APPENDIX L IMPACTS TO GREENHOUSE GAS EMISSIONS

L IMPACTS TO GREENHOUSE GAS EMISSIONS

L.1 NATIONAL POLICY AND REGULATION

The national policies and regulations for Bhutan include a comprehensive framework designed to promote sustainable development, environmental conservation, and social well-being. Central to these policies is the commitment to reducing GHG emissions, aligning with global efforts to combat climate change. The following sections outline Bhutan's commitments and national policy frameworks:

Bhutan's Commitment to GHG Emission Reduction

Bhutan is a signatory to three significant international conventions on Climate change, including:

1. The United Nations Framework Convention on Climate Change (UNFCCC) of 1992, ratified in 1994
2. The Kyoto Protocol of 1998, ratified in 2002, and
3. The Paris Agreement of 2016, ratified in the same year.

Policy Framework Supporting Implementation of GHG Reduction Targets

Bhutan has issued and adopted mitigation-related policies, legal documents, and strategies as well as programs, plans, and schemes to support the implementation of GHG reduction targets. Some of the key documents are listed below:

1. *Forest and Nature Conservation Act of Bhutan (1995):* Ensures the protection and sustainable utilization of flora, fauna, and other natural resources of Bhutan to benefit present and future generations incorporating the concepts of sustainable development.
2. *The National Environment Protection Act (NEPA) (2007):* An umbrella legislation on environment conservation and protection and outlines principles and a legal framework that has implications for all spheres of development in Bhutan.
3. *Bhutan Sustainable Hydropower Policy (2008):* Aims to mobilize fund and attract investments for accelerated hydropower development, enhance the revenue contribution to the Royal Government, and contribute towards the development of clean energy to mitigate problems related to global warming and climate change.
4. *National Strategy and Action Plan for Low Carbon Development (2012):* Ensures that national emissions of greenhouse gasses (GHG) remain less than the national sequestration capacity.
5. *Climate Change Policy of Kingdom of Bhutan (2020):* Aims to remain carbon neutral, ensure coordinated stakeholder participation, and integrate climate change challenges and opportunities into relevant plans and policies.
6. *2nd Nationally Determined Contributions (2021):* Maintains the commitment to remain carbon-neutral where the mission of greenhouse gases will not exceed carbon sequestration by its forests and sinks as first pledged in 2009 and reaffirmed in the first NDC.
7. *Low Emission Development Strategy (LEDS) for Surface Transport (2021):* Includes various targeted interventions to control emissions, such as promoting low-carbon vehicles, improving fuel efficiency, and enhancing public transportation systems. By addressing the transport sector, which is a significant source of GHG emissions in Bhutan, the plan plays a crucial role in the country's overall low emission development efforts.

Bhutan is a country with low greenhouse gas emissions, and its landscape is filled with forests, making it a net carbon sink according to its GHG inventories. Therefore, Bhutan does not have

a target to reduce greenhouse gas emissions but aims to maintain its carbon neutral status instead.

International Standards and Guidelines

The international standards and guidelines applicable for Bhutan include a range of frameworks designed to ensure sustainable development, environmental protection, and social responsibility. Key among these are the standards set by the Intergovernmental Panel on Climate Change (IPCC) and the Greenhouse Gas Protocol as detailed below:

Intergovernmental Panel on Climate Change (IPCC)

IPCC is a panel established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to provide independent scientific advice on climate change.

The IPCC has developed a variety of guidance documents and recommended methodologies for GHG emissions inventories, including:

- The 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006).
- The 2019 IPCC Guidelines for National Greenhouse Gas Inventories, Refinement to the 2006.
- IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019).
- The Physical Science Basis, the Contribution of Working Group I to the Sixth Assessment Report of the intergovernmental Panel on Climate Change (IPCC, 2021).

The Greenhouse Gas Protocol Standard

The 'Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard' was designed by the World Resources Institute (WRI) to develop internationally accepted GHG accounting and reporting standards for businesses.

The standard and guidance were designed to support the businesses prepare a GHG inventory that represents a true and fair account of their emissions, through the use of standardized approaches and principles. The GHG protocol has been adopted by the International Organization for Standardization, endorsed by GHG initiatives (such as Carbon Disclosure Project) and is compatible with existing GHG trading schemes. For this assessment, we will use the 'Construction CO_2-e Measurement Protocol'[76] as a guide for reporting in accordance with the Greenhouse Gas Protocol for construction companies. The Greenhouse Gas Protocol uses the methodologies and emission factors from the 2006 IPCC Guidelines as its basis.

L.2 ASSUMPTIONS

Assumptions:

1) **Vehicle Types and Ratio:** The types of vehicles will be based on the vehicles running along the old road in 2024 (Traffic Count Venue: Aie Bridge, Gelephu) and linked to ARUP's model projections. However, due to Bhutan's diverse fuel usage, the proportion of vehicles using each type of fuel will also be calculated, referencing research from the Vehicle

[76] Construction CO_2e Measurement Protocol, Available in; https://ghgprotocol.org/sites/default/files/2023-03/ENCORD-Construction-CO2-Measurement-Protocol-Lo-Res_FINAL_0.pdf

Emission Control Strategy Bhutan from ADB Vehicle Emission Control Strategy for Bhutan [77]. However, this calculation does not include two-wheeled vehicles.

