Chapter 4

Hydrogen Demand Potential in the Road Transport and Power Sectors

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CHAPTER 4

Hydrogen Demand Potential in the Road Transport and Power Sectors

4.1. Objectives

The study aims to forecast hydrogen demand in the road transport and power sectors in Brunei Darussalam. For road transport, private vehicle stock was first forecasted until 2040 based on 2009 statistics. Then the results were used to forecast energy demand and emissions for several scenarios. For the power sector, the electricity generation forecast, which was then converted into the corresponding fuel consumption, was first obtained.

4.2. Road Transport Sector

4.2.1. Methodological approach

a. Forecasting future private vehicle stock

The ordinary least squares (OLS) regression method was employed to project future vehicle stock. The population variable was loaded and tested into a commercial statistics software with the stocks of active private vehicles.

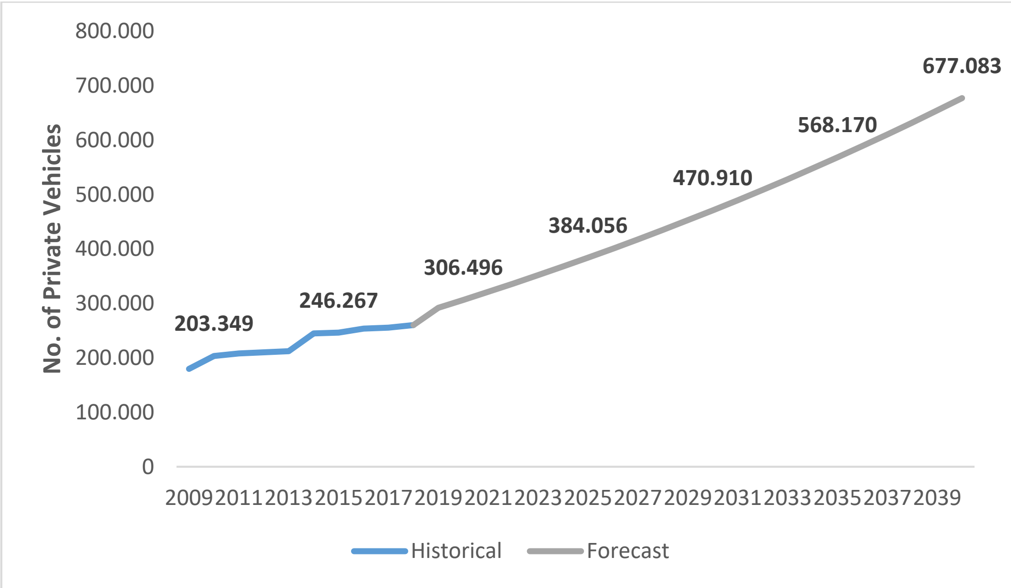
Based on the above tests, the final model is expressed as below:

$$PAV = -340{,}836 + 1.39POP \tag{1}$$

where PAV is the stocks of active private vehicle and POP is population.

Historically, the number of active vehicles grew at 4.2% per year from 179,738 in 2009 to 255,452 in 2017. These vehicles are envisaged to further increase to 677,083 by 2040 at a rate of 4.4% per year (Figure 4.1).

Figure 4.1: Historical and Projected Active Vehicle Stock



Source: Author (2020).

b. Estimating fuel consumption and energy demand

The annual fuel consumption of private vehicles was computed via the following equation:

$$FC_h = PAV_i . ADT . \frac{1}{FE_j} \quad (2)$$

where FC_h is the fuel consumption of fuel type h (litres), PAV_i is the number of active private vehicles of type i, ADT is the average mileage per vehicle (km per year), and FE_j is the fuel economy of vehicle of type j (km per litre). Subsequently from equation (2), this could be converted to energy demand equivalence through:

$$ED_h = \frac{FC_h}{1{,}000} . \rho_h . \theta_h . 0.0000000041868 \quad (3)$$

where ED_h is the energy demand of fuel type h (TJ), ρ_h is the density of fuel of fuel type h (kg per m^3), and θ_h is the net calorific value of fuel of fuel type h (kcal per kg).

