FIFA WORLD CUP Qatar2022

Greenhouse Gas Emission Analysis of a Demountable FIFA World Cup™ Stadium

FIFA World Cup 2022™

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Acronyms and abbreviations

CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
EF	Emission Factors
EoL	end-of-life
FIFA	Fédération Internationale de Football Association
GHG	greenhouse gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hour
PMS	Prototype Modular Stadium
PPS	Prototype Permanent Stadium
Q22	FIFA World Cup Qatar 2022 LLC
974	Stadium 974
SC	Supreme Committee of Delivery & Legacy
T&D	transmission and distribution
WTT	well-to-tank

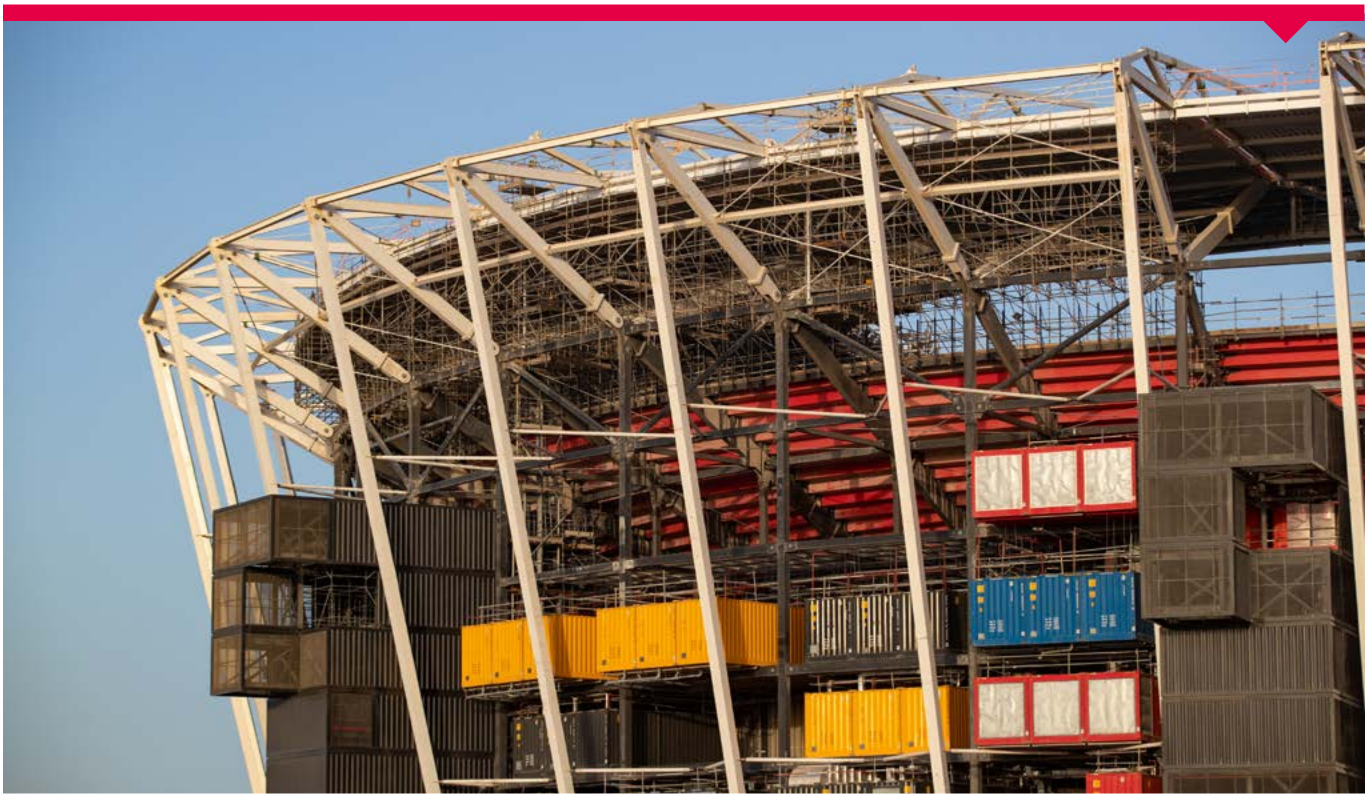
Executive Summary

1.0 Executive summary

Football stadiums are the heart and soul of the FIFA World Cup™ and their sustainability is key to leaving a lasting legacy in the host country. From the start of their collaboration on the FIFA World Cup Qatar 2022™, FIFA and the host country's Supreme Committee for Delivery and Legacy have paid great attention to the entire life cycle of the stadiums in Qatar to ensure that there is a positive legacy after the final whistle, for both football and society. In line with this commitment, Qatar is the first host country to create a temporary FIFA World Cup-compliant stadium. The design and concept is highly innovative and opens up new possibilities for future host countries of mega-sporting events. Utilising shipping containers as building blocks, Stadium 974 (974), also referred to as the Prototype Modular Stadium (PMS) in this report, is purposely designed to be fully demountable, transportable and rebuildable in a new location.

This study aims to provide a better and more detailed understanding of the conditions under which the use of a temporary FIFA World Cup stadium may be more climate-friendly from a carbon emission perspective, compared to building permanent stadiums. The results are intended to support future mega sporting event organisers in their infrastructure planning when assessing the use of temporary stadiums against the construction of new permanent ones. To do so, the greenhouse gas (GHG) emissions of Stadium 974's life cycle are estimated and compared to an equivalent permanent stadium. The comparator stadium, the Prototype Permanent Stadium (PPS), is modelled by averaging the emission data of the four permanent 40,000-capacity FIFA World Cup 2022 stadiums.

The study covers all emissions associated with the different stages of a stadium's life cycle, including the construction materials used to build the stadium, stadium operations, demounting, transportation and grounds rehabilitation. Due to the repeated need for transportation and construction at a new location, the temporary stadium's life cycle emissions will vary depending on the number of times it is reused. At each new location, the new temporary stadium requires foundations to be built, while the modular elements are simply transported and remounted. The stadium's end-of-life (EoL) emissions are excluded from the study due to the lack of underlying information such as the recyclability and recycling rates of each material or distance to the waste treatment facilities by waste type, which differ in each location.



For the comparison, the study presents three scenarios in which the temporary stadium is reused once (Scenario A), twice (Scenario B), or three times (Scenario C) in different locations around the world. It is therefore compared to the emissions of two, three or four newly built, permanent FIFA World Cup-compliant stadiums. A total of 39 cases are analysed. The purpose of the scenario analysis is to provide underlying data to draw generic conclusions which can then be used to assess any future scenario.

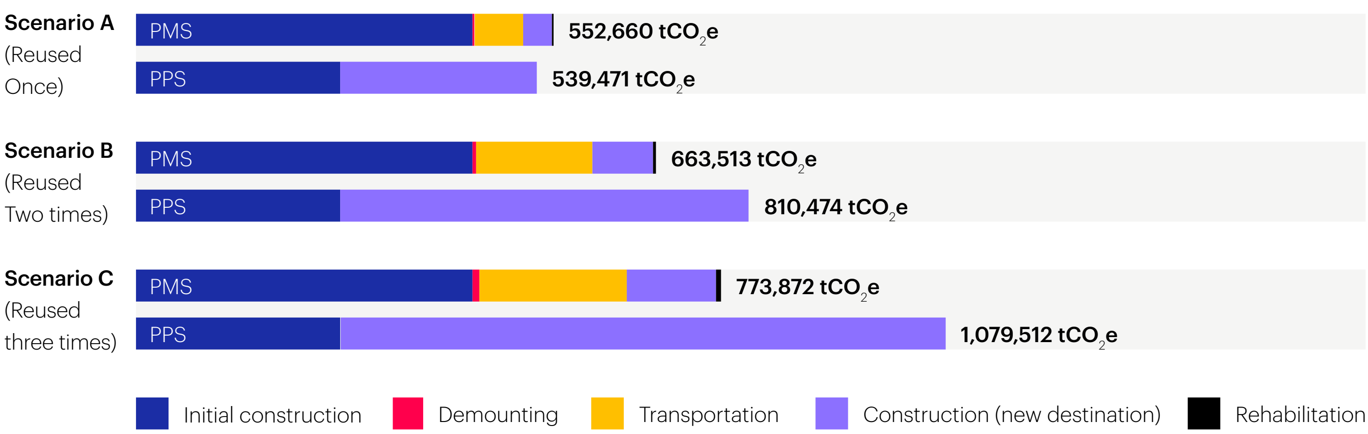
The results of the assessed scenarios presented in this study demonstrate that the construction of the temporary Stadium 974 initially emits more carbon emissions due to the use of carbon-intensive materials that enhance the durability of the stadium, enabling repeated demounting and reconstruction. However, due to the comparatively low emissions of the temporary stadium's reconstruction, its overall construction emissions end up being lower than the combined construction emissions of the permanent stadiums in the original and destination locations in each analysed scenario (Figure 1). Furthermore, while transport emissions could be a deciding factor in whether a temporary stadium is more sustainable from a carbon emission perspective than a permanent one under a one-time reuse case, they become, on average, less and less important under the two-time and three-time reuse cases. This is because the construction emissions of the second and third permanent stadiums become much more significant compared to the corresponding temporary stadium's transport, reconstruction and rehabilitation emissions. As can be clearly seen in Figure 1, the emissions related to the rehabilitation of the temporary stadium's grounds, as well as its demounting, have no impact on the results. The study concludes that the temporary stadium's carbon emissions are below those of the permanent stadium, as long as the total temporary stadium's travel distances are below 7,033km for a one-time reuse scenario, 40,118km for a two-time reuse scenario and 72,616km for a three-time reuse scenario.

It needs to be highlighted that a stadium's operational emissions are largely driven by the country's emission factor (EF), so the number of years that a stadium is operated at each location skews the results to a large extent. For this reason and for the purpose of the comparative analysis, the operational emissions have been excluded from the final results of the study, as reflected in Figure 1.

Consequently, for the construction of future temporary stadiums, careful consideration should be given to the number of times such stadiums are intended to be reused, the distance within which the stadiums will be transported for relocation, as well as the embodied emissions of the construction materials. These factors can heavily influence the total life cycle carbon emissions of the temporary stadium and therefore influence the overall results regarding the carbon benefits of reusing the stadium.

It needs to be noted that this study focuses purely on the assessment of the carbon emissions of the temporary Stadium 974, compared to the carbon emissions related to the construction of a permanent stadium. Further social, environmental and economic considerations that are outside the scope of the study should be taken into consideration by future mega-sporting event organisers when assessing the construction of a temporary or new permanent stadium.

Figure 1: PMS and PPS construction: carbon emissions comparison



02. Introduction

2.0 Introduction

Football stadiums are the heart and soul of the FIFA World Cup and their sustainability is key to leaving a lasting legacy in the host country. From the start of their collaboration on the FIFA World Cup Qatar 2022, FIFA and the host country's Supreme Committee for Delivery and Legacy have paid great attention to the entire life cycle of the stadiums in Qatar, to ensure that there is a unique tournament atmosphere for the fans as well as a positive legacy after the final whistle, for both football and society.

Qatar presented ground-breaking stadium designs with modular and temporary elements in its bid. After the final whistle, stadiums will be refurbished and dismantled, either partially or entirely, to be used for a variety of purposes in the same or a different location, thus ensuring a positive legacy that goes beyond the tournament and the host country.

Stadium 974 has a particularly unique design, utilising shipping containers as building blocks. It is purposely designed to be fully demountable, transportable and rebuildable in a new location. It will be the first temporary stadium used in a FIFA World Cup and is intended to be entirely dismantled after the tournament and shipped to a new location. The area where the stadium is currently located will be repurposed.

In this study, the GHG emissions of Stadium 974's life cycle are estimated and compared to equivalent permanent stadiums. The study covers all emissions associated with the different stages of a stadium's life cycle including the construction, materials used to build the stadium, stadium operations, demounting, transportation, and grounds rehabilitation. To compare Stadium 974's climate impact to that of a permanent stadium, the study presents three scenarios in which the temporary stadium is reused once, twice, or three times in different locations around the world and is thus compared to the emissions of two, three or four permanent FIFA World Cup-compliant stadiums. The locations have been chosen randomly from the list of countries in which Qatar supports football development activities, as they could provide potential legacy locations. However, there is no specific importance allocated to the chosen cities and countries. Rather, the purpose of the locations is to provide underlying data to draw generic conclusions which can then be used to assess any future scenario. Please note that, at the time of writing this report, no decision has been made regarding the future use or location of Stadium 974.

The results of the study aim to provide a better and more detailed understanding of the conditions under which the reuse of such a temporary stadium may be more climate-friendly compared to building new permanent stadiums for each mega-sporting event.

In 2012, FIFA introduced green-building certification as a mandatory requirement for all official stadiums.

The aim of this requirement is to ensure that the construction and renovation of stadiums are carried out in a more sustainable manner and that the design of stadiums considers key environmental, social and economic concerns that will allow for more sustainable operation of the stadiums in the long term. To fulfil this requirement, the Qatari hosts are applying the international GSAS certification standard to all eight stadiums hosting FIFA World Cup 2022 matches. The GSAS certification is applied to the design, construction and operational stages of all eight stadiums.

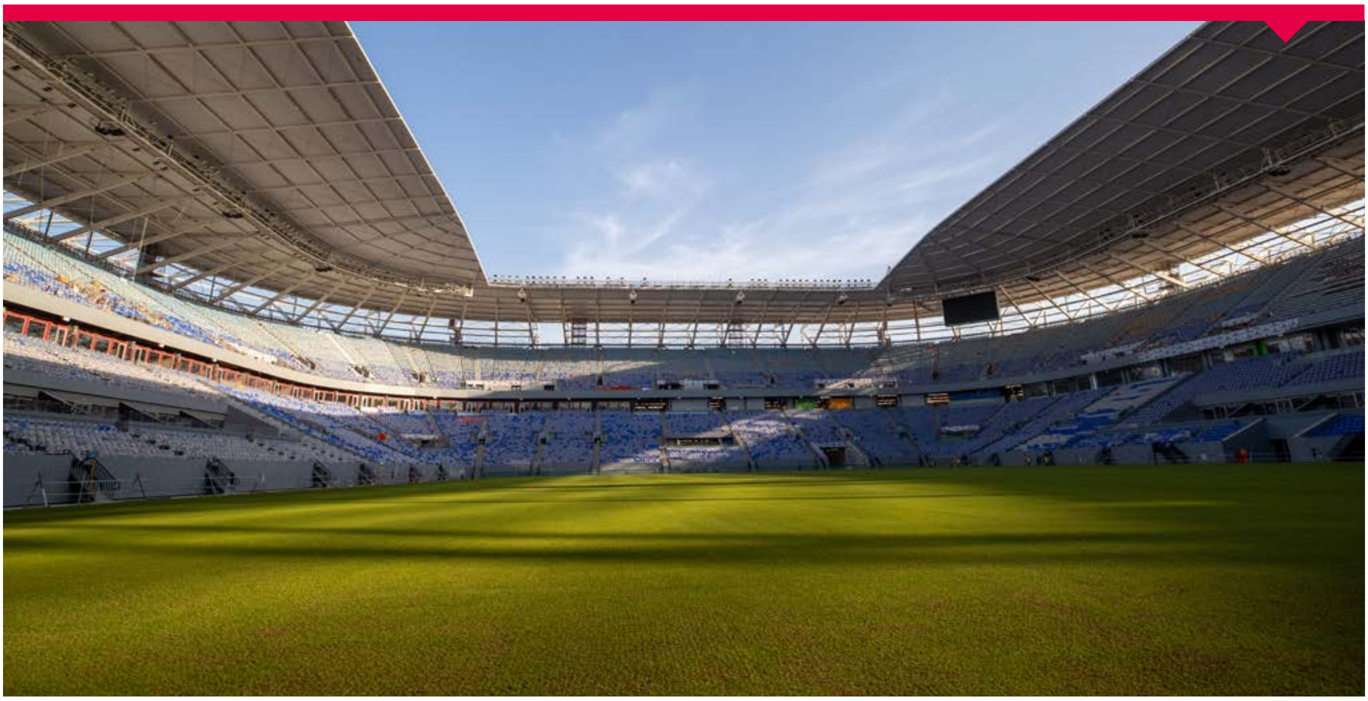
2.1 Methodology

The study considers two theoretical prototype stadiums, a PPS and a PMS, based on the data from the FIFA World Cup 2022 stadiums. Using the two prototype stadiums, the study analyses the life cycle carbon emissions to evaluate their competitive environmental performance in terms of carbon emissions. The life cycle carbon assessment examines the inputs, outputs and potential environmental impacts associated with the carbon emissions of a stadium throughout its life cycle. The total life cycle emissions are expressed in tCO_2e, using the 100-year GWP factors as published in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2014.