2) **Fuel Usage:** Assuming Heavy vehicles and Medium use only diesel, while light vehicles includes both diesel and gasoline-powered for conservative estimates, with no transition to electric vehicles (EVs) included.
3) **Vehicle Growth Rate:** Based on the statistical numbers of vehicles running along the old road in 2024 (Traffic Count Venue: Aie Bridge, Gelephu), with a gradual increase to ARUP's model projections, using the growth rate of vehicle from 2035 and 2053.
4) **Operational Period:** Covering a period of 25 years. The calculation of GHG emissions during the operation phase will begin in 2029 and end in 2053.

This approach ensures consistency and allows for a more accurate comparison of the emissions attributable to the different routes, or the two scenarios. The rationales are delineated below:

- **Consistency**: Using similar parameters for vehicle types, fuel usage, and growth rates ensures that the comparison is based on consistent data, making it easier to isolate the impact of the route differences on GHG emissions.
- **Control Variables**: By keeping these factors constant, variables that could otherwise skew the results are under controlled condition. This helps in focusing on the differences in emissions due to the route characteristics alone.
- **Realistic Projections**: Assuming similar growth rates and vehicle types reflects a realistic scenario, as these factors are likely to be influenced by broader economic and policy trends that affect both routes similarly.

L.3 EMISSION FACTOR

The tables below provide emission factors for fuel used in mobile combustion sources. Fuel use data are most accurate for calculating CO_2 emissions, while distance-traveled data are most accurate for calculating CH_4 and N_2O emissions. For transport emission sources, the recommended approach is to collect both fuel use and distance data. Where one type of data is unavailable, vehicle fuel economy information (e.g., MPG) can be used to convert between these data types. For non-U.S. or U.K. countries, if more specific emission factors are not available, the 'Other' region can be considered. Emission factors from "Other" region are based on LHV (or NCV). Reporting organizations should consistently use the same calorific value within an inventory.

TABLE L-1 GHG EMISSIONS FACTOR

CO_2 Emission factors by fuel				
Region	Fuel	Fossil CO_2 EF	Biogenic CO_2 EF	EF Unit
Other[1]	Jet Kerosene	2.57		kg/L
Other[1]	Aviation Gasoline	2.18		kg/L
Other[1]	Motor Gasoline/Petrol	2.29		kg/L
Other[1]	On-Road Diesel Fuel	2.91		kg/L
Other[1]	Residual Fuel Oil	3.01		kg/L
Other[1]	Liquefied Petroleum Gases (LPG)	1.47		kg/L

[77] Vehicle Emission Control Strategy Bhutan, Available in; vehicle emission control strategy bhutan (adb.org)

CO_2 Emission factors by fuel				
Other[1]	Compressed Natural Gas (CNG)	1.88		kg/m^3
US	Kerosene - Type Jet Fuel	9.75		kg/US Gallon
US	Aviation Gasoline	8.31		kg/US Gallon
US	Motor Gasoline	8.78		kg/US Gallon
US	Diesel Fuel	10.21		kg/US Gallon
US	Residual Fuel Oil[2]	11.27		kg/US Gallon
US	Liquefied Petroleum Gases (LPG)	5.68		kg/US Gallon
US	Compressed Natural Gas (CNG)	0.054		kg/scf
US	Liquefied Natural Gas (LNG)	4.50		kg/US Gallon
US	Ethanol (100%)		5.75	kg/US Gallon
US	Biodiesel (100%)		9.45	kg/US Gallon
US	E85 Ethanol/Gasoline*	1.32	4.89	kg/US Gallon
US	B20 Biodiesel/Diesel*	8.17	1.89	kg/US Gallon
UK	Aviation spirit (Aviation Gasoline)	2.283		kg/L
UK	Aviation turbine fuel (Jet Fuel)	2.520		kg/L
UK	Diesel (100% mineral diesel)	2.626		kg/L
UK	Fuel oil (Residual Fuel Oil)	3.163		kg/L
UK	Petrol (100% mineral petrol) (Motor Gasoline)	2.331		kg/L
UK	Processed fuel oils - residual oil	3.163		kg/L
UK	Compressed Natural Gas (CNG)	0.448		kg/L
UK	Liquefied Natural Gas (LNG)	1.166		kg/L
UK	Liquefied Petroleum Gases (LPG)	1.555		kg/L
UK	Natural gas (100% mineral blend)	2.050		kg/m^3
UK	Bioethanol[3]		1.52	kg/L
UK	Biodiesel ME[3]		2.39	kg/L
UK	E85 Ethanol/Gasoline*	0.350	1.292	kg/L
UK	B20 Biodiesel/Diesel*	2.101	0.478	kg/L

1 'Other' region EFs are from the Stationary Combustion worksheet (values from liquid basis and gas basis columns).
2 This value corresponds to Residual Fuel Oil No. 6.
3 UK DEFRA only presented values in CO2e, using GWP-100 from the IPCC's Fifth Assessment Report (AR5). CH4 and N2O values presented in this table were reverse calculated using the same GWP values in order to be provided per individual GHG.
*Note: EFs for biofuel blends (E85 Ethanol/Gasoline and B20 Biodiesel/Diesel) were calculated with corresponding EFs of pure fuels and percentage composition within the blend (e.g., 85% Ethanol EF and 15% Motor Gasoline EF). Commonly used alternative fuel names are provided in parenthesis.

