Report on LIME 3 Assessment of Vehicles

June 2019

Nissan Motor Co., Ltd.

1. General

1.1 Assessment implementors

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1.2 Report creation date

May 25, 2019

2. Goal of the study

2.1 Reasons for carrying out the study

Use LCA to assess the environmental impact throughout the life cycle of vehicles (gasoline, electric) and ascertain their environmental performance.

2.2 Intended applications

To ascertain the environmental performance of gasoline and electric vehicles, clarify processes that are critical to improving environmental impact, and provide information for making design improvements.

3. Scope of the study

3.1 Study subjects and specifications

One Nissan SYLPHY a gasoline vehicle with 1.8L internal combustion engine (vehicle weight: 1,230kg),manufactured, used, and disposed of in Japan, the United States, or Europe and one Nissan Leaf a electric vehicle with a 40kWh lithium-ion battery (vehicle weight: 1,510kg).

3.2 Functions and functional units

Set as the entire life cycle of a single vehicle (gasoline and EV) used for 10 years with a total driving distance of 150,000km. (Table 3.1-1)

Table 3.1-1. Specification sheet of gasoline vehicles (unit (kg/f.u.))

	SYLPHY	**LEAF**
Fuel	Gasoline	Electricity
Engine / motor	MRA8DE	EM57
Rechargeable battery	—	Li-ion 40kWh
Weight	1,230 kg	1,510 kg
Body type	Sedan	Hatchback
Engine capacity	1.798 L	—
Maximum net power	96kW/6000rpm	110kW/3283～9795rpm
Transmission	CVT	-
Fuel efficiency (JC08)	15.6 km/L	120Wh/km
Life time	10 years	
Total operating distance	150,000 km	

3.3 System boundaries

Manufacturing, fuel production, operation, maintenance, and disposal stages (Fig. 3.2-1).

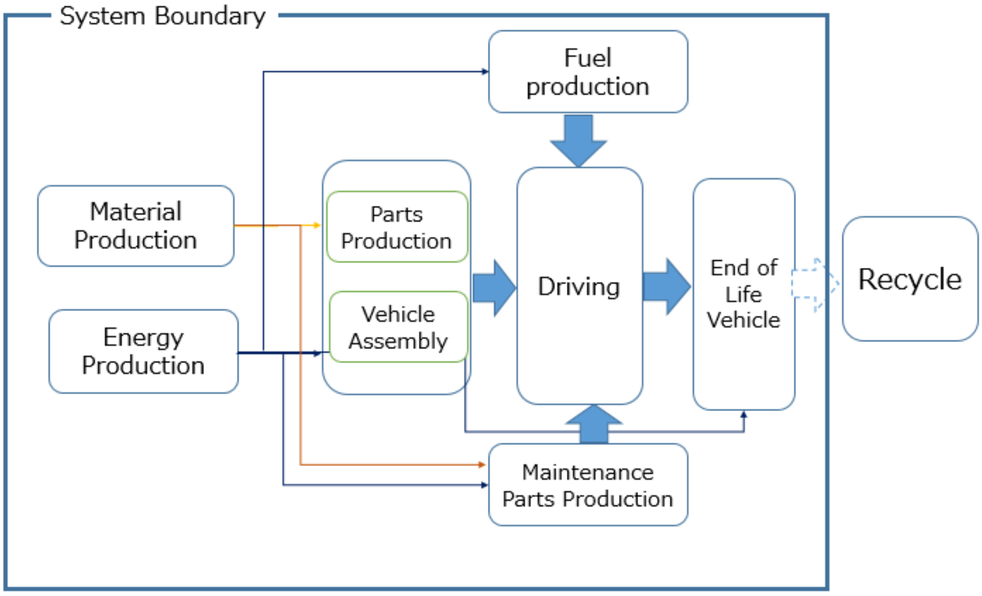

Fig. 3.2-1 Major vehicle product systems and system boundaries

3.4 Special notes (excluded processes, matters, etc.)

After disposal, vehicles are mainly recycled for iron, aluminum and other metals but the recycling processes were excluded from the scope of this assessment. Also, ASR (Automobile Shredder Residue) is incinerated and landfilled but energy recovery during incineration was excluded from the scope of this assessment. Furthermore, the construction, maintenance, and disposal of factories and machines related to parts production, assembly, fuel production, tools and parts required for maintenance, as well as the construction, maintenance and disposal of roads and related infrastructure used during vehicle operation are not included in the assessment.

