Visualizing the Shape of Society: An Analysis of Public Bads and Burden Allocation due to Household Consumption Using an Input-Output Approach

Andrew Chapman[1], Yosuke Shigetomi[2]

[1]International Institute for Carbon Neutral Energy Research (I2CNER). Kyushu University, Fukuoka, Japan.
[2]Graduate School of Fisheries and Environmental Sciences, Nagasaki University, Nagasaki Japan.

Abstract

This study investigates how our lifestyles can cause societal issue including a reduction in social equity due to the consumption of natural resources. Based on a range of household environmental footprints and their application to a quantitative social equity evaluation framework, a methodology is proposed which identifies the creation and origin of public bads within society. This research builds on the methodologies of energy policy sustainability evaluation incorporated with environmentally extended input output analysis in order to critically assess lifestyle-based consumption impacts, and to quantify the allocation of subsequent burdens across generations. Further, the proposed methodology is applied to a case study in Japan, an aging, shrinking population. Analysis identifies the increasing burden originating with elderly generations, and due to the resolution offered by the methodology, specifically identifies commodities and services which underpin these future burdens, allowing for policy implications to be drawn. The public bads and consumption burden indicator established through the described methodology is proposed as a footprint harmonizing tool to assess sustainability and supplement the footprint family.

Keywords: public bads, environmentally extended input-output analysis, footprint, household consumption, social equity

1. Introduction

Our lifestyle choices require the consumption of resources to sustain, and this consumption can be quantified in terms of the amount of capital expended, or alternatively in terms of the amount and types of resources that people consume. When the resources that people consume are limited in nature, imbalances can emerge between sectors of society, often dependent on income or other socio-economic factors. Further, consumption of finite resources and energy to sustain our lifestyles has flow-on impacts including the generation of social ills such as pollution, and the depletion of critical materials. Ideally, the benefits and burdens within society would be shared equitably, however, in the case of the environment, and the depletion of finite materials, those who benefit most do not necessarily bear the burden that their lifestyles entail (Johnson, 2012).

Japan, the focus of this study faces a combination of demographic issues including the highest level of urbanization, the most rapidly aging population and among the lowest working age population ratio when compared to its Asian peers and other nations with advanced economies (Chomik & Piggott, 2015). In addition, as the fertility rate is also declining, the population is shrinking, leading to a depletion in the labor force and negative impacts for the economy at large (Muto et al, 2016). The national government of Japan are cognizant of the demographic challenges at hand, and have identified the potential energy saving benefits that a declining population engenders (METI, 2014). At the same time, the Strategic Energy Plan (2014) recognizes that there are challenges ahead in coping with energy demand structure changes and the incorporation of technological innovation, complemented by the Long-term Energy Supply and Demand Outlook which takes into account demographic projections in designing the primary energy supply structure to 2030 (METI, 2015).

The aim of this research is to identify the impact of household lifestyle on the creation of public bads and environmental injustices between generations, and to assess this trend over time, as the population of Japan not only shrinks, but also ages. This research takes a unique analysis viewpoint, focusing on household lifestyle and consumption for household generations between the ages of 20 and 70 (and above). This research assesses the resultant generation of public bads such as air and land pollution from household waste, carbon dioxide and particulate matter from energy consumption, and the level of limited material consumption. Based on this assessment, the broader issues of environmental and energy injustice and social ramifications are addressed. This research combines the analytical aspects of household environmental footprints using environmentally extended input-output analysis (EEIOA) and a modified application of social equity quantification and identification of burden distribution.

2. Background and Literature Review

This research is underpinned by environmental and energy policy assessment methodologies which consider lifestyle, consumption and social equity aspects. The three key concepts of social equity, environmental justice and environmental footprints using EEIOA are detailed below, including a review of precedential scholarship which informs the unique approach proposed in this study.

2.1. Social Equity and Policy Burden

This research builds on existing research efforts to evaluate social equity as well as the burden imparted on society through policy implementation. Such evaluative approaches are often grouped within social impact-cognizant sustainability evaluations. Some examples include the consideration of social equity within sustainable development (Campbell, 1996, Wheeler, 2002), the unequal impacts of climate change on lower income groups (Running, 2015), and national sustainable energy transition policy studies for Germany (Joas et al., 2016), Japan (Nesheiwat and Cross, 2013) and Italy (Magnani and Osti, 2016), among others, as well as multi-nation comparative studies (Laes et al, 2014, Geels et al., 2016). More recently, the emergence of the concept of energy justice has focused socially aware energy system research on the three core tenets of distributive, procedural and recognition justice (McCauley et al., 2013, Heffron and McCauley, 2017). It is from this concept of energy justice, and a focus on the distribution of costs and benefits due to the implementation of specific energy policies (distributional justice) that the importance of social equity and its quantification was brought to the fore (Chapman et al, 2016). Utilizing an investigation of specific energy policies in various regions and at multiple scales including the solar feed-in tariff in Australia (Chapman et al, 2016), participatory energy system scenario design at the national level, and social outcomes of mega-solar siting at the regional level in Japan (Chapman and Pambudi, 2018, Fraser and Chapman, 2018), the Energy Policy Sustainability Evaluation Framework (EPSEF) was developed and refined using a number of social factors critical to energy policy. These factors typically included energy cost increases, health, employment, participation, subsidy allocation and greenhouse gas emissions, often using proxy indicators such as CO_2 and $PM_{2.5}$, among others.

2.2. Public Bads and Factors of Environmental Justice

This study addresses generational household consumption and its impact on social equity outcomes, specifically identifying the creation of public bads which cause an inequitable or unjust distribution of burdens across household generations. The investigation of public bad generation and their final distribution across society has precedents in the environmental justice movement, which seeks to identify and redress the disproportionate allocation of environmental burdens or benefits which cause social inequality (Chakraborty, Collins, & Grineski, 2016). Recent research has expanded the scope of environmental justice studies beyond the unequal distribution of environmental ills, to incorporate the issues of empowerment, social justice and public health (Capaccioli, Poderi, Bettega, & D'Andrea, 2017). This broadening of the research scope has led to a number of recent noteworthy studies which underpin the design of this research in terms of factors investigated and scale, while supporting its originality and contribution to the academic field. This study is concerned with the emergence of public bads which impact upon lifestyles, generated as a result of household consumption. In order to identify relevant factors for a comprehensive investigation of these public bads, precedential literature is evaluated to elicit key factors and proxy indicators, beginning with the health-related issue of air pollution. The literature identifies an example of a national level investigation of China's rapid growth and subsequent increase in air pollution, which demonstrated flow-on impacts to self-reported health and happiness levels. Although impacts varied according to income, education employment and other factors, lower and middle-income groups were influenced by these factors more than the higher income groups (Gu et al, 2017). A focused study on exposure to air pollutants (specifically particulate matter) due to commuting and inequality between socio-economic groups was undertaken in London, however this study found no systematic relationship between income and exposure, with transportation type heavily influencing results (Rivas, Kumar, & Hagen-Zanker, 2017). Considering water usage and the tenets of environmental Justice, Mahlanza et al's South African study clarifies the issues surrounding management of this limited resource (2016). Specifically, they identify issues with regard to policy development and stakeholder engagement and the expectation that access to water is a basic human right. Additionally, they find that when water provision is insufficient, householder's are forced to compromise on livelihood decisions, particularly the most vulnerable groups within society (Mahlanza, Ziervogel, & Scott, 2016). Waste, and particularly industrial waste, as addressed in this study, has been considered at the national level in India, identifying urban percentage as a strong predictor of waste generation, while also demonstrating that socially and economically disadvantaged groups are significantly more likely to generate hazardous industrial waste. For nations such as India undergoing rapid industrial development, the need to incorporate economic justice ideals into waste management approaches was extolled (Basu & Chakraborty, 2016). The scarcity of rare metals is well understood, and their concentration in specific geographic regions has led to the consideration of mining risk as a factor which can impact negatively upon householder's lifestyles. The fact that rare metals (this study focuses on neodymium) have unique properties with regard to modern technological applications, and suffer from a lack of alternatives, has led to research around global supply chains along with the need to address technical, environmental, social and recycling challenges faced by these materials (Golev et al., 2014).