TABLE L-2 CH_4 AND N_2O EMISSION FACTORS BY FUEL AND VEHICLE TYPE

CH_4 and N_2O Emission Factors by Fuel and Vehicle Type

Region	Fuel	Transport Type	Vehicle/Engine Type	CH_4 EF		N_2O EF	
				EF	EF Unit	EF	EF Unit Numerator
Other	Sub-bituminous Coal	Rail		2	kg/TJ	1.5	kg/TJ
Other	Diesel	Rail		4.15	kg/TJ	28.6	kg/TJ
Other	Diesel	Agriculture Equipment		4.15	kg/TJ	28.6	kg/TJ
Other	Diesel	Forestry Equipment		4.15	kg/TJ	28.6	kg/TJ
Other	Diesel	Industry Equipment		4.15	kg/TJ	28.6	kg/TJ
Other	Diesel	Household Equipment		4.15	kg/TJ	28.6	kg/TJ
Other	Motor Gasoline	Agriculture Equipment	4 stroke	80	kg/TJ	2	kg/TJ
Other	Motor Gasoline	Industry Equipment	4 stroke	50	kg/TJ	2	kg/TJ
Other	Motor Gasoline	Household Equipment	4 stroke	120	kg/TJ	2	kg/TJ
Other	Motor Gasoline	Agriculture Equipment	2 stroke	140	kg/TJ	0.4	kg/TJ
Other	Motor Gasoline	Forestry Equipment	2 stroke	170	kg/TJ	0.4	kg/TJ
Other	Motor Gasoline	Industry Equipment	2 stroke	130	kg/TJ	0.4	kg/TJ
Other	Motor Gasoline	Household Equipment	2 stroke	180	kg/TJ	0.4	kg/TJ
US	Residual Fuel Oil	Ship and Boat		1.1	g/US Gallon	0.31	g/US Gallon
US	Motor Gasoline	Ship and Boat	2 stroke	4.64	g/US Gallon	0.08	g/US Gallon
US	Motor Gasoline	Ship and Boat	4 stroke	2.26	g/US Gallon	0.01	g/US Gallon
US	Diesel Fuel	Ship and Boat		6.41	g/US Gallon	0.17	g/US Gallon
US	Diesel Fuel	Locomotives		0.8	g/US Gallon	0.26	g/US Gallon
US	Jet Fuel	Aircraft		0	g/US Gallon	0.3	g/US Gallon
US	Aviation Gasoline	Aircraft		7.06	g/US Gallon	0.11	g/US Gallon
US	Motor Gasoline	Agricultural Equipment[1]	2 stroke	6.92	g/US Gallon	0.47	g/US Gallon
US	Motor Gasoline	Agricultural Equipment[1]	4 stroke	1.94	g/US Gallon	1.21	g/US Gallon

CH_4 and N_2O Emission Factors by Fuel and Vehicle Type							
US	Motor Gasoline	Agricultural Equipment[1]	Off-Road Trucks	1.94	g/US Gallon	1.2	g/US Gallon
US	Diesel Fuel	Agricultural Equipment[1]		1.27	g/US Gallon	1.07	g/US Gallon
US	Diesel Fuel	Agricultural Equipment[1]	Off-Road Trucks	0.91	g/US Gallon	0.56	g/US Gallon
US	LPG	Agricultural Equipment[1]		0.33	g/US Gallon	0.95	g/US Gallon
US	Motor Gasoline	Construction Equipment[2]	2 stroke	7.98	g/US Gallon	0.12	g/US Gallon
US	Motor Gasoline	Construction Equipment[2]	4 stroke	2.85	g/US Gallon	1.47	g/US Gallon
US	Motor Gasoline	Construction Equipment[2]	Off-Road Trucks	2.85	g/US Gallon	1.47	g/US Gallon
US	Diesel Fuel	Construction Equipment[2]		1.01	g/US Gallon	0.94	g/US Gallon
US	Diesel Fuel	Construction Equipment[2]	Off-Road Trucks	0.91	g/US Gallon	0.56	g/US Gallon
US	LPG	Construction Equipment[2]		0.59	g/US Gallon	0.5	g/US Gallon
US	Motor Gasoline	Lawn and Garden Equipment	2 stroke	7.29	g/US Gallon	0.31	g/US Gallon
US	Motor Gasoline	Lawn and Garden Equipment	4 stroke	3.00	g/US Gallon	1.49	g/US Gallon
US	Diesel Fuel	Lawn and Garden Equipment		0.66	g/US Gallon	0.49	g/US Gallon
US	LPG	Lawn and Garden Equipment		0.41	g/US Gallon	0.63	g/US Gallon
US	Motor Gasoline	Airport Equipment		1.02	g/US Gallon	1.07	g/US Gallon
US	Diesel	Airport Equipment		1.89	g/US Gallon	1.16	g/US Gallon
US	LPG	Airport Equipment		0.35	g/US Gallon	0.89	g/US Gallon
US	Motor Gasoline	Industrial/Commercial Equipment	2 stroke	7.13	g/US Gallon	0.5	g/US Gallon
US	Motor Gasoline	Industrial/Commercial Equipment	4 stroke	2.74	g/US Gallon	1.54	g/US Gallon
US	Diesel	Industrial/Commercial Equipment		0.42	g/US Gallon	0.6	g/US Gallon
US	LPG	Industrial/Commercial Equipment		0.44	g/US Gallon	0.64	g/US Gallon
US	Motor Gasoline	Logging Equipment	2 stroke	9.68	g/US Gallon	0	g/US Gallon
US	Motor Gasoline	Logging Equipment	4 stroke	3.24	g/US Gallon	2.06	g/US Gallon
US	Diesel	Logging Equipment		0.49	g/US Gallon	1.27	g/US Gallon
US	Motor Gasoline	Railroad Equipment		3.24	g/US Gallon	1.81	g/US Gallon

