Environmental Research Letters

LETTER • OPEN ACCESS

Quantifying lifestyle based social equity implications for national sustainable development policy

To cite this article: Yosuke Shigetomi *et al* 2020 *Environ. Res. Lett.* **15** 084044

Environmental Research Letters

CrossMark

OPEN ACCESS

RECEIVED
30 March 2019

REVISED
4 May 2020

ACCEPTED FOR PUBLICATION
7 May 2020

PUBLISHED
11 August 2020

LETTER

Quantifying lifestyle based social equity implications for national sustainable development policy

Yosuke Shigetomi[1], **Andrew Chapman**[2], **Keisuke Nansai**[3,4], **Ken'ichi Matsumoto**[1] **and Susumu Tohno**[5]

[1] Graduate School of Fisheries and Environmental Sciences, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan
[2] International Institute for Carbon Neutral Energy Research (I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[3] Center for Material Cycles and Waste Management Research, National Institute for Environmental Studies, 16-2 Onogawa, Ibaraki 305-8506, Japan
[4] Integrated Sustainability Analysis (ISA), School of Physics, Faculty of Science, The University of Sydney, Camperdown, New South Wales 2006, Australia
[5] Graduate School of Energy Science, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

E-mail: y-shigetomi@nagasaki-u.ac.jp

Keywords: environmental footprint, household consumption, input-output analysis, Japan, social equity

Supplementary material for this article is available online

Abstract

The aim of this research is to address the challenge of achieving more equitable social outcomes through a reduction and fairer allocation of environmental burdens, and in doing so, contributing to national sustainable development policy. This novel study demonstrates the nature of societal outcomes through the lens of inequity with respect to lifestyle related environmental footprints and stakeholder preferences. Footprints are derived using input-output analysis, while environmental issue preferences and potential remedial actions are identified using a national survey. To highlight the value of the broadly applicable framework, here we demonstrate a case study of Japan, which is interesting due to shifting demographics engendering an aging, shrinking population. Key findings include that the mitigation of environmental footprints in line with household preferences can positively influence both societal equity outcomes and contribute to closing the gap between rich and poor. Importantly, broad participation, i.e. participation irrespective of income level, is shown to be more effective than participation from a single sector. These findings can assist policymakers to develop policies which are responsive to societal preferences and demographic trends while also furthering the debate toward clarifying norms for acceptable levels of social equity.

1. Introduction

Demand-side or consumption-based approaches focusing on people's lifestyles and the factors that influence them are essential, both for climate change mitigation and also for sustainable development which integrates environmental, economic and social issues (Bertram *et al* 2018, Creutzig *et al* 2018). Consumption-based accounting, a widely accepted, recognized methodology may offer a way to quantify lifecycle environmental pressures via international supply chains (i.e. environmental footprints) and their allocation to final consumers (Peters 2008, Wiedmann 2009, Nansai *et al* 2012, Hertwich and Wood 2018). The application of this methodology has also shed light on the socio-environmental inequalities engendered by uneven distribution of social and environmental burdens (Boyce *et al* 2016, De Schutter *et al* 2018), across nations and regions (Peters *et al* 2011, Simas *et al* 2015, Moran *et al* 2018, Wiedmann and Lenzen 2018, Zhang *et al* 2018, Nansai *et al* 2020b). For example, consumption by only 5% and 10% of the population in richer countries contributed to global energy consumption and greenhouse gas (GHG) emissions at a higher rate than for the entire bottom 50% (Hubacek *et al* 2017a, Oswald *et al* 2020). These inequalities were identified using environmentally extended input-output analysis (EEIOA).

Our lifestyles, expressed via household consumption, impart a substantial contribution toward our environmental footprints (Tukker *et al* 2010, Ivanova *et al* 2016), leading to focused investigations over the last two decades to detail these contributions

(Hertwich 2011, Wiedenhofer et al 2018). A key finding over this period highlights that household environmental footprints are not distributed evenly across income levels at both the national and global scale. For example, the difference in per-capita carbon footprints between the highest and lowest income groups was about 1.4 times in Japan (Shigetomi et al 2016), 4.5 times in the UK (Chitnis et al 2014), 13 times in China (Wiedenhofer et al 2017), and 14 times at the global level (Hubacek et al 2017b).

Alleviation of both environmental pressures and resultant inequalities is a prerequisite for achieving the 2015 United Nations Sustainable Development Goals (SDGs; United Nations 2015). For policymakers, it is essential to consider how to mitigate intricate environmental and social issues resultant from economic activity considering synergies and trade-offs (Liu et al 2018, Nansai et al 2019, Parkinson et al 2019, Vanham et al 2019). It is also crucial to identify how to encourage members of society to engage with policy so as to reduce environmental impacts while also yielding a personal benefit, consistent with their ideals (Vallet et al 2019). The footprinting approach contributes to illustrating the structure of pressures and inequalities linked with final consumption as presented in the above precedential studies. However, these studies have not assessed inequality under multiple environmental pressures. They also overlook stakeholder environmental preferences (in this case, those of household consumers) that will likely have an impact upon preferred abatement measures, in line with environmental justice ideals (Jenkins 2018). By addressing these challenges simultaneously, an improvement in environmental quality and amenity through a reduction in environmental burdens and a fairer allocation among stakeholders can be engendered, resulting in positive social equity outcomes (Finley-Brook and Holloman 2016).

Against this backdrop, this study develops a novel, holistic, inclusive approach which allows for the identification of emerging societal inequities due to disparity in the allocation of multiple environmental pressures and differing preferences and priorities for this allocation among stakeholders. Specifically, we aim to quantify social equity outcomes resulting from household consumption considering future trends of various environmental footprints, and by incorporating stakeholder values and priorities related to each footprint. By considering household consumption reflective of stakeholder behavior and preferences for the environment and society in the future, we can begin to extract the factors which shape stakeholder's environmental preferences, and how these may impact upon future consumption behavior. In this research, consistent with our evaluated stakeholder group's values, we consider a future society which reduces its environmental footprints and avoids their allocation to lower income groups to be a 'more equitable' outcome (i.e. vertical equity; Mooney and Jan 1997).

2. Methodology

2.1. Framework for quantifications of environmental burden and social equity

This study proposes the Input-Output Analysis Sustainability Evaluation Framework (IOSEF), consists of three steps: (1) estimation of households' environmental impacts, (2) measurement of stakeholder preferences to mitigate those impacts, and, (3) quantification of the distributional equity impacts of environmental burdens across households, based on potential future remedial actions. Note that in this framework, environmental impacts, stakeholders, and distributional equity impacts are defined as the environmental footprints, householders who create the footprints by income bracket, and the size and bias of those footprints, respectively.