Finally, with regard to the ethical consideration of intergenerational environmental justice Almassi investigates the notion of a reparative justice approach to climate ethics which deems climate exploitation and degradation as 'wrong', requiring redress for future generations (2017). Although this study does not specifically consider redress activities, the trend of future generational public bad creation is explored, leading to the potential for policy implication identification or remediation strategies.

Building on this precedential research, this study investigates the combined impact on public bad generation of five factors; an increase in greenhouse gas emissions (GHG), air pollution (PM), industrial waste, water consumption and rare metal depletion. Each of these five factors are impacted upon by household consumption, and the change in the level of impact is investigated per household generation.

2.3. Environmental Footprints using Environmentally Extended Input-output Analysis

The data which underpins each of the five proposed factors is determined from the perspective of environmental footprints, a suitable indicator to evaluate the life cycle environmental load generated by final consumption. In other words, environmental footprints measure how human consumption depends on either limited natural resources, or generates waste, or both (Hoekstra and Wiedmann, 2014). Footprint indicators have been developed to assess the various environmental issues (e.g. resource depletion), particularly climate change focusing on carbon (GHG/CO_2) footprints during the past two decades (Fang et al., 2014).

The EEIOA has been widely adopted to quantify regional environmental footprints owing to the methodological merit of ensuring system boundaries under the input-output table (IOT) which is incomplete when implementing a conventional LCA approach (Suh and Huppes, 2005). There are precedential studies analyzing the footprint for environmental indicators related to the five proposed factors; carbon footprint, air pollution footprint, water footprint, waste footprint, and critical metal footprint, within EEIOA. Thus, a brief review of EEIOA research is provided as it relates to the five indicators below.

Numerous studies have carried out EEIOA to quantify carbon footprints on various scales to date (Munksgaard and Pedersen, 2000; Wiedmann, 2009; Hertwich and Peters, 2009; Kanemoto et al., 2016; Wolfram et al., 2016; Hubacek et al., 2017; Malik et al., 2018; Steininger et al., 2018). The carbon footprint concept is the most widespread when compared with other footprint analysis within academia and society. Of interest, the globalization of production and trade of manufactured goods and its impact on global GHG emissions was discussed utilizing the carbon footprint as part of the fifth Annual Report from the Intergovernmental Panel on Climate Change (IPCC AR5 WG3, 2014). This particular application of the carbon footprint was based on Caldeira and Davis (2011) and Peters et al. (2011).

Several studies have also analyzed the footprint of various air pollutants such as PM_{10}, $PM_{2.5}$, carbonaceous aerosols (black carbon and organic carbon), sulfur oxides, nitrogen oxides and volatile organic compounds (Nansai et al., 2003; Sugiyama et al., 2009; Guan et al., 2014; Lin et al., 2014; Takahashi et al., 2014; Moran and Kanemoto, 2016; Nagashima et al., 2017; Zhang et al., 2017). Takahashi et al. (2014) also estimated the health impact (number of premature deaths) due to carbonaceous aerosols generated through the supply chain, based on the final consumption of each country and region, taking account the source-receptor relationship among them. Further, Zhang et al. (2017) elucidated the relationship between the number of premature deaths caused by $PM_{2.5}$ via international trade, showing the impacts of transboundary $PM_{2.5}$ pollution on global health.

With regard to the water footprint, linkages are identified with the virtual water concept (Hoekstra and Chapagain, 2007). The water footprint considers rainwater for crop production (green water), surface and ground water that evaporates or is incorporated into a product (blue water), and water required to assimilate pollutants based on existing ambient water quality standards (gray water) (Hoekstra and Mekonnen, 2012). Whilst the early approaches to water footprints were of a bottom-up nature, EEIOA has been applied to quantifying the water footprint of various regions as a top-down approach (Feng et al., 2011; Dong et al., 2013, 2014; Ono et al., 2015; Wang et al., 2016; Chen et al., 2017).

In order to assess the waste footprint, Nakamura and Kondo (2002) first introduced a new hybrid LCA model termed the waste input-output (WIO) model, enabling an estimate of waste generation associated with final consumption and waste treatment. Based on the IOA, incorporating the concept of WIO, the structure of waste footprints was examined in Japan (Kagawa et al., 2004; Kondo and Nakamura, 2005; Tsukui et al., 2015), Australia (Reynolds et al. 2014; Fry et al., 2016), France (Beylot et al., 2016, 2017), and Taiwan (Liao et al., 2015). Further, Tisserant et al. (2017) addressed the footprint of global solid waste.

The critical metal footprint quantifies the direct and indirect requirements of critical metals in the same manner as the material footprint (Wiedmann et al., 2015). The securing of scarce metals within rare earth elements is of great concern in terms of economic advantage and for their applications within new energy technologies. For these reasons the assessment of metal criticality has become prominent in recent years (Graedel et al., 2015). Based on the concept of the material footprint and criticality assessment, Nansai et al. (2015) developed a methodology for quantifying the mining risk of three critical metals (neodymium, cobalt, and platinum) in mining countries underpinning global consumption. They adopted the EEIOA with an economy-wide material flow analysis (IO-MFA) (Nakamura et al., 2007). In a similar manner, Nansai et al. (2017) assessed the supply risk of these metals generated at post-mining stage implying the direct and indirect vulnerability of the Japanese economy to such a risk. Nakajima et al. (2017) quantified the global land-use change derived from nickel consumption in Japan based on the IO-MFA with statistic data of land-use. These were expressed as footprint indicators.