The study assumes a 60-year stadium operation period for both prototypes according to BS ISO 15686-1: 2011 - Buildings and Constructed Assets – Service Life Planning. The detailed life-cycle stages and explanations are provided in Table 1 and Table 2. The duration of construction, demounting and transportation is not counted as part of the stadium's 60-year operational lifetime. The operational lifespan is broken down by location (Figure 1). It is assumed that the stadium will operate for eight years – four years at the first location and a further four at the next location, each corresponding to a FIFA World Cup cycle – and will then operate for the remaining lifespan at the final location. The operational lifetime breakdown is further discussed under each scenario section below.

The life cycle stages of a PMS include construction, operation, demounting and rehabilitation at the first location, transportation of modular stadium elements to a new location, as well as reconstruction and operation at the new location. The need for transportation and construction at a new location increases according to the number of times a PMS is reused. A PPS's life cycle stages are designed in parallel with those of a PMS, encompassing construction and operation at the first location, as well as construction and operation at a new location.

For the comparative analysis, when the PPS is built and operated in a new location, it is assumed, for the purpose of this study, that it ceases to operate in the first location. Since the PMS serves its function at any given moment in time in one location only – either at the first or the new one – the study only considers the PPS's operations in the location where the PMS operates during the same timeframe. However, in reality the PPSs are simultaneously in operation at multiple locations until the end of their service life (see Figure 2).

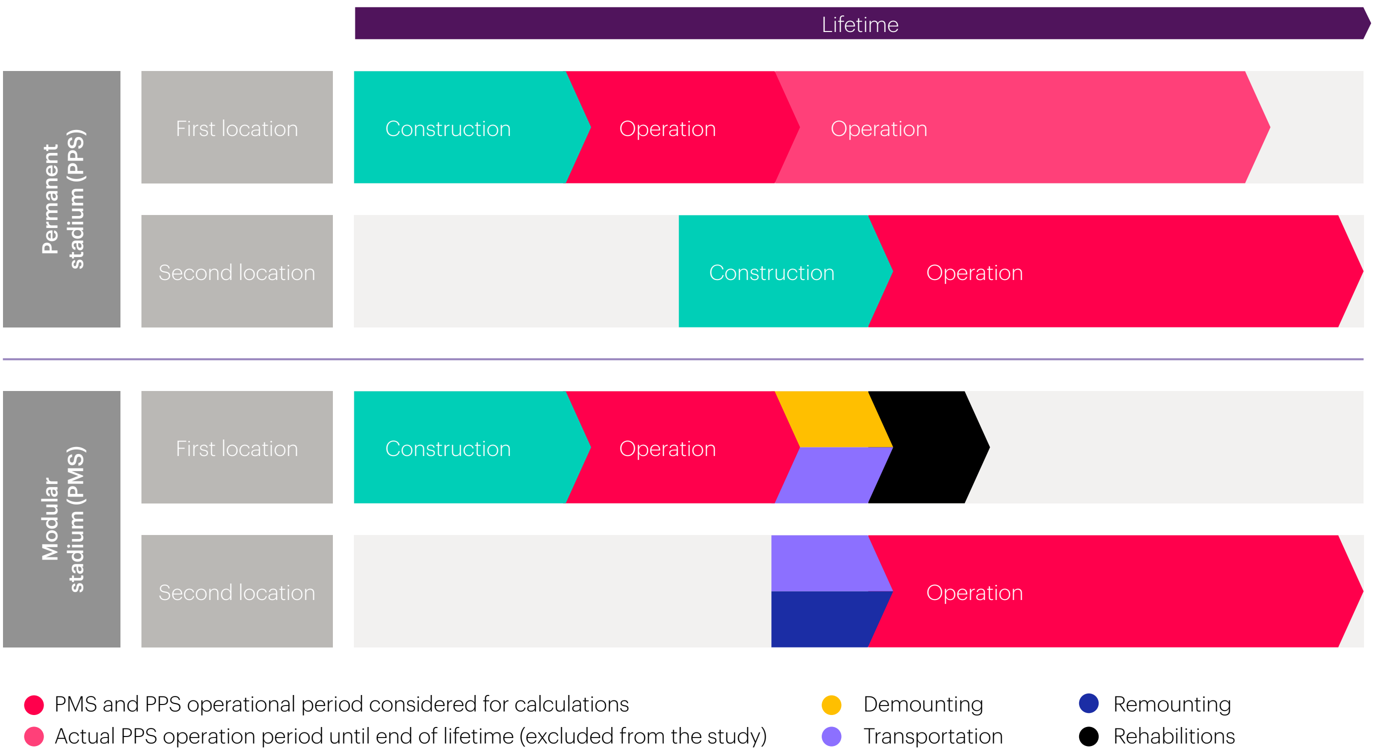


The study analyses three main scenarios in which the PMS is reused once, twice, and three times in different locations. The locations explored in the study are provided in Annexe III, together with the specific city and country of the locations, together with their nearest port.

At each new location, the new PMS requires the base structures/foundation to be reconstructed, while modular elements are simply transported and remounted. Moreover, for a PMS, transportation emissions are specific to the sea and road travel distance between the two locations between which the modular elements are transported.

For both PMS and PPS scenarios, the emissions relating to construction, operation, transportation, mounting and demounting are specific to the country in which the new stadium is built. The detailed emissions by phase are provided for a PPS and PMS in Annexe IV.

Figure 2: Life cycle methodology



2.1.1 Basis of calculation and assumption

Prototype Permanent Stadium (PPS)

The life cycle emissions of a PPS are calculated based on the 40,000-capacity stadiums used for the FIFA World Cup 2022, by averaging data from Education City Stadium, Al Thumama Stadium, Al Rayyan Stadium and Al Janoub Stadium.[1]

The operation emissions are calculated based on the energy and water consumption, waste and wastewater generation and refrigerant leakage data. The total operation emissions of the PPS are calculated by multiplying the emissions per day according to peak event days, training days, and non-event days by the total estimated years of operation.

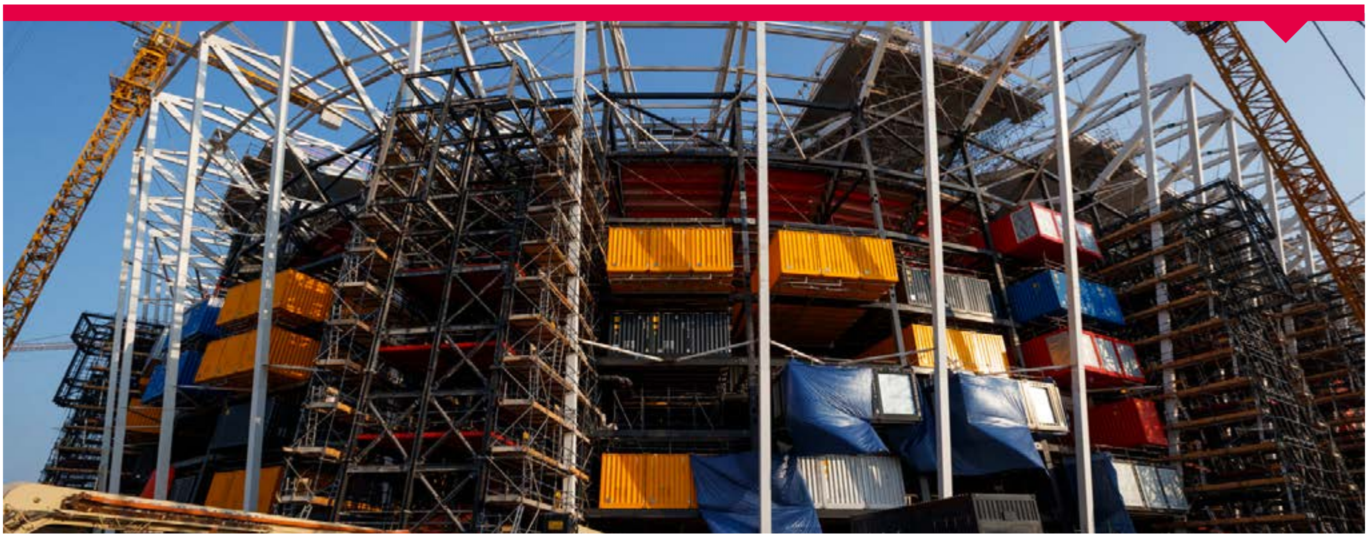


Table 1: Emissions calculation for life cycle stage – PPS

Stage of emission	Calculation basis
Construction emissions at the first location	The emissions are calculated by adding together the emissions from the material use, waste generated, consumption of water and energy and emissions from material transportation for the average four 40,000-capacity stadiums in Qatar.
Operation emissions (first and new locations)	The emissions are calculated based on the sum of emissions from energy and water consumption, waste, wastewater, maintenance, and refrigerant leakage. Assumptions are made about the number of years of operation for each location based on the modelling of corresponding scenarios. Energy consumption at a new location is calculated based on the energy consumption of the four stadiums in Qatar by applying the climatic conditions of each location. Further details are provided in Annexe V.[2] The country-specific EF for water and energy (including Scope 3) are used.[3] The country-specific EF are provided in Annexe II. The operational time period at the original and corresponding locations are accounted for and equivalent to the PMS scenarios. This assumption is made for the comparative life cycle carbon assessment conducted in this study.
Construction emissions	The emissions arising from construction of the stadium at a new location. The emissions are based on the construction emissions at the first location after adjusting the EF depending on the location.

1 Three methodologies for averaging the emissions of the four stadiums were applied: 1) total emissions, 2) emissions per seat, and 3) emissions per m2. The average of the three calculations combined is used for the PPS.
2 Energy Use Intensity (EUI) at a new location is calculated based on the US EPA's Energy Star Portfolio. A variation of EUI in each location compared with Qatar's EUI is applied to estimate the energy consumption of each new stadium location.
3 Scope 3 emission for energy includes emissions from Well-to-tank (WTT) and Transmission & Distribution (T&D) losses.

Prototype Modular Stadium (PMS)

The life cycle emissions of a PMS are calculated based on Stadium 974's estimated construction and operation data provided. Scenario-based emissions are calculated as further detailed in Table 2.

Table 2: Emissions calculation for life cycle stage – PMS

Stage of emission	Calculation basis
Construction emissions at the first location	Emissions during the construction of the stadium at the first location (i.e. Qatar). Emissions related to construction materials are included in this stage as material embodied emissions. The construction emissions of Stadium 974 are considered for the calculation and the breakdown of these emissions is provided in Annexe IV.
Operation emissions (first and new locations)	Emissions from the operations at the first and subsequent new locations. The same country-specific EF for water and energy (including Scope 3) are used for the PPS calculation. Operational years are assumed at each location according to scenarios.
Demounting emissions	These emissions include energy and water consumption for demounting the modular elements of the PMS after use.[4] The emissions are based on the demounting emissions estimate for Stadium 974. The emissions are recalculated with the EF of each location depending on relocation scenarios.
Transportation emissions	These emissions relate to the calculation of road and sea transportation of the modular construction material quantities[5] (excluding Stadium 974 base components) from one location to the next, according to the scenario provided. Road transportation emissions are calculated based on the distance between Stadium 974 and the nearest port and the distance between the nearest port of a new location and the centre of the city to which the stadium is relocated. Sea transportation emissions are also accounted for between the ports that the stadium is transported from and to. The cities used for each scenario can be found in Annexe III.
Construction emissions at new locations	The emissions arising from the construction of the stadium at a new location. The emissions from the construction of the stadium base structure at each location are calculated. The total emissions are reached by adding together the construction emissions at each location, based on the number of times the stadium is relocated.
Rehabilitation emissions	These emissions are calculated by construction emissions from landscaping and ancillary building and the infrastructure required to rehabilitate the PMS site after use.[6] Stadium disposal is not covered in the study.

4 Based on Stadium 974's emissions calculation for mounting modular construction, it is estimated that the same amount of carbon would be emitted for lowering down modular elements of Stadium 974 for the demounting stage.
5 Modular construction material quantity is based on the data reported by the Supreme Committee for Delivery and Legacy for the Global Sustainability Assessment System (GSAS) certification of Stadium 974.
6 Based on the emissions calculation for training pitch site construction, site rehabilitation emissions are estimated multiplying the site area of Stadium 974 by the unit emissions (CO2e/m2) of the training pitch site construction. Since the training pitch site construction mostly includes site preparation works (excavation and filing) and infrastructure and external works (roads, paths, paving, street furniture, irrigation, drainage, and outdoor lighting), the nature and methodology of the construction are considered similar to the rehabilitation construction of Stadium 974's site into a public space (e.g. parks).

2.1.2 Exclusion of EoL emissions

The study excludes emissions from the stadiums' EoL. The EoL analysis requires information on the recyclability and recycling rates of each wasted material, distance to the waste treatment facilities by waste type and so on. Such information also differs at each location. However, since this information is not available, it would have been necessary to rely entirely on hypothetical assumptions regarding the stadium's demolition waste treatment and the EoL stage is therefore not included in this assessment.

Based on a review of the literature relating to previous case studies, EoL stage emissions of a building ranges between 0.6% to 1.5% of the total life cycle carbon emissions.[7,8,9] It is therefore considered that the exclusion of EoL emissions will not significantly affect the results of the study.

