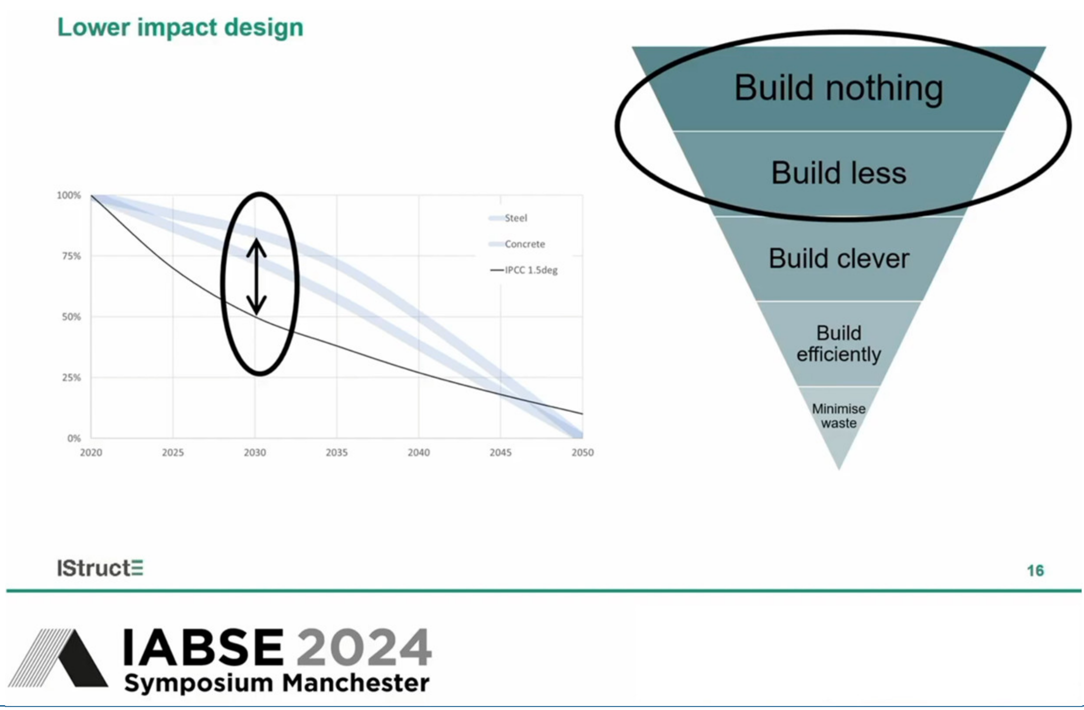
	2023		2030		2040		2050	
	Material	Transport	Material	Transport	Material	Transport	Material	Transport
Concrete	430	60	160	60	90	40	20	20
Reinforcement	820	300	450	300	280	180	170	120
Contruction steel	2500	100	1620	100	1010	60	600	40
PT-strands	820	200	510	200	320	120	190	80

FUTURE SCENARIO FOR CARBON FOOTPRINT OF ICELANDIC BRIDGES



WILL THIS SCENARIO BECOME REALITY AND IS IT SUFFICIENT?

- **Not everyone believes in those models**
- **Experience indicates that progress will be slower**
- **Also, environmental impact not limited to CO_2 emissions**
- **Designers and stakeholders can positively influence their projects by challenging the standard way of doing things**



Graphics: Will Arnold, UK Institution of Structural Engineers

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UN Sustainable Development Goals 3, 9, 11, 12 and 13

3. Good Health and well-being:
Ensure healthy lives and promote well-being for all at all ages.

9. Industry, Innovation and Infrastructure:
Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation

11. Sustainable Cities and Communities:
Make cities and human settlements inclusive, safe, resilient and sustainable

12. Responsible Consumption and Production:
Ensure sustainable consumption and production patterns.

13. Climate Action:
Take urgent action to combat climate change and its impacts

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UN Global Goals Nordic Road Sector Approaches

UN Sustainable Development Goals 3, 9, 11, 12 and 13

3. Good Health and well-being:
Ensure healthy lives and promote well-being for all at all ages.

9. Industry, Innovation and Infrastructure:
Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation

11. Sustainable Cities and Communities:
Make cities and human settlements inclusive, safe, resilient and sustainable

12. Responsible Consumption and Production:
Ensure sustainable consumption and production patterns.

13. Climate Action:
Take urgent action to combat climate change and its impacts

UN Sustainable Development Goal 9, Target 9.4

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Target

9.4

By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

Indicators

9.4.1

CO_2 emission per unit of value added

- https://sdgs.un.org/goals/goal9#targets_and_indicators

UN Sustainable Development Goal 12, Target 12.2

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.2

By 2030, achieve the sustainable management and efficient use of natural resources

Indicators

12.2.1

Material footprint, material footprint per capita, and material footprint per GDP

12.2.2

Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP

- https://sdgs.un.org/goals/goal12#targets_and_indicators

UN Sustainable Development Goal 12, Target 12.7

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Target

12.7

Promote public procurement practices that are sustainable, in accordance with national policies and priorities

Indicators

12.7.1

Number of countries implementing sustainable public procurement policies and action plans

- https://sdgs.un.org/goals/goal12#targets_and_indicators

KEY POINTS

1. **Awareness of bridge carbon footprint in design and construction is critical**
2. **Use of consistent tools allows definition and implementation of targets**
3. **Constantly re-evaluate targets by monitoring and challenging best practices for bridge projects**

Thank you!