CH_4 and N_2O Emission Factors by Fuel and Vehicle Type							
US	Diesel	Railroad Equipment		0.4	g/US Gallon	0.95	g/US Gallon
US	LPG	Railroad Equipment		2.00	g/US Gallon	0.01	g/US Gallon
US	Motor Gasoline	Recreational Equipment	2 stroke	9.8	g/US Gallon	0.11	g/US Gallon
US	Motor Gasoline	Recreational Equipment	4 stroke	2.72	g/US Gallon	1.48	g/US Gallon
US	Diesel	Recreational Equipment		0.73	g/US Gallon	0.66	g/US Gallon
US	LPG	Recreational Equipment		0.43	g/US Gallon	0.61	g/US Gallon

[1]Includes equipment, such as tractors and combines, as well as fuel consumption from trucks that are used off-road in agriculture.
[2]Includes equipment, such as cranes, dumpers, and excavators, as well as fuel consumption from trucks that are used off-road in construction.
Note: Energy-basis EFs (kg/TJ) are LHV (NCV).

L.4 GHG EMISSION CALCULATION

GHG emission calculation of construction phase, the calculation based on used of construction equipment and fuel consumption of each equipment. The GHG emission calculation result is show in table below.

TABLE L-3 GHG EMISSIONS CALCULATION IN CONSTRUCTION PHASE

Activity	Equipment		GHG emission					
	Type	Amount	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Scope 1 (ton CO_2-e)	Scope 2 (ton CO_2-e)	Total (ton CO_2-e)
Road Construction								
Site Clearance	Crane, mobile	1	159.28	0.44	3.71	163.42		163.42
	Excavator/loader, wheeled/tracked	1	142.81	0.39	3.33	146.53		146.53
	Lorry	1	71.28	0.19	1.66	73.13		73.13
Roadworks, Pavement, Drainage and Utilities	Air compressor, air flow > 10 m^3/min and <= 30 m^3/min	2	445.40	1.22	10.38	456.99		456.99
	Asphalt paver	2	1,187.97	3.25	27.68	1,218.90		1,218.90
	Crane, mobile	2	796.38	2.18	18.55	817.11		817.11
	Dump truck	2	761.18	2.08	17.73	781.00		781.00
	Excavator/loader, wheeled/tracked	2	714.04	1.95	16.64	732.63		732.63
	Generator, silenced, 75 dB(A) at 7 m	2	739.18	2.02	17.22	758.42		758.42
	Lorry	2	356.39	0.97	8.30	365.67		365.67
	Paint line marker	2	-	-	-		-	-
	Roller, vibratory	2	272.10	0.74	6.34	279.19		279.19
	Water pump, submersible	2	74.52				74.52	74.52
Culverts	Crane, mobile (diesel)	1	238.91	0.65	5.57	245.13		245.13
	Excavator/loader, wheeled/tracked	1	214.21	0.59	0.02	214.82		214.82
	Lorry	1	106.92	0.29	0.01	107.22		107.22
	Concrete lorry mixer	1	106.92	0.29	0.01	107.22		107.22
	Bar bender and cutter (electric)	1	74.52	-	-		74.52	74.52
	Poker, vibratory, hand-held	2	30.17	0.08	0.003	30.26		30.26
	Generator, silenced, 75 dB(A) at 7 m	1	221.75	0.61	5.167	227.53		227.53
	Saw, circular, wood	1	181.02	0.49	0.015	181.53		181.53
Slope Works	Breaker, hand-held, mass <= 10 kg	4	75.43	0.21	0.006	75.64		75.64
	Breaker, excavator mounted (hydraulic)	1	357.02	0.98	0.030	358.03		358.03
	Compactor, vibratory	1	251.42	0.69	0.021	252.13		252.13
	Drilling rig	1	471.42	1.29	0.040	472.75		472.75
	Excavator/loader, wheeled/tracked	1	357.02	0.98	0.030	358.03		358.03
	Generator, silenced, 75 dB(A) at 7 m	1	369.59	1.01	0.032	370.63		370.63
	Grout mixer	1	94.28	0.26	0.008	94.55		94.55
	Grout pump	1	118.95	0.33	0.010	119.29		119.29
	Lorry	1	178.20	0.49	0.015	178.70		178.70
Bridge Construction								
Piling Works	Air compressor, air flow > 10 m^3/min and <= 30 m^3/min	1	356.32	0.97	8.30	365.59		365.59
	Breaker, hand-held, mass <= 10 kg	1	30.17	0.08	0.00	30.26		30.26
	Concrete lorry mixer	1	285.11	0.78	0.02	285.92		285.92