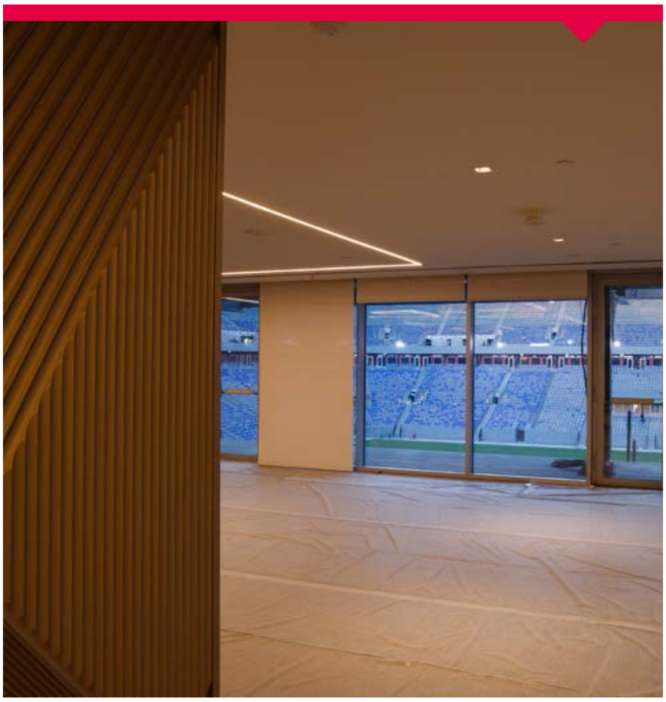
The study did not further investigate the difference in emissions between the PMS and PPS at the EoL stage. However, it is worth noting that the expected EoL emissions for the PMS would be much smaller than the PPS since steel and metal products are the main construction materials used for the PMS. These materials have a high recycling value and will therefore generally have a higher recycling rate than the construction materials used for the concrete-intensive PPS.

2.2 PPS energy operation model

For a general representation of a typical stadium, a PPS is derived based on the four 40,000- capacity stadiums built for the FIFA World Cup Qatar 2022. To provide more generic results, the bowl cooling, which is a particular feature of Qatar's permanent stadiums, is excluded from the PPS model. Instead, Stadium 974's bowl, which has no cooling, has energy consumption related to lighting, broadcasting and so on that is more representative of a typical stadium. As a result, the total estimated energy consumption of the PPS is calculated by replacing its bowl energy consumption with the one from Stadium 974 to ensure the overall energy consumption is more representative of a typical stadium, i.e. without bowl cooling. The formula used is as follows:

PPS energy consumption =
overall average energy consumption of four stadiums -
average bowl area energy consumption of four stadiums +
bowl area energy consumption of Stadium 974

The operational energy review and the comparison between the PPS and PMS have been discussed further in Annexe I.



7 Lotteau, M et al. (2015), Critical review of life cycle assessment (LCA) for the built environment at the neighborhood scale, Building and Environment 93 (2015) 165-178
8 Yang, X. et al. (2018), Building-information-modeling enabled life cycle assessment, a case study on carbon footprint accounting for a residential building in China, Journal of Cleaner Production 183 (2018) 729-743
9 Rashid, A.F. (2017), Environmental Impact Analysis on Residential Building in Malaysia using Life Cycle Assessment, Sustainability 2017, 9, 329

2.3 Stadium's operation energy reconfiguration by location

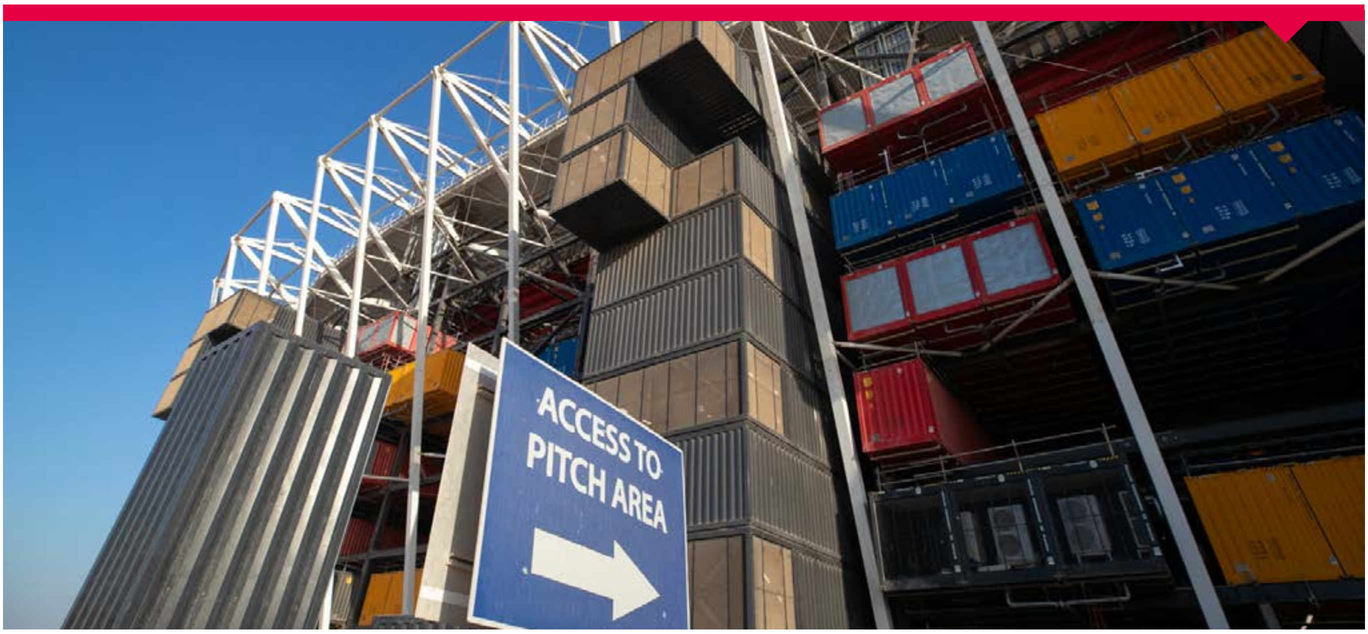
Energy consumption estimates of the FIFA World Cup Qatar 2022 were provided by the Supreme Committee for Delivery and Legacy, the entity in charge of the delivery of the host country infrastructure for the event. However, energy consumption varies depending on the climatic conditions of each location explored in the study. The estimated energy consumption of each location is calculated based on the stadium data in Qatar to which country-specific data from the US EPA Energy Star Portfolio is applied.

The following considerations have been taken into account to ascertain a country's energy consumption:

1. Climate zones representing each PMS location are selected in the Energy Star Portfolio.
2. Due to a lack of data for stadium buildings in the database, the school and office data from the EUI are used for comparison.
3. The percentage difference of the EUI data for each climate zone is applied to the energy consumption estimates of the stadiums when operated in Qatar.

Table 3: EUI for each location

Country	K-12 schools[10] average EUI (GJ/m²)	Office average EUI (GJ/m²)	Weighted average (GJ/m²)	% change from Qatar EUI
Qatar	0.73	0.75	0.740	-
Syria	0.45	0.76	0.605	-18.24%
Jordan	0.43	0.76	0.595	-19.59%
South Africa	0.29	0.73	0.510	-31.08%
Pakistan	0.56	0.75	0.655	-11.49%
Nepal	0.60	0.75	0.675	-8.78%
Brazil	0.37	0.74	0.555	-25.00%



10 K-12: "from kindergarten to 12th grade", is an American expression that indicates the range of years of publicly supported primary and secondary education found in the USA.

03.
Scenario analysis

3.0 Scenario analysis

To conduct the assessment, three scenarios will be used. Scenario A will look at the one-time reuse case of the PMS in three different new locations; Scenario B will assess two-time reuse cases with three new locations in addition to those under Scenario A; and Scenario C will analyse three-time reuse cases of the PMS, adding three additional locations to those analysed under Scenario B. Under the three scenarios, the locations chosen for each case analysed are the same for both the PMS and the PPS. These locations are chosen randomly based on countries where Qatar supports football development projects.

Their main purpose is to demonstrate a process and to provide underlying data to draw generic conclusions. The logic behind the choice of destinations, which may not always appear realistic, is therefore secondary. The next section presents the results of the three scenarios while the following chapter analyses the different phases and elements of the stadiums' life cycle emissions based on these scenarios in more detail.

Figure 3: Scenario A, B, and C locations map

It needs to be highlighted that, although the study assesses the reuse of the stadium in new locations, the legacy design of Stadium 974 provides the option to repurpose the stadium's building elements into several smaller building structures, such as different smaller facilities (sporting or otherwise). These structures would not require extensive transportation but could be rebuilt either in the same city – potentially even in the same location as the original stadium – or country. Such a solution would enable the host country or city to repurpose the event-specific stadium infrastructure for other uses after the event.

Given the high number of possible scenarios, the lack of available data at this point, and the consequent high number of assumptions required to conduct such an assessment, this specific scenario has not been included in this study. Such a scenario analysis could, however, constitute an interesting basis for a separate study to conduct further detailed and case-specific research that goes beyond this carbon emissions analysis.

3.1 Scenario A: One-time reuse

Scenario A explores one-time reuse cases in three future locations (Jordan, Brazil, and Nepal) for both the PMS and the PPS, as shown in Table 4. Scenario A assumes that both the PMS and PPS operate in the first location, Qatar, for four years (corresponding to the event cycle of major sports events) with the remaining 56 years operating in a new location.

In Scenario A, the PMS cases present fewer life cycle carbon emissions than the PPS cases in Figure 4. When comparing the PPS to the PMS, it results in relatively fewer life cycle emissions in case 3 compared to cases 1 and 2. This is driven by the low electricity EF in Nepal, resulting in very low operation emissions compared to those of the PPS in Brazil and Jordan. The EF at the final location plays a considerable role in the overall result due to the many years of operation at the final location.

Table 4: Locations for Scenario A

PMS scenario	First location	Second location	PPS scenario	Emission reduction in PMS cases w.r.t PPS cases (tCO_2e)
Case 1	Qatar	Jordan	Case 1.1	228,607
Case 2	Qatar	Brazil	Case 2.1	162,656
Case 3	Qatar	Nepal	Case 3.1	66,286
Operation years	4 years	56 years		

Figure 4: Life cycle emissions calculation for Scenario A cases

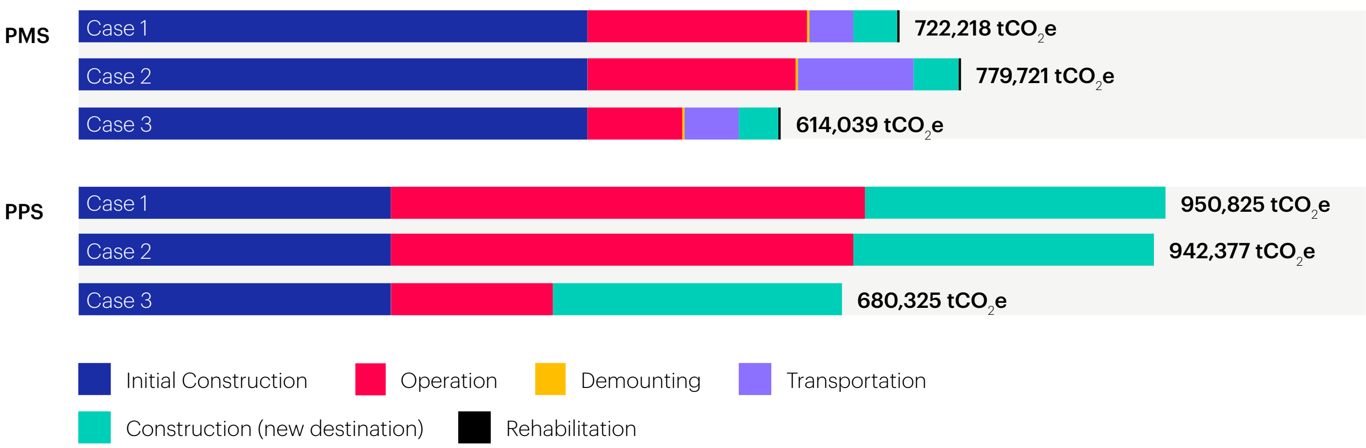
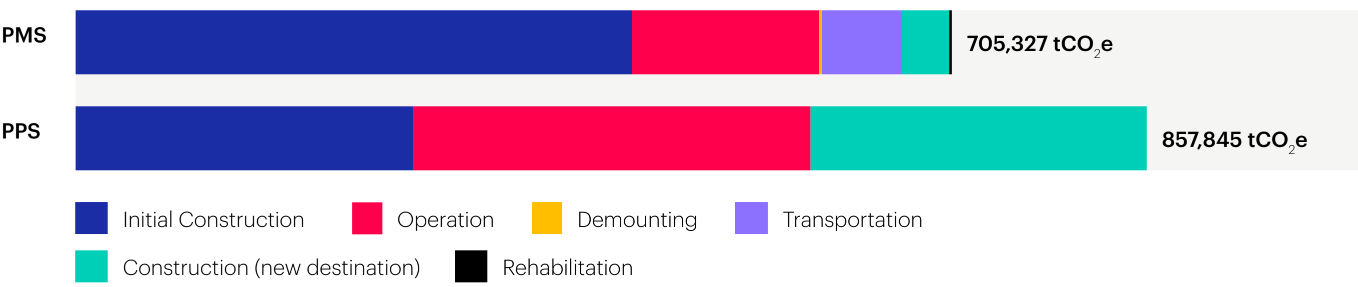


Figure 4 shows the averaged emissions of the PPS and the three PMS cases at each life cycle stage of Scenario A. The main contributor to carbon emissions for the PMS is the stadium construction at the first location, which contributes to 63.1% of the average life cycle emissions. A PMS's modular elements are mostly based on high embodied carbon metal and steel materials which result in a significant difference in carbon emissions between the average stadium construction of the PPS (270,373 tCO_2e) and the PMS (445,321 tCO_2e). Further analysis of construction materials is detailed in chapter three.

The overall operational emissions rank in second place, constituting 21.6% of the PMS's life cycle emissions. Stadium construction emissions at the new location and the emissions from transportation are responsible for 5.4% and 9.1%, respectively. The demounting and rehabilitation-related carbon emissions of the PMS are negligible (around 0.3%) compared to its construction, operation, and transportation emissions.

Similarly, operation emissions are the main contributors to the PPS's life cycle carbon emissions, contributing to 37% of its lifetime emissions. The stadium construction emissions at the first location and the emissions from the stadium construction at a new location constitute 31.5% and 31.4% of its life cycle emissions.

Figure 5: Life cycle emissions comparison between averaged PPS and PMS in Scenario A



3.2 Scenario B: Two-time reuse

Scenario B explores two-times stadium reuse cases of both the PMS and PPS as listed in Table 5, using three different locations in each case: Jordan, Brazil, and Nepal for the first one and Syria, South Africa, and Pakistan for the second. A total of nine cases are therefore examined for each PMS and PPS model. Scenario B assumes that both the PMS and the PPS operate for four years at the first location and a further four years at the second location. They then operate at the final location for the remaining operational lifetime of 52 years.

In Scenario B, all PMS cases have fewer life cycle carbon emissions than their corresponding PPS cases. There are noticeable variations in the PPS life cycle carbon emissions depending on the country in which it is operated. This is particularly the case for Nepal and Pakistan, which have low electricity EF. As in Scenario A, the operation emissions at the final location play a significant role in the life cycle emissions. However, the positive impact on operational emissions due to lower grid EF in a specific country may be balanced by higher transport emissions, as can be seen in Case 6, where the life cycle emissions are relatively high, driven by the long transport distance between Brazil and Pakistan.

