Identifying the carbon hotspots in a vehicle to grid system

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Abstract:
A life cycle inventory analysis is conducted in this study to identify the carbon hotspots in a vehicle to grid (V2G) system and its CO_2 emissions advantage to the conventional counterpart equivalent. CO_2 emissions are calculated by applying the data of each components and life cycle stages collected from statistics and literature surveys to the Japanese life cycle inventory database. The emissions differ by the assumptions made; therefore a sensitivity analysis is also carried out to understand the potential variation of the CO_2 emissions. The result indicates that about 35-42% CO_2 reduction can be expected for a V2G system in comparison with the conventional system. Since the main contributors to CO_2 emissions of both systems are dwelling, residential house construction, vehicle cycle and fuel cycle stages, these stages should be included in the system boundary of the analysis.

Keywords: *Vehicle to grid; carbon hotspots; life cycle inventory analysis*

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1. Introduction

Battery electric vehicle (BEV) has been regarded from the past as one of the solution technologies for energy and environmental problems surrounding automotive sector due to its high energy efficiency and zero emissions. Although its R&D has started in the 1970s, it has not penetrated the market mainly due to its low practicality and high cost compared with the conventional internal combustion engine vehicles such as gasoline vehicle (GV). Thanks to the drastic improvements of the lithium-ion battery performance in the late 2000s, a practical vehicle range is expected for the state-of-the-art BEV and it have been focused attention upon again as the promising technology for the future mobility. Indeed, some vehicle makers have launched the sales of BEVs with lithium-ion battery in Japanese vehicle market for fleet use in 2009 and personal use in 2010.

Currently, the smart grid technologies that can efficiently manage electricity demand and supply including the use of renewable energy by using information and communication technologies have been given worldwide attention to ensure more stability of the energy grid and realize low-carbon society. It is deemed that BEV can be a key component to be used as distributed energy storage device in the smart grid system. Vehicle to grid (V2G) is a system that can share mutually the power between a vehicle and a home and is regarded as one of the key technologies in smart grid strategies. After the great earthquake on March 2011, Japan is facing power shortage and anticipation has increased for full-scale promotion of renewable energy such as photovoltaic (PV) solar power and emergency power supplies. It is expected that V2G system should contribute to stable power supply and emergency situations where electricity is required.

Although the environmental emissions attributed to vehicle and household energy use might be reduced by a V2G system compared to the conventional counterpart equivalent, the construction of residential house and installation of V2G system components to the house induces additional environmental emissions by their production and end-of-life stages so that the emissions reduction effect of the total system should be evaluated from an life cycle point of view. One of the quantitative methods to evaluate the environmental aspects and potential impacts associated with products, processes and services throughout its life span is life cycle assessment (LCA), which considers the assessment of products or services in “cradle to grave” perspective. The concept of LCA is applied to Well to Wheel analyses (JHFC, 2011; ANL, 2014) to estimate the environmental advantages of various alternative energy vehicles over the entire automotive fuel pathway. There are also many studies that conducted LCA and estimated environmental burdens by each life cycle stage of vehicles (Kudoh et al., 2007; Samaras and Meisterling, 2008). In terms of evaluating the environmental merits of a V2G system, LCA of the system including all the components of V2H should be carried out.

This study focuses upon the life cycle CO_2 emissions of a V2G system with a home PV system and a BEV. A life cycle inventory (LCI) analysis is conducted to estimate the potential CO_2 reduction compared to the counterpart conventional system and to identify the carbon hotspots of the system.

2. Method and assumptions

2.1 System components, system boundary and functional unit

Table 1 shows the components and their system boundary of the target systems for LCI analysis in this study. The V2G system comprises a residential house, a PV system, a power control system (PCS) and a BEV. PCS is a charging system that can not only charge the BEV but also supply electricity to the house from the BEV. Its counterpart conventional system consists of a residential house and a gasoline vehicle (GV). Since the PCS, the energy charger for BEV, is included in the component of the V2G system, the petrol station is also included in the conventional system component to have equal footing for both systems.

Table 1 System components and boundary of this study

Target system	System components	System boundary
V2G and conventional system	Residential house	Construction Dwelling Demolition and end-of-life
	Vehicle (BEV and GV)	Production Use Maintenance
V2G	PV	Production End-of-life
	PCS	Production
Conventional system	Petrol station	Construction Demolition and end-of-life

The system boundary of each component consists of its production, use and end-of-life stages; however the end-of-life stage of a BEV, GV and PCS is not included due to data restrictions.