The procedures for the first step of the IOSEF are based on EEIOA in combination with a consumer expenditure survey, in line with precedential studies (e.g. Wier et al 2001, Dalton et al 2008, Kronenberg et al 2009, Jones and Kammen 2011, Chitnis et al 2014, Steen-Olsen et al 2016, Gill and Moeller 2018, Shigetomi et al 2018, Huang et al 2019, Ottelin et al 2019, Shigetomi et al 2019). This approach yields environmental footprints for targeted household brackets in the analyzed year, $U_{bk}^{(t)}$, as shown in equation (1).

$$U_{bk}^{(t)} = \sum_{i,j} \left(q_{ik}^{(t)} L_{ij}^{(t)} + d_{ik}^{(t)} \right) y_{ib}^{(t)} H_b^{(t)} \quad (1)$$

where both i and j denote goods and services (i.e. commodities) in the input-output table (IOT). Superscript t denotes the analyzed year. $q_{ik}^{(t)}$ represents the direct environmental pressure k ($k = 1 \ldots K$) per unit of output for commodity i. $L_{ij}^{(t)}$ represents the element of the Leontief inverse matrix (Miller and Blair 2009). $y_{ib}^{(t)}$ and $H_b^{(t)}$ represent household final demands per household and the number of households by income bracket b ($b = 1 \ldots B$), respectively. $d_{ik}^{(t)}$ represents the direct environmental pressure from unit expenditure (e.g. CO_2 emissions generated by driving).

In the second step, household preferences for year t, $p_{bk}^{(t)}$, are incorporated as a proxy for stakeholder 'malleability', representing potential future behaviors which reduce environmental footprints based on perceived personal or community merit (e.g. health information promoting footprint mitigation; Hermann et al 2017). Hence, $p_{bk}^{(t)}$ are used as weightings for each of the household environmental footprints. Each range of $p_{bk}^{(t)}$ is defined by a large-sample, representative survey which quantified householder

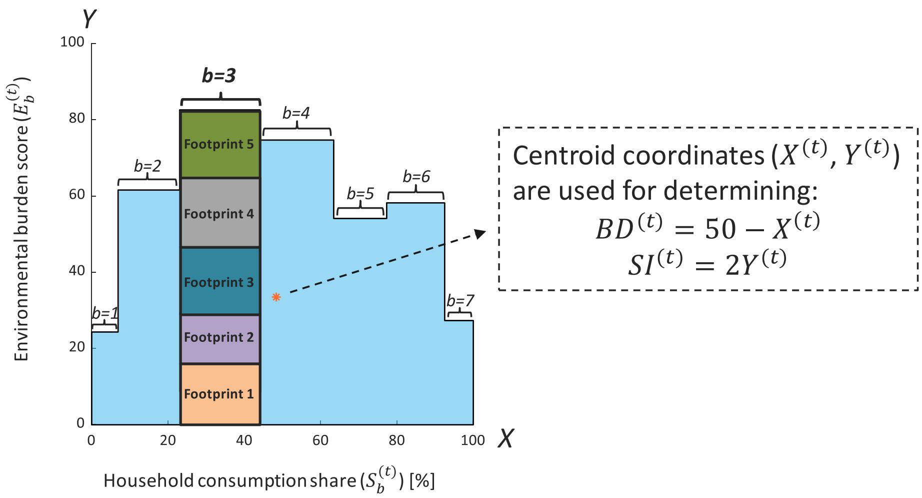

Figure 1. Schematic figure of the method for quantifying burden distribution ($BD^{(t)}$) and social inequity ($SI^{(t)}$) scores from the polygon made up of seven household brackets, based on the cumulative share of their consumption $\left(S_b^{(t)}\right)$, and environmental burden score ($E_b^{(t)}$; the sum of expected footprints 1…5) by household bracket. The third household bracket is detailed as an example in this figure.

importance weightings for issues around sustainability. The questions in this survey focused on the analyzed footprints, but also addressed aspects of lifestyle convenience and desirable income levels, enabling intelligence gathering on issues outside of the environment. A detailed explanation of the methods for determining household preferences using a national survey is elaborated in the supporting information (SI (https://stacks.iop.org/ERL/15/084044/mmedia)).

In the final step, an environmental burden score for each household bracket $\left(E_b^{(t)} = \frac{100}{K}\sum_k \frac{p_{bk}^{(t)}U_{bk}^{(t)}}{\tilde{U}_k}\right)$ is calculated by dividing each expected footprint $\left(p_{bk}^{(t)}U_{bk}^{(t)}\right)$ by the largest values $\left(\tilde{U}_k = \max_{b,t}\left(p_{bk}^{(t)}U_{bk}^{(t)}\right)\right)$ during the analyzed period and the number of footprints (K). Next, we prepare household consumption share by bracket $\left(S_b^{(t)} = \frac{\sum_i y_{ib}^{(t)}H_b^{(t)}}{\sum_{i,b} y_{ib}^{(t)}H_b^{(t)}}\right)$. Following this, area weighted centroid coordinates $\left(X^{(t)}, Y^{(t)}\right)$ of the resulting polygon are calculated using $E_b^{(t)}$, $S_b^{(t)}$, and the geometric operation for area weighted centroid calculation, as shown in equations (2) and 3.

$$X^{(t)} = \frac{\left\{E_1^{(t)}\left(S_1^{(t)}\right)^2 + \sum_{b=2}^{B} E_b^{(t)}\left(S_b^{(t)} - S_{b-1}^{(t)}\right)^2\right\}/2}{E_1^{(t)}S_1^{(t)} + \sum_{b=2}^{B} E_b^{(t)}\left(S_b^{(t)} - S_{b-1}^{(t)}\right)} \tag{2}$$

$$Y^{(t)} = \frac{\left\{\left(E_1^{(t)}\right)^2 S_1^{(t)} + \sum_{b=2}^{B} \left(E_b^{(t)}\right)^2\left(S_b^{(t)} - S_{b-1}^{(t)}\right)\right\}/2}{E_1^{(t)}S_1^{(t)} + \sum_{b=2}^{B} E_b^{(t)}\left(S_b^{(t)} - S_{b-1}^{(t)}\right)} \tag{3}$$

Finally, the burden distribution ($BD^{(t)} = X^{(t)} - 50$), and social inequity score ($SI^{(t)} = 2Y^{(t)}$) are determined based on these centroid coordinates. A schematic figure of the model is shown in figure 1. In this case, as an example, the polygon is comprised of five environmental footprints (i.e. $K = 5$) and seven household brackets (i.e. $B = 7$). As seen in the figure, each $E_b^{(t)}$ and $S_b^{(t)}$ are used for illustrating the height and width of the rectangles which make up the polygon. Here, $S_b^{(t)}$ is arranged in descending order of household income level.