Table 5: Locations for Scenario B

PMS Scenario	First location	Second location	Third location	PPS scenario	Emission reduction in PMS cases w.r.t PPS cases (tCO_2e)
Case 1	Qatar	Jordan	Syria	Case 1.1	483,807
Case 2	Qatar	Jordan	South Africa	Case 2.1	562,341
Case 3	Qatar	Jordan	Pakistan	Case 3.1	370,635
Case 4	Qatar	Brazil	Syria	Case 4.1	341,482
Case 5	Qatar	Brazil	South Africa	Case 5.1	514,144
Case 6	Qatar	Brazil	Pakistan	Case 6.1	232,207
Case 7	Qatar	Nepal	Syria	Case 7.1	414,524
Case 8	Qatar	Nepal	South Africa	Case 8.1	545,857
Case 9	Qatar	Nepal	Pakistan	Case 9.1	354,921
Operation years	**4 years**	**4 years**	**52 years**		

Figure 6: Life cycle emissions calculation for Scenario B cases

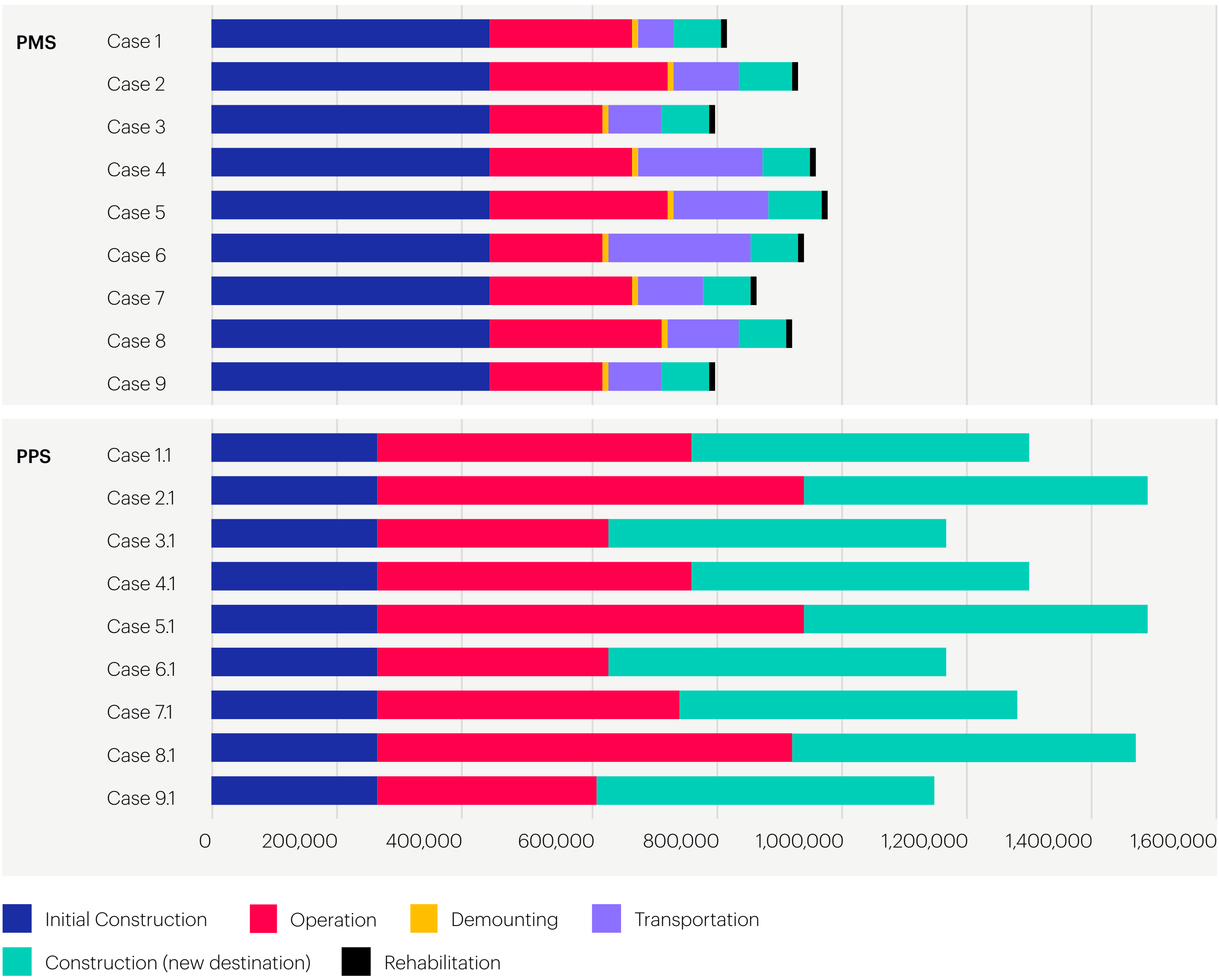
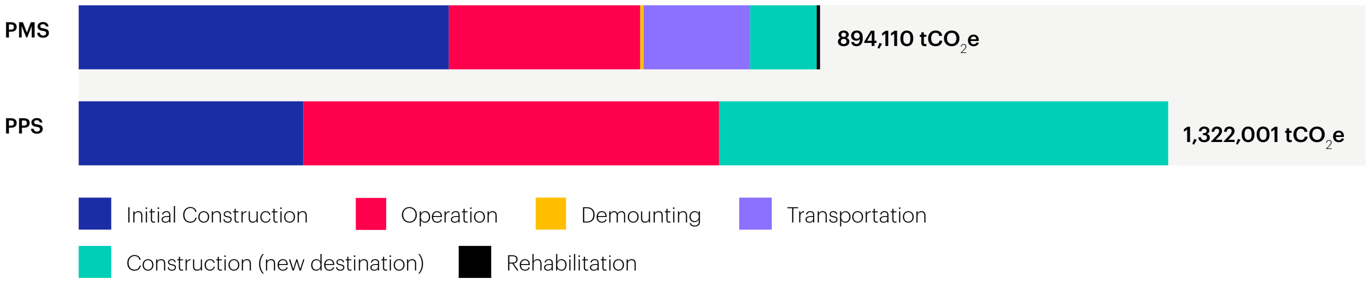


Figure 7 shows the average emissions of the PPS and PMS cases at each life cycle stage of Scenario B. It clearly shows that the main contributor to the PMS's life cycle carbon emissions is the stadium construction at the first location, with 49.8%. As discussed in Scenario A, the construction emissions of the PMS are considerably higher due to the high embodied carbon materials used in the modular construction of the PMS.

The stadium construction at the new locations constitutes 9% of the PMS's life cycle carbon emissions. Emissions from transportation and operation at both locations are responsible for 14.4% and 25.8% respectively. The demounting and rehabilitation emissions are minor compared to the construction, operation, and transportation emissions of the PMS.

For the PPS, the main contributor to life cycle emissions is the construction at the new locations, corresponding to 41.1%. The operation emissions at both locations and the stadium construction emissions at new locations are responsible for 38.4% and 20.5%, respectively.

Figure 7: Life cycle emissions comparison between PPS and PMS averages in Scenario B



3.3 Scenario C: Three-times reuse

Scenario C explores three-times reuse cases for both the PMS and PPS, using three locations each: Jordan, Brazil, and Nepal for the second location, Syria, South Africa and Pakistan for the third location and Pakistan, Nepal, and Brazil for the final location, examining a total of 54 cases. The Scenario C operation assumption follows the same principles as Scenario A and B: both the PMS and PPS operate for four years each at the first location and the next two locations and the remaining 48 years of their operational lifetime at the final location.

In Scenario C, similar to Scenario B, most of the PMS cases have lower total carbon emissions compared to the PPS cases. The relatively high life cycle carbon emissions in Case 18 of the PMS is driven by the long sea and road transport between Brazil and Pakistan. Interestingly, Figure 8 clearly shows how the operational emissions are considerably lower for cases where stadiums are built in Nepal, both for the PMS and PPS cases. As explained under Scenario A, this is driven by Nepal's low EF. It is the main reason why Cases 2, 8 and 17 result in the best-performing three-time reuse cases.

Table 6: Locations for Scenario C

PMS Scenario	First location	Second location	Third location	Fourth location	PPS scenario	Emission reduction in PMS cases w.r.t PPS cases (tCO_2e)
Case 1	Qatar	Jordan	Syria	Pakistan	Case 1.1	578,962
Case 2	Qatar	Jordan	Syria	Nepal	Case 2.1	462,579
Case 3	Qatar	Jordan	Syria	Brazil	Case 3.1	580,023
Case 4	Qatar	Jordan	South Africa	Pakistan	Case 4.1	515,090
Case 5	Qatar	Jordan	South Africa	Nepal	Case 5.1	411,236
Case 6	Qatar	Jordan	South Africa	Brazil	Case 6.1	569,996
Case 7	Qatar	Jordan	Pakistan	Pakistan	Case 7.1	779,539
Case 8	Qatar	Jordan	Pakistan	Nepal	Case 8.1	447,908
Case 9	Qatar	Jordan	Pakistan	Brazil	Case 9.1	515,667
Case 10	Qatar	Brazil	Syria	Pakistan	Case 10.1	436,638
Case 11	Qatar	Brazil	Syria	Nepal	Case 11.1	320,255
Case 12	Qatar	Brazil	Syria	Brazil	Case 12.1	477,487
Case 13	Qatar	Brazil	South Africa	Pakistan	Case 13.1	466,893
Case 14	Qatar	Brazil	South Africa	Nepal	Case 14.1	363,039
Case 15	Qatar	Brazil	South Africa	Brazil	Case 15.1	525,069
Case 16	Qatar	Brazil	Pakistan	Pakistan	Case 16.1	493,966
Case 17	Qatar	Brazil	Pakistan	Nepal	Case 17.1	309,479
Case 18	Qatar	Brazil	Pakistan	Brazil	Case 18.1	417,026
Case 19	Qatar	Nepal	Syria	Pakistan	Case 19.1	509,667
Case 20	Qatar	Nepal	Syria	Nepal	Case 20.1	427,987
Case 21	Qatar	Nepal	Syria	Brazil	Case 21.1	510,728
Case 22	Qatar	Nepal	South Africa	Pakistan	Case 22.1	498,607
Case 23	Qatar	Nepal	South Africa	Nepal	Case 23.1	429,455
Case 24	Qatar	Nepal	South Africa	Brazil	Case 24.1	516,994
Case 25	Qatar	Nepal	Pakistan	Pakistan	Case 25.1	577,657
Case 26	Qatar	Nepal	Pakistan	Nepal	Case 26.1	466,896
Case 27	Qatar	Nepal	Pakistan	Brazil	Case 27.1	499,953
Operation years	**4 years**	**4 years**	**4 years**	**48 years**		

Figure 8: Life cycle emissions calculation for Scenario C cases

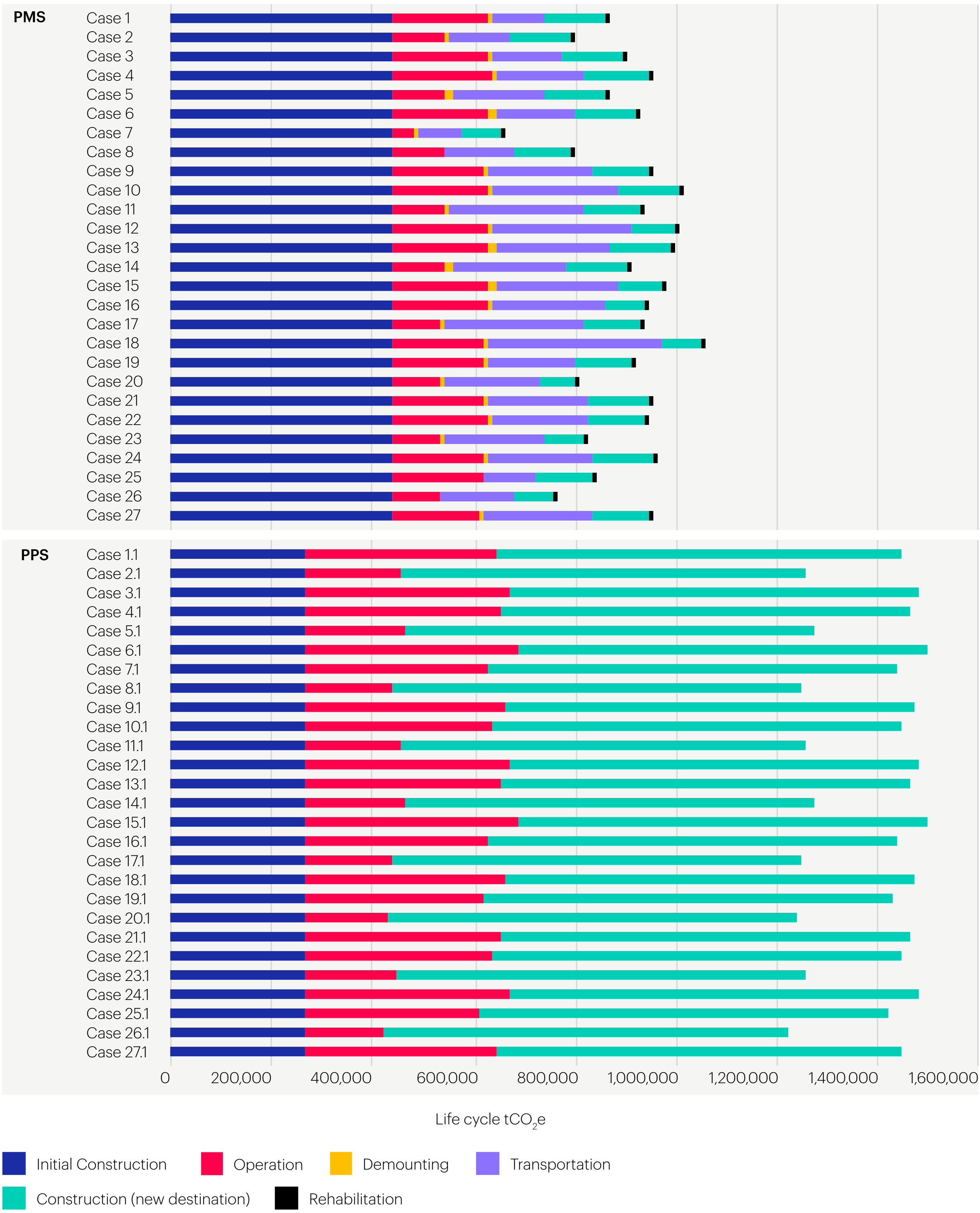
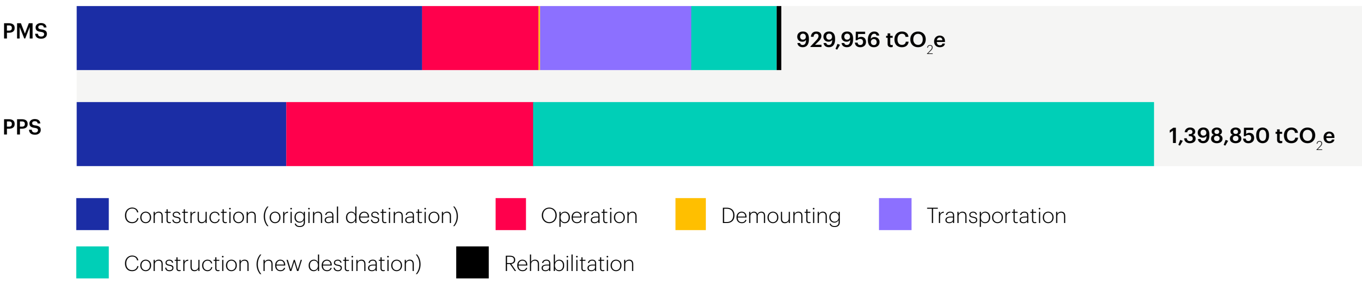


Figure 9 represents the average emissions of the PPS and PMS cases at each life cycle stage of Scenario C. The stadium construction emissions at the first location are still the key contributor to the PMS's life cycle emissions, which contributes to 47.9% of the total. The stadium construction emissions at the second, third and final locations constitute 12.7% of the life cycle emissions. Transportation emissions and the emissions from operations at all locations are responsible for 20.9% and 16.8% respectively.