c. Estimating greenhouse gas (GHG) emissions

The corresponding GHG emissions were calculated via the following equation:

$$EM_{nh} = ED_h . EF_{nh} . GWP_n \quad (4)$$

where EM_{nh} is the emission of GHG n from fuel type h (million tonnes CO_2e), EF_{nh} is the emission factor of GHG n from fuel type h (million tonnes per TJ), and GWP_n is the global warming potential of GHG n. The fuel types h considered in this case would be gasoline and diesel, from which carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the main GHGs n emitted. As Brunei Darussalam does not have its country-specific EF_{nh}, default values, which were sourced from the Intergovernmental Panel on Climate Change (IPCC), were used (Table 4.1).

Table 4.1: Emission Factors of Gasoline and Diesel Fuels

Fuel Type	**Emission Factor, EF_{nh}**		
	CO_2	**CH_4**	**N_2O**
Gasoline	0.0000693	0.000000033	3.2E–09
Diesel	0.0000741	3.9E–09	3.9E–09

Source: Intergovernmental Panel on Climate Change (IPCC) (2019).

The global warming potential of a GHG, GWP_n, is defined as the total contribution to global warming resulting from the emission of one unit of that gas with respect to one unit of the reference gas (CO_2), which is assigned a value of 1. Based on Table 4.2 below, for example 1 unit of N_2O contributes almost 300 times more than that of CO_2.

Table 4.2: Global Warming Potential of Greenhouse Gases

GHG	**GWP Value**
CO_2	1
CH_4	28
N_2O	265

Source: Intergovernmental Panel on Climate Change (IPCC) (2014).

4.2.2. Scenario description

Several scenarios were constructed in this study. Initially a reference case (business-as-usual scenario [BAU]) was developed to model and forecast consumption and energy demand as well as emissions from conventional fuels without the introduction of fuel cell vehicles (FCVs). The next step was to model and forecast the effect of incorporating FCVs on the energy and emission systems according to FCVs' level of penetration. This case scenario was further subdivided into case 1 (10% penetration), case 2 (30% penetration), and case 3 (50% penetration) (Table 4.3).

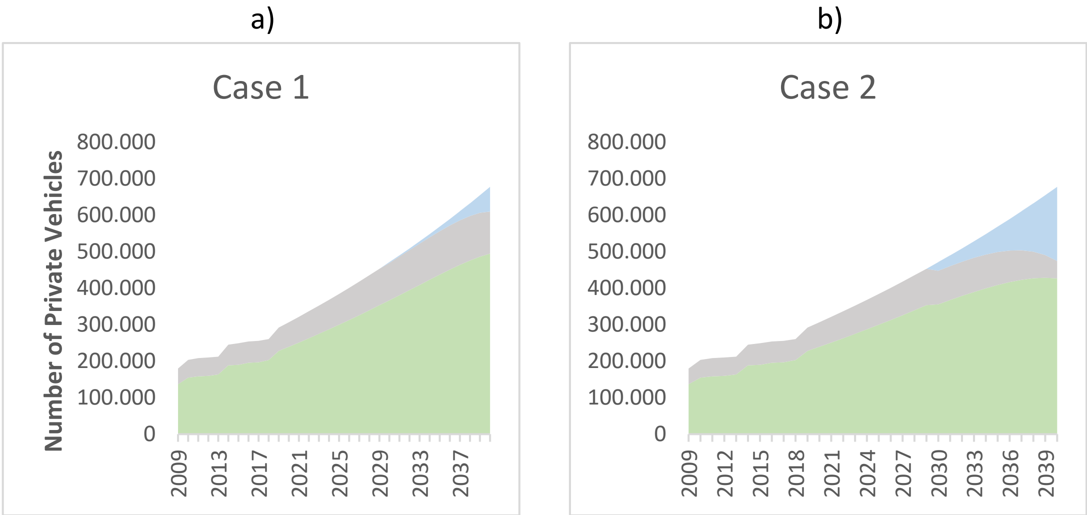
Table 4.3: BAU and FCV Scenarios Considered for Road Transport