$BD^{(t)}$ identifies the household brackets which are causing the greatest level of environmental burden in society (due to their consumption), relative to average consumption (i.e. the 50% mark on the x-axis). Hence, a positive $BD^{(t)}$ indicates that the majority of environmental burdens are generated by higher income households. $SI^{(t)}$ denotes the amount of environmental burdens in each household bracket and the bias between brackets. $SI^{(t)}$ has a maximum value of 100 and incorporates stakeholder importance weightings for each environmental footprint. A low $SI^{(t)}$ is desirable, as this indicates improving social equity outcomes due to reduced environmental burdens and discrepancy among households. The method for quantifying these scores builds on and adapts previous scholarship which outlined social equity outcomes of energy system and policy issues including fossil-fuel retirement (Chapman *et al* 2018), mega-solar siting (Fraser and Chapman 2018), bottom-up energy transitions (Chapman and Pambudi 2018), and social inequities considering consumption and shifting demographics (Chapman and Shigetomi 2018b).

2.2. Case study of japan using multiple environmental footprints and stakeholder behavior

To demonstrate the operation of the IOSEF, this study details trends in social inequity of household

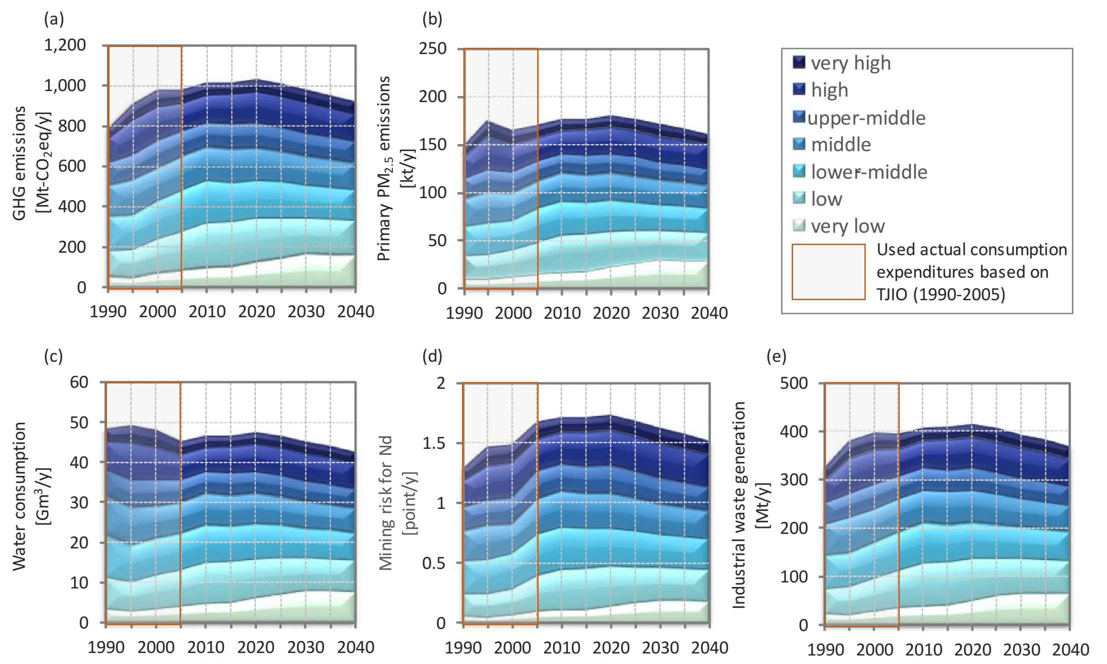

Figure 2. Projected household footprints in Japan between 1990 and 2040 under the BaU scenario. (a) carbon, (b) primary $PM_{2.5}$, (c) blue and green water, (d) mining risk for neodymium (Nd), and (e) industrial waste. Note that during 1990–2005 these footprints were estimated using actual consumption expenditure consistent with the TJIO.

consumption in Japan during 1990–2040 and how they may be influenced by changing household behaviors over time. Japan is facing the social issues of an aging, shrinking population. It is therefore anticipated that shifting demographics, along with changing social and economic conditions have implications on both the values and priorities of stakeholders in different age and income groups (Chapman and Shigetomi 2018a). In this study, prediction of environmental footprints by income bracket was conducted based on a previous study (Chapman and Shigetomi 2018b). In addition, we defined 'active' and 'proactive' desirable future scenarios to demonstrate how burden distribution and social inequity may be affected by household preferences and responsive behaviors. The dataset utilized, desirable future scenario settings and assumptions are detailed in the SI.

3. Results

3.1. Demographic trends and household footprint variation

An estimation of household environmental footprints from 1990–2040 is shown in figure 2. These estimates incorporate trends of household income group composition and consumption expenditure but do not account for weighting or stakeholder preferences. This estimation is utilized in the business as usual (BaU) scenario. Details of household income group composition and consumption expenditure trends from 1990–2040 can be found in the SI.

Between 1990 and 2005 variations in household footprints are reported using actual consumption expenditures based on the Time series Japan Input-Output table (TJIO; MIC 2010). From 2010 onwards, consumption is projected according to the change in household numbers within each income group, utilizing a constant consumption structure as at 2005 (i.e. both per-household consumption and footprint per unit of output are constant at 2005 levels). Trends affecting the five household footprints during 1990–2005 are reflective of changes in consumption patterns and demographics, while those after 2010 show the influence of anticipated Japanese demographics (Inagaki 2013, IPSS 2018, MHLW 2016). Notably, the mining risk household footprint (Nansai *et al* 2015) rapidly increased from 1990 to 2005 in response to an increase in the demand for information and communication devices such as personal computers and cellular phones. All footprints except for blue and green water peak around 2020, with the water footprint peaking in 1995.

Post-2020 household footprints are also projected including stakeholder preference weightings. Note that scenarios based on stakeholder preferences are applied from 2020 onwards, reflective of the timing of the national survey. Figure 3 demonstrates the potential difference in footprints between the BaU and active and proactive desirable future scenarios.