Activity	Equipment		GHG emission					
	Type	Amount	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Scope 1 (ton CO_2-e)	Scope 2 (ton CO_2-e)	Total (ton CO_2-e)
	Crane, mobile	1	637.11	1.74	0.05	638.90		638.90
	Excavator/loader, wheeled/tracked	1	571.23	1.56	0.05	572.84		572.84
	Generator, silenced, 75 dB(A) at 7 m	1	591.35	1.62	0.05	593.01		593.01
	Lorry	1	285.11	0.78	0.02	285.92		285.92
	Piling, large diameter bored, grab and chisel	1	754.27	2.06	0.06	756.39		756.39
	Water pump	1	59.62	-	-		59.62	59.62
Construction of Pile Caps and Piers	Air compressor, air flow > 10 m^3/min and <= 30 m^3/min	1	133.62	0.37	3.11	137.10		137.10
	Bar bender and cutter	1	178.85				178.85	178.85
	Breaker, hand-held, mass <= 10 kg	1	11.31	0.03	0.26	11.61		11.61
	Concrete lorry mixer	1	106.92	0.29	2.49	109.70		109.70
	Concrete mixer (petrol)	1	29.65	0.29	1.37	31.32		31.32
	Concrete pump, stationary/lorry mounted	1	37.71	0.10	0.88	38.70		38.70
	Crane, mobile (diesel)	1	238.91	0.65	5.57	245.13		245.13
	Excavator/loader, wheeled/tracked	1	214.21	0.59	4.99	219.79		219.79
	Lorry	1	106.92	0.29	2.49	109.70		109.70
	Poker, vibratory, hand-held	2	30.17	0.08	0.70	30.96		30.96
	Generator, silenced, 75 dB(A) at 7 m	1	221.75	0.61	5.17	227.53		227.53
	Saw, circular, wood	2	362.05	0.99	8.44	371.47		371.47
Construction of Superstructure	Bar bender and cutter (electric)	1	178.85	-	-		178.85	178.85
	Concrete lorry mixer	1	106.92	0.29	2.49	109.70		109.70
	Concrete mixer (petrol)	1	29.65	0.29	1.37	31.32		31.32
	Concrete pump, stationary/lorry mounted	1	37.71	0.10	0.88	38.70		38.70
	Crane, mobile (diesel)	1	238.91	0.65	5.57	245.13		245.13
	Generator, silenced, 75 dB(A) at 7 m	1	221.75	0.61	5.17	227.53		227.53
	Lorry	1	106.92	0.29	2.49	109.70		109.70
	Poker, vibratory, hand-held	2	30.17	0.08	0.70	30.96		30.96
	Saw, circular, wood	2	362.05	0.99	8.44	371.47		371.47
	Large Travelling formwork for in-situ balanced cantilever construction	2	-	-	-			
Miscellaneous								
River Training Works	Crane, mobile (diesel)	1	159.28	0.44	3.71	163.42		163.42
	Excavator/loader, wheeled/tracked	1	142.81	0.39	3.33	146.53		146.53
	Generator, silenced, 75 dB(A) at 7 m	1	147.84	0.40	3.44	151.68		151.68
	Lorry	1	71.28	0.19	1.66	73.13		73.13
Landscape Works	Crane, mobile (diesel)	1	79.64	0.22	1.86	81.71		81.71
	Excavator/loader, wheeled/tracked	1	71.40	0.20	1.66	73.26		73.26
	Generator, silenced, 75 dB(A) at 7 m	1	73.92	0.20	1.72	75.84		75.84
	Lorry	1	35.64	0.10	0.83	36.57		36.57
Tree Felling / Transplanting Works	Breaker, hand-held	1	7.54	0.02	0.18	7.74		7.74
	Crane, mobile (diesel)	1	159.28	0.44	3.71	163.42		163.42
	Excavator/loader, wheeled/tracked	1	142.81	0.39	3.33	146.53		146.53
	Lorry	1	71.28	0.19	1.66	73.13		73.13

Activity	Equipment		GHG emission					
	Type	Amount	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Scope 1 (ton CO_2-e)	Scope 2 (ton CO_2-e)	Total (ton CO_2-e)
	Saw, circular, wood	1	120.68	0.33	2.81	123.82		123.82
Construction of Concrete Batching Plant	Air compressor, air flow > 10 m^3/min and <= 30 m^3/min		89.08	0.24	2.08	91.40		91.40
	Breaker, hand-held, mass > 35 kg	1	12.57	0.03	0.29	12.90		12.90
	Concrete lorry mixer	1	214.09	0.59	4.99	219.66		219.66
	Crane, mobile (diesel)	1	159.28	0.44	3.71	163.42		163.42
	Dump truck	1	152.24	0.42	3.55	156.20		156.20
	Excavator/loader, wheeled/tracked	1	142.81	0.39	3.33	146.53		146.53
	Generator, silenced, 75 dB(A) at 7 m	1	147.84	0.40	3.44	151.68		151.68
	Poker, vibratory, hand-held	1	49.68				49.68	49.68
Total			**17,328.36**	**47.85**	**264.97**	**17,67.15**	**363.02**	**18,034.38**

GHG emission calculation of operation phase, the calculation separated into Scenario 1 and 2. In both scenarios calculate based on same amount of vehicle and growth rate. The GHG emission calculation result is show in table below.