For the PPS, the main contributor to life cycle carbon emissions is construction at new locations, corresponding to 57.8% of the life cycle emissions, since new stadiums are constructed in multiple locations requiring a large quantity of materials. The total operation emissions and the stadium construction emissions at the first location are responsible for 22.8% and 19.3% respectively. Demounting and rehabilitation emissions are negligible.

Figure 9: Life cycle emissions comparison between averaged PPS and PMS in Scenario C



04. Summary assessment of scenario results

4.0 Summary assessment of scenario results

As seen under Scenarios A-C, the life cycle carbon emissions of a PMS and PPS increase depending on the number of reuse/relocation scenarios. Overall, the PMS's life cycle carbon emissions are less than the emissions of the PPS.

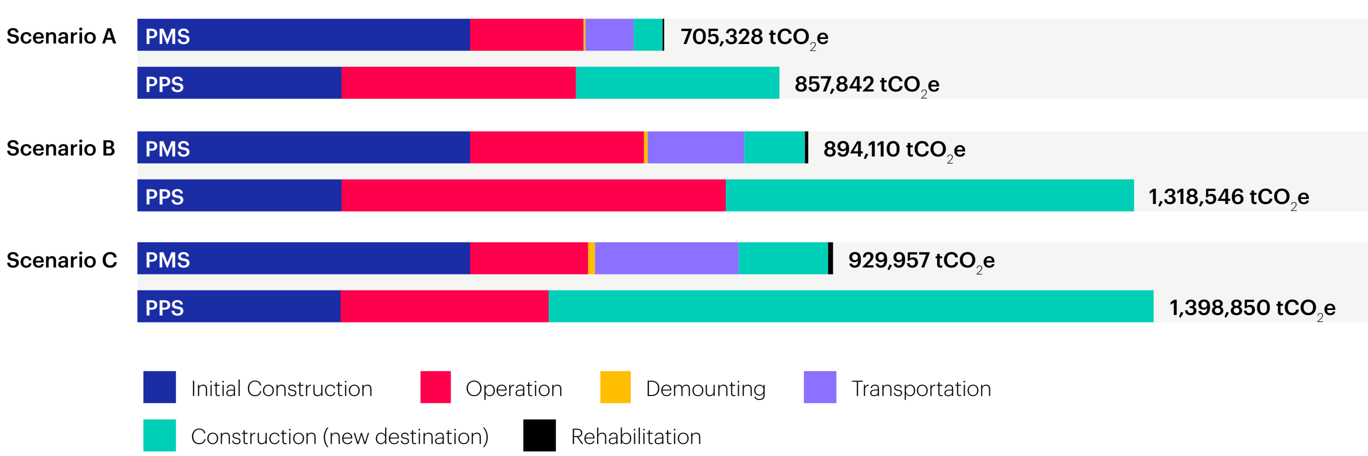
One of the key factors driving this difference is the stadium operation emissions and, depending on the number of reuses, the transport emissions. From the estimates on stadium operation data provided for the FIFA World Cup Qatar 2022, the estimated operational energy consumption of Stadium 974 is far less than the average for the four 40,000-capacity stadiums (PPS). This leads to a significant difference in the stadium operation emissions between the PMS (3,323 tCO_2e /year) and the PPS (6,076 tCO_2e /year). More details on the factors driving this difference can be found in Annexe I. The reason for the energy performance characteristics of both stadiums is not considered to be the main purpose of this study and this factor is not investigated further.

The stadium operation emissions also depend on where the stadium is relocated since the carbon EF for water and energy vary largely by country. The study finds that there is a maximum difference of 14 times in the electricity EF across the locations, the largest outliers assessed being South Africa (1.25 $kgCO_2e$ /kWh) and Nepal (0.085 $kgCO_2e$ /kWh).

Therefore, the results of Scenarios A-C suggest excluding the stadium operation emissions in the following comparative life cycle carbon emissions assessment for the following reasons. First, the operational energy estimates provided are not comparable between the PMS and the PPS, which greatly affects the results of the study. Second, the electricity EF are different from country to country based on the energy mix used for electricity generation and they trigger a substantial variance in the operational carbon emissions. Third, there is more variance in the operation stage emissions than the emissions associated with the different construction methodologies between the PMS and the PPS due to the long lifetime of the stadiums assumed in the study. Depending on the variance of these factors, such as the stadium's lifetime or the chosen locations, the results of the study would vary considerably.

This section of the study therefore focuses on the construction methodology-oriented carbon emissions analysis between the PMS and the PPS. The fundamental advantage of the PMS lies in the reduction of virgin materials required for the stadium construction, but it requires comparatively more carbon-intensive construction materials which then enable its reuse. On the other hand, the PPS requires the construction of a new stadium whenever there is a need for such a stadium in each location, resulting in overall higher emissions of the PPS compared to the PMS in all of the cases analysed.

Figure 10: PMS and PPS life cycle carbon emissions



4.1 Insight on PMS construction-related carbon emissions

To assess the construction-related emission[11], the following section excludes stadium operation emissions. The corresponding results for each scenario are presented in Figure 11. It is notable that, if operation emissions are excluded, the PMS has slightly higher carbon emissions than the PPS under a one-time reuse case. As the number of stadium reuses increases, the gap between the PPS and PMS construction emissions increases correspondingly, and the modular construction methodology becomes more advantageous from a life cycle carbon emission perspective than the conventional construction.

For further investigation of the PMS construction-related emissions at each new location, Figure 12 provides a breakdown of the carbon emissions by stage, excluding the construction at the first location. The construction emissions at the new locations (the base construction and remounting of modular elements) constitute 57% of these emissions and the transportation of the modular elements accounts for 40% on average.

Since the study examines a vast combination of relocation scenarios for the PMS, the transportation emission ranges between 21% to 54%, depending on where they are relocated. If the PMS is relocated within the region or even to a location in the same country, the study finds that the life cycle carbon emissions of the PMS can be significantly reduced. The PMS will then be a more sustainable construction method than the PPS in all scenarios, including one-time reuse.

Figure 11: PMS and PPS construction carbon emissions comparision

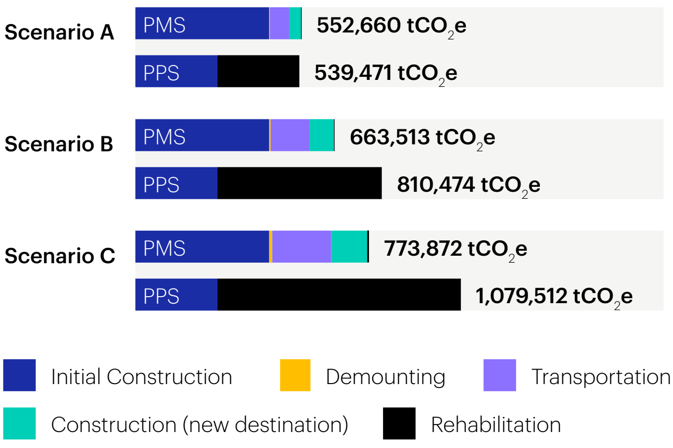
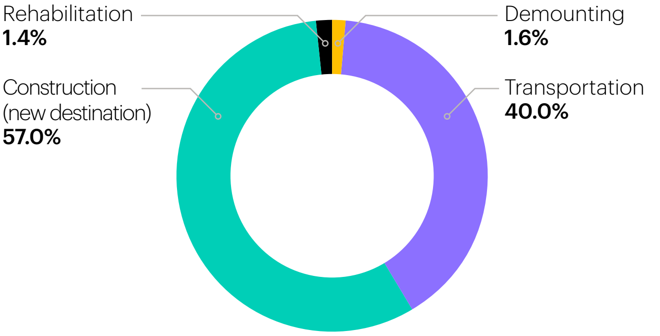


Figure 12: PMS construction-related emissions at new locations with stage breakdown



11 PMS construction-related emissions include emissions for demounting, rehabilitation, transportation and remounting (with base structure construction). PPS construction-related emissions include emissions for construction in new locations.

4.2 Variance in embodied carbon emissions of construction materials

The initial PMS construction emissions (445,321 tCO_2e) are around 65% higher than the PPS construction emissions (270,373 tCO_2e). As shown in Figure 12, most of the construction emissions are attributable to the emissions of the construction materials sourced. Figure 13 shows a breakdown of these materials for the PMS, based on Stadium 974 data. Accordingly, 68.6% of carbon emissions stem from metal (40.5%) and steel (28.1%) and the emissions from concrete only account for 6.4%. It is a noticeable difference from the PPS, for which concrete is the primary material emission source. A detailed data breakdown is provided in Annexe II.

The PMS's life cycle carbon emissions could be further reduced if the design were based on less carbon-intensive materials. However, metal and steel-based materials are chosen due to the flexibility and durability of the modular elements for reuse, enabling a quick and efficient process to dismantle and then reassemble the stadium. This makes it difficult to replace them with a currently available alternative material that displays the same robustness and has a lower carbon content. The analysis shows that the embodied carbon, i.e. the carbon used to produce, transport and install the materials, plays an important role in the overall results. According to building life cycle assessment studies, embodied carbon can account for anything between 2% to 80% of a building's whole-life cycle carbon emissions[12]. The share of life cycle emissions attributable to embodied carbon is expected to increase further, with reductions in operational emissions owing to improved operational efficiency and performance as well as reductions in the carbon intensity of the electricity supply. Consequently, for future demountable stadiums, careful consideration should be given to the sourcing of the steel. Factors such as transport distance from manufacture to installation, recycled content and steel mill manufacturing process (blast furnace v. electric-arc furnace) can decrease the total carbon emissions during the construction of a stadium and therefore influence the overall results regarding the carbon benefits of reusing the stadium.

12 annik Giesekam (2015), Construction sector views on low carbon building materials, Building Research & Information (2016), Vol 44 - Issue 5, 423-444.

Figure 13: PPS and PMS initial construction carbon emissions

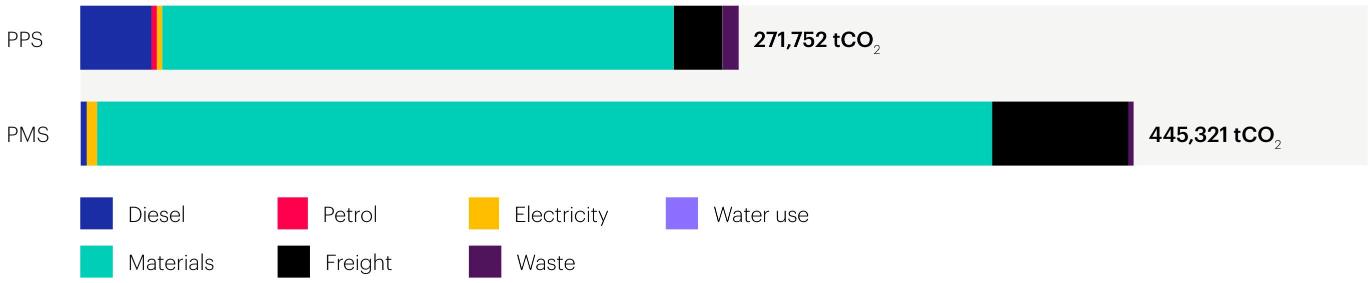
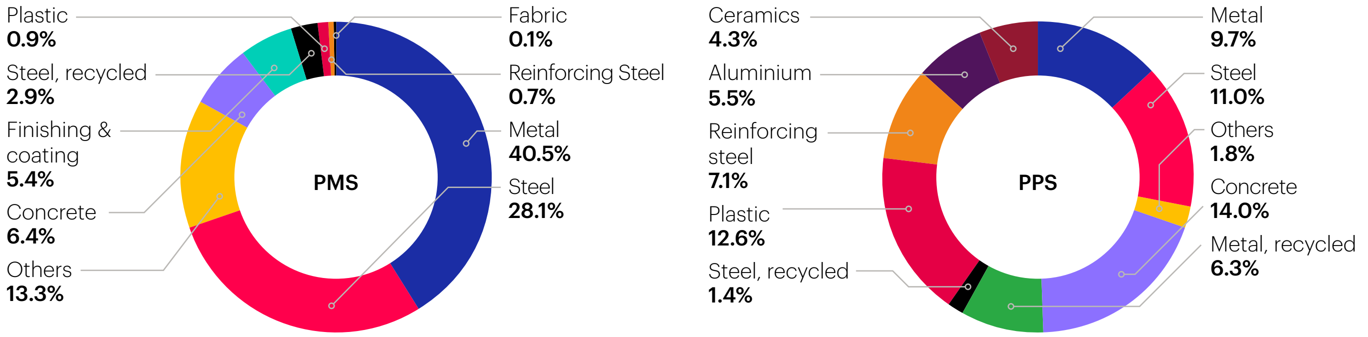
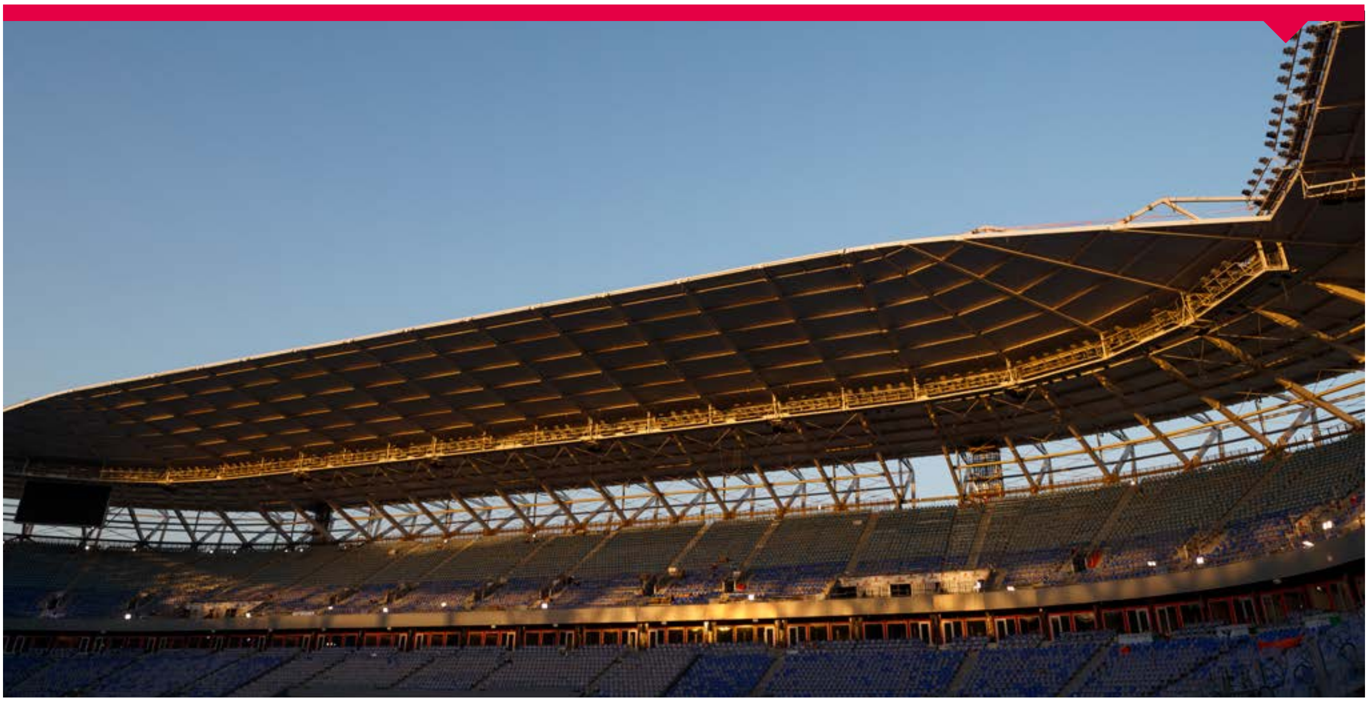