In comparing the BaU scenario with the other scenarios, footprints are estimated to be up to 9.7% lower under the active desirable future scenario and up to 29% lower under the proactive desirable future scenario by 2040. The largest difference is observed for the water footprint, followed by industrial waste, $PM_{2.5}$ and carbon. For neodymium mining risk footprints, no difference is observed between the BaU

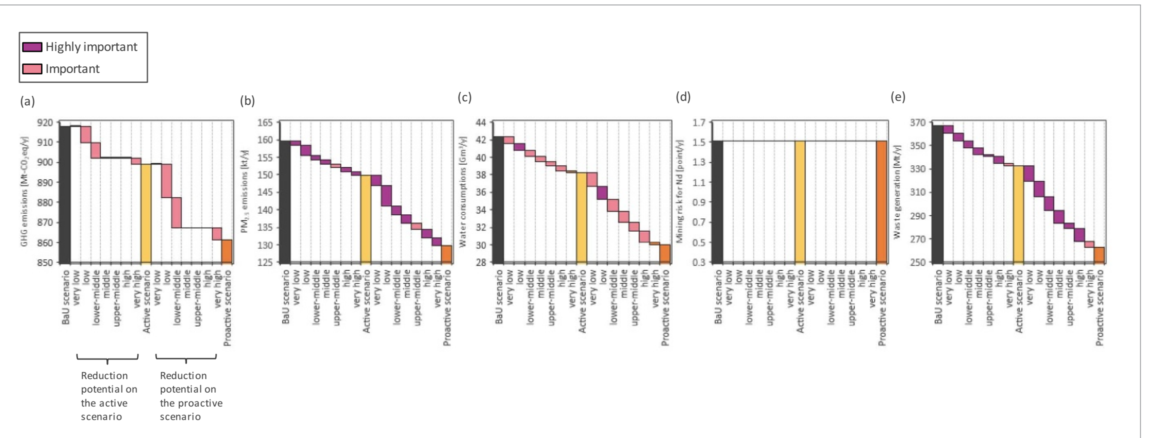

Figure 3. Difference between BaU and desirable future scenario footprints depending on proactiveness in 2040. The left (dark gray), central (yellow), and right (orange) bars denote footprint values in 2040 for the BaU, Active, and Proactive desirable future scenarios respectively. The columns between the initial, central and end bars show the expected contribution of each income group toward footprint changes. (a) carbon, (b) primary $PM_{2.5}$, (c) blue and green water, (d) mining risk for neodymium, and (e) industrial waste.

and other scenarios as no preference to reduce them was expressed among households (i.e. all weighting factors were 0 during the studied period). As seen in figure 3, only the very low, low, and very high-income households are likely to achieve a reduction in carbon footprint due to their high level of environmental consciousness. These income brackets include the majority of elderly households who are likely to have higher consciousness about environmental protection and addressing climate change (Chapman and Shigetomi 2018a). It was also identified that very high-income households tend to have a higher education level (these two factors are heavily inter-related), which is linked to higher environmental knowledge and therefore consciousness. Importantly, if the very low-income bracket reduce their carbon footprint in line with their reported level of responsiveness to conducive public policy (i.e. by 5%), the total footprint would be decreased by some 8.5 Mt-CO_2eq/y (0.91% overall). This anticipated reduction is 2.7 times larger than that of very high-income households due in part to a larger number of lower income households. Although all income groups show some propensity toward reducing waste, water, and $PM_{2.5}$ footprints, the low-income group had the largest contribution to overall potential future reductions.

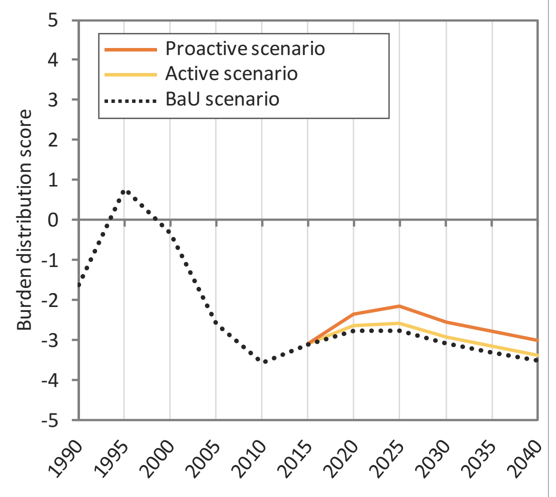

Figure 4. Trends for burden distribution scores between 1990–2040. Household preference weightings are applied to desirable future scenarios from 2020 onward. The burden distribution score represents the origin of the majority of environmental burdens in terms of household income group relative to average consumption, and the shift in burden allocation over time. A negative score (as shown post-2000) indicates that the majority of environmental burdens are generated by lower income households, and an improving score indicates progress toward societally preferred levels of burden allocation.

3.2. Social inequity impacts considering stakeholder environmental burden preferences

Based on the results for environmental burdens as estimated in the previous section, burden distribution and relative social inequity scores were calculated as shown in figures 4 and 5 respectively.

Burden distribution scores peak above 0, taking a positive value in 1995, however, after 1995 scores rapidly decline out to 2010, with a small increase occurring between 2010 and 2025. This trend as observed in figure 4 is partially due to marked increases in contributions from lower income households toward overall environmental footprints. According to national statistics, Japanese household's average income increased in the late 90's, compared to 1990 levels. However, after 1999, incomes reduced until 2010. After 2010, average income was slightly increased to 2015 (MHLW 2016). Without exogenous shocks to economic growth (e.g. policy intervention or natural disasters), average incomes are likely to decrease due mainly to the aging, shrinking population (Inagaki 2013). It is notable that although burden distribution scores are comparatively higher under active and proactive desirable future scenarios, they worsen even when incorporating householder preference weightings during 2025–2040. The peak burden distribution score occurs in 2025 under the

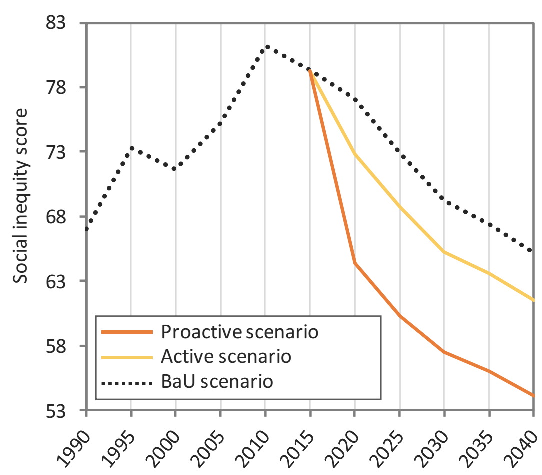

Figure 5. Trends for social inequity scores between 1990–2040. Household preference weightings are applied to desirable future scenarios from 2020 onward. The social inequity score represents the level of overall environmental burdens imparted on households, with a lower score as shown here indicating improving social outcomes in line with reducing environmental burdens overall and reduced variance among household brackets.

active desirable future scenario, at approximately the same level as the BaU scenario in 2005. The proactive desirable future scenario is approximately 0.6 points higher at the same time. These results indicate that reducing environmental burdens in line with householder preferences and merit-seeking behavior engenders the co-benefit of alleviating lower income households' level of burden.