Since the lifetime differs by each component, the life cycle CO_2 ($LCCO_2$) emissions of the component are discounted over its lifetime and the functional unit in this study is set to be annual CO_2 emissions from the system (household).

In terms of V2H system installed with PV that is under demonstration or in market, electricity generated by PV can be charged first into BEV and then used as dwelling energy. Since it was impossible to obtain the raw data from the actual system, however, it should be noted that this effect is not considered in our calculations.

2.2 LCI database used

The life cycle inventory database IDEA (Inventory Database for Environmental Analysis) (Tahara et al., 2010), which has been developed by National Institute of Advanced Industrial Science and

Technology, is used to calculate the $LCCO_2$ emissions from the target systems. IDEA covers about 3,000 basic processes in Japan including energy, chemicals, metals and nonmetals, machinery, building materials, civil construction, etc. The database is developed using statistical data, model calculation and literatures. Since the embodied CO_2 emission intensity including all the upstream emissions are given per activity unit of a process (e.g. in physical or monetary unit), the amount of $LCCO_2$ emissions can be calculated by multiplying the amount of activity to the embodied emission intensity.

2.3 Assumptions made for LCI analysis

Residential house: A detached wooden house with the lifetime of 35 years is assumed as the typical Japanese residential house. Dwelling energy use per year is cited from the statistics. Almost all the components are treated as industrial waste at its demolition and end-of-life stage.

PV solar panel system: The target is a polycrystalline silicon type PV solar panel system for household use with 3.8kW capacity. Its lifetime is set as 25 years.

PCS: This is the key component of the V2G system that can not only charge a BEV but also supply electricity to the house from the BEV. Its lifetime is set as 10 years. Due to lack of available data, its inventory is approximated by the power conditioner of the PV system assumed.

Petrol station: Although the inventory varies according to the size and specification of the components, it is approximated in this study by assuming construction and end-of-life stages of a steel-reinforced concrete (SRC) structure with 30 years lifetime. Almost all the components are treated as industrial waste at its demolition and end-of-life stage. The emissions are calculated by assuming that the total amount of emissions of all the petrol stations that exist nationwide are attributed to and shared with all the passenger vehicles in Japan.

GV and BEV: CO_2 emissions from vehicle cycle (vehicle production stage) of GV and BEV are cited from our previous study (Kudoh et al., 2007). The lifetime is set as 11 years (average for Japanese passenger vehicles). Emissions from fuel cycle (vehicle use stage) of GV are estimated from statistics. This study assumes a BEV with 24kWh capacity lithium ion battery, vehicle range of 160km and charging efficiency of 0.85. Fuel cycle emissions of BEV are calculated by considering the average annual driving distance and CO_2 emissions of the grid electricity. The following assumptions are made fro the emissions from vehicle maintenance stage; vehicle tires replaced by every 30000km driving; engine oil for GV replaced by every 5000km driving, and; lead acid battery for GV replaced by every 25000km driving.

3. Results

Fig.1 shows the estimated CO2 emissions from conventional system using a GV and V2G system using a PV system and a BEV. Since the emissions vary by the assumptions made, a sensitivity analysis is also conducted to capture the potential variation. Table 2 gives the assumed cases and their parameters settings for the sensitivity analysis.

The estimated emissions from V2G system are 5.7 [$t\text{-}CO_2$/household/year], which show 36% reduction compared with the baseline conventional system of 8.9 [$t\text{-}CO_2$/household/year] for the default case. The emissions of minimum CO_2 case are 4.1 and 7.2 [$t\text{-}CO_2$/household/year] for V2G and conventional systems, while they are 7.6 and 12 [$t\text{-}CO_2$/household/year] for maximum CO_2 case, respectively. The following findings can be made from Fig.1: (a) the largest carbon hotspot is the residential energy use, which accounts for 38—55% of the total, (b) emissions from residential house construction stage accounts for 17-30% of the total, (c) fuel and vehicle cycle of BEV account for 10-17% and 6-10% of the V2G emissions, while those of GV account for 22-29% and 3-5% of the conventional system emissions, (d) PV production and end-of-life account for 4% of the emissions from the V2G system, and (e) the emissions from other stages (house demolition, maintenance stages of vehicles, petrol station construction and demolition, and PCS production) are smaller than 2% of the target system.

