FUEL USAGE TRENDS AND INVENTORY FOR MALAYSIA ROAD TRANSPORT SECTOR

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ABSTRACT

The shift towards sustainable transport in Malaysia demands a clear understanding of the environmental performance, trends, and status of major fuels in use. This study compiles and compares existing Life Cycle Inventory (LCI) data for key transport fuels such as petrol, natural gas, and coal-derived fuels, alongside an analysis of their production, consumption, and trade trends. Secondary data are gathered from national statistics, trade records, published literature, and environmental databases to assess energy use, emissions, and resource flows across the fuel life cycle. The compiled information provides an up-to-date overview of Malaysia's transport fuel landscape, serving as a reference for evaluating life cycle impact assessment, energy analysis, and potential transition pathways toward low-carbon mobility.

KEYWORDS

Life Cycle Inventory (LCI), Transport fuels, Fuel trend analysis, Energy transition

1.0 INTRODUCTION

The transportation sector in Malaysia remains one of the country's largest energy consumers and contributors to greenhouse gas (GHG) emissions, accounting for approximately 23% of total national emissions in recent years [1]. Road transport overwhelmingly dominates, responsible for nearly 99% of transport-related CO_2 emissions [2]. and about 87% of total transport energy use [3]. In 2021, Malaysia's transport sector consumed around 722,150 TJ of energy, largely from petroleum-based fuels such as petrol and diesel [1].

To curb emissions from transport, the Malaysian government has introduced a range of policies and initiatives promoting cleaner and more efficient vehicles. These include the National Automotive Policy (NAP 2020), the nationwide adoption of Euro-5 diesel standards, and ongoing efforts to expand the use of biofuels, electric vehicles (EVs), and hydrogen-powered transport [4,5].

As the world moves toward low-carbon energy systems, understanding how fuel production and processing differ across regions has become increasingly important. Life Cycle Inventory (LCI) data provide essential information on material inputs, energy consumption, and emissions associated with each stage of fuel production and refining.

This study focuses on compiling and comparing LCI data for major transport fuels including coal, petrol and natural gas derived fuels using secondary data from published inventories and databases. The comparison emphasizes variations in energy use, emissions, and resource consumption across different fuel systems. Rather than performing a full life cycle impact assessment, the aim of this study is to provide a clear, data-driven overview of existing LCI inventories, which can serve as a reference for future Life Cycle Assessment research, dataset harmonization, and national inventory development efforts.

2.0 STATUS OF ROAD TRANSPORT IN MALAYSIA

Road transport is a key driver of economic growth and national development [6]. However, the expansion of vehicle use has led to a substantial increase in energy demand, especially for petroleum-based fuels, thereby exacerbating environmental degradation through higher CO_2 emissions. Segar et al. [7] indicates that Malaysia is projected to experience increased air pollution in the coming years, underscoring the need for immediate mitigation strategies.

Increasing emissions from the transport sector contribute to climate change and present substantial risks to public health [8]. Pollutants such as particulate matter (PM), nitrogen oxides (NO_x), and carbon monoxide (CO) emitted from vehicle exhaust are associated with respiratory illnesses, cardiovascular diseases, and diminished air quality in urban environments [9]. These effects are especially pronounced in densely populated Malaysian cities, where traffic congestion exacerbates exposure to pollution [10]. Consequently, mitigating emissions from road transport is essential for both environmental protection and public health.

Long-term data on Malaysia's vehicle registration composition, presented in Table 1, show a clear transformation in road transport patterns from 1990 to 2018. Over this period, the share of motorcars increased significantly from 33.15% to 47.12%, reflecting Increased population size and disposable incomes, as well as fuel subsidies and decentralization [11]. Meanwhile, motorcycles, although dominant in the early 1990s, declined from 55.58% to 46.46% by 2018.

Electric vehicle (EV) adoption in Malaysia has progressed more slowly than global trends, primarily due to structural and market challenges. [12]. For many years, EV growth was constrained by insufficient charging infrastructure particularly along major highways, the high purchase cost relative to conventional vehicles, and limited consumer awareness about EV technology and maintenance. The absence of a domestic battery recycling industry and standardized safety guidelines also contributed to cautious adoption among consumers [12].

In recent years, however, Malaysia's EV landscape has begun to change significantly. According to the Malaysian Automotive Association (MAA), EV sales jumped by 19% from 38,214 units in 2023, to 45,562 units [13]. This increase reflects stronger consumer confidence and the positive effects of government-led incentives and awareness campaigns [14].

Malaysia's national policy framework has also become more coordinated, particularly through the Low Carbon Mobility Blueprint (LCMB) [15] and the National EV Task Force, which were designed to drive sustainable transportation and strengthen EV infrastructure nationwide [16]. In addition, the Malaysia Automotive, Robotics and IoT Institute (MARii) emphasized that Malaysia's automotive sector is now better positioned to support EV growth, guided by the National Automotive Policy (NAP) 2020 [17].

A significant turning point is the entry of national car manufacturers, Proton and Perodua, into the EV market, alongside major Chinese automakers. The introduction of locally produced and more affordable EV models is expected to attract a wider consumer base, making electric mobility increasingly accessible to middle-income Malaysians [18]. Collectively, these developments signal a transition toward a more inclusive and sustainable transport ecosystem that aligns with Malaysia's long-term decarbonization and energy transition goals [18].