2.4. Multiple Footprint Derivation from Household Consumption

Household consumption is the main driver of various footprints which are derived from final demands, particularly in developed nations (Hertwich et al., 2011; Ivanova et al., 2016). EEIOA is often applied to quantifying environmental footprints, mostly the carbon footprint, derived from household consumption as a proxy of lifestyle (Zhang et al., 2015). In-depth studies of household environmental footprints have been carried out using EEIOA in conjunction with a consumption expenditure survey focusing on the age of the household head and income distribution since the 2000's (e.g. Wier et al., 2001; Webber and Matthews, 2008; Jones and Kammen, 2011; Chitnis et al., 2014; Wiedenhofer et al., 2017). The older people, for example, generally consume more household heat and energy than the younger people because they tend to stay longer in their houses and feel more sensitive to the temperature than younger people. Younger people are more likely to consume to support the cost of their private vehicle and for the cost of information and communications than older people. These differences in lifestyle mainly relate to direct energy consumption from households, and will affect the environmental footprint (Kronenberg, 2009; Shigetomi et al., 2014; 2015). There are several studies which reveal the differences arising from regional household footprints due to differing lifestyles, household compositions, and geography (Jonnes and Kammen, 2014; Baiocchi et al., 2015; Ivanova et al., 2017; Gill and Moeller, 2018). In Japan, several precedential studies analyzed the structure of household carbon footprints from similar perspectives (Shigetomi et al., 2014, 2018). In terms of studies which assess other household footprints in Japan, Takase et al. (2005) quantified landfill consumption under scenarios related to lifestyle changes while considering the life cycle up to the disposal stage for each scenario using the WIO model. Shigetomi et al. (2015) estimated the impact of future demographic trends on three critical metal footprints from 2005 to 2035 in Japan. Further, Shigetomi et al. (2016) examined the trade-off between carbon and critical metal footprints of Japanese households.

While the environmental footprint is an indicator which can represent single environmental loads, it has also been adapted to simultaneously assess several footprints within the same system (Ewing et al., 2012; Steen-Olsen et al., 2012; Tukker et al., 2016; Ivanova et al., 2017; Simas et al., 2017; Tian et al., 2017). In this sense, the application of a "footprint family" that considers more than one footprint indicator has been promoted as a way to develop sustainable and interdisciplinary policy measures within the European Commission (Galli et al., 2012, 2013; Fang et al., 2014). An examination of the potential complementary linkages between the footprint family concept and the planetary boundary (Steffen et al., 2015) to explore the gaps in environmental sustainability at the global scale (Fang et al., 2015).

In the next section, the methodology used to estimate public bads generated from Japanese households by incorporating the EEIOA approach (augmented by an embodied $PM_{2.5}$ emissions study), with the EPSEF is elaborated. To the best of the author's knowledge, no research to date has visualized and discussed the negative social equity impacts of household consumption integrating an environmental footprint evaluation approach.

3. Methodology

This research combines the environmental evaluation methodologies of EEIOA and the EPSEF in order to holistically evaluate lifestyle and consumption impacts on social equity by measuring the creation of public bads and the resultant burden imparted between 2005 and 2035 in Japan.

The EPSEF was originally employed to quantify and distribute social equity outcomes across income levels, to determine both the efficacy and the fairness of varying policy approaches or technological interventions. In order to make these assessments, the EPSEF relies on a range of factors, perceived to be important to stakeholders, which underpin social equity, as well as detailed data regarding societal demographics. For this study, the EPSEF is modified to express the creation of public bads resulting from household consumption across generations. In addition, the origin of these public bads is investigated to determine which household generations are exerting burden on society over time, and which generations bear this burden.

The public bads investigated in this research build on and integrate the author's previous social equity quantification and household footprinting research in line with precedential literature, aiming to link the concepts of public bad creation and resultant environmental injustices arising between household generations.

Thanks to a significant historical progression of EEIOA studies in Japan, databases for embodied environmental load intensities (direct and indirect loads per monetary unit) are plentiful, enabling the assessment of various footprints of household consumption based on the Japanese IOT (JIOT) of 2005 (MIC, 2009). Using these established resources can comprehensively cover estimates of the footprints corresponding to the four factors of GHG, water, waste and mining risk for the critical metal selected in this study. Only the embodied intensity for $PM_{2.5}$ emissions is not yet established. Therefore, it is necessary to create this resource to enable the proposed study.

The methodology is in 3 parts: 1) Public bads factor definition, 2) Estimation of household footprints including the derivation of consumption induced $PM_{2.5}$ emissions, and, 3) Application of (2) to the modified EPSEF to be expressed in terms of public bads and the consumption burden imparted by the lifestyle of household generations in Japan.

3.1. Public Bads Factor Definition

The five factors analyzed which represent societal public bads and their creation in this study were chosen as they represent the environmental impacts associated with the generation of products and services from the point of resource extraction to final consumption in the household as detailed in Figure 1.

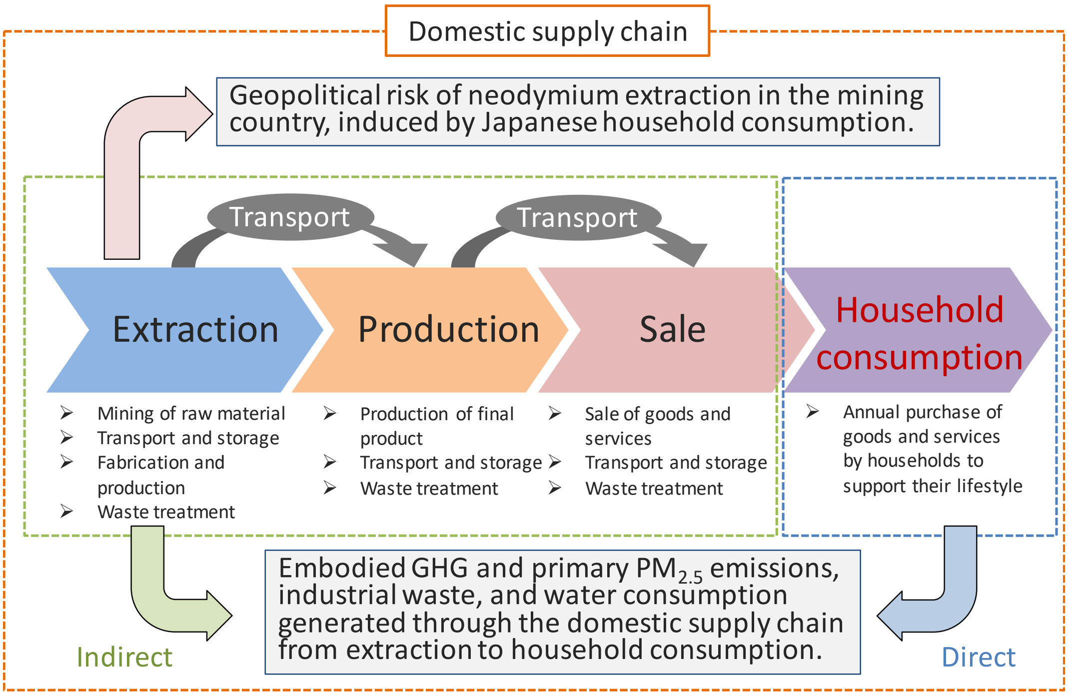


Figure 1. Scheme of the environmental footprints associated with household consumption responsible for public bads analyzed in this study

The factors include climate change, underpinned by the carbon footprint (CF), atmospheric pollution, underpinned by the $PM_{2.5}$ footprint (AF), waste treatment, in this case specifically the industrial waste footprint (IF), and resource depletion, underpinned by both the water footprint (WF) and the mining risk footprint (MRF). In terms of mining risk, this footprint demonstrates the degree of risk of material supply being limited in (or by) mining nations (Nansai et al., 2015). Neodymium (Nd) is selected in this study due to its use in modern technological devices, ranging from communications and ICT devices through to renewable energy technology such as wind turbines, and a motor for electric vehicles (Shigetomi et al., 2017).