Vehicles produced in Japan, North America, and Great Britain are assumed to be subject to average use in their respective regions and operated under the certified fuel efficiency modes specific to each country.

4. Inventory analysis

4.1 Foreground data

Regarding material and weight data for vehicle component parts, we used internally integrated data taken from International Material Data System (IMDS).

Energy intensity is based on data calculated via the following methods using information from company factories.

For each process of casting, stamping, forging, welding, parts assembly, painting, resin molding, and resin coating, we allocated environmental load per product mass based on the share of energy used at each factory during the one-year period of FY2016, which is calculated from the total mass of production in each factory. For each processes of vehicle painting and vehicle assembly, we allocated environmental load per vehicle produced based on the share of energy volume used at each factory during the one-year period of FY2016, which is calculated from the number of vehicle produced in each facility. For forging process, we allocated environmental load per part based on the number of parts in each process during the one-year period of FY2016.

For the use stage, we used fuel efficiency in JC08 mode for Japan, in combined LA4 (City) and highway mode for the USA, and in NEDC mode for Europe. Fuel efficiency figures are shown in Table 4.1-1.

For the disposal stage, we used internal data gathered from research related to recycling.

Table 4.1-1 Fuel efficiency

	USA	Japan	Europe
Gasoline (km/L)	13.6	15.6	14.9
EV (Wh/km)	186	120	146

4.2 Background data

Tire and lead-acid battery manufacturing data was taken from the LCA Japan Forum 2017 Ver.1 1). Other data was taken from the GaBi database 8.7 2).

Used power ratios are shown in Fig. 4.2-1 to 4.2-3 and electricity and gasoline inventories are shown in Table 4.2-1.