Environmental burdens arising from household consumption influence both burden distribution and social inequity scores. Considering the results shown in figure 5, social inequity peaks in 2010 even though the majority of household footprints are projected to peak in 2020. This confirms that the social inequity score reflects not only the level of environmental burdens but also the balance of consumption across society. For example, contradictory to the result seen for burden distribution, social inequity is expected to reduce after 2010, indicating that social equity is improved by a fairer distribution of environmental burdens (i.e. burden distribution scores increase) and a reduction in footprints in certain income levels. Demographic changes influence scores, along with changing levels of environmental burden. Results suggest that a continuous decline in social inequity will occur, mainly due to the expected decrease in environmental burdens, which outweigh the worsening of their distribution post 2025. In comparing the active desirable future scenario to the BaU scenario, social inequity scores are expected to decrease by between 3.7–4.3 points during 2020–2040. Under the proactive desirable future scenario, social inequity scores drop markedly in 2020, and continue decreasing until 2040 to a level lower than that observed in 1990 for the BaU scenario. The active and proactive desirable future scenarios achieve superior social equity outcomes 15 and 20 years earlier than the BaU scenario, respectively, due to stakeholder preferences, malleability toward policy, and footprint reducing behaviors.

4. Discussion

4.1. Usefulness of social inequity indicators proposed in this study

The IOSEF, as proposed in this study, demonstrates how disparity in household consumption causes societal distortion via the supply chain, in terms of consumption distribution, environmental burdens and household preferences. The IOSEF has the potential to be a useful tool to aid in measuring social inequity and burden distribution allocation across time and demographics. Based on the results shown in the Japanese case study, the framework can also provide a strong evidence base for policy intervention. This will engender the achievement of policy goals, including the reduction of undesirable environmental burdens (e.g. environmental footprints—the root cause of social inequity), in line with household preferences.

Combining household preferences and responsiveness with demographic and household consumption trends alongside EEIOA, it is possible to investigate broad footprint categories and identify specific goods and services which generate the most environmental burdens, as well as those who are consuming them (Chapman and Shigetomi 2018b). Owing to the high resolution of commodity sectors in the input-output model utilized in this study (~400 sectors), it is possible to distinguish details within environmental burdens and to detail the impact of changes in household consumption on burden distribution and social inequity scores. The usefulness of the framework in this respect is demonstrated in figure 6, detailing a sensitivity analysis of burden distribution and social inequity scores with respect to potential changes of 10% for consumption of commodities $\left(\sum_b y_{ib}^{(t)}\right)$ based on the BaU Scenario in 2040.

A salient example from figure 6 shows that if all households reduced 10% of gasoline consumption for private transport, burden distribution and social inequity scores would decrease by 0.05 and 0.40 respectively. This indicates that although the impact of environmental burdens 'felt' by society are diminished (i.e. the social inequity score drops), those borne by lower income groups increase (i.e. the burden distribution score is increasingly negative). However, when electricity consumption is reduced by 10%, the social inequity score decreases by 0.28 while the burden distribution score increases by 0.01, implying positive outcomes for both social inequity and burden distribution. Here we can deduct that a reduction in electricity consumption would be

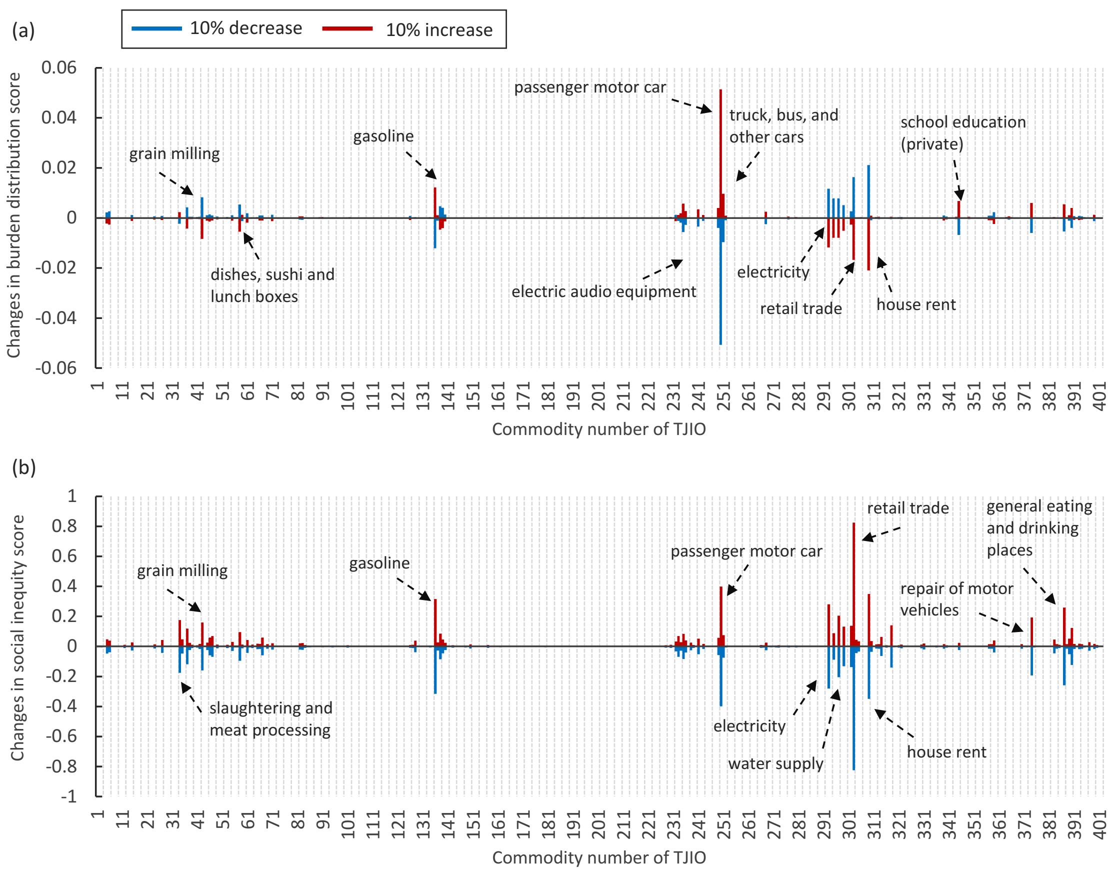

Figure 6. Sensitivity analysis of (a) burden distribution score and (b) social inequity score. Colored bars above the axis denote a positive effect on scores when consumption levels increase (red) or decrease (blue) by 10% compared to the BaU scenario in the year 2040. The ten most influential commodities are labeled.

preferable to a reduction in gasoline in terms of the improvement of social equity and the alleviation of burden allocation simultaneously. The framework, therefore, highlights the importance of stakeholder participation in improving social equity outcomes, i.e. through bottom-up policy implementation and the devolution of detailed footprint mitigation policy responsibility to stakeholders.