Table 1: Percentage of Registered Road Transport Vehicles in Malaysia [11]

Year	Motorcars	Motorcycles	Taxi	Buses	Goods Vehicles	Others
1990	33.15	55.58	0.63	0.49	6.96	3.19
1995	37.02	52.32	0.8	0.52	6.39	2.95
2000	39.12	50.54	0.63	0.46	6.28	2.98
2005	43.69	47.3	0.53	0.39	5.43	2.66
2009	44.73	47.01	0.42	0.35	4.92	2.57
2014	53.42	40.5	0.54	0.1	3.12	1.9
2018	47.12	46.46	1.04	0.08	3.33	2.42

3.0 Data Selection and Representativeness of Data Inventories

The selection of Life Cycle Inventory (LCI) datasets followed a hierarchical and systematic approach. Priority was first given to datasets developed from field studies conducted in Southeast Asian countries, as these are more representative of Malaysian operating conditions. When such datasets were unavailable, datasets from other regions were considered. It is important to note that field-based LCI data remain limited not only in Malaysia but globally. Therefore, most published LCA studies rely heavily on established databases such as openLCA, ecoinvent, and SimaPro [63, 64]. Because this study focuses on gathering primary data through fieldwork, only a small amount of such data could be collected, while the remaining inventory was sourced from these widely used databases. Moreover, LCA is a complex, robust, and flexible methodology, and selecting a single dataset that perfectly represents Malaysian conditions is not feasible. Instead, conducting an LCA requires integrating multiple data sources and considering geographical, technological, and methodological factors. The inventories used here therefore serve as a transparent and practical foundation for LCA modelling in Malaysia and highlight the need for future work to develop more Malaysia-specific datasets.

4.0 Coal Trend, Status, and Composition

Coal is a sedimentary rock rich in carbon and other combustible elements, formed over extended periods under pressure and heat from ancient plant matter [19]. It remains a critical fuel for electricity generation and industry worldwide, particularly in fossil-fuel dependent economies [20]. In Malaysia, coal is a significant part of the electricity generation mix, accounting for approximately 57% of electricity generation as of 2023, making it the single largest source for power generation [21]. Despite this significant role, domestic coal production is modest, and the country relies heavily on imports, primarily from Indonesia and Australia [22]. The total known reserve was estimated at 249 million short tons in 2023, with nearly 99% located in Sarawak [22]. The most common types of coal used in Malaysia are bituminous and sub-bituminous [23].

Table 2 presents the chemical composition of Mukah–Balingian coal. The relatively high carbon and moderate oxygen contents indicate that Mukah–Balingian coal is sub-bituminous [24]. The low sulphur content suggests a lower potential for sulphur dioxide (SO_2) emissions during combustion, making it comparatively cleaner than high-sulphur coals [24].

The Mukah–Balingian region in central Sarawak, Malaysia, is one of the main coal-bearing areas in Malaysia. Coal deposits in this region are predominantly sub-bituminous, suitable for thermal power generation [26]. The area has been actively explored and mined by companies Sarawak Energy Berhad (SEB), primarily to supply coal to the Mukah Power Plant and other local energy projects [27].

Table 2: Chemical composition of Mukah Balingian coal [25].

Element	Mukah Balingian Coal (%)
Carbon (C)	72.8
Hydrogen (H)	4.6
Nitrogen (N)	1.9
Sulphur (S)	0.4
Oxygen (O)*	20.3

Figure 1 presents the trends in Malaysia's coal production, consumption, and imports from 2014 to 2023. Coal production exhibits moderate fluctuations, with values typically ranging from 2.49 and 4.11 million short tons. Production increased modestly from 2016-2019, peaking at 3.81 million short tons before stabilising around 4 million short tons in 2020-2023. This pattern can be attributed to market, environmental, and operational factors during 2016-2019 [28].

Notably, the sustained low price of natural gas enhanced the cost-competitiveness of gas-fired electricity generation, which in turn reduced coal demand in the power sector [28]. Coal consumption demonstrates a generally upward trend and consistently exceeds domestic production throughout the observed period. This persistent gap underscores Malaysia's ongoing dependence on coal imports to meet national demand, as local production remains inadequate.

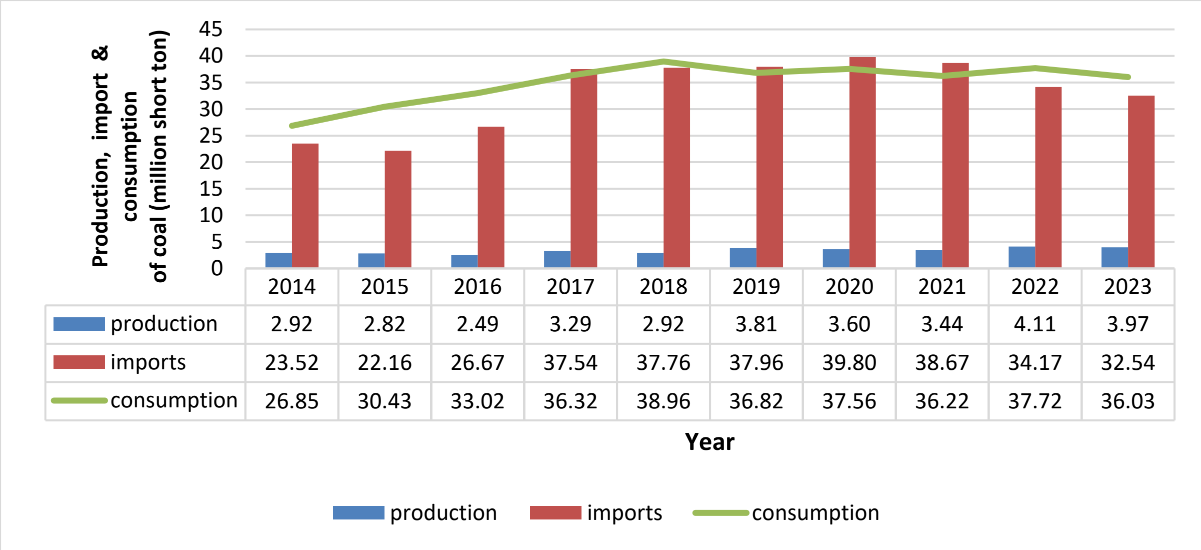


Figure 1: Trend of production, consumption and import of coal in Malaysia from 2012-2022 [38]

Meanwhile coal imports shown significantly higher throughout the entire period, rising steadily from about 23.52 million short ton in 2014 to 32.54 million short tons in 2023. Import levels remain high over the years, underscoring Malaysia's strong dependence on imported coal to support its energy needs. The country's dependence on imported coal is largely influenced by cost factors rather than by issues of energy security [29]. The graph demonstrates an increasing disparity between domestic coal production and total consumption, indicating that imports have become the primary means of maintaining the national coal supply.