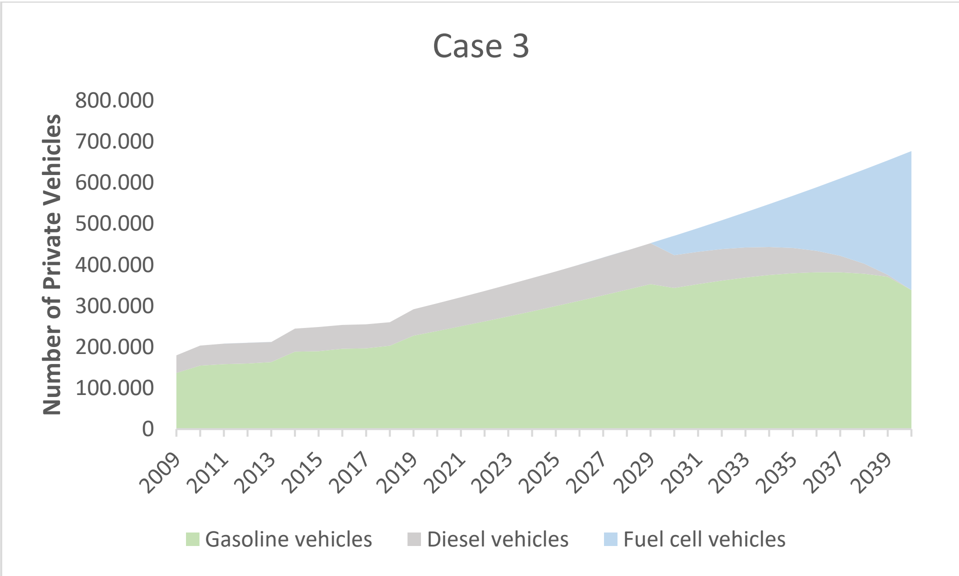
	BAU	Case 1	Case 2	Case 3
FCV introduction	No	Yes	Yes	Yes
FCV introduction year	–	2030	2030	2030
FCV initial penetration	–	1%	5%	10%
FCV target penetration in 2040	–	10%	30%	50%

BAU = business-as-usual scenario, FCV = fuel cell vehicle.
Source: Author (2020).

BAU assumes 78% and 22% shares of gasoline and diesel vehicles, respectively, between now and 2040. Each FCV scenario (Figure 4.2) assumes that the introduction year for a given FCV fleet indicates the starting year of the new buyers' market for FCV of 2030. For case 1, penetration of FCVs would begin at 2,355 vehicles at 1% share, which would reach 67,708 vehicles by 2040. For case 2, FCVs would grow from 23,545 vehicles (5% share) to 203,125 vehicles (30% share) whilst for case 3, FCVs would reach 338,541 vehicles (50% share) from 47,091 vehicles (10% share). With these cases, diesel is assumed to be phased out completely by 2040, as gasoline vehicles and FCVs would be the major fuels by then.

Figure 4.2: Changes in the Scenarios



c) 

Source: Author (2020).

4.2.3. Results and discussion

The introduction of hydrogen as an alternative fuel changes the landscape of the road transport sector in terms of final energy consumption and emissions according to variations in scenarios.

a. Hydrogen consumption

Table 4.4 shows gasoline, diesel, and hydrogen consumption in 2040. The total consumption from conventional fuel sources ranges from 484,141 to 755,260 m^3, with case 3 having zero diesel consumption. Hydrogen consumption ranges from 20,566 tonnes (58.79 ktoe) to 102,832 tonnes (293.97 ktoe).