4.2. Policy implications considering social equity associated with lifestyle consumption

The approach posited in this study offers the following benefits for sustainable policymaking. First, it enables the evaluation of social equity incorporating multiple footprint quantification associated with lifestyle consumption. Policymakers have identified the need for national sustainable development progress monitoring, which can be complex, particularly utilizing quantitative models (Allen *et al* 2016). Under the posited approach, mitigation of social inequity related to SDGs 10.2 and 10.3 can contribute toward progress in achieving SDG 3.9 ($PM_{2.5}$), 4.3 and 7.2 (mining risk for Nd), 6.4 (water), 12.5 (industrial waste), and 13.2 (GHG). The combination of IOSEF outputs with environmental burdens and their respective breakdown provides policymakers with a snapshot of progress toward goals, pathways toward improvement, as well as key sectors which require attention for redress from the demand-side. In addition, the IOSEF can identify underlying demographic and income trends which impact upon both SDGs (Dasgupta *et al* 2015) and stakeholder responsiveness.

Second, the consideration of social inequity and burden distribution scores allows for comprehensive policymaking which recognizes the benefits of reduced environmental burdens, and of a societally desirable level of burden sharing. One way to close the income-footprint gap in the context of climate change mitigation is through income transfer from higher to lower income levels utilizing taxation revenue (Abrell *et al* 2018, Oishi *et al* 2018). Another way to achieve this goal is by using targeted policy. An example relative to the findings of this research is the encouragement of stakeholders who are concerned about water resources to reduce their consumption of high water footprint products such as meat for example, through conducive policies or subsidies. It is also essential to motivate stakeholders to be aware of the impacts of consumption by increasing education surrounding simple actions to reduce footprints. These may include such things as reducing excessive calorie intake and food loss, increasing walking and bicycle use, participating in community activities (e.g.

volunteering), and sharing and repairing goods (Vita *et al* 2019).

Through the development and case study implementation of the IOSEF utilizing stakeholder engagement, we identified that there is no 'one-size-fits-all' policy approach. Additionally, the IOSEF identifies quantitatively that the participation of all stakeholders at varying levels, i.e. some effort from each income level, engenders better outcomes than the same reduction made by a single income level group. Further, a modal shift from automobiles to walking/cycling could be beneficial not only for various footprints that worsen social inequity but also for people's health, which can positively affect their propensity to take appropriate action (Herrmann *et al* 2017, Malik *et al* 2018, Nansai *et al* 2020a). It would also be relatively easy for low-income households to undertake these simple activities which have the dual benefit of reducing transport related costs and taxes as well as shrinking environmental burdens. Considering the difference in footprints between demographics with similar preferences gives an additional policymaking option which may be fit for both demographic and preference (i.e. carbon footprint preferences between low and very high-income households; see figure 3). The IOSEF allows policymakers to test various approaches prior to their implementation, in order to improve societal equity and burden distribution allocation outcomes considering lifestyles, consumption and stakeholder propensity for participation in environmental footprint reducing activities.

5. Conclusion

The IOSEF, a new sustainability assessment framework which considers fairness and lifecycle perspectives, allows for the consideration of policy implications to improve social equity with respect to multiple lifecycle environmental pressures and household consumption. In addition, the tool is also useful in its ability to help highlight priority SDGs requiring redress. Through a case study application to Japan, results demonstrate that there is no one-size-fits-all policy which will improve social equity and burden allocation outcomes for all stakeholders (e.g. households). For this reason, multi-faceted, fit for purpose policy is required. This research builds on this finding to enable policy which is both appropriate and responsive to stakeholder preferences and demographics. Developing policies which consider preference and demographics (i.e. income level, age etc) will lead to desirable outcomes whereby each sector of society is able to contribute in their own way, seeking their own perceived benefits. The overall goal of this approach is improved social equity, which the proposed framework can measure quantitatively.

This study is unique, as it demonstrates for the first time the nature of societal outcomes through the lens of inequity underpinned by lifestyle related environmental burdens. In achieving this goal, there are several limitations to be aware of which may affect overall results arising from use of the framework. To improve accuracy, it is essential to consider the factors underpinning footprint estimates. In the case study, factors are fixed based on 2005 footprint intensities, consumption patterns and policy interventions, in order to clarify the impact of demographic changes. Incorporating scenario approaches which consider technology innovation (Barrett and Scott 2012, Wolfram *et al* 2016, Wiebe 2016), consumption pattern changes (Girod *et al* 2014, Wynes and Nicholas 2017, Koide *et al* 2019, Vita *et al* 2019), and economic policy schemes for boosting income level (Hubacek *et al* 2017b, Shigetomi *et al* 2018) are expected to further improve societal equity and burden distribution allocation outcomes. Also, the methodology employed to determine proactiveness levels using a national survey is in the early stages of development. Environmental awareness cannot be directly translated from the degree of pro-environmental behavior, although there is some evidence that increasing awareness engenders a reduction in environmental burdens (Li *et al* 2019). Additionally, the survey method employed and the influence of different ways of asking questions also has an impact on responses (Pew Research Center 2015).

To overcome these methodological limitations, further investigations are required to validate the applicability of the proposed framework in other jurisdictions, particularly with regard to the availability of IO tables within and across regions (e.g. Faturay *et al* 2017, Stadler *et al* 2018, Wakiyama *et al* 2020).

Acknowledgments

This research was supported in part by JSPS KAKENHI Grant Numbers JP16H01797, JP18K18231 and JP18K11754, Kyushu University QR Program 'Tsubasa', and Nagasaki University Global Research Fund. We would like to thank Professor Shunichi Hienuki and Professor Yasushi Kondo for their valuable comments on this research.

Data availability statement

The data that supports the findings of this study is available upon request from the authors.