Scenario 1 GHG emission calculation

TABLE L-4 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF HEAVY VEHICLES (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	378,921	9,130	24	212	9,366
2030	413,851	9,971	27	232	10,230
2031	452,002	10,890	29	253	11,172
2032	493,669	11,894	32	277	12,203
2033	539,177	12,991	35	302	13,328
2034	588,881	14,188	38	330	14,556
2035	643,166	15,496	42	361	15,899
2036	659,190	15,883	43	370	16,296
2037	675,614	16,278	44	379	16,701
2038	692,447	16,684	45	388	17,117
2039	709,699	17,100	46	398	17,544
2040	727,382	17,526	47	408	17,981
2041	745,504	17,962	49	418	18,429
2042	764,078	18,410	50	428	18,888
2043	783,115	18,869	51	439	19,359
2044	802,627	19,339	52	450	19,841
2045	822,624	19,820	54	461	20,335
2046	843,120	20,314	55	473	20,842
2047	864,126	20,820	56	485	21,361
2048	885,656	21,339	58	497	21,894
2049	907,722	21,871	59	509	22,439
2050	930,338	22,416	61	522	22,999
2051	953,517	22,974	62	535	23,571
2052	977,274	23,547	64	548	24,159
2053	1,001,623	24,133	65	562	24,760

TABLE L-5 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF MEDIUM VEHICLES (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	243,349	3,823	10	89	3,922
2030	265,782	4,176	11	97	4,284
2031	290,282	4,561	12	106	4,679
2032	317,042	4,981	13	116	5,110
2033	346,268	5,441	14	126	5,581
2034	378,188	5,942	16	138	6,096
2035	413,051	6,490	17	151	6,658
2036	423,342	6,652	18	154	6,824
2037	433,890	6,818	18	158	6,994
2038	444,700	6,988	19	162	7,169
2039	455,780	7,162	19	166	7,347
2040	467,136	7,340	20	171	7,531
2041	478,774	7,523	20	175	7,718
2042	490,703	7,710	21	179	7,910
2043	502,929	7,903	21	184	8,108
2044	515,459	8,099	22	188	8,309
2045	528,302	8,301	22	193	8,516
2046	541,465	8,508	23	198	8,729
2047	554,955	8,720	23	203	8,946
2048	568,782	8,937	24	208	9,169
2049	582,953	9,160	25	213	9,398
2050	597,477	9,388	25	218	9,631
2051	612,363	9,622	26	224	9,872
2052	627,620	9,862	26	229	10,117
2053	643,258	10,108	27	235	10,370

TABLE L-6 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF LIGHT VEHICLES (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	2,485,447	27,990	76	652	28,718
2030	2,714,566	30,570	83	712	31,365
2031	2,964,805	33,388	91	777	34,256
2032	3,238,113	36,466	99	849	37,414
2033	3,536,615	39,828	108	927	40,863
2034	3,862,634	43,499	118	1,013	44,630
2035	4,218,707	47,509	129	1,106	48,744
2036	4,323,816	48,693	133	1,134	49,960
2037	4,431,544	49,906	136	1,162	51,204
2038	4,541,955	51,150	139	1,191	52,480
2039	4,655,118	52,424	143	1,221	53,788
2040	4,771,100	53,730	146	1,251	55,127
2041	4,889,972	55,069	150	1,283	56,502
2042	5,011,805	56,441	154	1,315	57,910
2043	5,136,674	57,847	158	1,347	59,352
2044	5,264,654	59,288	162	1,381	60,831
2045	5,395,823	60,766	166	1,415	62,347
2046	5,530,260	62,280	170	1,451	63,901
2047	5,668,046	63,831	174	1,487	65,492
2048	5,809,265	65,422	178	1,524	67,124
2049	5,954,003	67,052	183	1,562	68,797
2050	6,102,346	68,722	187	1,601	70,510
2051	6,254,386	70,435	192	1,641	72,268
2052	6,410,214	72,189	197	1,681	74,067
2053	6,569,924	73,988	202	1,723	75,913

TABLE L-7 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF LIGHT VEHICLES (GASOLINE)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	3,728,171	29,198	286	1,351	30,835
2030	4,071,849	31,889	312	1,476	33,677
2031	4,447,208	34,829	341	1,612	36,782
2032	4,857,169	38,040	372	1,761	40,173
2033	5,304,922	41,547	407	1,923	43,877
2034	5,793,951	45,377	444	2,100	47,921
2035	6,328,061	49,560	485	2,294	52,339
2036	6,485,724	50,794	497	2,351	53,642
2037	6,647,316	52,060	510	2,410	54,980
2038	6,812,933	53,357	522	2,470	56,349
2039	6,982,677	54,686	535	2,531	57,752
2040	7,156,650	56,049	549	2,595	59,193
2041	7,334,958	57,445	562	2,659	60,666
2042	7,517,708	58,877	576	2,725	62,178
2043	7,705,011	60,344	591	2,793	63,728
2044	7,896,981	61,847	606	2,863	65,316
2045	8,093,734	63,388	621	2,934	66,943
2046	8,295,389	64,967	636	3,007	68,610
2047	8,502,069	66,586	652	3,082	70,320
2048	8,713,897	68,245	668	3,159	72,072
2049	8,931,004	69,945	685	3,238	73,868
2050	9,153,519	71,688	702	3,319	75,709
2051	9,381,579	73,474	719	3,401	77,594
2052	9,615,321	75,305	737	3,486	79,528
2053	9,854,886	77,181	756	3,573	81,510

