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Inclusive environmental impact assessment indices with consideration of public acceptance: Application to power generation technologies in Japan ☆

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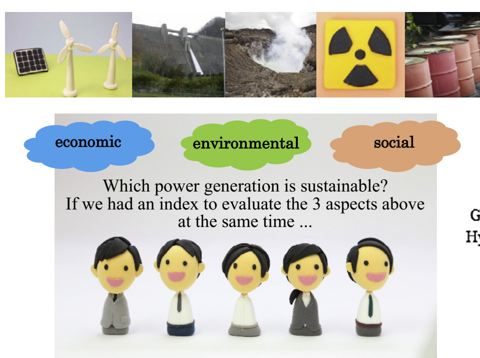
HIGHLIGHTS

- We propose indices to evaluate economic, environmental and social costs of artefacts.
- These indices assessed the sustainability of eight power generation technologies.
- Conjoint analysis quantified public expectation and concern about these technologies.

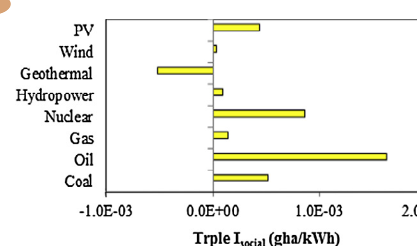
GRAPHICAL ABSTRACT



Social cost (= public expectation and concern) is newly added to existing indices that already consider economic and environmental costs as follows.

TripleI → Triple I_{social}

If this index is negative, it is thought that a corresponding technology is sustainable.



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ABSTRACT

Public acceptance is one of the most important issues when considering the sustainability of anthropogenic systems. The development of energy systems in the future will depend on the balance of environmental impact, economic feasibility, and public acceptance. On the basis of existing inclusive environmental impact indices, such as the Inclusive Impact Index (Triple I) and emergy, in the present work we propose two novel indices, Triple I_{social} and Triple $I_{emergy\text{-}social}$, that can be used to evaluate public acceptance together with economic and environmental aspects simultaneously. This is the claim of originality of this work. In this study, we applied these indices to eight power generation technologies and, to quantify public expectations and concern, we conducted a questionnaire survey about these technologies. The conjoint analysis reveals the marginal rate of allowance to compensate (MRAC), a term we propose as a replacement of the marginal willingness to pay, in units of monetary value, ecological footprint, or emergy for six attributes considered to affect public acceptance. Triple I_{social} and Triple $I_{emergy\text{-}social}$ of the power generation technologies are calculated using MRAC, and it suggests that only the geological thermal energy is sustainable while the others need to be improved in terms of monetary, environmental, and/or social costs to reach a level at which these technologies are regarded as sustainable.

1. Introduction

Agenda 21 [1], an action plan for sustainable development that was adopted at the Earth Summit held in Brazil in 1992, asserted that indices such as the gross domestic product (GDP), which had

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Nomenclature

$Amount_n$	amount of energy input during the lifecycle of each product type n
B	economic benefit (yen/yr)
B_{sale}	sale price (yen)
BC	biocapacity (gha)
C	economic cost (yen/yr)
CCS	carbon dioxide capture and storage
d_{jl}	1 if respondent l chooses choice j; 0 otherwise
EF	ecological footprint (gha)
Emergy	available energy of one form that is used up in transformations directly and indirectly to make a product or service [6] (sej)
$EP_{current}$	current electricity price (yen)
ER	ecological risk (gha)
GDP	gross domestic production (yen/yr)
GHG	greenhouse gas
HR	human risk (yen/yr)
i	each attribute
III	symbol of Triple I used in equations (gha)
III_{emergy}	Triple I, in which EF is converted into emergy (sej)
III_{social}	symbol of Triple I_{social} used in equations (gha)
$III_{emergy\text{-}social}$	symbol of Triple $I_{emergy\text{-}social}$ used in equations (sej)
IPP	independent power provider
j	each choice branch
l	each respondent
L_i	likelihood function of choosing branch j for attribute i
$Level_i$	standard level for each attribute i
MRAC	marginal rate of allowance to compensate (yen, gha, or sej)
MWTA	marginal willingness to accept (yen)
MWTP	marginal willingness to pay (yen)
n	each product type
NEM	national emergy money ratio
Output	amount of target production output
P_{ij}	probability of choosing branch j for attribute i
Social $Impact_{EF}$	cost of public expectations and concern (gha)
Social $Impact_{emergy}$	cost of public expectations and concern (sej)
t	t-value of partial utility
Total Energy Flow	amount of solar energy input during lifecycle (sej)
Triple I	Inclusive Impact Index (gha)
Triple I_{social}	Triple I including social cost (gha)
Triple $I_{emergy\text{-}social}$	emergy including social cost (sej)
$Transformity_n$	amount of solar energy necessary for producing a unit amount of each product type n (sej/[each product unit])
V_{ijl}	observable utility for respondent l
VSL	value of statistical life
U_{ijl}	total utility for respondent l
x_1	attribute for calculating cost
x_{ijl}	attribute vector for choice branch j *chosen by respondednt l*
α	estimated partial utility value
β	β-value of partial utility
γ	factor to convert monetary values to EF (gha/(yen/yr))
ε_{ijl}	unobservable utility for respondent l