Table 1 outlines the public bads, specific factors, and footprints analyzed within this study.

Table 1. Public bads, underpinning factors, footprints and data sources.

Public Bads	Factors	Footprints	Inventory source
Climate Change	GHG (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6)	Carbon Footprint (**CF**)	3EID (Nansai and Moriguchi, 2013)
Atmospheric Pollution	Primary $PM_{2.5}$	Atmospheric Pollution Footprint (**AF**)	Created in this study using the Japan input-output table 2005, 3EID, and EDGAR v.4.3.1
Resource Depletion	Blue/Green Water	Water Footprint (**WF**)	Ono et al. (2015)
	Critical Metal	Nd Mining Risk Footprint (**MRF**)	Nansai et al. (2015)
Waste Treatment	Industrial Waste	Industrial Waste Footprint (**IF**)	Tokyo City University's Research on Environmental Impact Assessments (2013)

3.2. Estimating Household Footprints to Determine Public Bads Factor Values

As detailed in the literature review and summarized in Table 1, all factors critical to this research are derived through an application of EEIOA based on existing data sources, except for $PM_{2.5}$.

The CF, AF, IF, WF, and MRF of household are quantified using the household consumption expenditure of Japan based on the consumer expenditure survey, the 2005 JIOT, and the embodied (direct and indirect) GHG emissions, $PM_{2.5}$ emissions, industrial waste generation, green and blue water consumption, and mining risk score for neodymium per unit of expenditure; the so-called footprint intensity. The basic formula for calculating the household environmental footprint based on EEIOA is as shown in Eq. (1).

$$\mathbf{U} = \left(\hat{\mathbf{d}} + \hat{\mathbf{e}}\mathbf{L}\right)\mathbf{y}_{\text{house}} \tag{1}$$

where $\mathbf{U}$ and $\mathbf{y}_{\text{house}}$ consist of the targeted environmental footprint vector and household final demand vector respectively. Vector $\hat{\mathbf{d}}$ contains the elements of the amount of environmental load directly generated from households per unit of expenditure. Vector $\hat{\mathbf{e}}$ represents the amount of direct environmental load per unit of expenditure from goods and services (commodities). $\mathbf{L}$ denotes the Leontief inverse matrix (Millar and Blair, 2009), as represented in Eq. (2).

$$\mathbf{L} = \left(\mathbf{I} - \mathbf{A}\right)^{-1} \tag{2}$$

where $\mathbf{I}$ and $\mathbf{A}$ denote the identity matrix and the coefficient matrix derived from the IOT. Thus, $\left(\hat{\mathbf{d}}+\hat{\mathbf{e}}\mathbf{L}\right)$ represents the footprint intensity. Focused on the public bads generated in the consumer country, Eqs. (1) and (2) are rewritten using vector $\hat{\mathbf{M}}$ containing the elements of the ratio of imported commodities to quantify the domestic environmental footprints $\mathbf{U}^{\mathrm{domestic}}$ as follows:

$$\mathbf{U}^{\mathrm{domestic}}=\left(\hat{\mathbf{d}}+\hat{\mathbf{e}}\mathbf{L}'\right)\left(\mathbf{I}-\hat{\mathbf{M}}\right)\mathbf{y}_{\mathrm{house}} \qquad (3)$$

$$\mathbf{L}'=\left(\mathbf{I}-\left(\mathbf{I}-\hat{\mathbf{M}}\right)\mathbf{A}\right)^{-1} \qquad (4)$$

In this study, the CF intensity relies on the Embodied Energy and Emission Intensity Data for Japan Using Input-Output Tables (3EID; Nansai and Moriguchi, 2013) and the Energy Balance Table (METI, 2016). The direct household GHG (e.g. household heating, cooking, and driving a passenger car) was estimated using the emission factors for energy commodities (gasoline, kerosene, liquefied natural gas (LPG), city gas, electricity, and the other petroleum products) and its consumption share in line with the Energy Balance Table. The IF and WF intensities reference Tokyo City University's Research on Environmental Impact Assessments (2013) and Ono et al. (2015), respectively. The MRF intensity used in this study, is derived from the GLIO model (Nansai et al., 2009) that specifies the global supply chains of Japanese commodities based on the JIOT (Nansai et al., 2015). Direct household water usage is considered in the WF inventory. Because the industrial pollutions and neodymium mining are not created directly by households, those direct loads are not estimated per unit of expenditure. Further, because neodymium is not mined in Japan, the supply risk associated with domestic commodities consumed by households throughout the global supply chain is observed.

With respect to the AF intensity, the sectoral $PM_{2.5}$ emissions in Japan are incorporated using the Emission Database for Global Atmospheric Research (EDGAR) v.4.3.1 (European Commission, 2016) in coordination with the JIOT. EDGAR provides the annual amount of primary $PM_{2.5}$ emitted directly from 25 sectors for the period 1970-2010 according to the IPCC 1996 standard. First, the amount of direct $PM_{2.5}$ emissions from households was estimated by multiplying the emission amounts from "1A4: Residential and other sectors" by the percentage of direct energy consumption by the residential sector per summation of direct energy consumption by both residential and commercial sectors, referring to the Energy Balance Table (METI, 2016). Because direct emissions are generated from households through the usage of kerosene for heating, the direct emissions intensity for household consumption is also calculated by dividing the amount of the direct emissions by the total output of kerosene on the JIOT. In addition, residual $PM_{2.5}$ emissions (the emission by "1A4: Residential and other sectors" minus the emission of the residential sector calculated above) are defined as those which were emitted from commercial activities, used to estimate the indirect $PM_{2.5}$ emissions as follows.

In order to estimate indirect emissions, the 25 sectors within EDGAR were mapped to approximately 400 commodities contained within the JIOT. Next, the sectoral $PM_{2.5}$ emissions reported within EDGAR were allocated onto the corresponding commodities with respect to direct energy consumption by commodity, referred to within 3EID. In the same manner as for the direct emission intensity from households, the direct emission intensity arising from commodities were calculated by dividing the amount of direct emissions by the total output of the corresponding commodity within the JIOT. Finally, the direct emission intensities of commodities were multiplied with the Leontief inverse matrix of the JIOT, resulting in the indirect $PM_{2.5}$ emissions intensity.