Scenario 2 GHG emission calculation

TABLE L-8 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF HEAVY VEHICLE (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	378,921	2,840	7	66	2,913
2030	413,851	3,102	8	72	3,182
2031	452,002	3,388	9	78	3,475
2032	493,669	3,700	10	86	3,796
2033	539,177	4,041	11	94	4,146
2034	588,881	4,414	12	102	4,528
2035	643,166	4,821	13	112	4,946
2036	659,190	4,941	13	115	5,069
2037	675,614	5,064	13	117	5,194
2038	692,447	5,190	14	120	5,324
2039	709,699	5,320	14	123	5,457
2040	727,382	5,452	14	127	5,593
2041	745,504	5,588	15	130	5,733
2042	764,078	5,727	15	133	5,875
2043	783,115	5,870	16	136	6,022
2044	802,627	6,016	16	140	6,172
2045	822,624	6,166	16	143	6,325
2046	843,120	6,320	17	147	6,484
2047	864,126	6,477	17	150	6,644
2048	885,656	6,639	18	154	6,811
2049	907,722	6,804	18	158	6,980
2050	930,338	6,973	19	162	7,154
2051	953,517	7,147	19	166	7,332
2052	977,274	7,325	20	170	7,515
2053	1,001,623	7,508	20	174	7,702

TABLE L-9 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF MEDIUM VEHICLE (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	243,349	1,189	3	27	1,219
2030	265,782	1,299	3	30	1,332
2031	290,282	1,419	3	33	1,455
2032	317,042	1,549	4	36	1,589
2033	346,268	1,692	4	39	1,735
2034	378,188	1,848	5	43	1,896
2035	413,051	2,019	5	47	2,071
2036	423,342	2,069	5	48	2,122
2037	433,890	2,121	5	49	2,175
2038	444,700	2,174	5	50	2,229
2039	455,780	2,228	6	51	2,285
2040	467,136	2,283	6	53	2,342
2041	478,774	2,340	6	54	2,400
2042	490,703	2,398	6	55	2,459
2043	502,929	2,458	6	57	2,521
2044	515,459	2,519	6	58	2,583
2045	528,302	2,582	7	60	2,649
2046	541,465	2,647	7	61	2,715
2047	554,955	2,713	7	63	2,783
2048	568,782	2,780	7	64	2,851
2049	582,953	2,849	7	66	2,922
2050	597,477	2,920	7	68	2,995
2051	612,363	2,993	8	69	3,070
2052	627,620	3,068	8	71	3,147
2053	643,258	3,144	8	73	3,225

TABLE L-10 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF LIGHT VEHICLE (DIESEL)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	2,485,447	8,708	23	202	8,933
2030	2,714,566	9,510	25	221	9,756
2031	2,964,805	10,387	28	242	10,657
2032	3,238,113	11,345	31	264	11,640
2033	3,536,615	12,391	33	288	12,712
2034	3,862,634	13,533	36	315	13,884
2035	4,218,707	14,780	40	344	15,164
2036	4,323,816	15,149	41	352	15,542
2037	4,431,544	15,526	42	361	15,929
2038	4,541,955	15,913	43	370	16,326
2039	4,655,118	16,309	44	379	16,732
2040	4,771,100	16,716	45	389	17,150
2041	4,889,972	17,132	46	399	17,577
2042	5,011,805	17,559	47	409	18,015
2043	5,136,674	17,997	49	419	18,465
2044	5,264,654	18,445	50	429	18,924
2045	5,395,823	18,905	51	440	19,396
2046	5,530,260	19,376	52	451	19,879
2047	5,668,046	19,858	54	462	20,374
2048	5,809,265	20,353	55	474	20,882
2049	5,954,003	20,860	57	486	21,403
2050	6,102,346	21,380	58	498	21,936
2051	6,254,386	21,913	59	510	22,482
2052	6,410,214	22,459	61	523	23,043
2053	6,569,924	23,018	62	536	23,616

TABLE L-11 GHG EMISSIONS CALCULATION IN OPERATION PHASE OF LIGHT VEHICLE (GASOLINE)

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2029	3,728,171	9,083	89	420	9,592

Year	Vehicle/year	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
2030	4,071,849	9,921	97	459	10,477
2031	4,447,208	10,835	106	501	11,442
2032	4,857,169	11,834	115	547	12,496
2033	5,304,922	12,925	126	598	13,649
2034	5,793,951	14,117	138	653	14,908
2035	6,328,061	15,418	151	713	16,282
2036	6,485,724	15,802	154	731	16,687
2037	6,647,316	16,196	158	749	17,103
2038	6,812,933	16,600	162	768	17,530
2039	6,982,677	17,013	166	787	17,966
2040	7,156,650	17,437	170	807	18,414
2041	7,334,958	17,872	175	827	18,874
2042	7,517,708	18,317	179	848	19,344
2043	7,705,011	18,773	183	869	19,825
2044	7,896,981	19,241	188	890	20,319
2045	8,093,734	19,720	193	913	20,826
2046	8,295,389	20,212	198	935	21,345
2047	8,502,069	20,715	202	959	21,876
2048	8,713,897	21,231	208	983	22,422
2049	8,931,004	21,760	213	1,007	22,980
2050	9,153,519	22,303	218	1,032	23,553
2051	9,381,579	22,858	223	1,058	24,139
2052	9,615,321	23,428	229	1,084	24,741
2053	9,854,886	24,012	235	1,111	25,358