ORCID iDs

Andrew Chapman https://orcid.org/0000-0002-2519-2382
Ken'ichi Matsumoto https://orcid.org/0000-0002-9349-9765

Susumu Tohno https://orcid.org/0000-0002-3936-5600

References

Abrell J, Rausch S and S G A 2018 How robust is the uniform emissions pricing rule to social equity concerns? *J. Environ. Econ. Manage.* **92** 783–814

Allen C, Metternicht G and Wiedmann T 2016 National pathways to the Sustainable Development Goals (SDGs): A comparative review of scenario modelling tools *Environ. Sci. Policy* **66** 199–207

Barrett J and Scott K 2012 Link between climate change mitigation and resource efficiency: A UK case study *Glob. Environ. Change* **22** 299–307

Bertram C, Luderer G, Popp A, Minx J C, Lamb W F, Stevanović M, Humpenöder F, Giannousakis A and Kriegler E 2018 Targeted policies can compensate most of the increased sustainability risks in 1.5 °C mitigation scenarios *Environ. Res. Lett.* **13** 064038

Boyce J K , Zwickl K and Ash M 2016 Measuring environmental inequality *Ecol. Econ.* **124** 114–23

Chapman A J, McLellan B C and Tezuka T 2018 Prioritizing mitigation efforts considering co-benefits, equity and energy justice: fossil fuel to renewable energy transition pathways *Appl. Energy* **219** 187–98

Chapman A and Shigetomi Y 2018a Developing national frameworks for inclusive sustainable development incorporating lifestyle factor importance *J. Clean. Prod.* **200** 39–47

Chapman A and Shigetomi Y 2018b Visualizing the shape of society: an analysis of public bads and burden allocation due to household consumption using an input-output approach *Sci. Total Environ.* **639** 385–96

Chapman A J and Pambudi N A 2018 Strategic and user-driven transition scenarios: toward a low carbon society, encompassing the issues of sustainability and societal equity in Japan *J. Clean. Prod.* **172** 1014–24

Chitnis M, Sorrell S, Druckman A, Firth S K and Jackson T 2014 Who rebounds most? Estimating direct and indirect rebound effects for different UK socioeconomic groups *Ecol. Econ.* **106** 12–32

Creutzig F *et al* 2018 Towards demand-side solutions for mitigating climate change *Nat. Clim. Change* **8** 268–71

Dalton M, O'Neill B, Prskawetz A, Jiang L and Pitkin J 2008 Population aging and future carbon emissions in the United States *Energy Econ.* **30** 642–75

de Schutter L, Wieland H P, GÖzet B and Giljum S 2017 *Environmental Inequality in Europe - towards an environmental justice framework for Austria in an EU context* (Wien: Institute for Ecological Economics (WU)) (https://emedien.arbeiterkammer.at/viewer/resolver?urn=urn:nbn:at:at-akw:g-2057305)

Dasgupta P, Duraiappah A, Managi S, Barbier E, Collins R, Fraumeni B, Gundimeda H, Liu G and Mumford K J 2015 How to measure sustainable progress *Science* **350** 748–748

Faturay F, Lenzen M and Nugraha K 2017 A new sub-national multi-region input–output database for Indonesia *Econ. Syst. Res.* **29** 234–51

Finley-Brook M and Holloman E 2016 Empowering energy justice *Int. J. Environ. Res. Public Health* **13** 926

Fraser T and Chapman A J 2018 Social equity impacts in Japan's mega-solar siting process *Energy Sustain. Dev.* **42** 136–51

Gill B and Moeller S 2018 GHG emissions and the rural-urban divide. a carbon footprint analysis based on the German official income and expenditure survey *Ecol. Econ.* **145** 160–9

Girod B, V V D P and H E G 2014 Climate policy through changing consumption choices: options and obstacles for reducing greenhouse gas emissions *Glob. Environ. Change* **25** 5–15

Herrmann A *et al* 2017 Household preferences for reducing greenhouse gas emissions in four European high-income countries: does health information matter? A mixed-methods study protocol *BMC Public Health* **18** 1–12

Hertwich E G 2011 The life cycle environmental impacts of consumption *Econ. Syst. Res.* **23** 27–47

Hertwich E G and Wood R 2018 The growing importance of scope 3 greenhouse gas emissions from industry *Environ. Res. Lett.* **13** 104013

Huang Y, Shigetomi Y, Chapman A and Matsumoto K 2019 Uncovering household carbon footprint drivers in an aging, shrinking society *Energies* **12** 3745

Hubacek K, Baiocchi G, Feng K, Muñoz Castillo R, Sun L and Xue J 2017a Global carbon inequality *Energy, Ecol. Environ.* **2** 361–9

Hubacek K, Baiocchi G, Feng K and Patwardhan A 2017b Poverty eradication in a carbon constrained world *Nat. Commun.* **8** 912

Inagaki S 2013 Future outlook for changes in households with older people and levels of poverty *Kikan Shakai Hosho Kenkyu* **48** 396–409

IPSS 2018 *Household Projections in Japan: 2015-2040* National Institute of Population and Social Security Research, (http://www.ipss.go.jp/pp-ajsetai/e/hhprj2018/t-page_e.asp)

Ivanova D, Stadler K, Steen-Olsen K, Wood R, Vita G, Tukker A and E G H 2016 Environmental impact assessment of household consumption *J. Ind. Ecol.* **20** 526–36

Jenkins K 2018 Setting energy justice apart from the crowd: Lessons from environmental and climate justice Energy *Res. Soc. Sci.* **39** 117–21

Jones C M and Kammen D M 2011 Quantifying carbon footprint reduction opportunities for U.S. households and communities *Environ. Sci. Technol.* **45** 4088–95

Koide R, Lettenmeier M, Kojima S, Toivio V, Amellina A and Akenji L 2019 Carbon footprints and consumer lifestyles: an analysis of lifestyle factors and gap analysis by consumer segment in Japan *Sustainability* **11** 1–25

Kronenberg T 2009 The impact of demographic change on energy use and greenhouse gas emissions in Germany *Ecol. Econ.* **68** 2637–45

Li J, Zhang D and Su B 2019 The impact of social awareness and lifestyles on household carbon emissions in China *Ecol. Econ.* **160** 145–55

Liu J *et al* 2018 Nexus approaches to global sustainable development *Nat. Sustain.* **1** 466–76

Malik A, Lenzen M, Mcalister S and Mcgain F 2018 The carbon footprint of Australian health care *Lancet Planet. Heal.* **2** e27–35

MHLW 2016 *Graphical Review of Japanese Household: From Comprehensive Survey of Living Conditions, 2016* Japan Ministry of Health, Labour and Welfare, (https://www.mhlw.go.jp/toukei/saikin/hw/k-tyosa/k-tyosa18/index.html)

MIC 2010 Time-series Japanese input-output table, Japan Ministry of Internal Affairs and Communications Online: (http://www.soumu.go.jp/toukei_toukatsu/data/io/k_gaiyou.htm)

Miller R E and Blair P D 2009 *Input–Output Analysis* (Cambridge: Cambridge University Press) (Online: http://ebooks.cambridge.org/ref/id/CBO9780511626982)