In order to obtain consumption expenditure by household attribute (in this case using the age of the household head: 20's; ≤29, 30's; 30-39, 40's; 40-49, 50's; 50-59, 60's; 60-69, 70's; ≥70) for calculation of footprints during the target period, the method used in previous studies (Shigetomi et al. 2014; 2015; 2016) can be applied. Overall, the breakdown of consumption expenditure consists of approximately 400 commodity sectors consistent with the JIOT. The estimation of consumption expenditure is made with respect to demographic trends anticipated by the national population census of Japan (National Institute of Population Social Security Research, Population Statistics of Japan, 2013) and the consumer expenditure survey (MIC, 2009). Finally, factors other than demographic trends such as technology were assumed not to change from 2005 onwards under the estimation. The limitations of such an approach are detailed in Section 5.3.

3.3. EPSEF Public Bads and Consumption Burden Application

Following the derivation of consumption-based environmental loads for each household generation within the time period ranging from 2005-2035, the EPSEF is employed to calculate the relative public bads creation across household generations, which, in combination consumption per generation, can identify an overall 'public bads score' as well as the origin of these bads, expressed as the 'consumption burden' for each timeframe analyzed. The calculations are based on the EEIOA footprint results, according to the following formulae:

Firstly, the household footprints are normalized thus:

$$EV_{ij}^{(t)} = \frac{HF_{ij}^{(t)}}{MaxHF_{i}^{(t)}} \tag{5}$$

where EV is the normalized household footprint value, HF are the household footprints, with *i*, and *t* representing the types of household footprint, and the analyzed timeframe respectively.

Second, the normalized household footprint values for each time period are summed and the relative public bads score can be calculated, including a factor for weighting of consumers perceived importance of each footprint, thus:

$$rPB_j^{(t)} = \frac{\sum_i EV_{ij}^{(t)} \times w_i}{\sum_i w_i} \quad (6)$$

where *rPB* is the relative public bads score, and *w* is the weighting score for each of the footprints. Weighting of footprints is usually achieved through a survey of relevant stakeholders, as undertaken in previous studies (e.g. Chapman et al, 2018). For the purposes of this study, which is to demonstrate the development of a novel indicator, each of the footprints are weighed equally ($w=1$), however ideally, future jurisdiction specific studies would include the stakeholder determined importance weightings for each investigated footprint.

Third, the household expenditure ratio is derived as follows:

$$ER_j^{(t)} = \frac{F_j^{(t)}}{\sum_j F_j^{(t)}} \quad (7)$$

where *ER* is the household expenditure ratio, and *F* is the total final consumption expenditure by household generation.

Finally, for each of the household generations (*j*), the household expenditure ratio and relative public bads values are plotted to form a polygon, from which the area weighted centroid is derived (using geometric decomposition) to inform the consumption burden (x value) and public bads score (y value).

4. Results and Discussion

In the following section the estimated footprints are detailed for each of the five public bads underpinning factors from 2005-2035. This is followed by a visualization and discussion of the results yielded by the EPSEF in its application to the public bads score calculation for each time period, along with a consumption burden calculation. Advantages and limitations of the proposed methodology are also addressed.

4.1. Household Environmental Footprints

The footprints for each of the public bad factors explored in this study are shown in Figure 2 using actual data from 2005. Households in their 50's caused the greatest contribution toward consumption expenditure among all of the footprints, followed by those in their 40's and 60's. This is due to not only consumption trends, but also heavily influenced by the relatively large number of households in their 40's, 50's and 60's compared to other age groups in Japan. As Japan ages, and the number of children being born decreases, it is likely that this trend will be exacerbated.

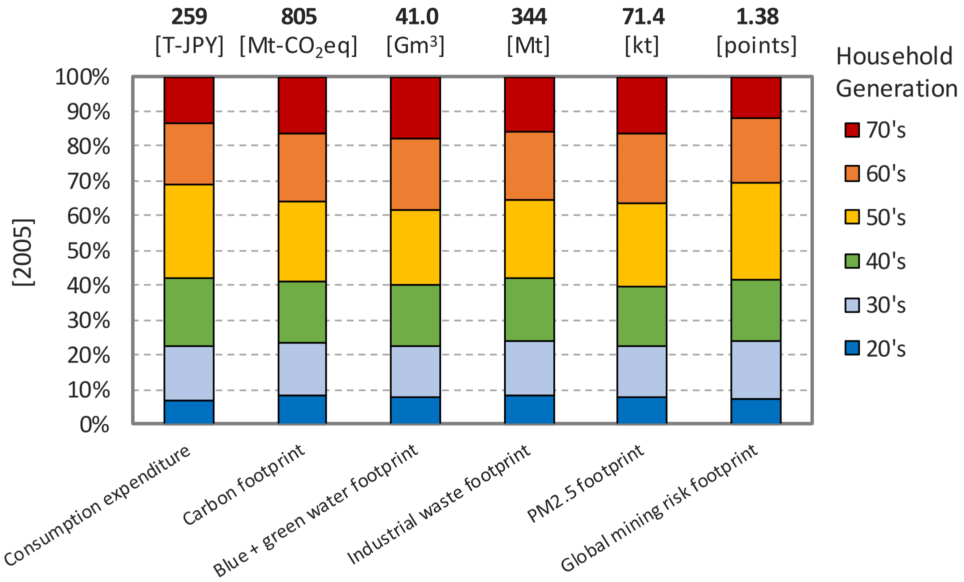
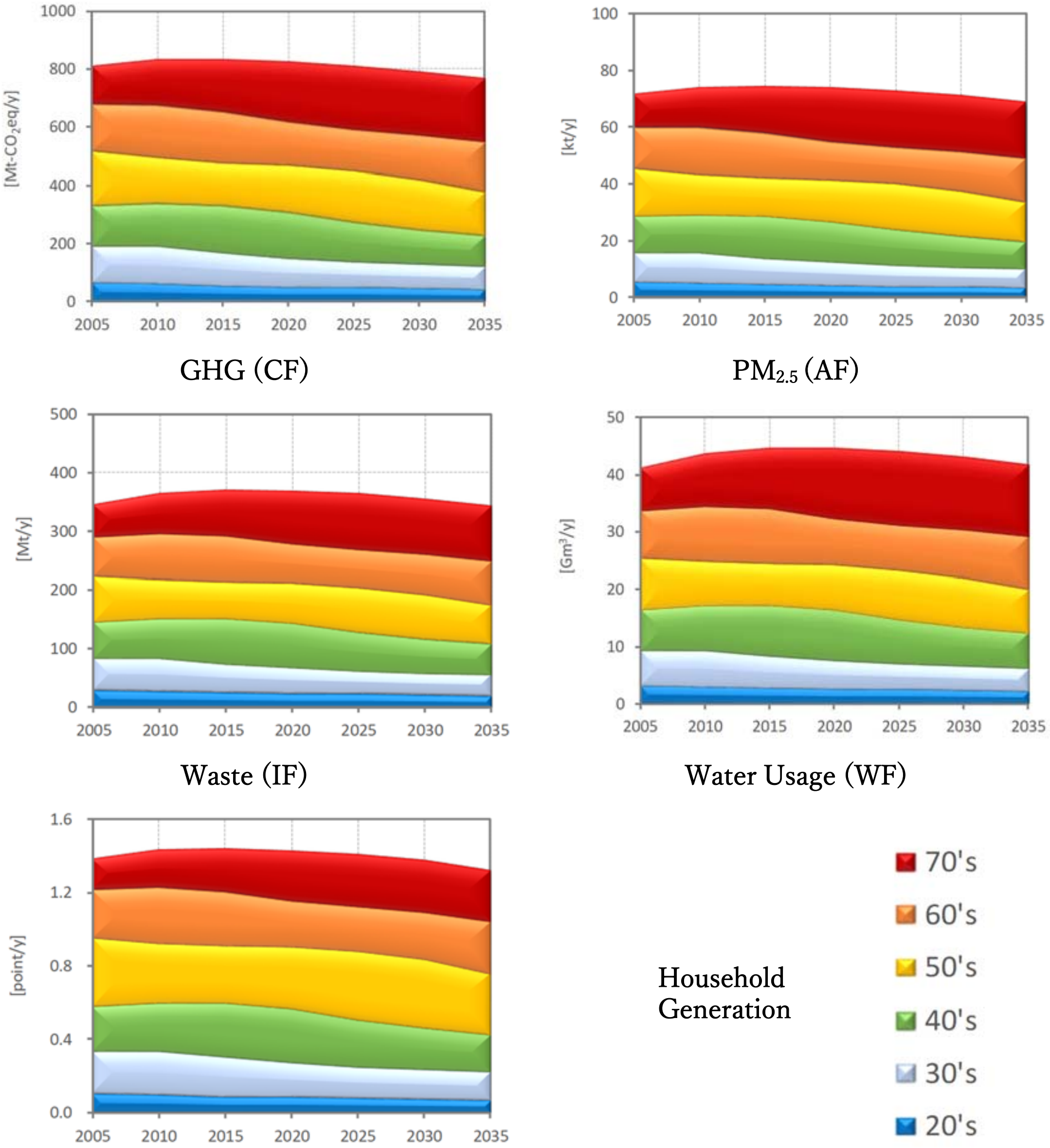