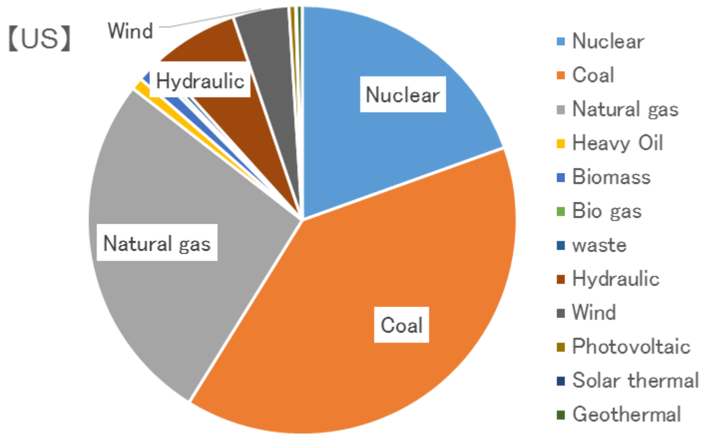

Fig. 4.2-1 Electricity structure in the USA

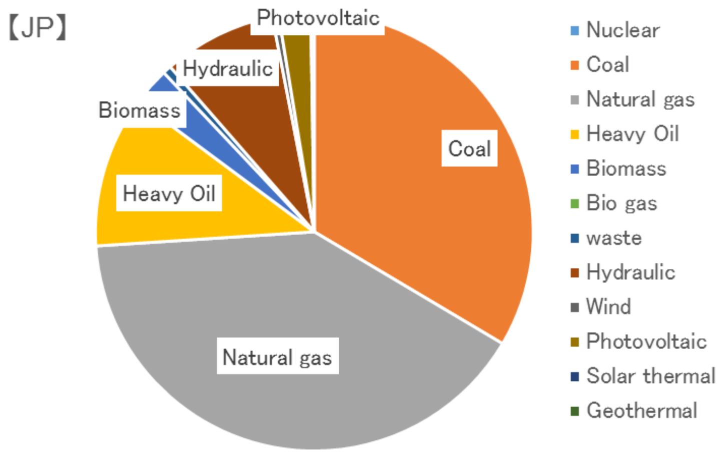

Fig. 4.2-2 Electricity structure in Japan

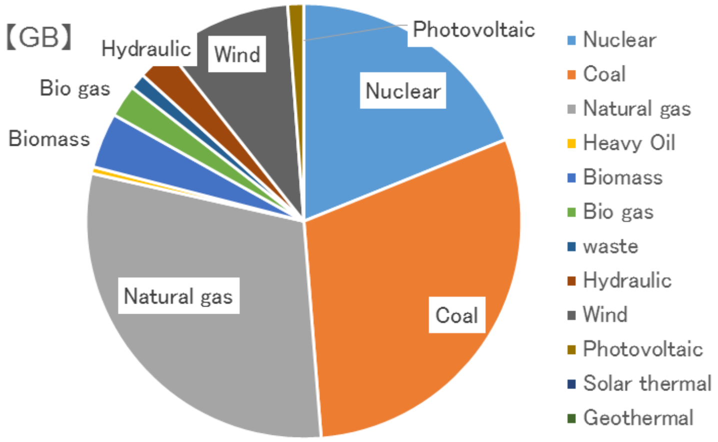

Fig. 4.2-3 Electricity structure in Great Britain

Table 4.2-1 Electricity and gasoline inventories

	Gasoline (/kg)			Electricity(/kWh)		
	US	JP	GB	US	JP	GB
GWP(kg-CO2e)	0.817	0.566	0.770	0.614	0.661	0.477
AP（kg SO2 e)	2.3E-03	3.5E-03	2.7E-03	2.0E-03	1.1E-03	1.6E-03
ADPelement（kg Sb e)	7.0E-07	5.1E-08	2.4E-07	1.4E-07	1.3E-07	1.2E-07
POCP(kg Ethene e)	3.6E-04	3.4E-04	4.0E-04	1.2E-04	8.4E-05	8.5E-05
Primary Energy Demand(MJ)	54.7	50.7	53.0	10.6	9.93	10.1
Blue water consumption(kg)	20.1	0.28	6.50	3.38	2.55	2.30

4.3 Items in the inventory analysis and the results

Table 4.3-1 shows a list of inventory analysis items for gasoline vehicles and EV.

Table 4.3-1. LCI analysis results of vehicles (unit (kg/f.u.))

			Production	Fuel Production	Driving	Maintenance	Disposal
Consumption Load	Depletion resource	Coal	○	○		○	○
		Oil(fuel)	○	○		○	○
		Natural gas	○	○		○	○
		Uranium					
		Oil(Raw)	○				○
		Iron	○			○	
		Copper	○				
		Bauxite	○				
		Nickel	○				
		Chrom	○				
		Lead	○			○	
		Zinc	○				
Emission Load	Outdoor air pollution	CO_2	○	○	○	○	○
		CH_4	○	○	○	○	○
		N_2O	○	○	○	○	○
		HFC-134a	○				
		CO	○	○	○	○	○
		NMVOC	○	○	○	○	○
		NOx	○	○	○	○	○
		PM10	○	○		○	○
		PM2.5	○	○			
		SOx	○	○	○	○	○
	Aquatic pollution	COD	○				
		T-N	○				
		PO_4^{3-}					
	Soil pollution	ASR(disposal)					○

5. Impact assessment

5.1 Assessment steps and impact categories

For the impact assessment, we used the Japanese version of the LIME3, Life-cycle Impact Assessment (LCIA) Method based on Endpoint modeling to conduct a three-step assessment comprised of characterization, a damage assessment, and integration. Impact categories for assessment in each step are shown in Table 5.1-1. For the LIME3 coefficient, we used the discount rate of 3% applied to the G20.

Table 5.1-1. Applicable environmental impact categories and assessment steps

	Damage assessment
Climate change	○
Air pollution	○
Photochemical oxidants	○
Water resource consumption	○
Land use	
Resource consumption (fossil fuels, mineral resources)	○
Forest resource consumption	
Waste products	○

	Integrated
IF1	
IF2	○

5.2 Impact assessment results

5.2.1 Damage assessment

The results of damage assessments (breakdown by substance) for gasoline vehicles for the four protection areas are shown in Figure 5.2-1 to 5.2-9. From left, US: Manufactured and operated in the USA (US coefficient), JP: Manufactured and operated in the Japan (Japan coefficient), GB: Manufactured and operated in Great Britain (GB coefficient), Ave: Manufactured and operated in Great Britain (global average coefficient for resource, GB for others).

With gasoline vehicles, the impact differences between countries was minor. Looking at the impact on human health, the global warming impact of the use stage is significant, followed by water consumption but air pollution impact level varied depending on the country. Water consumption impact was significant during vehicle manufacturing and the material production for maintenance parts. In particular, consumption volume during the production of natural rubber was significant. Similarly, the impact of global warming on biodiversity was significant during the use stage. At the same time, the impact of primary production was significant in terms mineral and energy resource consumption during the manufacturing phase. Looking at the impact on social assets, energy consumption (petroleum) was significant during the use stage.