4.1 Coal Inventories

Three coal inventory datasets were analysed: two representing underground operations in China based on the Eco-invent background model [30,31] and one site-specific field study of open-pit mining in Indonesia [32]. These datasets reveal pronounced variability in key input and output parameters as shown in Table A1. The observed variation highlights two primary dimensions of difference: (i) data source and methodological approach, and (ii) regional and local mining context.

Table A1: Coal inventories [30,31,32]

Category	Parameter	Unit	China [30]	Indonesia [32]	China [31]
INPUTS					
Energy use	Electricity	kWh	33.07	–	36.80
	Diesel	L	0.002	13.42	0.58
	Biodiesel	L	–	5.75	–
	Heat	MJ	–	–	92.86
Explosives	Explosives total	kg	0.04	–	0.02
	Ammonium nitrate	kg	–	1.05	–
	Dynamite	kg	–	0.003	–
	Detonator	kg	–	0.01	–
	Emulsion	kg	–	1.11	–
Raw materials / consumables	Water (total)	L	290.00	655.35	387120.00
	Rainwater	L	–	10 748.82	–
	Groundwater	L	–	–	2430.00
	Oxygen gas	kg	–	–	10.00
	Steel	kg	1.30	–	6.914
	Cement	kg	5.65	–	–
	Wood	kg	0.56	–	–
	Lime	kg	–	0.59	–
	Other chemicals	kg	0.14	–	–

	Natural gas	m3			11.95
Infrastructure & transport	Lorry transport	t·km	1.16	–	–
OUTPUTS					
Product	Coal (product)	ton	1.00	1.00	1.00
Emissions to air	CO_2	kg	44.35	43.12	12.22
	CH_4	kg	18.48	0.87	1.80
	CO	kg	0.07	–	0.21
	NO_x (as NO_2)	kg	–	0.54	0.07
	SO_2	kg	–	0.22	28.23
	N_2O	kg	–	0.00	–
	H_2O_2 (Hydrogen dioxide)	g	22.18	–	–
	Ammonia	g	66.52	–	–
	Particulates < 2.5 µm	g	8.14	–	0.03
	Particulates < 10 µm	g	16.71	–	0.10
Emissions to water	COD (Chemical Oxygen Demand)	g	5.87	–	–
	Ammonia as N	g	0.42	–	–
	Chloride	kg	–	–	15.01
	Sulfur in water	kg	–	–	4.95
	TSS	kg	–	0.00	–
Emissions to soil / metals	Lead	mg	0.06	–	–
	Chromium	mg	0.02	–	–
	Arsenic	mg	0.25	–	–
	Cadmium	mg	0.01	–	–
	Mercury	mg	0.01	–	–
	Silicon	kg	–	–	0.18
	Sulfur (soil)	kg	–	–	0.06
Solid waste / residues	Wastewater (treated)	t	0.35	–	–
	Coal gangue	t	0.15	–	–
	Overburden material	kg	–	32 462	–
	Soil removed	kg	–	316.99	–

Electricity consumption per tonne of coal remains consistent across all studies (33–37 kWh/ton), reflecting comparable utilization of electrical equipment, including conveyors, fans, and processing units [33]. In contrast, diesel consumption exhibits significant variation. Indonesian mining operations report substantially higher diesel use (13.42 L/ton) compared to Chinese operations (0.002–0.58 L/ton), indicating a greater reliance on diesel-powered haulage and machinery characteristic of open-pit mining in Indonesia. Conversely, Chinese mines demonstrate higher levels of electrification and mechanization, resulting in reduced dependence on diesel fuel.

Water consumption shows the most extreme variability. Tao et al. (2022) report only 290 L per tonne, whereas Wu et al. (2022) report 387,120 L, indicating that certain mines rely heavily on underground pumping and dust suppression systems [61]. High groundwater inflow commonly requires continuous dewatering, explaining the large water inputs in some Chinese underground mines [61].

For material inputs, steel (1.30–6.914 kg) and cement (5.65 kg) reflect construction, reinforcement, and equipment maintenance activities [34]. Explosive use (0.02–0.04 kg) is relatively consistent across studies, suggesting similar blasting requirements per tonne of coal.

Underground mining activities are generally associated with higher methane (CH_4) emissions due to coal seam degassing and ventilation requirements, while surface mining typically shows lower CH_4 emissions but generates larger amounts of overburden material and water use [30-32]. Variations in energy consumption (electricity, diesel, and heat) further contribute to differences in CO_2 emissions, reflecting in diesel use, electricity grid mix, and ventilation power [35]. Additionally, disparities in methane management practices, such as drainage and capture technologies, as well as water management and waste handling systems, lead to further emission variability [65]. These methodological and technological differences explain the observed emission ranges, even among datasets originating from the same country. While, particulate matter emissions (<10 µm) range from 0.10 to 16.71 g, which is influenced by local dust control practices.

The inventory indicates that coal production is highly resource-intensive and has considerable environmental impacts. Regional differences, resulting from geological, technological, and operational factors, highlight the necessity of utilizing site-specific life cycle inventory (LCI) data for precise environmental assessments.