Figure 2. Scheme of the environmental footprints associated with household consumption responsible for public bads analyzed in this study in 2005

Total consumption expenditure first increases until 2010, and then drops over time, approximately 9.9% by 2035 when compared to 2005 levels, under the assumptions outlined in the methodology. Using these assumptions, Figure 3 details the trends of each footprint and household generation, projected to 2035.



GHG (CF)

PM$_{2.5}$ (AF)

Waste (IF)

Water Usage (WF)

Nd Mining Risk (MRF)

Figure 3. Footprints by household generation 2005-2035

Each of the footprints peak around the year 2015. In 2035, the CF is expected to be 5.1% lower than in 2005, showing the largest decrease compared with other footprints. The MRF and AF are projected to decrease by 4.4% and 4.0% respectively, while the decrease in IF is negligible between 2005-2035. In 2035 only the WF is expected to be higher than in 2005. With regard to the generational contributions, households in their 60's and 70's become most influential toward the year 2035 for all footprints. For instance, elderly household's contributions account for 42-52% of the total footprints, while those in their 20's and 30's only account for 14-15%. This result reflects the Japanese demographic shift into the future, where an aging, shrinking society will increase the average age of households, due to a larger number of households in their 60's and 70's. Reducing population, particularly due to low child birth rates mean that in 2035, the relative number of households in their 20's and 30's will be even lower than today, exacerbating this gap in terms of consumption and contribution to footprints. In particular, during the period investigated, contributions from households in their 70's will grow markedly, becoming the largest CF, AF, IF and WF by household generation in 2025. With regard to the MRF, households in their 50's account for the largest footprint per household generation in the year 2005.

4.2. Public Bads and Consumption Burden

First, the public bads score for each of the time periods investigated is shown in Figure 4. The dotted line represents the number of households in each age group, while the blue line expresses the percentage of consumption occurring in each group. Public bads are represented by the colored polygon, expressing the overall amount of public bads by the color shade, while the percentage of public bads originating from each age group is represented by the polygon shape.

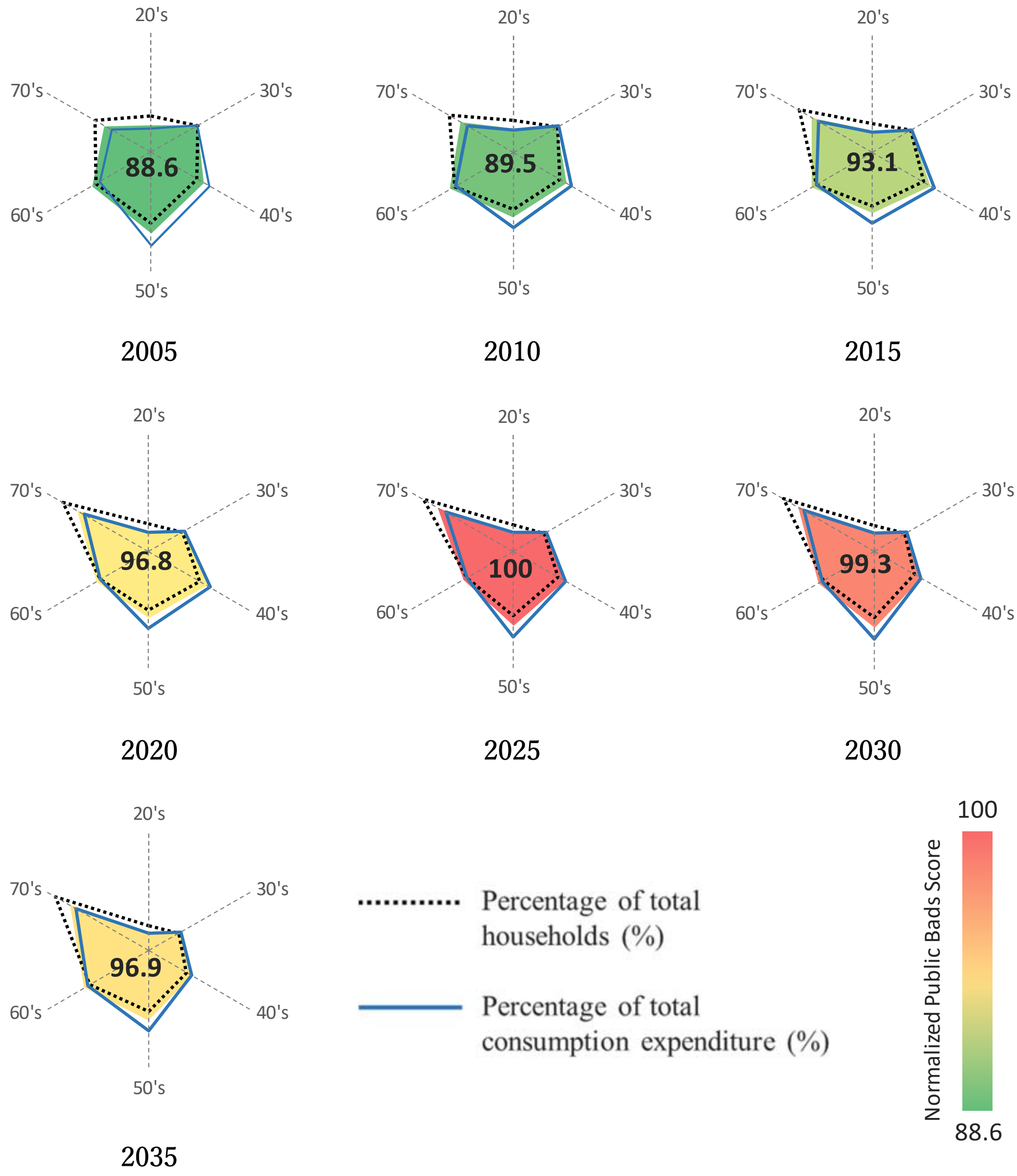


Figure 4. Public Bads Score, Household and Consumption Distribution.