Attributable factors of the impact include significant GWP during operation for human health and biodiversity, the large consumption of coal during power generation for primary production, and the large consumption of petroleum during use for societal assets.

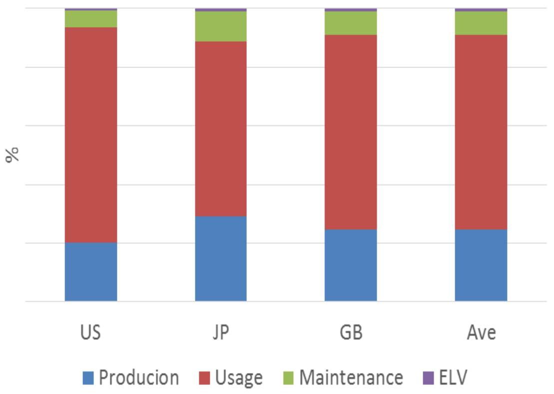

Fig. 5.2-1. Gasoline vehicle damage assessment results (Human health: by life stage)

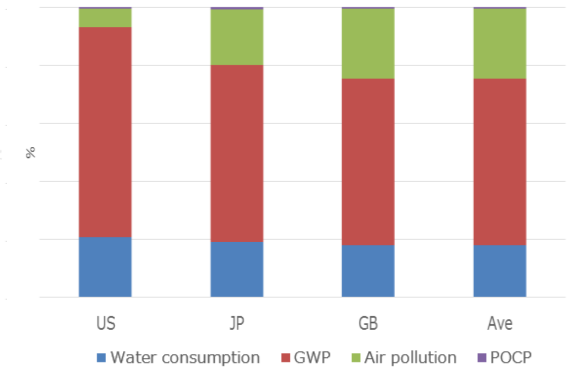

Fig. 5.2-2. Gasoline vehicle damage assessment results (Human health: by impact category)

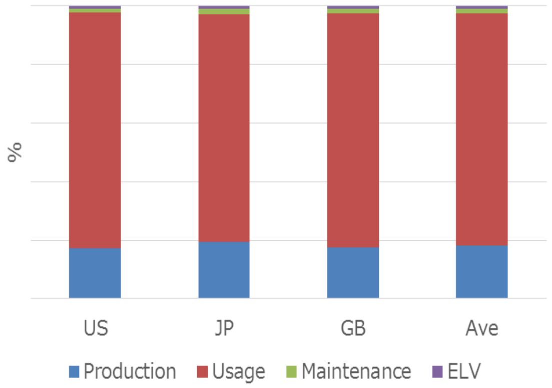

Fig. 5.2-3. Gasoline vehicle damage assessment results (Biodiversity: by life stage)

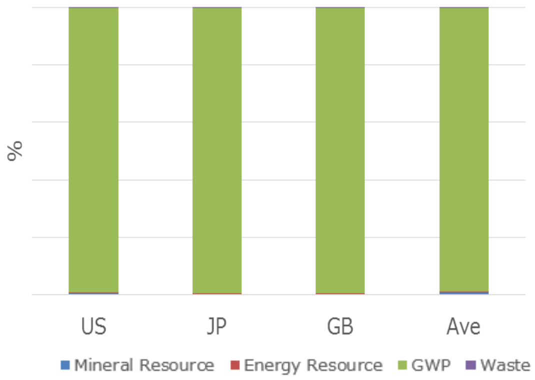

Fig. 5.2-4. Gasoline vehicle damage assessment results (Biodiversity: by impact category)

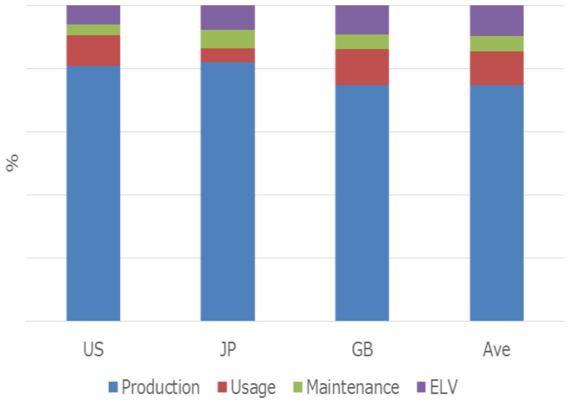

Fig. 5.2-5. Gasoline vehicle damage assessment results (Primary production: by life stage)