5.0 Petrol Trend, Status and Composition

5.1 Current scenarios of Petroleum

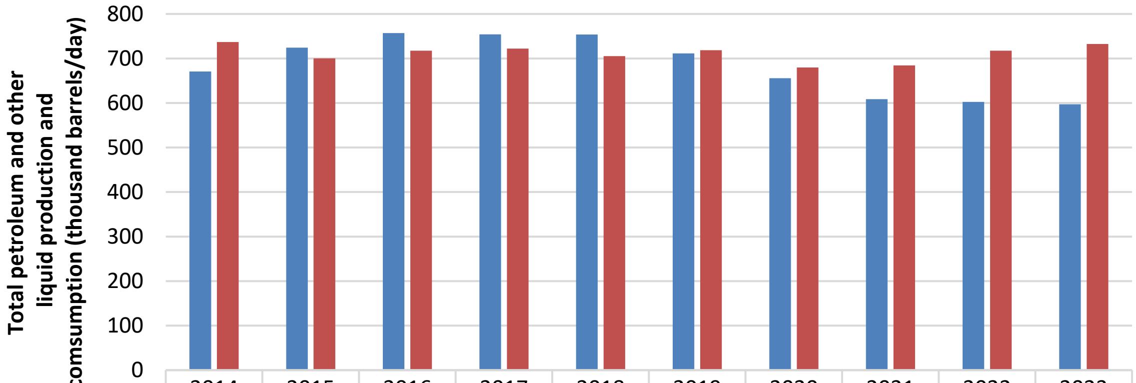
Petroleum exploration in Malaysia's offshore areas began in the 1950s with the introduction of marine seismic surveys off Sarawak, followed by the first offshore drilling in 1957 [36]. Since the formation of PETRONAS in 1974, the country has produced an estimated 9 billion barrels of oil and 50 trillion cubic feet of natural gas, establishing Malaysia as a significant regional hydrocarbon producer [36], Malaysia remains the second-largest producer of petroleum and other liquids in Southeast Asia and ranked fifth globally in LNG exports in 2023 [37].

Over the years, Malaysia's petroleum and other liquids output has been trending downward as illustrated in Figure 2. Production declined from 2017 to 2023 to around 597,000 barrels per day, mainly due to the maturity of key fields [38]. At the same time, domestic consumption rebounded sharply after the pandemic, driven largely by recovering petrol demand in 2022 [38]. These parallel trends falling production and rising consumption have accelerated Malaysia's shift toward becoming a full net oil-importing nation. Figure 2 also shows the import of crude oil in Malaysia from 2014-2023. As a result, the country faces growing energy security concerns linked to increasing dependence on imported crude and refined products [39].

Although production is declining, Malaysia still maintains significant hydrocarbon potential. In 2023, proven oil reserves were estimated at 2.7 billion barrels, the second largest in Southeast Asia [38]. PETRONAS also reported 19 new oil and gas discoveries during that year, potentially adding more than 1 billion barrels of oil equivalent to national reserves. Notably, 16 discoveries were made in the Sarawak Basin, while three were located offshore Sabah, indicating continued prospects for upstream development [38].

5.2 Petroleum product – Petrol

Petrol-powered vehicles remain the dominant mode of private transport in Malaysia, accounting for the majority of the 36.3 million registered vehicles nationwide as of 2024 [40]. More than 80% of these consist of passenger cars and motorcycles that rely on RON95 or RON97 fuels [1].



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
production	670.8	724.4	756.9	754.3	753.7	711.4	655.5	608.7	602.6	597.2
consumption	737.0	700.1	717.3	722.3	705.3	718.6	679.7	684.3	717.4	732.5

Figure 2: Total petroleum and other liquids production and consumption, 2014-2023 [38]

This indicates that Malaysia remains highly dependent on petrol as the primary energy source for the transport sector. RON95 and RON97 fuels transitioned from the Euro 2M to the Euro 4M standard in 2020 and 2015, respectively [41]. These advancements support Malaysia's emission reduction objectives, as specified in the National Energy Transition Roadmap (NETR) and the nation's long-term low-carbon development strategies, which prioritize cleaner mobility and improved air quality.

For the chemical composition of petrol, PETRONAS does not provide detailed compositional information in its Safety Data Sheets (SDS), and the same limitation applies to other petroleum companies in Malaysia, as such data are considered confidential. Therefore, the chemical composition reported by [42] was used as the reference. The fuel properties of RON 95 and RON 97 illustrate in Table 3. The PETRONAS website reports that the new Malaysian fuel specifications require a substantial reduction in sulphur content to 50 ppm, which is ten times lower than the previous Euro 2M standard for RON95 petrol. Additionally, benzene content has been reduced by 30% to 3.5%, and vapour pressure has been decreased by 7% to 65 kPa. These changes demonstrate that the current petrol formulation is significantly cleaner, resulting in reduced vehicle emissions and enhanced engine performance [43].

Table 3: Fuel Properties of RON95 and RON97 [42].

Description	RON95	RON97
Octane number	95	97
Initial boiling point (°C)	35.7	35.7
Final boiling point (°C)	197.2	200.5
Density @ 15°C (kg/L)	0.764	0.7639
Reid vapour pressure (kPa)	66	65.5

Recognising the need to reduce this reliance and strengthen long-term energy security, Malaysia has embarked on an ambitious pathway toward carbon neutrality by 2050. National frameworks such as the National Energy Transition Roadmap (NETR) outline strategies to decarbonize key sectors, diversify the national energy mix, and enhance overall climate resilience [44,45]. Globally, transport electrification has emerged as a central strategy for reducing greenhouse gas (GHG) emissions, with battery electric vehicles (BEVs) projected to account for nearly 50% of the global vehicle stock by 2050 [46]. However, Malaysia's EV adoption remains modest, constrained by limited charging infrastructure, high upfront costs, and relatively low domestic fuel prices [47]. These challenges highlight the need for continued policy support, targeted incentives, and infrastructure expansion to accelerate Malaysia's transition away from petrol dependency.