Table 4.4: Gasoline, Diesel, and Hydrogen Consumption (2040)

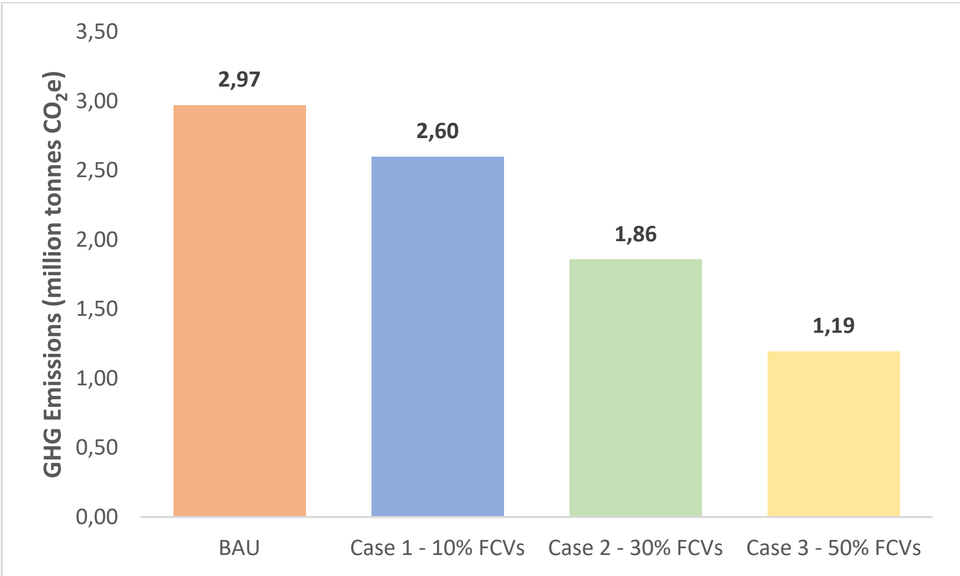
Fuel Consumption	Unit	Business-As-Usual Scenario	Case 1	Case 2	Case 3
Gasoline	m^3	755,260	706,846	610,017	484,141
Diesel	m^3	395,861	305,893	125,956	0
Gasoline and diesel	m^3	1,151,121	1,012,738	735,973	484,141
Hydrogen	Nm^3	–	228,769,285	686,307,854	1,143,846,423
	ktoe	–	58.79	176.38	293.97
	tonne	–	20,566	61,699	102,832

Source: Author (2020).

b. Reduction of GHG emissions

Figure 4.3 schematically illustrates the GHG emissions from the road transport sector for these scenarios. Emissions from BAU are envisaged to reach approximately 2.97 million tonnes CO_2e. With 10% FCVs, emissions would be reduced by 12% to 2.60 million tonnes CO_2e compared to BAU. Reductions of 37% and 60% would be projected with 30% and 50% FCVs, respectively.

Figure 4.3: Projected Greenhouse Gas Emissions Compared to BAU (2040)



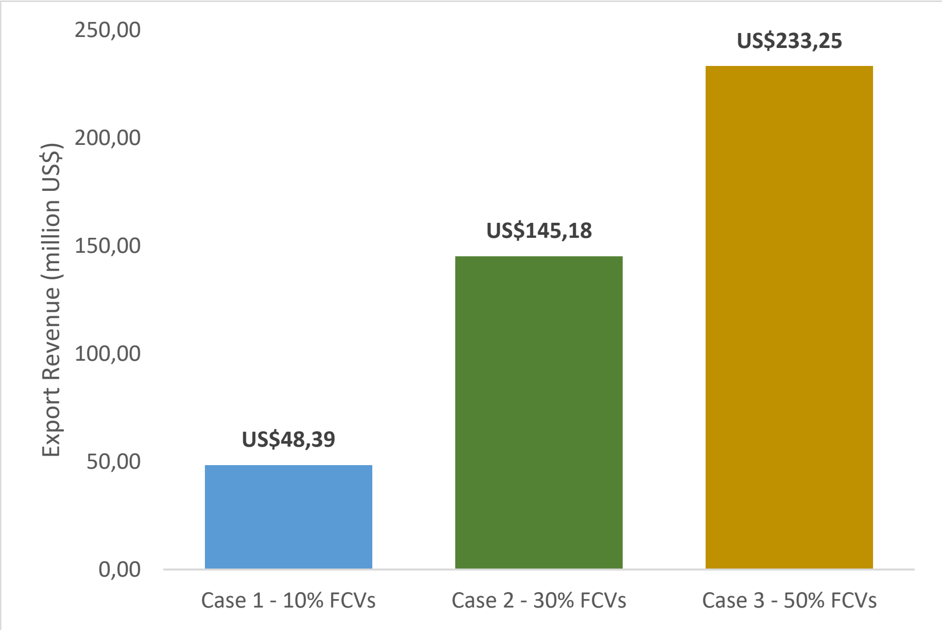
BAU = business-as-usual, FCV = fuel cell vehicle, GHG = greenhouse gas.
Source: Author (2020).