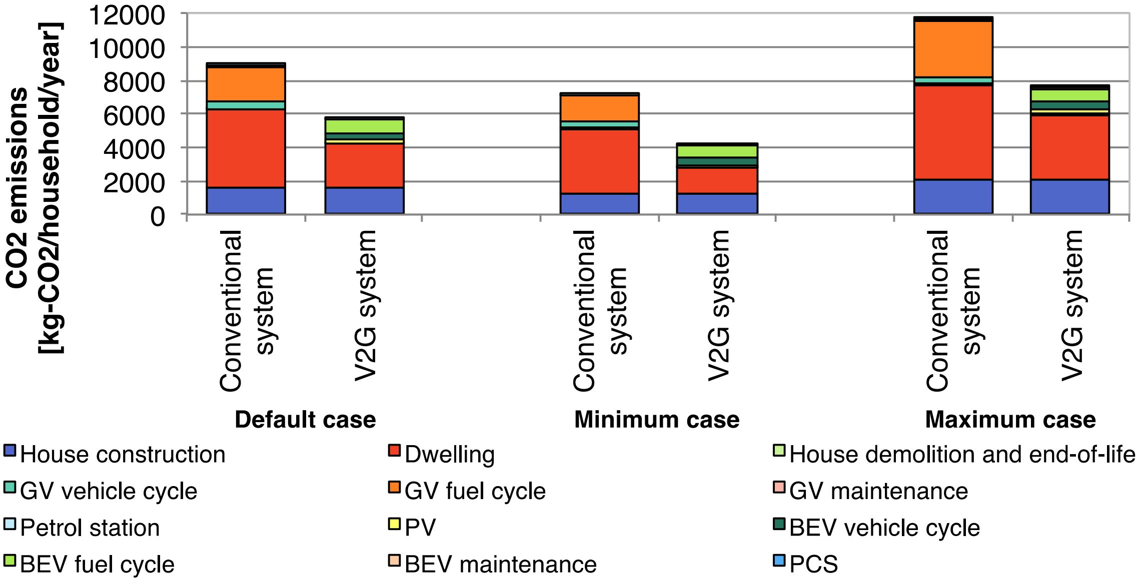

Fig. 1 $LCCO_2$ emissions from conventional and V2G systems.

Table 2 Assumed parameters for sensitivity analysis

Cases	Parameters
Default case	Gross floor area of a detached owned house: 132.3 [m^2], Target area for dwelling stage: Japanese average, Amount of industrial waste from a house demolition: 0.8 [t/m^2], Price of industrial waste: 5000 [JPY/t], PV annual power generation: 4455 [kWh], PV lifetime: 25 [years], Amount of industrial waste from a petrol station demolition: 2.5 [t/m^2], Ground area of a petrol station: 1000 [m^2], Target area for fuel cycle: Japanese average, Annual driving distance of vehicles: 9100 [km]
Minimum CO_2 case	Gross floor area of a detached owned house: 99 [m^2], Target area for dwelling stage: Kyushu district, Amount of industrial waste from a house demolition: 0.6 [t/m^2], Price of industrial waste: 1000 [JPY/t], PV annual power generation: 5046 [kWh], PV lifetime: 30 [years], Amount of industrial waste from a petrol station demolition: 1.9 [t/m2], Ground area of a petrol station: 500 [m^2], Target area for fuel cycle: Kanto district, Annual driving distance of vehicles: 8400 [km]
Maximum CO_2 case	Gross floor area of a detached owned house: 165 [m^2], Target area for dwelling stage: Tohoku district, Amount of industrial waste from a house demolition: 1 [t/m^2], Price of industrial waste: 10000 [JPY/t], PV annual power generation: 3863 [kWh], PV lifetime: 2520 [years], Amount of industrial waste from a petrol station demolition: 3.1 [t/m^2], Ground area of a petrol station: 1500 [m^2], Target area for fuel cycle: Chubu district, Annual driving distance of vehicles: 9400 [km]

4. Conclusion and discussions

A LCI analysis for a V2G system and its conventional counterpart in terms of CO_2 emissions is conducted in this study to identify the carbon hotspots in a V2G system. The result indicates that 35-42% CO_2 reduction can be expected by the target V2G system in comparison with the conventional counterpart. Since the main contributors to CO_2 emissions of both systems are dwelling, residential house construction, vehicle cycle and fuel cycle stages, these components and their life cycle stages should be included in the system boundary of V2G system when conducting LCAs.

It should be noted that the estimation in this study uses the data obtained by statistics and literature surveys and neither by the actual V2G system nor the conventional system due to some data restrictions. For a more detailed analysis of a V2G system, it is necessary to use the raw data obtained from the actual system for the calculation, if available. Especially for the residential house of a V2G system, its heat insulation and air tightness properties are usually better than the conventional house, which may lead to more CO_2 emissions from the house construction stage but less emissions from the dwelling stage.

5. References

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