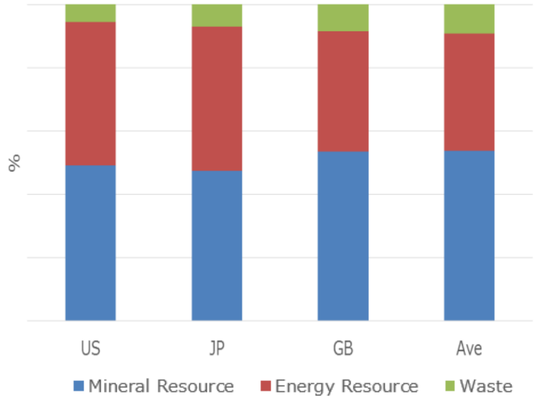

Fig. 5.2-6. Gasoline vehicle damage assessment results (Primary production: by impact category)

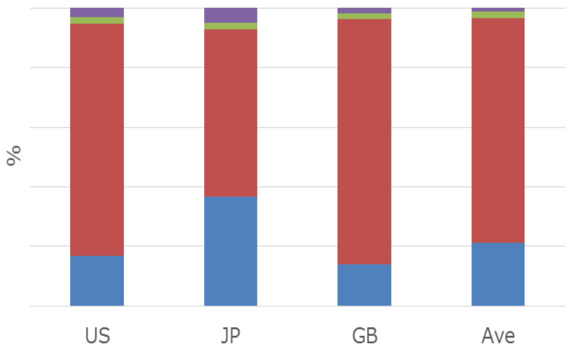

Fig. 5.2-7. Gasoline vehicle damage assessment results (Social asset: by life stage)

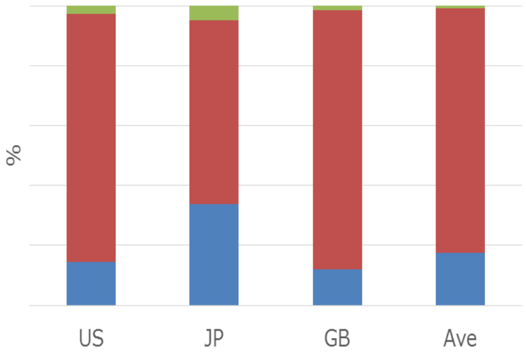

Fig. 5.2-8. Gasoline vehicle damage assessment results (Social asset: by impact category)

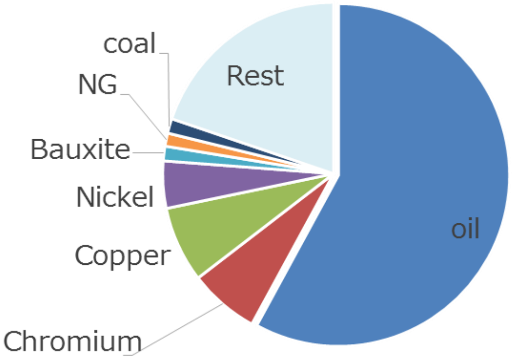

Fig. 5.2-9. Gasoline vehicle damage assessment results (Social asset in Japan: by mineral and energy type)

The results of damage assessments for EV for the four protection areas are shown in Figure 5.2-10 to 5.2-18. With EV, the impact differences between countries was large compared to gasoline vehicles. The impact on human health was largely represented by the global warming impact during the manufacturing stage and then the use stage. In Great Britain, the impact of air pollution was significant. This is the impact of mineral resource mining and concentrating and the impact of PM2.5 caused by SO2 emissions during power production during the use stage. As with gasoline vehicles, water consumption impact was significant during vehicle manufacturing and the material production for maintenance parts. In particular, consumption volume during the production of natural rubber was significant. The impact on biodiversity was mainly global warming which was significant during the manufacturing stage as well as the use stage. At the same time, the impact on primary production was significant in terms of mineral and energy resource consumption during the manufacturing stage but when comparing with gasoline vehicles, the impact was also significant during the use stage (fuel production). The impact on social assets was significant in terms of resource consumption during the manufacturing stage (mineral resources).

Attributable factors of the impact include significant GWP during operation for human health and biodiversity, the large consumption of coal during power generation for primary production, and the large consumption of minerals (cobalt, copper, nickel, etc.) during production for social assets.