c. Crude oil export revenue

The introduction of hydrogen in the road transport sector could also potentially influence export revenue from crude oil as a result of fuel savings. Assuming the average price of crude oil in 2040 hovers at US$55.60 per barrel (World Bank, 2020),[2] potentially Brunei Darussalam could export additional crude oil; that extra revenue will range from US$48.70 million to US$233.25 million by 2040 (Figure 4.4).

[2] The author assumes that this price stays on a level with the 2035's forecasted price the World Bank.

Figure 4.4: Potential Crude Oil Export Revenue (2040)



FCV = fuel cell vehicle.
Source: Author (2020).

4.3. Power Sector

4.3.1. Methodological approach

a. Forecasting electricity generation

The country's overall electricity generation is envisaged to grow to 17.76 TWh by 2040 under BAU (ERIA, 2019). Electricity from natural gas will account for about 79% of the total generation, whilst coal and oil will contribute to 20.5% and 0.16%, respectively. Under the alternative policy scenario (APS) in the same year, 13.08 TWh of electricity is forecasted and the reduction is due to the inclusion of 0.9 TWh of renewable energy, as well as the decommissioning of the diesel power plants in Temburong in 2021 and the improvement in efficiency in all power stations (ERIA, 2019).

b. Estimating hydrogen gas consumption

Hydrogen consumption from a gas turbine can be estimated via the following equation:

$$HC_{Energy} = EG \; x \; HR \; x \; \alpha \qquad (5)$$

where HC_{Energy} is the hydrogen consumption (energy form) (MJ), EG is the electricity generated from the gas turbine, HR is the average heat rate of gas turbine, and α is the calorific percentage of hydrogen in the gas turbine. Subsequently from equation (5), this could be converted to volumetric consumption equivalence through:

$$HC_{Volume} = \frac{HC_{Energy}\, x\, \frac{1}{HCal}}{1{,}000}$$
(6)

where HC_{Volume} is the hydrogen consumption (volumetric form) (thousand m^3), and $HCal$ is the calorific value of hydrogen (lower calorific value). The value of $HCal$ is assumed to be 10.7 MJ per m^3.

c. Estimating GHG emissions

Similar to those in the road transport sector, the corresponding GHG emissions were calculated via the following equation:

$$EM_{nh} = ED_h . EF_{nh} . GWP_n$$
(7)

where EM_{nh} is the emission of GHG n from fuel type h (million tonnes CO_2e), EF_{nh} is the emission factor of GHG n from fuel type h (million tonnes per TJ), and GWP_n is the global warming potential of GHG n. The fuel type h considered in this case would be natural gas, from which carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the main GHGs n emitted. As Brunei Darussalam does not have its country-specific EF_{nh}, default values, which were sourced from the IPCC, were used (Table 4.5).

Table4.5: Emission Factors of Natural Gas

Fuel Type	Emission Factor, EF_{nh}		
	CO_2	**CH_4**	**N_2O**
Natural Gas	0.0000561	0.000000001	0.0000000001

Source: Intergovernmental Panel on Climate Change (IPCC) (2007).