Mooney G and Jan S 1997 Vertical equity: weighting outcomes? or establishing procedures? *Health Policy (New. York).* **39** 79–87

Moran D, Kanemoto K, Jiborn M, Wood R, Többen J and Seto K C 2018 Carbon footprints of 13 000 cities *Environ. Res. Lett.* **13** 064041

Nansai K, Fry J, Malik A, Takayanagi W and Kondo N 2020a Carbon footprint of Japanese health care services from 2011 to 2015 *Resour. Conserv. Recycl.* **152** 104525

Nansai K *et al* 2012 Characterization of economic requirements for a "carbon-debt-free country" *Environ. Sci. Technol.* **46** 155–63

Nansai K, Kondo Y, Giurco D, Sussman D, Nakajima K, Kagawa S, Takayanagi W, Shigetomi Y and Tohno S 2019 Nexus between economy-wide metal inputs and the deterioration of sustainable development goals *Resour. Conserv. Recycl.* **149** 12–19

Nansai K, Nakajima K, Kagawa S, Kondo Y, Shigetomi Y and Suh S 2015 Global mining risk footprint of critical metals necessary for low-carbon technologies: the case of neodymium, cobalt, and platinum in Japan *Environ. Sci. Technol.* **49** 2022–31

Nansai K *et al* 2020b Affluent countries inflict inequitable mortality and economic loss on Asia via PM2.5 emissions *Environ. Int.* **134** 105238

Oishi S, Kushlev K and Schimmack U 2018 Progressive taxation, income inequality, and happiness *Am. Psychol.* **73** 157–68

Oswald Y, Owen A and Steinberger J K 2020 Large inequality in international and intranational energy footprints between income groups and across consumption categories *Nat. Energy* **5** 231–9

Ottelin J, Heinonen J, Nässén J and Junnila S 2019 Household carbon footprint patterns by the degree of urbanisation in Europe *Environ. Res. Lett.* **14** 114016

Parkinson S *et al* 2019 Balancing clean water-climate change mitigation trade-offs *Environ. Res. Lett.* **14** 014009

Peters G P 2008 From production-based to consumption-based national emission inventories *Ecol. Econ.* **65** 13–23

Peters G P, Minx J C, Weber C L and Edenhofer O 2011 Growth in emission transfers via international trade from 1990 to 2008 *Proc. Natl. Acad. Sci.* **108** 8903–8

Pew Research Center 2015 *Coverage in Internet Surveys, Who Web-Only Surveys Miss and How that Affects Results* (https://www.pewresearch.org/methods/2015/09/22/coverage-error-in-internet-surveys/)

Shigetomi Y, Nansai K, Kagawa S and Tohno S 2016 Influence of income difference on carbon and material footprints for critical metals: the case of Japanese households *J. Econ. Struct.* **5** 1

Shigetomi Y, Nansai K, Kagawa S and Tohno S 2018 Fertility-rate recovery and double-income policies require solving the carbon gap under the Paris agreement *Resour. Conserv. Recycl.* **133** 385–94

Shigetomi Y, Ohno H Chapman A, Fujii H, Nansai K and Fukushima Y 2019 Clarifying demographic impacts on embodied and materially retained carbon toward climate change mitigation *Environ. Sci. Technol.* **53** 14123

Simas M, Wood R and Hertwich E 2015 Labor embodied in trade: the role of labor and energy productivity and implications for greenhouse gas emissions *J. Ind. Ecol.* **19** 343–56

Stadler K *et al* 2018 EXIOBASE 3: developing a time series of detailed environmentally extended multi-regional input-output tables *J. Ind. Ecol.* **22** 502–15

Steen-Olsen K, Wood R and Hertwich E G 2016 The carbon footprint of Norwegian household consumption 1999–2012 *J. Ind. Ecol.* **20** 582–92

Tukker A, Cohen M J, Hubacek K and Mont O 2010 The impacts of household consumption and options for change *J. Ind. Ecol.* **14** 13–30

United Nations 2015 *Transforming our world: the 2030 agenda for sustainable development* Online: (http://www.crcnetbase.com/doi/10.1201/b20466-7)

Vallet A, Locatelli B, Levrel H, Dendoncker N, Barnaud C and Quispe Conde Y 2019 Linking equity, power, and stakeholders' roles in relation to ecosystem services *Ecol. Soc.* **24** art14

Vanham D *et al* 2019 Environmental footprint family to address local to planetary sustainability and deliver on the SDGs *Sci. Total Environ.* **693** 133642

Vita G, Lundström J R, Hertwich E G, Quist J, Ivanova D, Stadler K and Wood R 2019 The environmental impact of green consumption and sufficiency lifestyles scenarios in europe: connecting local sustainability visions to global consequences *Ecol. Econ.* **164** 106322

Wakiyama T, Lenzen M, Geschke A, Bamba R and Nansai K 2020 A flexible multiregional input–output database for city-level sustainability footprint analysis in Japan *Resour. Conserv. Recycl.* **154** 104588

Wiebe K S 2016 The impact of renewable energy diffusion on European consumption-based emissions *Econ. Syst. Res.* **28** 133–50

Wiedenhofer D, Guan D, Liu Z, Meng J, Zhang N and Wei Y M 2017 Unequal household carbon footprints in China *Nat. Clim. Change* **7** 75–80

Wiedenhofer D, Smetschka B, Akenji L, Jalas M and Haberl H 2018 Household time use, carbon footprints, and urban form: a review of the potential contributions of everyday living to the 1.5 °C climate target *Curr. Opin. Environ. Sustain.* **30** 7–17

Wiedmann T 2009 A review of recent multi-region input-output models used for consumption-based emission and resource accounting *Ecol. Econ.* **69** 211–22

Wiedmann T and Lenzen M 2018 Environmental and social footprints of international trade *Nat. Geosci.* **11** 314–21

Wier M, Lenzen M, Munksgaard J and Smed S 2001 Effects of Household Consumption Patterns on CO_2 Requirements *Econ. Syst. Res.* **13** 259–74

Wolfram P, Wiedmann T and Diesendorf M 2016 Carbon footprint scenarios for renewable electricity in Australia *J. Clean. Prod.* **124** 236–45

Wynes S and Nicholas K A 2017 The climate mitigation gap: education and government recommendations miss the most effective individual actions *Environ. Res. Lett.* **12** 074024

Zhang W, Wang F, Hubacek K, Liu Y, Wang J, Feng K, Jiang L, Jiang H, Zhang B and Bi J 2018 Unequal exchange of air pollution and economic benefits embodied in China's exports *Environ. Sci. Technol.* **52** 3888–98