Imbalance in the ‘shape’ of society can be observed where consumption exceeds the percentage of households in certain household generations, and likewise for the generation of public bads. The public bads score begins at its lowest level in 2005, increasing steadily to a peak in 2025, before returning to moderate levels similar to 2020, by 2035. The Japanese population, predominantly in the 70’s and above age group grows steadily to 2035.

Next, the public bads score and consumption burden outcomes are combined as shown in Figure 5. In this way it is possible to visualize the amount of public bads originating from each age group, and the increase in the average age of consumption burden generation out to 2035.

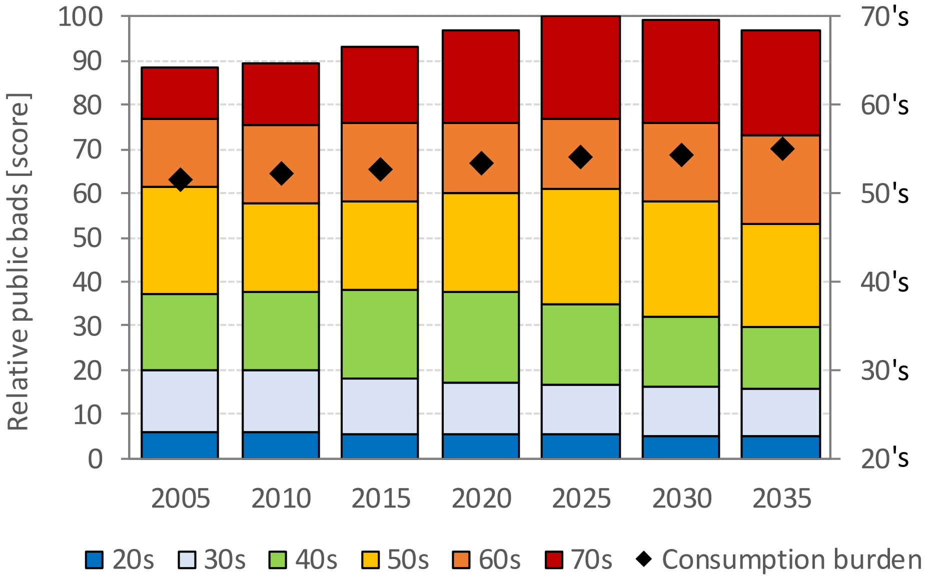


Figure 5. Public Bads Score and Consumption Burden 2005-2035

The peak in public bads score can be observed to occur in 2025, as was seen in Figure 5, however even as public bads decrease overall post 2025, the consumption burden continues to originate from an ever-increasing age group, implying an ever-growing social and environmental burden on younger generations.

5. Discussion

5.1. Methodological Advantages, Application and Academic Contribution

This research brings together the two methodologies of household consumption based environmental footprint derivation (using EEIOA) and social equity quantification (using a modified application of the EPSEF). These two methodologies are well matched, as they both focus on the quantification of social phenomena, namely our lifestyles and the allocation of societal benefits and burdens. Where the EPSEF was previously reliant on projected energy system data over time to calculate social equity changes and allocation of costs and benefits according to income levels, the EEIOA methodology provides an assessment of household consumption and resultant footprint impacts, distributed by household attribute (household generation in this study) – easily applied to the EPSEF model. This combination allows for a visualization of both public bads generation and the source of societal burden arising from these footprints over time. The newly proposed tool and resultant indicator allows for the identification of influential footprints on public bads creation and allocates responsibility for environmental injustices in terms of age group and lifestyle. Further, with the inclusion of factor weighting according to stakeholder preference, policy development can be aided through the identification of desired societal outcomes, and the quantification of current lifestyle impacts on actual outcomes. With this comprehensive assessment approach in place, the proposed indicator detailed in this study could become a harmonized footprint tool to assess societal sustainability as a next step, enhancing the Footprint Family approach (Fang et al., 2016).

Through the consideration of lifestyle, and in particular the act of consumption in order to sustain it, this research proposes a novel indicator which expresses public bads and calculates which sector of society is most responsible for imparting societal burden. The need for such an indicator is anticipated due to the adverse impact on social equity and causing of environmental injustice due to the generation of public bads, and their unequal distribution, in light of ongoing demographic changes, particularly in developed nations.

The first application of this evaluatory framework was undertaken in Japan, an interesting test case due to the current societal trends of an aging, shrinking society. As shown in the results, each of the individual footprints are expected to peak in the year 2015. The peak of public bads however does not occur until the year 2025. This is due to the consumption burden imparted by an ever-increasing number of older households, and the nature of their consumption along with the shrinking population, particularly in younger generations. Further, the origin of the burden for public bads shifts toward older households in every time period investigated due to the consumption patterns of older households (including heavy reliance on specific services and products) and also due to the changing ‘shape’ of society, dominated by households in their 50’s, 60’s and 70’s.

In addition to the overview of public bads and consumption burden provided in section 4.2 (summarized in Figure 5), owing to the sectoral resolution achieved in the proposed methodology, it was also possible to identify the types of consumption which make the largest contribution to each household footprint, considering some 400 commodities. Table 2 outlines the commodities which have the largest impact on each of the investigated footprints in Japan, demonstrating their growth between the reference year of 2005 and the final year investigated, 2035.

Table 2. Top five growth commodities between 2005 and 2035 for each household environmental footprint.

Factor	Rank	Commodity	Growth (2005-2035)
GHG [Mt]	1	Kerosene	3.89
	2	Medical services	0.61
	3	Hotels	0.57
	4	Frozen fish and shellfish	0.43
	5	Vegetables	0.30
$PM_{2.5}$ [kt]	1	Kerosene	0.50
	2	Rice production	0.12
	3	Hotels	0.06
	4	Medical services (Medical Corp.)	0.06
	5	Misc. ceramic, stone and clay products	0.06
Waste [Mt]	1	Sewage disposal	0.90
	2	Hotels	0.71
	3	Kerosene	0.68
	4	Electricity	0.48
	5	Dairy farm products	0.48
Water Usage [Mm^3]	1	Rice production	359
	2	Water supply	182
	3	Inland water fisheries and culture	130
	4	Fruits	98.9
	5	Dairy farm products	80.6
Mining Risk [10^{-3} points]	1	Household air-conditioners	2.06
	2	Household electric appliances (excl. air-con)	1.91
	3	Electricity	0.54
	4	Rice production	0.33
	5	Medical services (Medical Corp.)	0.28

In terms of GHG and $PM_{2.5}$ and waste, the growing impact of kerosene in the year 2035 is evident. Kerosene is favored as a space heating fuel in Japan (particularly among the elderly, or those living in older homes), and a shift toward alternatives (city gas or electricity) could help to reduce the CF, AF and IF impact on the generation of public bads. Further, the impact of rice production in Japan is felt especially in terms of water usage and $PM_{2.5}$ emissions. In cultural terms, rice is an essential part of the Japanese diet, and seeking an alternative is unlikely to be successful. Regulations which encourage greater stewardship of the water resource, such as enclosed irrigation may be more appropriate in this case.