been traditionally used to represent national development, were insufficient for evaluating sustainability and that therefore new indices had to be developed. Elkington [2] and Willard [3] suggested that, when considering the sustainability of anthropogenic systems, the "triple bottom lines", which consist of environmental, economic, and social costs, should be taken into account.

Existing indices, such as the Inclusive Impact Index (Triple I) [4,5], which combines EF, as an environmental impact index, with monetary value, as an economic index, into a single parameter, and emergy, which is "the available energy of one form that is used up in transformations directly and indirectly to make a product or service" [6], evaluate sustainability from two perspectives only: environment and economics. To the authors' knowledge, there are no indices that take into account all the three bottom lines. It has been pointed out that taking the social cost into consideration in the evaluation of large-scale industrial projects is particularly difficult [7].

In general, the cost of social impact is often represented in terms of risk, the definition of which is the product of the occurrence probability and the magnitude of the potential loss. However, in cases where the loss is unexpectedly large, there is often a tangible discrepancy between the evaluated risk and people's concern, and there may be cases where the risk cannot be expressed as the product of the occurrence probability and the magnitude of the loss. There have been a lot of articles to criticise the probability risk assessment method and they are well described by van Asselt [8], for instance. After the Fukushima nuclear disaster in 2011, it is in Japan said that nuclear power is still cheap and comparative to fossil fuels in price, even after including all possible loss compensations.

Here is the motivation of this work: only economic and environmental evaluations may not be enough to tell people's expectations and concern. In the present study, we define the cost of social impact as expectations and concern of general people and attempt to quantify this parameter. In addition, we propose new indices that consider all aspects of the triple bottom line concept by combining the above-mentioned cost of social impact with environmental and economic evaluation based on indices such as Triple I and emergy. As a case study, we apply this newly-developed indices to the evaluation of power generation technologies in Japan and examine the effectiveness of the indices.

Specifically, we conduct a survey based on conjoint analysis to quantify the cost of public expectations and concern: the cost of social impact in terms of the public's attitude towards power generation technologies is converted into ecological footprint (EF). This value is then combined with the two original indices, Triple I and emergy, to calculate the effectiveness of the technologies under the assumption that major electricity companies introduce new power plants while keeping the electricity price fixed. In addition, we discuss evaluation of power generation technologies for independent power providers (IPP) who are free to change the price of electricity.

There have been numerous studies on public acceptance of electricity technology options. Rashad and Hammad [9] conducted comparative assessment of the environmental and health impacts of nuclear and other electricity-generation systems and claimed the advantage of nuclear power because of its high energy density and the fact that it is almost free of the air polluting gases. Wang et al. [10] conducted a questionnaire survey in four urban cities of China and identified the drivers and barriers to general public's acceptance of tiered electric price (TEP), using an ordinary regression model. Their results show that middle income earners are the groups that are mostly opposed to TEP and that public environmental awareness was highlighted during the implementation of TEP. Hensher et al. [11] focused on the quality and