4.3.2. Scenario description

The development of scenarios in this section is similar to that for road transport, albeit with different set parameters. The reference case (BAU) was developed based on power stations' consuming 100% natural gas and operating at present efficiency. The other three scenarios – cases 1 to 3 – were developed based on the conditions shown in Table 4.6. All the scenarios would have the initial penetration of 5% hydrogen (calorific percentage α) and would be further progressed depending on each scenario's conditions (Tables 4.7, 4.8, and 4.9). It should be noted that for case 1, there is no development of a new gas turbine construction as the hydrogen would be mixed only in the existing turbines. Such development would only be considered in cases 2 and 3.

Table4.6: BAU and Case Scenarios Considered for the Power Sector

	BAU	Case 1	Case 2	Case 3
Hydrogen	No	Yes	Yes	Yes
Hydrogen Introduction Year	–	2035	2035	2035
Hydrogen Initial Penetration	–	5%	5%	5%
Hydrogen Target Penetration 2040	–	10%	30%	50%
Power Plant Efficiency	30%	30%	60%	60%

Source: Author (2020).

Table4.7: Calorific Percentages of Natural Gas and Hydrogen for Case 1 Scenario

Year	Natural Gas	Hydrogen
2035	95%	5%
2036	94%	6%
2037	93%	7%
2038	92%	8%
2039	91%	9%
2040	90%	10%

Source: Author (2020).

Table 4.8: Calorific Percentages of Natural Gas and Hydrogen for Case 2 Scenario

Year	Natural Gas	Hydrogen
2035	95%	5%
2036	90%	10%
2037	85%	15%
2038	80%	20%
2039	75%	25%
2040	70%	30%

Source: Author (2020).

Table 4.9: Calorific Percentages of Natural Gas and Hydrogen for Case 3 Scenario

Year	Natural Gas	Hydrogen
2035	95%	5%
2036	90%	10%
2037	80%	20%
2038	70%	30%
2039	60%	45%
2040	50%	50%

Source: Author (2020).

4.3.3. Results

a. Hydrogen consumption

Table 4.10 shows the natural gas and hydrogen consumption in 2040. The total consumption from natural gas ranges from 3,912 million m^3 (4,318 ktoe) to 5,749 million m^3 (4,788 ktoe). Hydrogen consumption ranges from 258 million m^3 (66 ktoe) to 1,837 million m^3 (470 ktoe).

Table 4.10: Natural Gas and Hydrogen Consumption (2040)

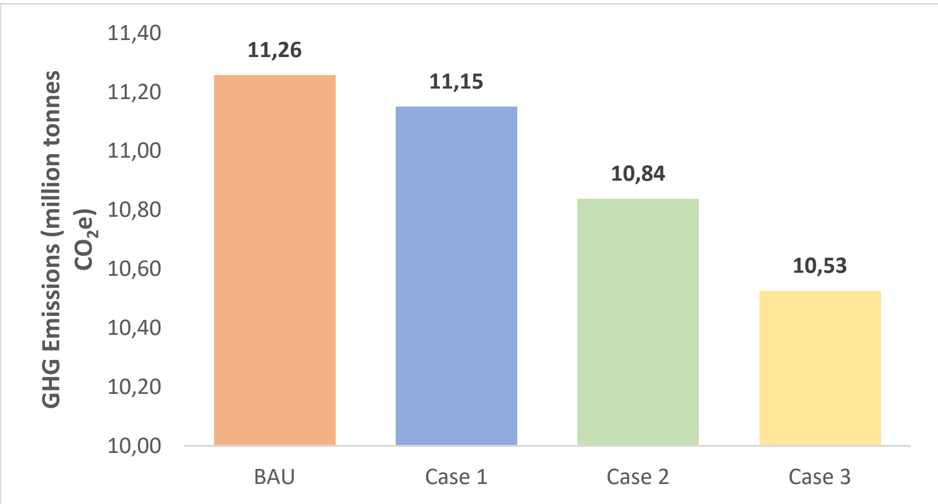
Fuel Consumption	Unit	BAU	Case 1	Case 2	Case 3
Natural gas	million m^3	5,749	5,670	4,647	3,912
	ktoe	4,788	4,722	4,506	4,318
Hydrogen	million m^3	–	258	1,102	1,837
	ktoe	–	66	282	470