Figure 14: PMS and PPS carbon emissions breakdown of construction materials





4.3 General optimisation of PMS scenarios

As pointed out in the introduction, the locations included in the scenarios of this study are random and based on countries where Qatar supports football development projects. To provide a basis for more general conclusions for the assessment of additional, future real-case scenarios, a formula has been developed to calculate the life cycle carbon emissions for both the PPS and PMS, according to the PMS's number of relocation/reuses and transport distance. This formula excludes the stadium operation stage and is generated based on the 78 location combinations explored in Scenarios A-C of this study. This formula can be applied to any scenario if the number of locations and the total number of kilometres between two locations for road and sea transportation is provided. Further analysis of the optimal scenario for the PMS is explored below.

PPS

N_D = Number of new locations

Formula derivation

Total emissions (tCO_2e) = **270,373** + (**269,713** * N_D)

The above equation is where the construction emissions of the PPS at the original location (Qatar) are 270,373 tCO_2e and the average construction emissions of the PPS at new locations are 269,713 tCO_2e.

PMS

N_D = Number of relocated destinations (number of stadium reuses)

D_T (km) = Total travel distance to the final location

E_{TA} = Average emissions per km for transportation of entire modular stadium elements for Scenario A= **6.638 tCO_2e**

E_{TB} = Average emissions per km for transportation of entire modular stadium elements for Scenario B = **6.688 tCO_2e**

E_{TC} = Average emissions per km for transportation of entire modular stadium elements for Scenario C = **6.747 tCO_2e**

Formula derivation
The formula for the PMS is defined based on each of the three scenarios:

Scenario A
Total Emissions (tCO_2e) = **445,321 + (3213 * N_D) + (6.638* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)**

Scenario B
Total Emissions (tCO_2e) = **445,321 + (3213 * N_D) + (6.688* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)**

Scenario C
Total Emissions (tCO_2e) = **445,321 + (3213 * N_D) + (6.747* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)**

The above equations are based on the results of the study set out below.

- *The construction emissions of the PMS in the original location (Qatar) is 445,321 tCO_2e.*
- *The demounting emissions of the PMS are 3,213 tCO_2e.*
- *The average emissions per km for transporting modular stadium elements via road and sea are specific to the scenarios and denoted as E_{TA}, E_{TB}, and E_{TC}, where E_{TA} = 6.638 tCO_2e , E_{TB} =6.688 tCO_2e, and E_{TC} = 6.747 tCO_2e. Please see Annexe VI for the detailed calculation of the distance coefficient and the formula.*
- *The average construction emissions of the PMS at new locations is 39,426 tCO_2e (only the stadium base needs to be constructed).*
- *The remounting emissions of the PMS at new locations are 3,213 tCO_2e, which are considered equal to the demounting emissions.*
- *The average rehabilitation emissions of the PMS is 2,231 tCO_2e.*

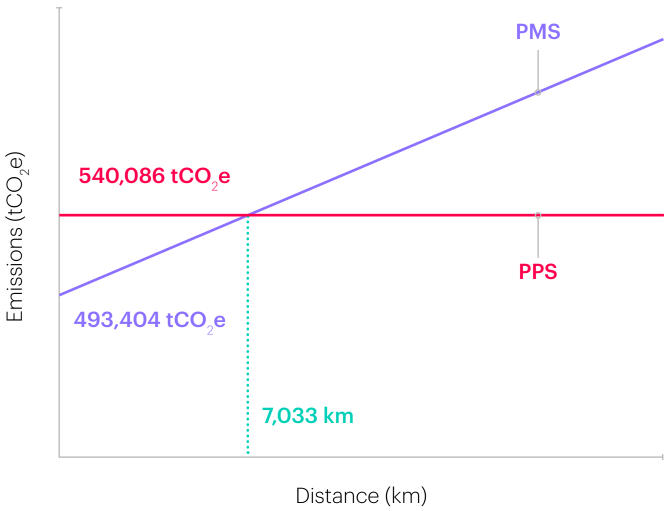
The following sections assess the maximum possible travel distance to maintain lower total carbon emissions for the PMS compared to the PPS for each of the scenarios.

4.3.1 Scenario A

$270{,}373 + (269{,}713 * N_D) = 445{,}321 + (3213 * N_D) + (6.638 * D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)$

$N_D = 1$ and D_T = Distance in km

Figure 15: Scenario B optimisation – PPS v. PMS



In Scenario A, the PMS is reused once, so the number of relocations (N_D) is one. By comparing the formulae of both the PPS and PMS above, the PMS total emissions are less than those of the PPS until the total travel distance (D_T) reaches 7,033 kilometres. The PMS cases will therefore be more environmentally advantageous than the PPS from the life cycle carbon emission perspective when the PMS is relocated within a total sea and road travel distance of 7,033 kilometres. The study calculates the travel distance from Doha to Kathmandu, Nepal, which is 7,023 kilometres, indicating an approximate travel range in which the PMS has potentially fewer life cycle carbon emissions.

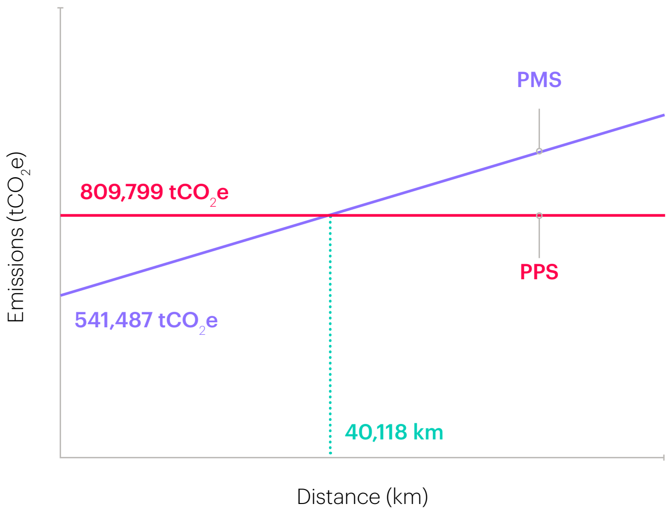
4.3.2 Scenario B

To identify the minimum distance at which PMS cases are less carbon-intensive than PPS cases, the PPS and PMS formula are compared.

$270{,}373 + (269{,}713 * N_D) = 445{,}321 + (3213 * N_D) + (6.688 * D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)$

$N_D = 2$ and D_T = Distance in km

Figure 16: Scenario B optimisation – PPS v. PMS



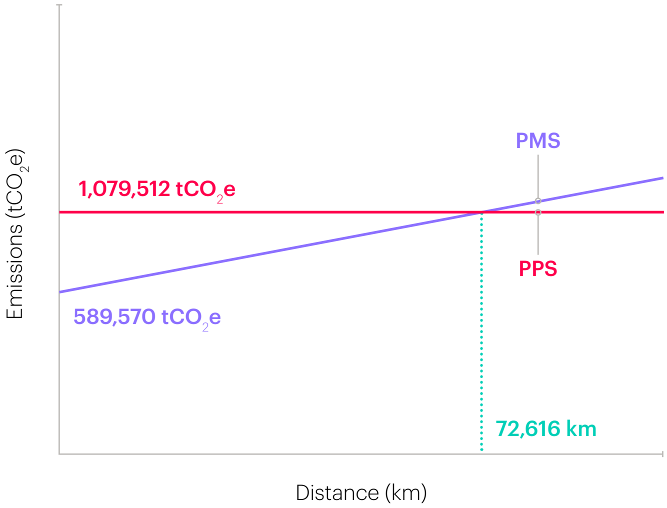
In Scenario B, the PMS is reused twice. In this scenario, the PMS cases have fewer life cycle carbon emissions than PPS cases as long as the total travel distance of the modular elements is below 40,118 kilometres, meaning that the average trip per relocation should be below 20,059 kilometres. Based on the travel distance calculation sampled in this study, the sea and road travel distances from Doha to Brasilia is 16,360. Therefore, under Scenario B, the PMS is more environmentally advantageous than the PPS, even when the PMS is relocated further than the distance between Doha and Brasilia on average.

4.3.3 Scenario C

$270{,}373 + (269{,}713 * N_D) = 445{,}321 + (3213 * N_D) + (6.747 * D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)$

$N_D = 1$ and D_T = Distance in km

Figure 17: Scenario C optimisation – PPS v. PMS



In Scenario C, the PMS is reused three times. In this scenario, the PMS cases have fewer life cycle carbon emissions than PPS cases, as long as the transport distance of the modular elements is below 72,616 kilometres and, thus, when each relocation distance is below 24,205 kilometres. Therefore, for any possible travel distance within the range of 24,205 kilometres per relocation, the life cycle carbon emissions of the PMS will be always lower than the PPS in Scenario C.

05.
Conclusion

5.0 Conclusion

The GHG emissions of the temporary Stadium 974's life cycle were estimated with the aim of providing a better and more detailed understanding of the conditions under which the use of a temporary FIFA World Cup stadium may be more climate-friendly compared to building permanent stadiums. Qatar is the first host country to create a temporary FIFA World Cup-compliant stadium. The design and concept are highly innovative and open up new possibilities for future host countries of mega-sporting events.

The study compared the actual life cycle emissions of Qatar's temporary Stadium 974 (PMS), which was designed to be fully demountable, transportable and rebuildable in a new location, against a comparable permanent stadium. The PPS was modelled by averaging the emission data from the four permanent 40,000-capacity FIFA World Cup 2022 stadiums.

For the temporary stadium, the study assessed the carbon emissions of the initial construction, operation, demounting, transportation, reconstruction and operation in new locations as well as rehabilitation of the temporary stadium grounds. These emissions were compared to the corresponding emissions of a permanent stadium in each location.

A comparison of the life cycle GHG emissions was made for three scenarios: one-time reuse, two-time reuse and three-time reuse of the temporary stadium in new locations using three different locations for each reuse. In summary, depending on how far away from its first location the stadium will be reused, the temporary Stadium 974 is more beneficial from a life cycle carbon emission perspective if it replaces the construction of a permanent stadium in at least one other location. In total, 39 cases based on various combinations of the nine different reuse locations were analysed and compared against each other for each stadium type. This enabled the following four key conclusions to be drawn.

1. **First**, the operational emissions of the temporary Stadium 974 are considerably lower than those of the comparable permanent stadium. This can mainly be attributed to the fact that permanent stadiums have more infrastructure requirements for legacy use than temporary stadiums, which results in larger operational energy demand and corresponding emissions.

2 **Second**, operational emissions should be excluded for the comparative assessment between a temporary and permanent stadium, since they are variables that are largely driven by a country's EF and the number of years during which a stadium is operated in each location. These factors end up determining the overall results to a large extent. For instance, for this study, the destination countries chosen show an EF variance of up to a factor of 14. The results could have varied greatly, had other destinations been chosen for this study.

3 **Third**, the construction of the temporary stadium initially emits more carbon emissions due to the use of carbon-intensive materials such as metal and steel that enhance the durability of the stadium to enable repeated demounting and reconstruction. However, due to the comparatively low emissions of the temporary's stadium reconstruction in the new locations, the overall construction emissions of the permanent stadiums end up exceeding those of the temporary stadium in each analysed case.

4 **Fourth**, for every scenario, there is a limit of how far the temporary stadium can be transported before its life cycle emissions become higher than if a new permanent one had been built. Transport emissions naturally increase the more times a temporary stadium is relocated, as well as the farther the stadium is transported. Although these emissions could be a deciding factor in whether a temporary stadium is more sustainable from a carbon emission perspective than a permanent one under a one-time reuse case, they become, on average, less and less important under two-time and three-time relocation cases. This is because the construction emissions of the second and third permanent stadiums become much more significant compared to the corresponding temporary stadium's transport, reconstruction and rehabilitation emissions. A conclusion has been reached that the temporary stadium's carbon emissions are below those of the permanent stadium, as long as the total temporary stadium's travel distances are below 7,033km for a one-time reuse scenario, 40,118km for a two-time reuse scenario and 72,616km for a three-time reuse scenario.

The present study only assessed the life cycle carbon emissions. There are other factors that should be considered when planning such temporary sports infrastructure solutions. For instance, a modular stadium can minimise the risk of leaving behind sports infrastructure that may not be needed by the host country after the event, and can instead benefit communities in other locations in need of such infrastructure. The use of a temporary stadium could potentially become even more sustainable by reusing the stadium's building blocks within the same country for different purposes such as for various smaller sports facilities, office spaces, commercial buildings and so on, thus avoiding international transport emissions. The design of Stadium 974 enables such a scenario. Economically, the use of a modular stadium by a host city or country could provide benefits, as it could enable cost sharing arrangements between various host countries – and thus savings – as well as new market opportunities for rental arrangements by private companies or event organisers in host cities. Furthermore, a stadium can be placed temporarily in an economically high-value location which is easily accessible, reducing intra-city fan travel needs for the duration of an event – as is the case in Qatar – and made available for future commercial development. The economic and social benefits of such temporary sports infrastructure could provide an interesting area for further in-depth research to complement the analysis of this current study.