5.3 Petrol inventories

The three inventory datasets for petrol refining, representing operations in Sri Lanka, Europe, and Switzerland [48,49], shown in Table A2, show clear variability in the composition of key input and output flows. Primary data for the Sri Lankan petrol refining system were compiled from operational information from annual, progress, and audit reports published by governmental and private-sector stakeholders for the period 2018–2019. In contrast, the European and Swiss datasets compiled by Jungbluth et al. (2018) are derived from Ecoinvent's background system.

In terms of energy consumption, Sri Lanka shows markedly higher energy requirements, particularly for fuel gas, crude oil feedstock, and fuel oil, alongside the highest electricity consumption. In contrast, European and Swiss refineries exhibit lower electricity demand and rely more on refinery gas, natural gas, and heavy fuel oil. Water consumption patterns also differ substantially, with Europe and Switzerland reporting large volumes of cooling and process water, while Sri Lanka records only limited water withdrawals. Chemical and catalyst usage is also more extensive in Europe and Switzerland, especially in Swiss refineries, which utilize high amounts of nickel, molybdenum, and platinum-group metals. Waste generation shows a similar trend, where Sri Lanka produces significantly more refinery sludge per functional unit, while Europe and Switzerland report smaller but more comprehensively documented waste streams. Air and water emissions are also highest in European and Swiss datasets. Overall, Table A2 shows the inventories of petrol in 3 locations, each showing distinct input and output flows.

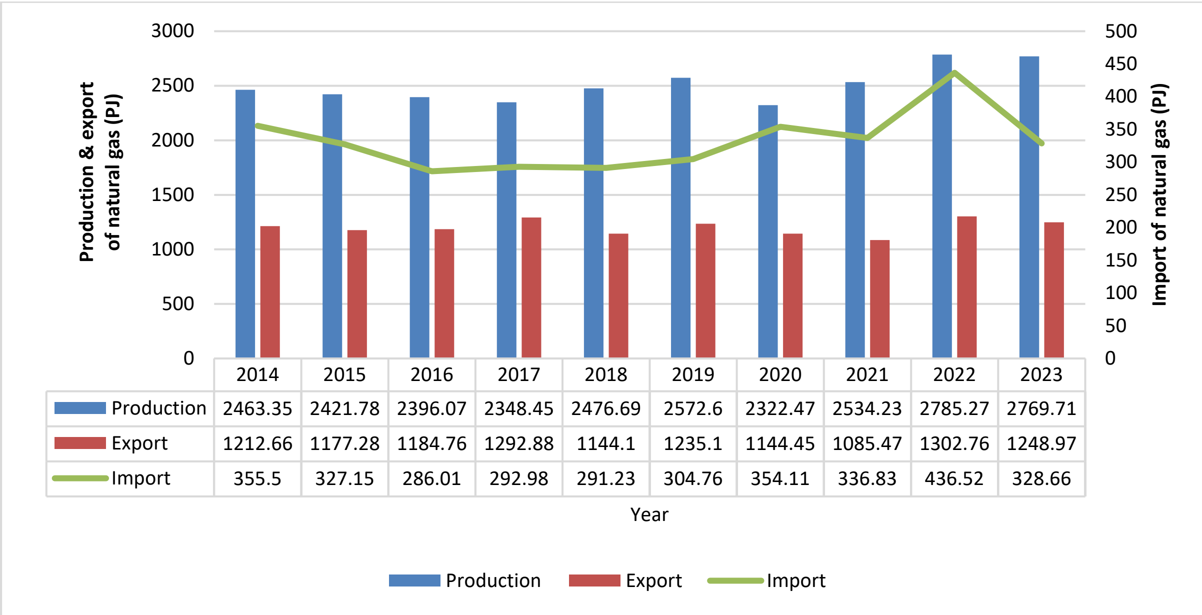
Table A2: Petrol inventories [48,49].

Category	Parameter / Flow	Unit	Sri Lanka [48]	Europe [49]	Swiss [49]
INPUTS					
Energy use	Electricity	kWh	49.37	30.06	37.06
	Natural gas (burned in furnace)	MJ		24.97	29.47