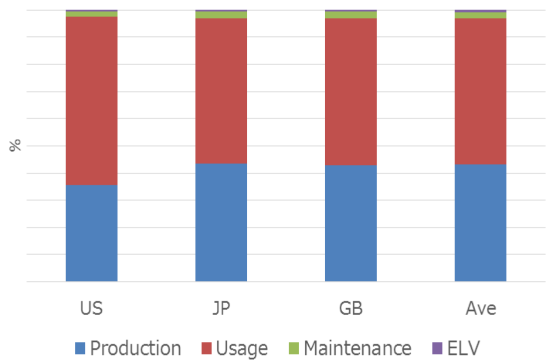

Fig. 5.2-10. Results of damage assessments for EV (Human health: by life stage)

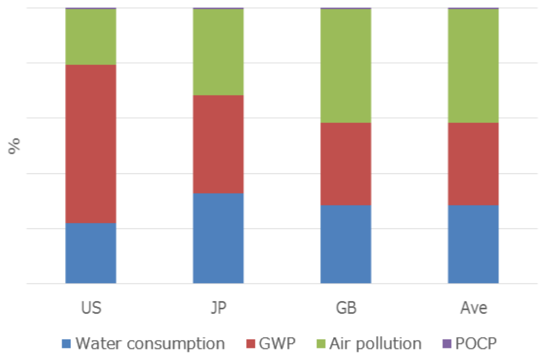

Fig. 5.2-11. Results of damage assessments for EV (Human health: by impact category)

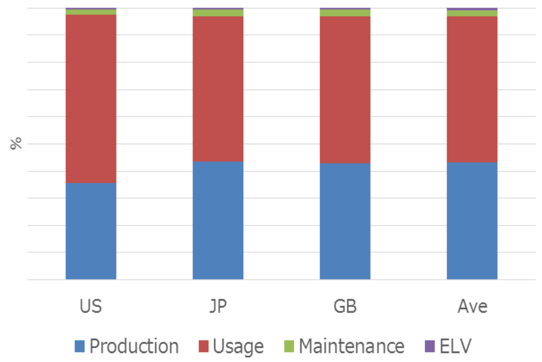

Fig. 5.2-12 Results of damage assessments for EV (Biodiversity: by life stage)

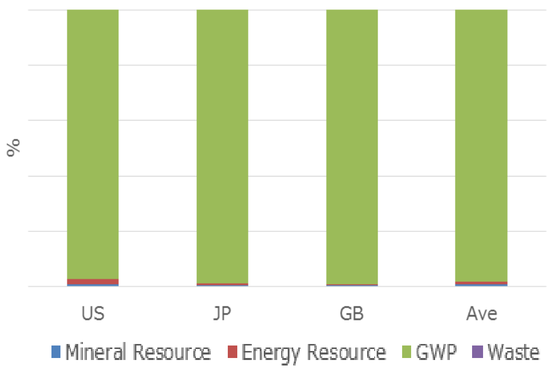

Fig. 5.2-13. Results of damage assessments for EV (Biodiversity: by impact category)

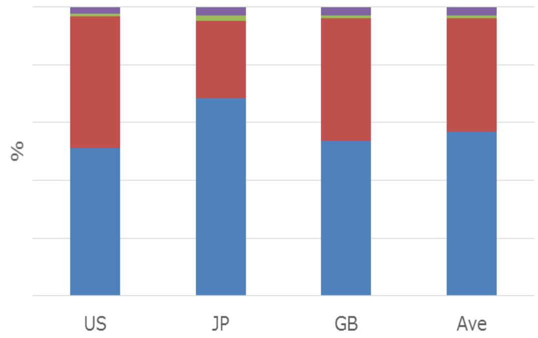

Fig. 5.2-14 Results of damage assessments for EV

(Primary production: by life stage)

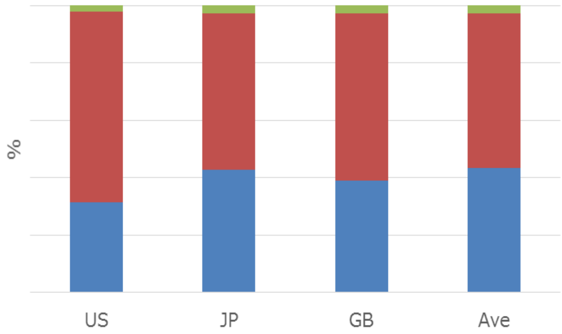

Fig. 5.2-15 Results of damage assessments for EV

(Primary production: by impact category)