BAU = business-as-usual scenario.
Source: Author (2020).

b. Reduction of GHG emissions

Figure 4.5 schematically illustrates the GHG emissions from the power sector for these scenarios. Emissions from BAU are envisaged to reach approximately 11.26 million tonnes CO_2e. With case 1, emissions would be reduced by 1.0% to 11.15 million tonnes CO_2e compared to BAU. Reductions by 3.7% and 6.5% would be projected in cases 2 and 3, respectively.

Figure 4.5: Projected Greenhouse Gas Emissions Compared to BAU (2040)

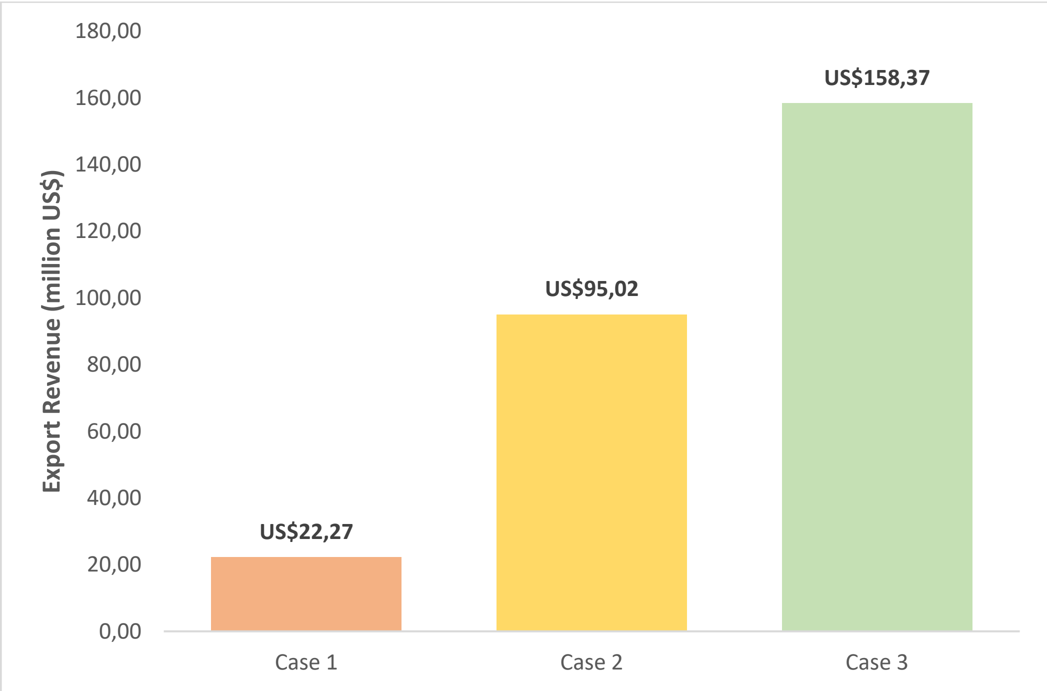


BAU = business-as-usual scenario.
Source: Author (2020).

c. Export revenue from liquefied natural gas

Similar to road transport, the effect of hydrogen introduction in the power sector is the significant increase in the export of liquefied natural gas (LNG). Again, assuming the average price of LNG in 2040 is US$8.50 per MMBTu (World Bank, 2020), Brunei Darussalam could gain additional revenue ranging from US$22.27 million to US$158.37 million by 2040 (Figure 4.6).

Figure 4.6: Potential Natural Gas Export Revenue (2040)



Source: Author (2020).