	Refinery gas (burned in furnace)	MJ		23.50	29.47
	Heavy fuel oil (burned in furnace)	MJ		23.50	29.47
	Petroleum coke (burned in furnace)	MJ		23.50	29.47
	Fuel gas	MJ	197.63	–	
	Crude oil (input feedstock)	kg	140.09	18.16	
	Fuel oil (energy input)	MJ	168.47	–	
Water resources	Water, unspecified natural origin	m^3		18.27	22.57
	Water, cooling	m^3		18.27	22.57
	Water (from river)	kg	13.77	–	
	Water (from water bodies)	kg	64.18	–	
Chemicals & process materials	Ammonia	kg		18.34	22.57
	Calcium chloride	kg		18.27	89.87
	Hydrochloric acid (30%)	kg		18.27	12.71
	Sulphuric acid	kg		18.27	22.57
	Chlorine (liquid)	kg		71.43	22.57
	Nitrogen (liquid)	kg		18.27	22.37
	Sodium hypochlorite	kg		18.27	22.57
	Soap	kg		18.27	87.64
	Lubricant	kg		18.27	22.57
	Naphta	kg		18.16	22.57
Catalyst	Molybdenum	kg		41.05	58.78
	Nickel	kg		49.94	69.36
	palladium, at regional storage	kg		70.91	88.89
	platinum, at regional storage	kg		70.91	88.89
	rhodium, at regional storage	kg		70.91	88.89
Transport & logistics	Lorry transport (>16 t)	t·km		18.27	22.57
	Rail transport	t·km		18.27	22.57
OUTPUTS					
Product	Petrol	kg	100.00	100	100
Waste	Refinery sludge	t	0.81	0.02	22.57
Water emissions	Chemical Oxygen Demand (COD)	kg		20.65	24.87
	Biological Oxygen Demand (BOD)	kg		19.90	24.19
	Oils (unspecified)	kg		29.88	38.75
	Benzene (in effluent)	kg		18.52	22.85
	Hydrocarbons (aromatic)	kg		18.27	22.57
	Nitrate	kg		18.27	
	Sulfate	kg		18.52	
Soil emissions	Oil spill	kg	0.07	–	
Air emissions	CO_2	kg	1.10		
	NO_x	kg	0.01	23.90	29.47
	SO_2	kg	0.02	13.70	
	PM_{10}	kg	0.10	18.34	22.61
	Hydrocarbon	kg	0.31	18.34	22.61
	Aldehydes	kg	0.00	–	
	Ammonia	kg	0.00	18.27	22.57
	Water vapor	kg	57.92	–	
	Benzene	kg	–	18.34	22.61
	Toluene	kg		18.34	22.61
	Xylene	kg		18.34	22.61
	Methane, fossil	kg	–	18.34	22.61

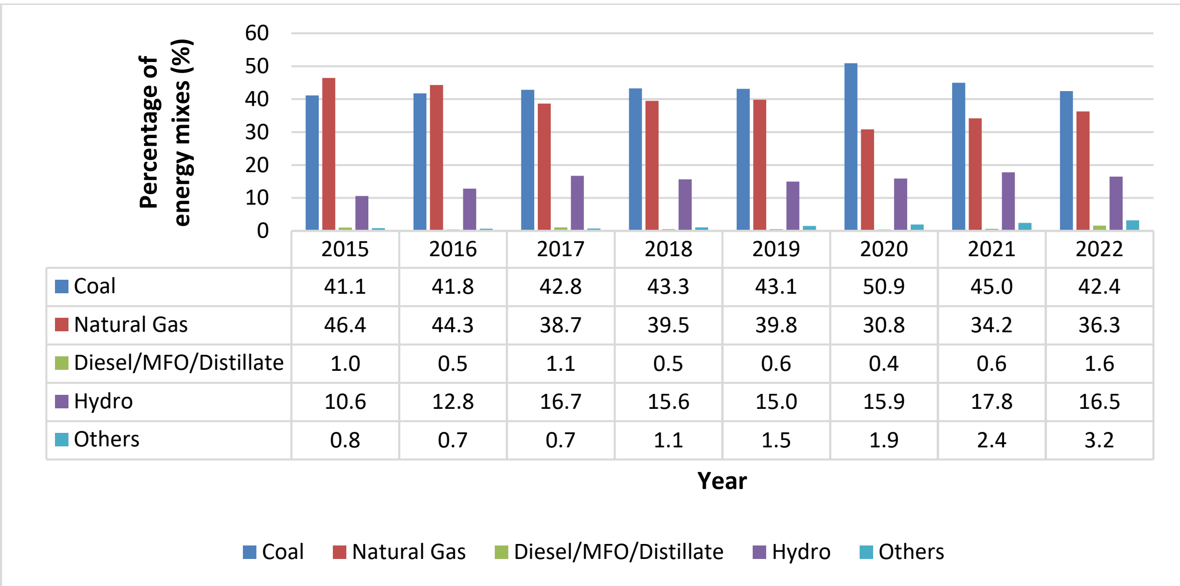
6.0 Natural Gas Trend, Status and Composition

Malaysia, besides being an oil producer, also plays a major role as one of the leading natural gas producers in Southeast Asia and ranks as the ninth-largest producer globally [50]. Production of natural gas has generally increased over the years, the trend fluctuates, reflecting the challenges of relying on aging fields and the uneven pace of new project development [51]. At the same time, exports remain consistently high due to Malaysia's long-term LNG export commitments, particularly as the country retained its position as the world's fifth-largest liquefied natural gas (LNG) exporter in 2023 [52]. Despite being a major producer, Malaysia's imports have risen steadily from the mid-2000s onward, signalling that domestic demand is growing faster than supply can accommodate [54]. Combination of fluctuating natural gas production, rising energy demand, and persistent export obligations raises concerns that Malaysia may increasingly depend on imported natural gas, heightening long-term energy security risks and reinforcing projections that the country could eventually become a net importer [38]. Figure 3 shows the trends of production, export and imports of natural gas in Malaysia [38]. Based on the graph, natural gas production in Malaysia remains consistently high, with exports also substantial, reflecting Malaysia's role as a major regional gas producer. Imports remain relatively small but show a slight increase in recent years, indicating growing domestic demand for certain gas products despite high production levels. Overall, the data highlight Malaysia's unique position of being both a significant natural gas exporter and a modest importer.