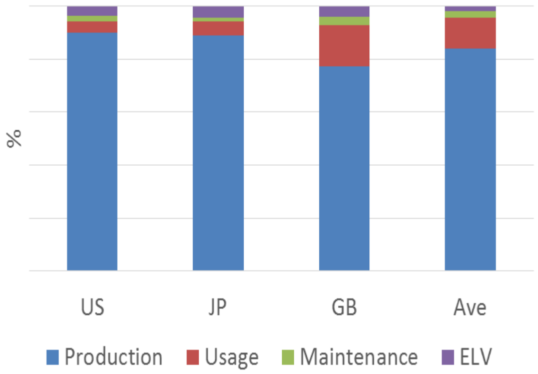

Fig. 5.2-16. Results of damage assessments for EV

(Social asset: by life stage)

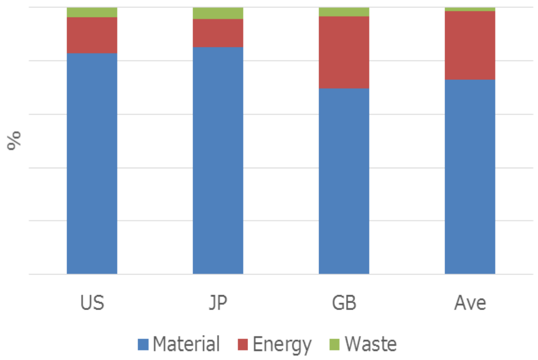

Fig. 5.2-17. Results of damage assessments for EV

(Societal asset: by impact category)

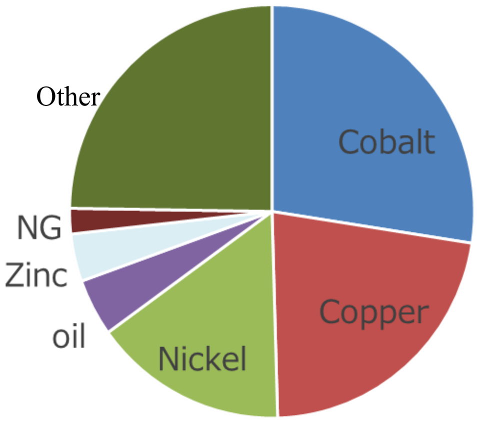

Fig. 5.2-18. Results of damage assessments for EV

(Social asset in Japan: by mineral and energy type)

5.2.3 Weighting

Gasoline vehicle weighting results are shown in Fig. 5.2-19 and 5.2-20. Looking at the environmental impact for the entire life cycle, with gasoline vehicles the impact was significant during the use stage with major impact items being CO_2 emissions and energy resource consumption in the form of crude oil. In particular, we saw that the impact of petroleum consumption (gasoline consumption) during use was most significant.

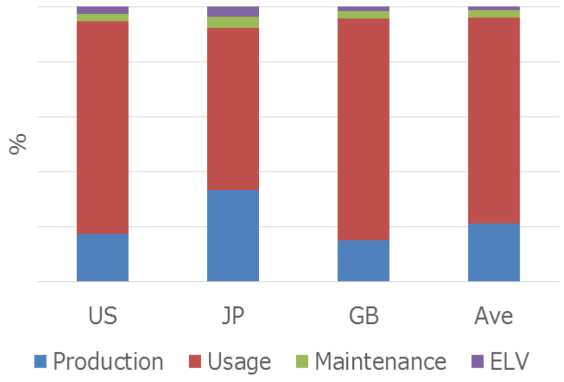

Fig. 5.2-19. Gasoline vehicle integration results

By life stage

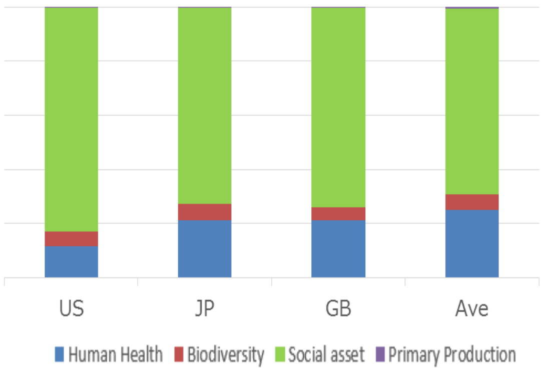

Fig. 5.2-20. Gasoline vehicle integration results

By impact category

EV weighting results are shown in Fig. 5.2-21 and 5.2-22. Looking at the environmental impact for the entire life cycle, with EV the impact was significant during the manufacturing stage with major impact items being the impact of mineral resources on social assets. In particular, while the impact ratio varies between countries, the impact of power components such as cobalt, nickel, and copper was significant.