Annexes

Annexe I
Review of operational energy consumption for PPS and PMS

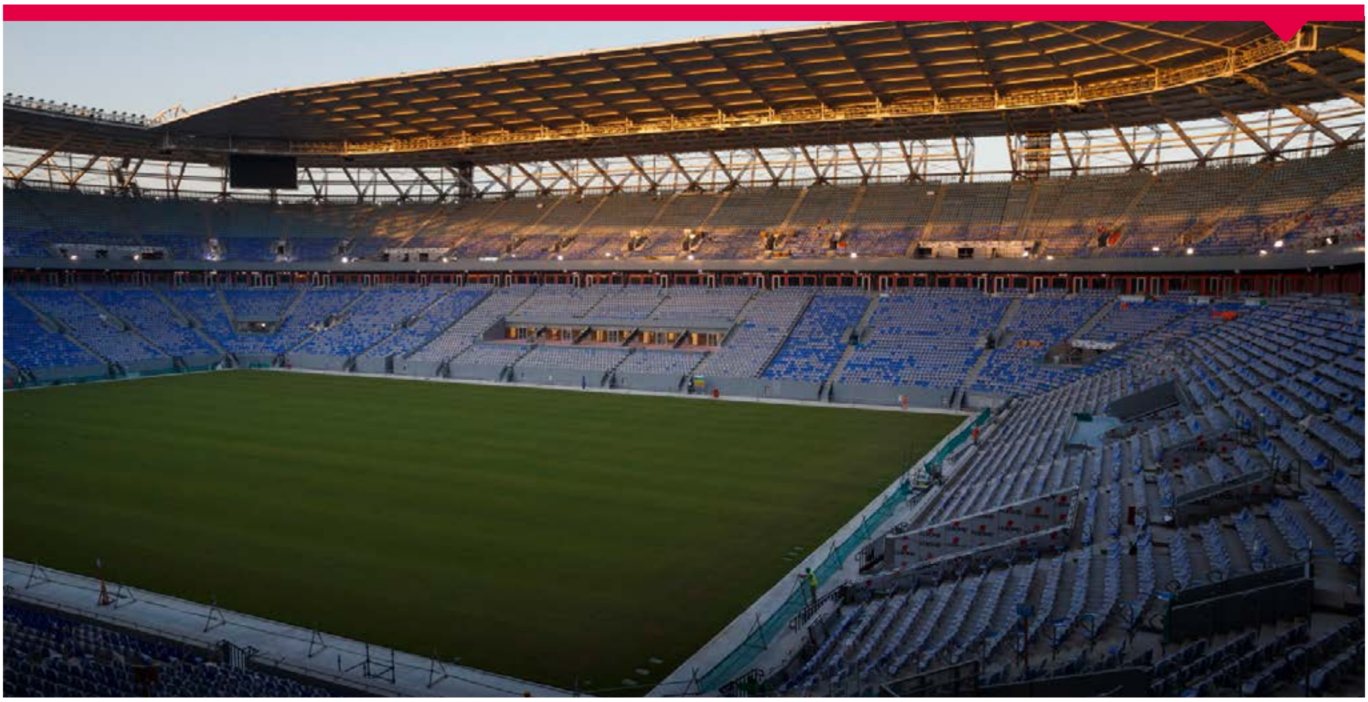
The study found that there is a noticeable difference in operational energy consumption between the PPS and PMS, based on the data provided. The energy consumption of the PPS and PMS is 8,328,588 kWh/year and 4,384,835 kWh/year respectively, as shown in Table 7. Although both stadiums have a capacity of 40,000 people, the PMS's internal area (36,346m^2), based on Stadium 974, is much smaller than that of the PPS (73,712m^2). The difference in area results in the above-mentioned difference in energy consumption.

To test the hypothesis suggesting that the difference in energy consumption was based on the difference in size, the study examined the EUI of the PPS and the PMS. The EUI of the PMS was calculated as 121 kWh/m^2, which was then multiplied by the size of the PPS (73,712m^2). The assessment shows that the adjusted energy consumption of Stadium 974 would be 8,892,664 kWh/year, which is slightly higher than that of PPS.

However, the study did not adopt this type of adjusted energy consumption for the PMS.

Table 7: PPS and PMS operation energy comparison

PMS Scenario	Total stadium Area (m^2)	Bowl area (m^2)	Stadium w/o bowl (m^2)	Energy consumption (kWh)	EUI (kWh/m^2)
PPS	118,942	45,230	73,712	8,328,588	113
PMS	80,531	44,185	36,346	4,384,835	121
Adjusted PMS	-	-	73,712	8,892,664	121



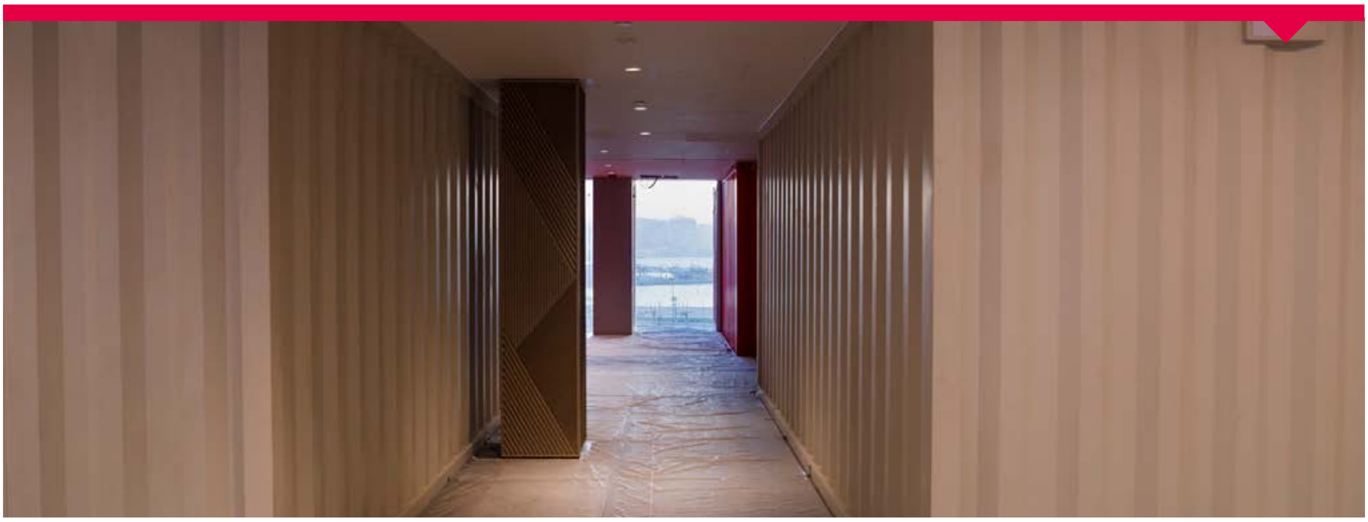
Annexe II
Emission Factors (EF)

Table 8: EF – Electricity (KgCO_2e/kWh)

Activity	Scope 2	Scope 3 – WTT & T&D	Reference
Jordan	0.499	0.165	IEA (2019)
Brazil	0.590	0.056	IGES (2017)
Nepal	0	0.085	IEA (2019)
Syria	0.650	0.211	IEA (2019)
South Africa	1.031	0.223	IGES (2015)
Pakistan	0.417	0.144	IEA (2019)
Qatar	0.5		Qatar's National Emission Inventory Report (Scope 2 and 3 combined)

Table 9: EF – Water (KgCO_2/m3)

Country	Water emissions	Reference
Jordan	0.344	Reference BEIS
Brazil	0.344	Reference BEIS
Nepal	0.344	Reference BEIS
Syria	0.344	Reference BEIS
South Africa	12.6	Same as Qatar EF[13]
Pakistan	0.344	Reference BEIS
Qatar	12.6	Mannan et al. 2019



13 Based on projections in which Cape Town would rely on 40% desalinated water for the city's total water consumption by 2040. This scenario is similar to Qatar, which relies on 54% of the country's water consumption of desalinated water. The water consumption emission factor for the city of Cape Town is therefore assumed to be the same as that of Qatar. The authors consider that such a forecasted value provides a more practical analysis for future stadium developments.

Annexe III
Stadium construction material emissions breakdown

Table 10: Average material emissions from four 40,000-capacity permanent stadiums (key materials)

Materials	Emissions (tCO_2e)	Percentage
Concrete	117,929	14.0%
Plastic	106,490	12.6%
Steel	93,200	11.0%
Metal	82,230	9.7%
Reinforcing steel	60,320	7.1%
Metal, recycled	53,066	6.3%
Aluminium	46,593	5.5%
Ceramics	35,966	4.3%
Other	15,014	1.8%
Steel, recycled	11,499	1.4%

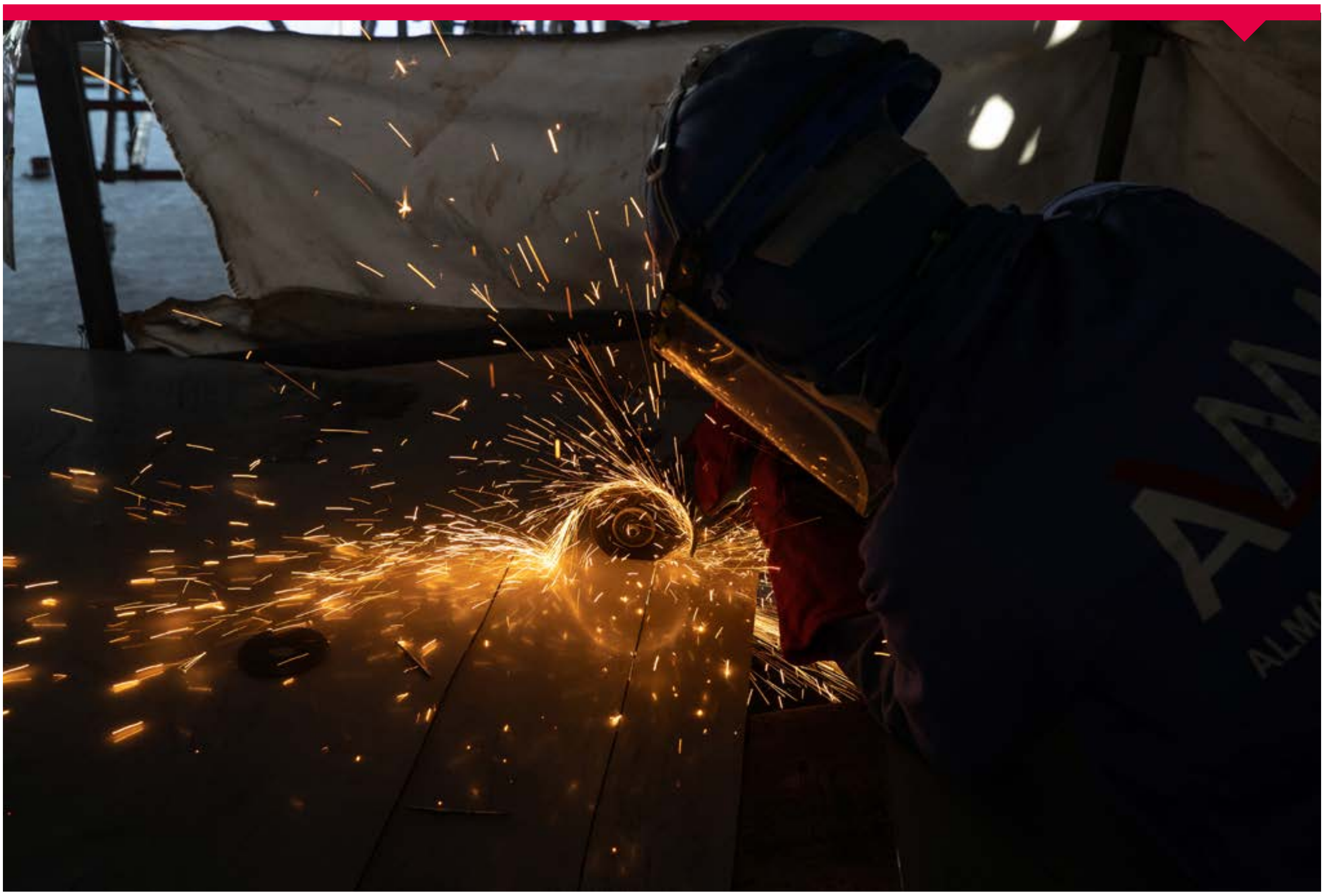
Table 11: Material emissions for 40,000-capacity modular stadium (key materials)

Country	Emissions (tCO2e)	Percentage
Metal	15,4159	40.5%
Finished unspecified	105,744	27.8%
Steel	83,694	22.0%
Others	50,732	13.3%
Concrete	24,206	6.4%
Paint	20,705	5.4%
Steel, recycled	10,952	2.9%
Plastic	3,353	0.9%
Reinforcing steel	2,668	0.7%
Fabric	570	0.1%

Annexe IV
Stadium construction – destination cities

Table 12: Stadium location cities and ports near proposed stadium locations

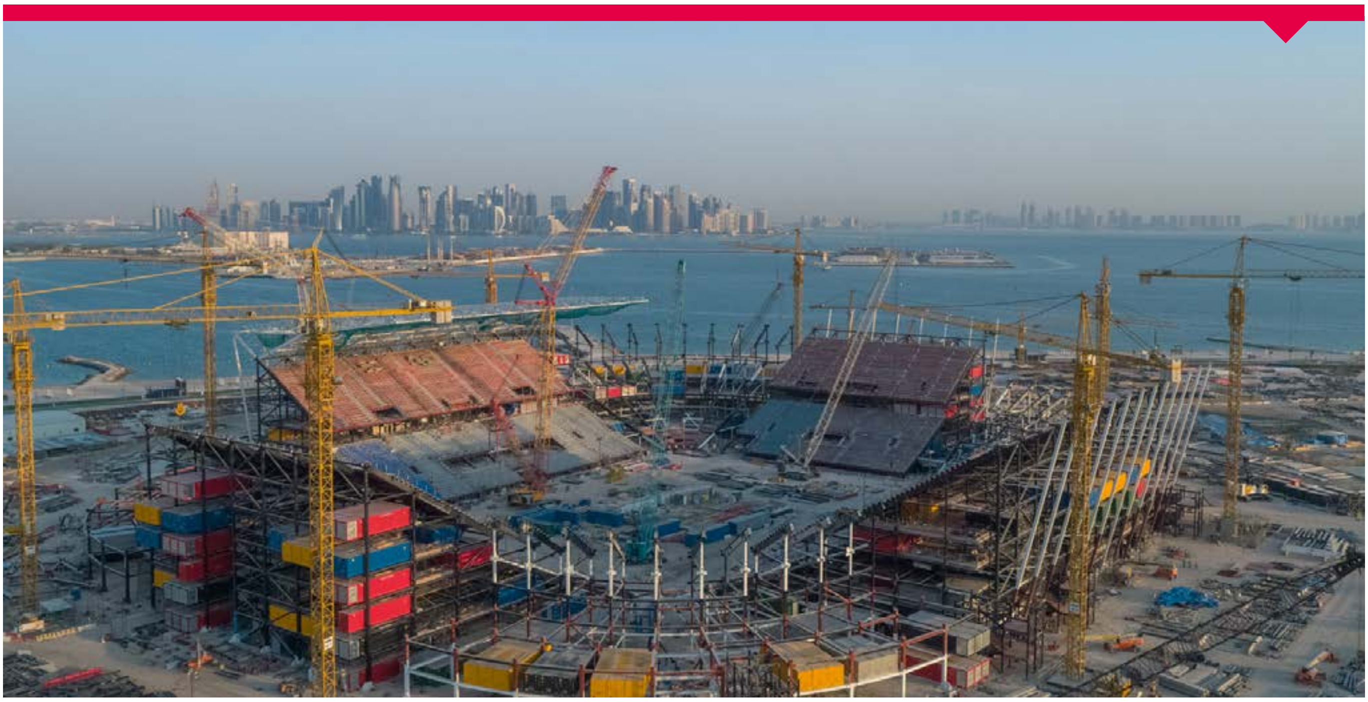
Country	City of stadium	Nearest port
Jordan	Amman	Aqaba Port
Brazil	Brasilia	Port of Rio de Janeiro
Nepal	Kathmandu	Haldia Port
Syria	Damascus	Latakia Port
South Africa	Cape Town	Cape Town Harbour
Pakistan	Islamabad	Karachi Port