	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Production	2463.35	2421.78	2396.07	2348.45	2476.69	2572.6	2322.47	2534.23	2785.27	2769.71
Export	1212.66	1177.28	1184.76	1292.88	1144.1	1235.1	1144.45	1085.47	1302.76	1248.97
Import	355.5	327.15	286.01	292.98	291.23	304.76	354.11	336.83	436.52	328.66

Figure 3: Trend of production, consumption and import of natural gas in Malaysia from 2012-2022 [59]



	2015	2016	2017	2018	2019	2020	2021	2022
Coal	41.1	41.8	42.8	43.3	43.1	50.9	45.0	42.4
Natural Gas	46.4	44.3	38.7	39.5	39.8	30.8	34.2	36.3
Diesel/MFO/Distillate	1.0	0.5	1.1	0.5	0.6	0.4	0.6	1.6
Hydro	10.6	12.8	16.7	15.6	15.0	15.9	17.8	16.5
Others	0.8	0.7	0.7	1.1	1.5	1.9	2.4	3.2

Figure 4: Energy mixes in Malaysia [60]

As shown in Figure 4, electricity consumption in Malaysia is predominantly fuelled by coal and natural gas, which together make up the largest share of the national energy mix. Coal consistently remained a major source, fluctuating between 41% and 51%, with its peak in 2020, while natural gas ranges from about 30% to 46%, remaining the second-largest source. In contrast, diesel and other non-renewable fuels (classified as "Others") contribute only a very small portion, typically below 3%. If this trend continues, whereby coal remains the dominant source of electricity generation, it raises significant concerns for Malaysia's energy transition [62]. The sustained reliance on coal contributes to elevated carbon emissions and deteriorating air quality [62]. In the context of Malaysia's ambition to expand the adoption of electric vehicles (EVs), this poses a critical challenge. Although EVs produce no direct tailpipe emissions, the electricity required to charge them is still largely generated from coal [55]. As a result, the environmental benefits of electrifying the transport sector may be limited if the national power mix continues to be heavily dependent on high-emission fossil fuels [55].

6.1 Natural gas inventories

The natural gas inventory is compiled from two main sources: literature field-based data from Indonesia; and natural gas extraction datasets developed by Jungbluth and colleagues for Eco-invent database. Table A3 illustrate the natural gas inventories from Indonesia. The Indonesian inventories, obtained from Afghani et al. (2024) and Muhamad et al. (2022), provide primary data collected directly from natural gas extraction sites [56,57]. These datasets include detailed measurements of energy use, chemical inputs, water consumption, supporting materials, and emissions based on real operational conditions. This data is valuable because it reflects field practices within Southeast Asia, a region with geological and production characteristics more comparable to Malaysia. In contrast, the Jungbluth datasets represent modelled life cycle inventories for both onshore and offshore natural gas production, developed using engineering data, literature sources, and industrial information [58].

Table A3: Natural gas inventories per 100kg of natural gas [56,57]

Category	Parameter / Flow	Unit	Indonesia [56]	Indonesia [57]
INPUTS				
Energy	Electricity	Kwh	599,678.81	—
	Fuel gas	MMSCF	0.067	—
	Natural resources	MMSCFD	1.04	1.02
Raw material	Water	m^3	0.14	—
Supporting material	Methyldiethanolamine	kg	0.76	—
	EG (Ethylene Glycol)	kg	0.72	—
OUTPUTS				
Product	Natural gas	MMSCFD	1	1
	Condensate	kg	723	—
	Sales gas	MMSCFD	1	—
Byproduct	Condensate	kg	—	1.07E-02
Water treatment emissions	Arsenic	kg	—	1.58E-08
	Cadmium	kg	—	1.80E-08
	Chromium VI	kg	—	1.13E-07
	Chemical Oxygen Demand (COD)	kg	—	5.97E-04
	Copper	kg	—	2.25E-08
	Lead	kg	—	1.13E-07
	Mercury	kg	—	1.13E-07
	Nickel	kg	—	4.51E-08
	Phenol	kg	—	2.77E-06
	Vanadium	kg	—	1.80E-07
	Zinc	kg	—	1.35E-08
Water use	Water, unspecified (water)	litre	1529	—
Air emissions	CO_2	kg	3.637	2.36E+02
	NO_x	kg	1.5	2.27E-01
	PM_{10}	kg	0.17	1.40E-05
	SO_2	kg	0.51	2.69E-02
	CH_4	kg	4.07	4.69E-03
	N_2O	kg	1.96	2.09E-03

Table A4 shows the inventories of offshore and onshore of natural gas extraction per one unit of infrastructure developed. These inventories form the foundation of the natural gas datasets later incorporated into the Eco-invent database and provide comprehensive coverage of infrastructure, resource extraction, pipeline transport, waste flows, and emissions to air, water, and soil. By combining Indonesia's field-based inventories with the established model-based datasets created by Jungbluth, this study integrates both empirical and theoretical information to construct a more complete representation of natural gas extraction in the absence of Malaysia-specific LCI data.

Table A4: Natural gas inventories per 1 unit infrastructure developed [58].