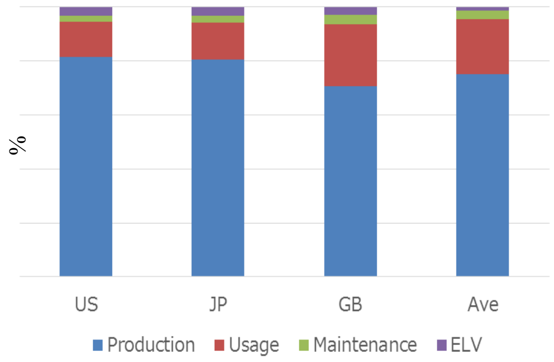

Fig. 5.2-21. EV integration results

By life stage

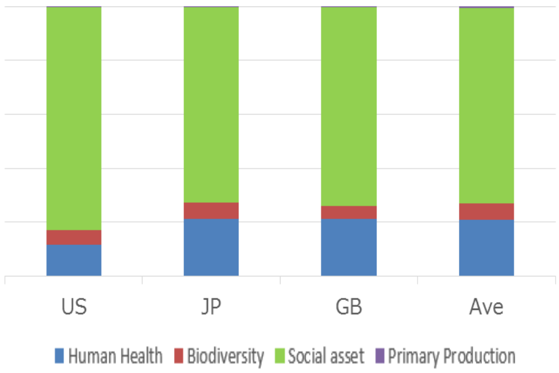

Fig. 5.2-22. EV integration results

By impact category

6. Conclusion

6.1 Summary of survey results

We compared the environmental impact for the entire life cycle (manufacturing, fuel production, operation (10 years, 150,000km)), maintenance, and disposal) of gasoline vehicles and EV in Japan, the US, and Great Britain.

With gasoline vehicles, country-specific differences were minimal and environmental impact was largely represented by the operating stage and vehicle production. In particular, gasoline production has an impact due to Oil-well drilling and vehicle operation has a global warming impact due to CO_2 emissions. From these results, it was clear that the impact on social assets caused by Oil-well drilling and the impact on human health caused by global warming were the main environmental impacts.

With EV, there were country-specific differences during manufacturing and use stages. The environmental impact of the manufacturing stage was mainly the impact of excavating mineral resources while the environmental impact of the use stage was mainly the impact on social resources and human health. The impact on social assets was mainly the previously mentioned impact of mineral resources for batteries. The environmental impact of global warming was mainly material and parts production during the manufacturing stage and the impact of CO_2 emissions during fuel production (power generation).

As a comprehensive evaluation of gasoline vehicles and EV, the results indicate that while impact targets differ, both have a significant impact on social assets. To reduce the environmental impact of these vehicles, for gasoline vehicles it is effective to suppress fuel consumption during operation. For EV, due to the significant impact of mineral resource consumption on social assets, there is thought to be potential to reduce environmental impact by recycling and reusing batteries.

6.2 Limits and future issues

This assessment covers the main processes in the life cycle, and the validity of the results is considered to be secured. However, substances subject to assessment are evaluated based on certified values and regulatory values for operating fuel economy and exhaust emissions. There is the possibility assessment results will vary significantly depending on assessment conditions, including fuel consumption ratios, driving conditions, and region of operation. As such, there is a need to conduct a sensitivity analysis of these factors. Furthermore, these results indicate the social asset impact to be significant but social impact itself is highly impacted by the country analyzed (advanced, developing) and discount rate. As such, there is also a need to conduct a sensitivity analysis based on assumptions made regarding the LIME 3 coefficient.

R&D for EV battery is being conducted actively but we targeted commercially available vehicles at the time of this assessment. Considering the ongoing development of batteries, it would be preferable to continue conducting assessments.

Similarly, various proposals are being made regarding EV battery reuse and recycling as well as the use of EV batteries as social infrastructure. There is a need to validate the effects of such use.

Reference literature

1) LCA Japan Forum 2017, ver.1: 309111 Vehicle Lead-Acid Batteries, 231113 Passenger Vehicle Tires
2) Thinkstep: GaBi, Software 8.7