TABLE L-12 SUMMARY OF GHG EMISSIONS CALCULATION IN OPERATION PHASE

	GHG emission			
	CO_2 (ton CO_2-e)	CH_4 (ton CO_2-e)	N_2O (ton CO_2-e)	Total GHG emission (ton CO_2-e)
Scenario 1	3,379,221	19,125	111,037	3,509,383
Scenario 2	1,051,279	5,916	34,512	1,091,707

L.5 OTHER REFERENCE

The source of fuel consumption that use in calculation are shown in table C1. Note that the fuel consumption that use in calculation comes from assumption by almost of fuel consumption that disclose as a public.

Equipment type	Source
Crane, mobile	Housing Element Update (2021-2029) Santamonica; https://www.santamonica.gov/media/Housing-Element-Update-2021-to-2029/APPENDIX%20E-ENERGY%20CAKCULATIONS.pdf
Excavator/loader, wheeled/tracked	Housing Element Update (2021-2029) Santamonica; https://www.santamonica.gov/media/Housing-Element-Update-2021-to-2029/APPENDIX%20E-ENERGY%20CAKCULATIONS.pdf
Lorry	U.S. Department of Energy; Energy Efficiency & Renewable Energy - Long-Haul Truck Idling Burns Up Profits ; https://afdc.energy.gov/files/u/publication/hdv_idling_2015.pdf
Air compressor, air flow > 10m3/min and <= 30m3/min	Housing Element Update (2021-2029) Santamonica; https://www.santamonica.gov/media/Housing-Element-Update-2021-to-2029/APPENDIX%20E-ENERGY%20CAKCULATIONS.pdf
Asphalt paver	AP1000F Asphalt Paver Fuel Burn – Medium ; https://www.ezyquip.com.au/product/ap1000f-asphalt-paver/
Dump truck	Equipment World ; https://www.equipmentworld.com/regulations/equipment/article/14948071/the-owning-and-operating-costs-of-dump-trucks?__cf_chl_tk=kZuW4y6OEb_d6lk5XQqrpJcwSEKEVeaJ9uWAN2Lfmzc-1728375797-0.0.1.1-10559
Generator, silenced, 75 dB(A) at 7 m	Housing Element Update (2021-2029) Santamonica; https://www.santamonica.gov/media/Housing-Element-Update-2021-to-2029/APPENDIX%20E-ENERGY%20CAKCULATIONS.pdf
Paint line marker	-
Roller, vibratory	Average from displacement from example roller of Sakai ; https://sakai.co.id/wp-content/uploads/2021/09/sv520_2018.01.19.pdf
Water pump, submersible	Energy Bot; https://www.energybot.com/energy-usage/water-pump.html
Concrete lorry mixer	U.S. Department of Energy; Energy Efficiency & Renewable Energy - Long-Haul Truck Idling Burns Up Profits ; https://afdc.energy.gov/files/u/publication/hdv_idling_2015.pdf
Concrete mixer	Adam jin ; https://www.scribd.com/document/458748773/fuel-consumption
Bar bender and cutter (electric)	Average Bar bender and Cutter; https://wmhkzw.en.made-in-china.com/product/nNqmLdMcXPVY/China-3kw-380V-Manual-Control-Electric-Steel-Bar-Bender-Machine.html
Poker, vibratory, hand-held	Average Poker, vibratory, hand-held; https://www.multivibe.com/gas-concrete-vibrators
Saw, circular, wood	Average Saw, Circular, wood; https://shuntool.com/article/how-many-watts-circular-saw
Breaker, hand-held, mass <= 10kg	Average Breaker hand-held; https://www.atlascopco.com/content/dam/atlas-copco/construction-technique/portable-energy/documents/8_handheld_tools/tools-book/2023/handheld-tools-book-en.pdf
Breaker, excavator mounted (hydraulic)	Centex Excavation; https://centexexcavation.com/how-much-fuel-does-an-excavator-use-per-hour/

Equipment type	Source
Compactor, vibratory	Adam jin ; https://www.scribd.com/document/458748773/fuel-consumption
Drilling rig	Adam jin ; https://www.scribd.com/document/458748773/fuel-consumption
Grout mixer	Average Grout mixer; https://quikspray.com/grout-mixers/
Grout pump	Average Grout pump; https://concretepumping.com/topic/schwing-runs-fuel-efficiency-test-4-pumps-pumping-into-each-other-for-5-hours
Piling, large diameter bored, grab and chisel	Adam jin ; https://www.scribd.com/document/458748773/fuel-consumption
Concrete pump, stationary/lorry mounted	Average concrete pump, stationary; http://schwingpartsstore.com/wp-content/uploads/2019/08/2019-SP-Product-Guide-min.pdf

*The fuel consumption values provided are general estimates and may not be highly accurate. However, if you have the energy consumption data for construction equipment, you can advise us accordingly.