Category	Parameter / Flow	Unit	Offshore	Onshore
INPUTS				
Resource (in ground)	Natural gas in ground	Nm^3	1.88E+11	7.33E+11
Water resources	Water, unspecified natural origin (US)	m^3	–	2.76E+08
	Water, fossil	m^3	–	4.96E+08
Technosphere inputs	Inorganic chemicals, at plant	kg	8.72E+07	3.49E+08
	Organic chemicals, at plant	kg	6.63E+07	2.59E+08
	Freight transport, 16–32 t truck	tkm	1.54E+07	5.97E+07
	Freight transport, rail	tkm	9.23E+07	3.59E+08
Infrastructure	Well for exploration & production	m	6.94E+06	2.69E+07
Gas facilities	Offshore gas production plant	unit	4.23E+00	–
	Onshore gas production plant	unit	–	2.10E+02
	Pipeline, long-distance, high capacity	km	1.19E+03	7.57E+03
Energy inputs	Electricity (medium voltage)	kWh	8.62E+09	3.35E+08
	Diesel burned at extraction	MJ	8.21E+09	3.20E+08
	Sweet gas burned in turbine	MJ	4.02E+11	1.57E+10
OUTPUTS				
Product	Natural gas at production	Nm^3	1.88E+11	7.33E+11
Waste	Natural gas, vented	Nm^3	6.33E+04	2.03E+08
	Natural gas, sweet, flared	Nm^4	1.80E+09	7.04E+07
	Radioactive waste disposal	m^3	3.15E+04	1.22E+03
	Water to municipal incineration	kg	1.58E+07	6.12E+05
Water emissions (river)	Oils, unspecified	kg	6.53E+06	1.51E+05
	BOD_5	kg	–	4.76E+05
	COD	kg	–	4.76E+05
	DOC	kg	–	1.31E+05
	TOC	kg	–	1.31E+05
	AOX	kg	–	1.56E+00
	Nitrogen	kg	–	1.17E+02
	Sulfur	kg	–	4.05E+02
Water emissions (ocean)	BOD_5	kg	2.06E+07	–
	COD	kg	2.06E+07	–
	DOC	kg	5.66E+06	–
	TOC	kg	5.66E+06	–
	AOX	kg	5.66E+06	–
	Nitrogen	kg	5.04E+03	–
	Sulphur	kg	1.74E+04	–
Soil emissions	Oils, unspecified	kg	–	2.32E+06
Air emissions (low pop. density)	SO_2	kg	1.63E+07	6.32E+07
	NO_x	kg	8.31E+07	3.23E+08
	Halon-1301	kg	1.83E+03	–
	HFC-23	kg	7.34E+03	–

7.0 CONCLUSION

This study compiles existing Life Cycle Inventory (LCI) datasets for petrol, natural gas, and coal-derived fuels alongside an overview of Malaysia's transport and energy trends. The compiled information highlights several important issues and implications for understanding Malaysia's fuel landscape and future energy transition pathways.

Malaysia's road transport system remains heavily dependent on petroleum fuels, particularly petrol [1], due to high private vehicle ownership and relatively low fuel prices [11]. While electric vehicle (EV) adoption has begun to increase, progress is still gradual [12] because of challenges related to charging infrastructure, vehicle affordability, and consumer familiarity. The environmental benefits of EVs are further influenced by Malaysia's electricity generation mix [60], which is currently dominated by coal and natural gas [62]. Therefore, upstream emissions associated with EV charging must be carefully considered when evaluating EV sustainability [55]. Over the next decade, national policies, fiscal incentives, and planned infrastructure expansion are expected to accelerate EV adoption, potentially reducing reliance on conventional fuels such as petrol and diesel and lowering associated life cycle inventories. However, in the near to medium term, increased electricity demand from EV charging may shift part of the environmental burden from the transport sector to the power generation sector [66]. As renewable energy penetration increases, the life cycle impacts of EV-related electricity consumption are expected to decline [67]. Although this study applies current fuel inventory data, future assessments should incorporate dynamic LCI datasets that reflect evolving EV penetration rates and anticipated grid decarbonization pathways in Malaysia.

Coal and natural gas trends also reveal structural challenges for Malaysia. Coal remains the largest source of electricity generation for EV charging, despite Malaysia having minimal domestic coal production. This heavy dependence on imported coal exposes the country to external market fluctuations and maintains a high-carbon power sector. Natural gas production, meanwhile, shows fluctuating trends influenced by the maturity of domestic fields and the uneven pace of new developments [51]. Long-term LNG export commitments further limit domestic supply, while rising internal demand has led to increasing levels of natural gas imports. These trends highlight the importance of evaluating upstream processes for fossil fuels, as they directly shape Malaysia's long-term energy security and environmental outlook.

The fuel inventories compiled for this study demonstrate notable differences that reflect technological, geographical, and methodological variations. The original dataset contained more detailed input and output information, but this study streamlined it by retaining only the most relevant and essential data.

Field-based natural gas inventories from Indonesia offer insights that reflect real extraction activities in Southeast Asia. In comparison, the Jungbluth inventories in the Eco-invent database are based on modelled onshore and offshore extraction systems, using engineering assumptions and data from the literature. The main differences between these sources come from using real-world data versus modelled inputs, as well as differences in system boundaries. The Indonesian inventory focuses on processes at actual extraction sites, while Jungbluth uses a broader "cradle-to-gate" approach that may cover different process stages. The functional units also differ, Jungbluth's data is reported per infrastructure, while the Indonesian inventory measures impact per 1 MMSCFD of natural gas produced.

For petrol refining, datasets from Sri Lanka, Europe, and Switzerland illustrate how refinery configuration, energy sources, and emission control technologies influence upstream impacts. Coal mining inventories from China and Indonesia similarly show wide variations between underground and open pit mining operations, affecting energy use, water consumption, and pollutant emissions. These differences underscore the need to interpret LCI datasets within their specific regional and technological contexts.

In conclusion, although the compiled LCI datasets originate from different regions and technological systems, its collectively contribute to a clearer understanding of upstream fuel processes relevant to Malaysia. The analysis highlights the importance of context-specific data, the limitations of relying on proxy inventories, and the need for more comprehensive local data collection to support Malaysia's long-term transition toward a low-carbon and resilient transport system.

7.1 Future work

Future studies should expand the current analysis by incorporating a broader range of fuel pathways that reflect Malaysia's evolving transport and energy transition objectives. Specifically, future work can include a comparative life cycle assessment (LCA) of diesel, biodiesel, and hydrogen as alternative or complementary fuels to natural gas. As a developing country, Malaysia faces various constraints including the high cost of new technologies, limited charging infrastructure, and the need to maintain energy security which makes it challenging to rely solely on EVs for rapid decarbonization. Hence, in addition to promoting EV adoption, it is crucial to examine other viable alternative fuels such as cleaner diesel technologies, sustainable biodiesel derived from local feedstocks, and hydrogen, all of which can serve as complementary pathways in Malaysia's broader low-carbon transition.

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