Annexe V
Construction emissions – PPS

Table 13: PPS emissions – construction emissions by location

Stadium location	Qatar	Syria	Jordan	South Africa	Pakistan	Nepal	Brazil
Capacity	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**	**40,000**
Emissions (tCO_2e)							
Scope 1	**30,029**	**30,029**	**30,029**	**30,029**	**30,029**	**30,029**	**30,029**
Diesel	30,024	30,024	30,024	30,024	30,024	30,024	30,024
Petrol	5	5	5	5	5	5	5
Scope 2	**1,157**	**1,503**	**1,158**	**2,190**	**979**	**149**	**1,126**
Electricity	1,157	1,503	1,158	2,190	979	149	1,126
Scope 3	**240,565**	**238,258**	**238,258**	**241,736**	**238,258**	**238,258**	**238,258**
Water use	2,405	98	98	3,575	98	98	98
Materials	211,292	211,292	211,292	211,292	211,292	211,292	211,292
Freight	20,959	20,959	20,959	20,959	20,959	20,959	20,959
Waste	5,910	5,910	5,910	5,910	5,910	5,910	5,910
Construction emissions of a PPS	**271,750**	**269,789**	**269,445**	**273,955**	**269,266**	**268,436**	**269,413**



Construction, demounting, transportation and rehabilitation emissions – PMS

Table 14: PMS – construction emissions by location

Stadium location	Qatar	Syria	Jordan	South Africa	Pakistan	Nepal	Brazil
	Complete stadium construction	Stadium base construction	Stadium base construction	Stadium base construction	Stadium base construction	Stadium base construction	Stadium base construction
Emissions (tCO_2e)							
Scope 1	**2,694**	**2,694**	**2,694**	**2,694**	**2,694**	**2,694**	**2,694**
Diesel	2,694	2,694	2,694	2,694	2,694	2,694	2,694
Petrol	0	0	0	0	0	0	0
Scope 2	**4,816**	**7,821**	**6,027**	**11,400**	**5,098**	**777**	**5,863**
Electricity	4,816	7,821	6,027	11,400	5,098	777	5,863
Scope 3	**437,811**	**83,831**	**83,831**	**84,611**	**83,831**	**83,831**	**83,831**
Water use	455	22	22	802	22	22	22
Materials	380,422	26,874	26,874	26,874	26,874	26,874	26,874
Freight	56,597	3998	3998	3998	3998	3998	3998
Waste	337	337	337	337	337	337	337
Construction emissions of a PPS	445,321	41,747	39,952	46,106	39,023	34,702	39,788

Table 15: PMS – demounting emissions by location

Stadium location	Emissions (tCO_2e)
Qatar	2,461
Syria	4,236
Jordan	3,264
South Africa	6,175
Pakistan	2,761
Nepal	421
Brazil	3,175

Table 16: PMS – transportation emissions of modular elements of a PMS

Transportation emissions		
Description	**Value**	**Unit**
Total weight of the modular materials transported	192,879	Tonnes
Transport by road		
Type of trucks used for road transport	Rigid (>7.5 tonnes-17 tonnes)	
Number of trucks/trips required to transport total material (per km), considering one truck can carry 17 tonnes of material (100% laden)	11,345.8319	Trips or trucks required
Emissions for the truck per km travelled if 100% laden	0.70825	$kgCO_2/km$
Total emissions per km to carry 192,879 tonnes of material	8,035.69	$kgCO_2/km$
Transport by sea		
Type of cargo ship used for sea transport	Container ship	3000-4999 TEU
Emissions for the cargo ship per km travelled (considering 4000 TEU Cargo Ship)	0.033662	$kg\ CO_2/km$
Total emissions per km to carry 192,879 tonnes of material	6,492.7	$kg\ CO_2/\ km$

Table 17: PMS – rehabilitation emissions

Rehabilitation emissions	Emissions (tCO_2e)
	2,231

Annexe VI
Transportation combined emission coefficient

Table 18: Distance coefficient calculation – Scenario A

	EF
By road	8,036 tCO_2e/km

Table 19: Distance coefficient calculation – Scenario A for PMS

Scenario A								
Case	Travel distance by road (km)	Emissions by road (tCO_2e)	Travel distance by sea (km)	Emissions by sea (tCO_2e)	Total transportation emissions	Total distance	Road distance %	Sea distance %
Case 1	374	3,005,346	5,432	35,267,788	38,273,135	5,806	6%	94%
Case 2	1,205	9,683,001	15,153	98,384,264	108,067,265	16,358	7%	93%
Case 3	1,008	8,099,971	6,015	39,055,498	47,155,469	7,023	14%	86%
Average					**64,498.62**	**9,729**	**9%**	**91%**

Scenario A – Formula

Calculation of distance coefficient – E_{TA} for PMS

Distance Coefficient = [{(Road EF) * (Average Road Distance %)} + ({(Sea EF) * (Average Sea Distance %)}]

Distance Coefficient = [(8.036*0.09) + (6.493*0.91)]

Therefore, Scenario A: Distance Coefficient = **E_{TA} = 6.638 tCO_2e/km**

Scenario A – PMS Formula = 445,321 + (3213 * N_D) + (6.638* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)

N_D = 1 and D_T = Distance in km

Table 20: Distance coefficient calculation – Scenario B for PMS

Scenario B								
Case	Travel distance by road (km)	Emissions by road (tCO_2e)	Travel distance by sea (km)	Emissions by sea (tCO_2e)	Travel distance by sea (km)	Total distance (km)	Road distance %	Sea distance %
Case 1	1,049	8,429	6,756	43,865	52,295	7,805	13%	87%
Case 2	748	6,011	15,785	102,485	108,495	16,533	5%	95%
Case 3	2,126	17,084	10,473	67,998	85,082	12,599	17%	83%
Case 4	2,711	21,785	26,695	173,321	195,106	29,406	9%	91%
Case 5	2,410	19,366	21,226	137,813	157,179	23,636	10%	90%
Case 6	3,788	30,439	29,812	193,558	223,997	33,600	11%	89%
Case 7	2,317	18,619	15,214	98,781	117,400	17,531	13%	87%
Case 8	2,016	16,200	16,111	104,601	120,801	18,127	11%	89%
Case 9	3,394	27,273	10,680	69,345	96,618	14,074	24%	76%
Average					**128,552.49**		**13%**	**87%**

Scenario B – Formula

Calculation of distance coefficient – E_{TB} for PMS

Distance Coefficient = [{(Road EF) * (Average Road Distance %)} + ({(Sea EF) * (Average Sea Distance %)}]

Distance Coefficient = [(8.036*0.13) + (6.493*0.87)]

Therefore, Scenario B: Distance Coefficient = **E_{TB} = 6.688 tCO_2e/km**

Scenario B – PMS Formula = 445,321 + (3213 * N_D) + (6.688* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)

N_D = 2 and D_T = Distance in km

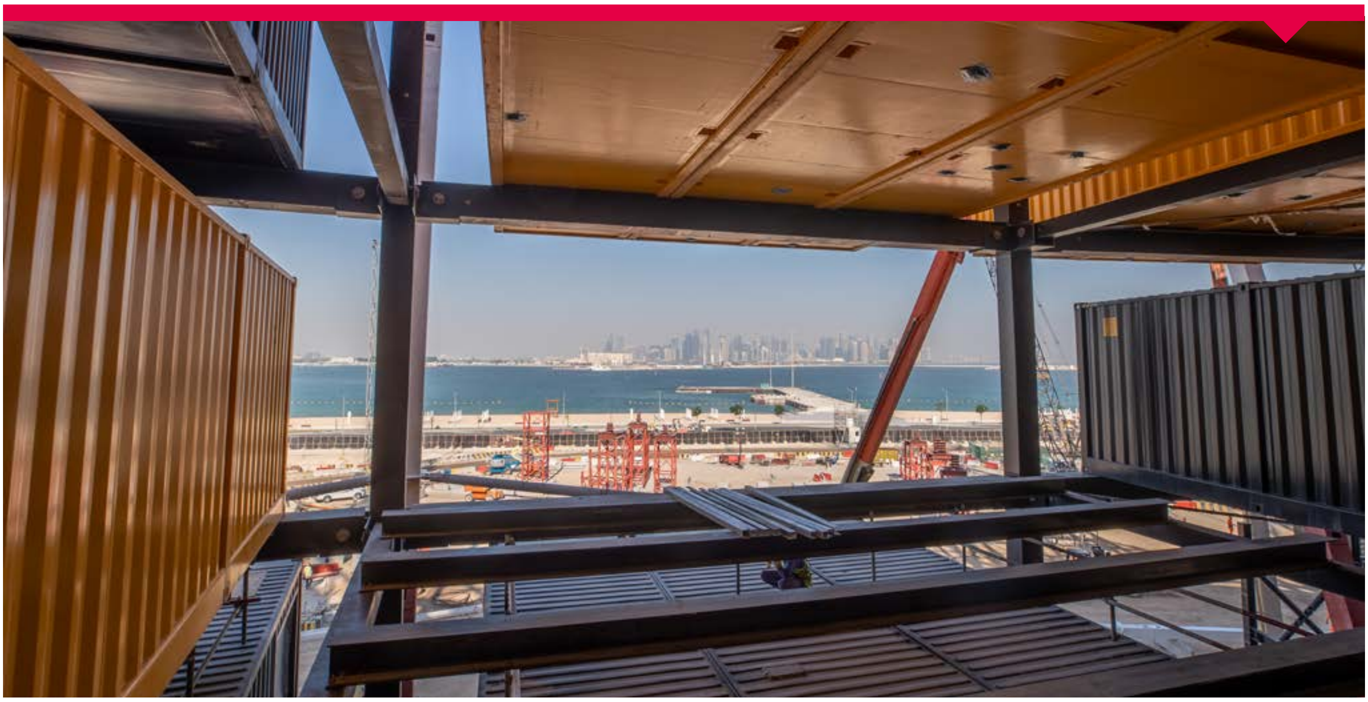


Table 21: Distance coefficient calculation – Scenario C for PMS

Scenario C								
Case	Travel distance by road (km)	Emissions by road (tCO_2e)	Travel distance by sea (km)	Emissions by sea (tCO_2e)	Travel distance by sea (km)	Total distance (km)	Road distance %	Sea distance %
Case 1	2,804	22,532,062	12,653	82,151,221	104,683,283	15,457	18%	82%
Case 2	2,358	18,948,146	15,957	103,602,886	122,551,032	18,315	13%	87%
Case 3	2,555	20,531,176	18,298	118,801,824	139,333,000	20,853	12%	88%
Case 4	2,202	17,694,579	24,506	159,107,868	176,802,447	26,708	8%	92%
Case 5	1,756	14,110,664	25,880	168,030,029	182,140,693	27,636	6%	94%
Case 6	1,953	15,693,694	21,857	141,912,867	157,606,561	23,810	8%	92%
Case 7	2,126	19,599,037	10,473	67,998,412	87,597,449	12,599	17%	83%
Case 8	4,512	36,257,013	15,138	98,288,068	134,545,080	19,650	23%	77%
Case 9	4,709	37,840,043	25,132	163,172,141	201,012,184	29,841	16%	84%
Case 10	4,466	35,887,371	32,591	211,606,731	247,494,102	37,057	12%	88%
Case 11	4,020	32,303,455	35,895	233,058,396	265,361,852	39,915	10%	90%
Case 12	4,217	33,886,486	38,236	248,257,334	282,143,819	42,453	10%	90%
Case 13	3,864	31,049,889	29,947	194,435,779	225,485,667	33,811	11%	89%
Case 14	3,418	27,465,973	31,321	203,357,940	230,823,913	34,739	10%	90%
Case 15	3,615	29,049,003	32,923	213,759,112	242,808,115	36,538	10%	90%
Case 16	3,788	32,954,346	29,812	193,557,992	226,512,338	33,600	11%	89%
Case 17	6,174	49,612,322	34,477	223,847,647	273,459,969	40,651	15%	85%
Case 18	6,371	51,195,352	44,470	288,731,720	339,927,072	50,841	13%	87%
Case 19	4,072	32,721,311	21,113	137,079,028	169,800,339	25,185	16%	84%
Case 20	3,626	29,137,395	24,417	158,530,693	187,668,089	28,043	13%	87%
Case 21	3,823	30,720,425	26,758	173,729,631	204,450,056	30,581	13%	87%
Case 22	3,470	27,883,828	24,832	161,224,176	189,108,004	28,302	12%	88%
Case 23	3,024	24,299,913	26,206	170,146,337	194,446,250	29,230	10%	90%
Case 24	3,221	25,882,943	27,808	180,547,509	206,430,452	31,029	10%	90%
Case 25	3,394	29,788,286	10,680	69,345,154	99,133,440	14,074	24%	76%
Case 26	5,780	46,446,262	15,346	99,634,809	146,081,071	21,126	27%	73%
Case 27	5,977	48,029,292	25,339	164,518,882	212,548,174	31,316	19%	81%
Average					**194,442.76**	**29,013.29**	**14%**	**86%**

Scenario C – Formula

Calculation of distance coefficient – E_{TC} for PMS

Distance Coefficient = [{(Road EF) * (Average Road Distance %)} + ({(Sea EF) * (Average Sea Distance %)}]

Distance Coefficient = [(8.036*0.14) + (6.493*0.86)]

Therefore, Scenario C: Distance Coefficient = **E_{TC} = 6.747 tCO_2e/km**

Scenario C – PMS Formula = 445,321 + (3213 * N_D) + (6.747* D_T) + (39426 * N_D) + (3213 * N_D) + (2231 * N_D)

N_D = 3 and D_T = Distance in km

Impressum

Prepared for:
Fédération Internationale de Football Association (FIFA)
FIFA-Strasse 20, P.O. Box 8044 · Zurich · Switzerland
+41 (0)43 222 7777 · contact@fifa.org
www.fifa.com

Prepared on behalf of South Pole by:
Doyoon Kim, Senior Sustainability Expert
+(974) 4454 8339
dkim@qf.org.qa

Francis Jacob, Sustainability Specialist
+(974) 4454 1898
fjacobs@qf.org.qa

Qatar Foundation
P.O. Box 5825, Doha, Qatar
www.qf.org.qa

Contact:
Eva Van Der Want
Senior Sustainability Advisor
+41 (0) 43 215 29 92
e.vanderwant@southpole.com

Publication date:
November 2021