In terms of services consumed, hotels and medical services impart a significant impact on all footprints except for water usage. As the Japanese population ages, reliance on medical services is likely to increase, and is reflected in this result. Promotion of a healthy lifestyle to lower reliance on medical services may reduce this impact. In terms of hotels however, it is unlikely that a consumer-side response will be as effective as the introduction of regulations which enforce the responsible consumption of resources which impact upon the environment. In terms of mining risk, in line with expectations, the commodities with the largest impact are household air-conditioners and electrical appliances. In order to ameliorate these impacts, the identification of potential alternatives for neodymium, or the introduction of a recycling regime will be necessary as mining risk is exacerbated in the future.

5.2. National Policy Relevance

The Japanese government established a series of economic policies based on "the Plan to Realize the Dynamic Engagement of All Citizens" aimed at tackling the issues of an aging, shrinking society (Prime Minister of Japan, 2016). The plan was implemented to increase the fertility rate, income and to improve social welfare related to support for parents with children and older people. Regarding environmental impacts, however, increasing household income and household size requires special attention, because it may boost household expenditure, in turn resulting in the deterioration of environmental footprints if no countermeasures are implemented (Shigetomi et al., 2018). Hence, addressing the potential gap between society and the environment is of high importance for national sustainability. The relative public bads score proposed in this study, gives an additional insight to resolve this gap with respect to public bads associated with lifestyles. The public bads score is a single indicator harmonizing various indicators under the ideals of societal and environmental justice, helping policy makers to consider the measures detailed in Section 5.1 in order to improve social equity, which can contribute to minimizing this gap.

Our results also encompass domestic sustainable development in line with the United Nation's Sustainable Development Goals (UN SDGs). The concept of adopting IOA to quantify public bads is relevant for the 12th SDG: Responsible consumption and production (Allen et al., 2016). With respect to the footprint indicators selected in this study, SDGs including number 6: Clean water and sanitation, number 7: Affordable and clean energy, and numbers 12 and 13: Climate action, are all considered in reducing the WF, AF, MRF, IF, and CF, respectively. Further, the aim of this study, identifying the social inequities associated with our lifestyle, is linked to the 10th SDG: Reducing inequalities. In addition to the consideration of the SDGs, the approach modelled in this study provides a starting point for the engagement of stakeholders in determining nationally important SDGs and their perceived importance. Through the incorporation of a nationally and generationally sensitive evaluation of factor and SDG importance, the proposed indicator may provide an avenue for the complementary, bottom-up development of policy measures to address SDGs as part of a national framework.

5.3. Limitations of this Study

Although this research details a novel indicator, which has applications in both social evaluations and policy development, several limitations have been identified through its application in Japan as a test case.

First, in terms of footprint quantification, owing to data constraints, this study assumed that all of the factors except for changes in the number of households and household size remain fixed at 2005 levels. Changes in GDP growth, industrial structures, technological innovations, and consumption patterns among households can be an important driver of the targeted footprints. In addition, no consideration of any influence from financial crises or natural disasters is made for the footprint derivation. In 2011, Japan was seriously impacted by the Great East Japan Earthquake, and as a result, almost all nuclear power plants have remained idle to date. This will no doubt have a large influence on supply chains, consumption patterns, and the energy mix. Therefore, it is necessary to improve the accuracy of estimating public bads for the period from 2010 to 2035 by incorporating dynamic projections of currently fixed factors. A detailed methodology for footprint estimation and known limitations can be found in Shigetomi et al. (2015). A further limitation of the estimation methodology is that system boundaries within domestic supply chains are inconsistent among the analyzed footprints due to footprint intensity data constraints. Ideally, the domestic environmental footprints would be evaluated within the same system boundary, as the aim of this study is to visualize public bads as deleterious toward society due to inequitable national commodity consumption. However, although it is possible to calculate the CF and AF within Japan, it is impossible to calculate the IF and WF without eliminating the loads generated in foreign countries under the assumption that imported commodities are produced using the same technology that is used within Japan. Accordingly, the CF and AF intensities are calculated according to Eq. (4). However, the IF and WF intensities are established based on Eq. (2), as described in section 3.2, and these footprints are therefore overestimated when compared to the case in which the footprint intensities exclude imported commodities.

Second, the selection of critical factors which underpin footprint derivation are currently based on precedential literature, outlined in the literature review. In order to apply this framework more broadly, these factors and their importance need to be tested with stakeholders in order to inform appropriate factors for inclusion in the evaluation, and the perceived importance of factors to stakeholders in each generation investigated, to inform factor weighting for the public bads and consumption burden application of the EPSEF. Also, it would be more desirable, for example, to consider gray water in the water footprint regarding an assessment of the dependence on industrial waste treatment as well as direct residential waste in the waste footprint under the broader factors for the stakeholders' importance, although both of these were not quantified in this study due to data limitations. Such an investigation would allow for a more accurate reflection of the desirable distribution of costs and burdens and allow the model to be applied in a variety of jurisdictions, cognizant of stakeholder preferences.

6. Conclusions

This research proposes a novel indicator, which can quantify the impact of lifestyles, across generations on the creation of public bads, and the allocation of resultant societal burden. The indicator is underpinned by five environmental footprints influenced by lifestyles, which are measured from the point of resource extraction through to consumption as a product or service in the household. The contribution of this research is twofold, firstly allowing for the quantification of publics bads, and secondly through the provision of a visualization of the changing 'shape' of society and allocation of societal burden over the evaluated time period. Both of these contributions have practical applications in the development of energy-related policy approaches and the comparative evaluation of policy both within and across jurisdictions.

The methodology and indicator proposed work as a footprint harmonizing tool with potential applications complementary to the footprint family approach.

In terms of the Japanese case study presented in this research, several policy implications are identified. As the aging of the Japanese population continues to 2035 (and beyond), it is identified that the generation of public bads is centered around elderly household generations (50's and above). As these generations have different needs, particularly in terms of the use of medical and related services, policy which can address the environmental impact of these activities may need to be prioritized.

Future work will include the assessment of stakeholder preferences toward the selection and weighting of critical consumption and lifestyle-based factors, as well as the consideration of a dynamic industrial sector and the influence of exogenous factors on the footprint derivation methodology.

Acknowledgements: This research was supported by Kuyshu University QR Program Funding Grant (29290).

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