Ecological Indicators 24 (2013) 240–245

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

EcoTime—An intuitive quantitative sustainability indicator utilizing a time metric

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ARTICLE INFO

Article history:
Received 29 December 2011
Received in revised form 18 June 2012
Accepted 24 June 2012

Keywords:
Sustainability
Indicators
Footprint
EcoTime
Time

ABSTRACT

Sustainability indicators strive to convey the impacts of human activities on natural resource utilization, yet many fail to express these impacts in a simple relatable manner. We introduce a new sustainability indicator, EcoTime, which recasts an environmental burden of a process or item (e.g., the emission of 10 kg CO_2 associated with a car trip) in time units (seconds, days, etc.). The EcoTime units represent the burden's share of a benchmark quota calculated according to location or context. For example, a developed country's average yearly CO_2 emissions of 11 ton per capita would translate to 365 EcoTime days in which case the 10 kg CO_2 mentioned above would equal ≈8 EcoTime hours. Since time units are commonly used the EcoTime indicator is easy to communicate to a varying audience alleviating challenges often associated with existing sustainability indicators. It leverages our innate ability to easily grasp contrasting time units over several orders of magnitude, ranging from seconds to years. Another key advantage of EcoTime is that its value shifts attention from the absolute environmental impact, which may not be meaningful to most people, to impact magnitude relative to world resource availability or usage, thus giving the burden an intuitive, intrinsic context. In addition, EcoTimes of different impact types can be conveniently and succinctly grouped as a vector (e.g., GHG emissions, water, or land footprints), or, because of the similar units, as a composite scalar. We provide several case study examples of the methodology.

1. Introduction

The efficacy of efforts to mitigate growing human demand for natural resources can increase significantly by novel methods for effectively and intuitively communicating consumption costs. While some of those efforts (e.g., carbon caps) are top-down, the bottom-up approach emphasizes individual voluntary choices, which collectively can have significant impacts. Incorporating sustainability considerations in individuals' decision making requires conveying to consumers the environmental impacts of products and services, through text, label, or qualitative indices (Gallastegui, 2002). Any delivery mechanism comprises of two stages. The first tallies the environmental burdens exerted by the evaluated process or item. In the second stage, the information is distilled into a representation that simultaneously retains the meaningful quantitative information gathered in the first stage and casts it in a format that can be readily understood by an average, scientifically uninitiated person. In this paper, we focus on the latter, recasting resource consumption estimates obtained by any methodology into a quantitative yet intuitive indicator.

Life Cycle Analysis (LCA) (ISO 14040; Baumann and Tillman, 2004) inclusively considers the production, active use, and end of life stages of a product, assembling the natural resource inventory utilized in the product's full life cycle, tracking and summing those burdens into an aggregate value. Parallel efforts at carbon footprint calculations (Weidmann and Minx, 2008) emphasize the overall greenhouse gas (GHG) emissions associated with a product or service. Efforts to expand the scope of footprint indicators have yielded the concept of ecological footprint (Wackernagel and Rees, 1996). The ecological footprint expresses humanity's environmental pressure in terms of required land resources relative to available land. The ecological footprint thus calculates impacts in units of area, namely global hectares (gha), a hypothetical hectare featuring global mean productivity. The ecological footprint had been mostly used for calculating national footprints but has also been applied for specific consumption items (Collins and Fairchild, 2007). A similar concept underlies water footprint estimates (Hoekstra, 2009), where costs, in liters or m^3, account for the full production and consumption life cycle. While some human activities, such as agriculture, lend themselves naturally to ecological footprint-like methodology, recasting other resources, such as GHG emissions, in terms of equivalent land resources is very challenging.

The indicators developed so far suffer from a common limitation in communicating the results to consumers. Costs of 1.2 kg

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1470-160X/$ – see front matter
http://dx.doi.org/10.1016/j.ecolind.2012.06.018

of carbon, 0.014 m^2 or 730 L of water are easy to dismiss with respect to the overall world resources; is 1.2 kg of carbon a lot or negligible? Dealing with very large or very small values is far from intuitive for most people. In addition, using unique units for each impact type creates another barrier in dissemination, further limiting these indicators' utility. Approaches such as the EcoIndicator (PRe consultants, 2000a), or the Swiss Scarcity Methodology (Frischknecht et al., 2006) try to address those issues by normalization to a standard resource usage or pollution. Monetary value as a composite indicator can overcome some of these difficulties, but entails other fundamental difficulties such as the issue of substitutability (weak and strong sustainability (Gutés, 1996)) as well as establishing the exact direct (market) and indirect (non-market) costs of services and goods (Costanza et al., 1997).

Because of the limitations of existing indicators, we set out to develop a metric that will have intuitive units, will be generic for different sectors, and will give a sense of intrinsically available world resources, a metric that conveys a clear sense of whether a given impact is small or large relative to available natural resource.

Used regularly by most, time is intuitively comprehended over >7 orders of magnitude (seconds to years). The obvious finality of time engenders an intuitive sense of the available resources, making time an appealing impact metric that rises above the aforementioned limitations of existing metrics. Indeed, time has been used as a proxy for resource depletion, well-being, or societal progress (Sicherl, 2007). For environmental health implications, DALY, Disability Adjusted Life Year, is a widespread indicator that uses time units to measure disease burden. Based on detailed information on the prevalence and timing of specific diseases, DALY is an estimate of years lost to illness or premature death (Gold et al., 2002).

In presenting the ecological footprint, Wackernagel and Rees (1996) used resource usage associated with reading a newspaper, or drinking a glass of orange juice, cast in time equivalents, as examples. Similarly, the idea of the overshoot day (Williams, 2006), the day within a year when humanity has consumed the available resources for that year, strives to convey the immediacy of resource depletion, forming a tractable and easily understood metric.

The ultimate aim of our approach is to devise a clear measure of the environmental consequences of products and services used daily. We set out to achieve this objective by converting current and future indicators' values into a metric based on a time basis, forming the EcoTime indicator. Below we explain the methodology, apply it to several case studies, and discuss EcoTime's strengths and limitations.

2. Results

2.1. EcoTime methodology

The methodology we suggest is based on transforming environmental burdens (e.g. resource consumption) to a time unit (EcoTime minutes, hours, days, etc.), which conveys the magnitude of consumption in relation to a benchmark quota (Fig. 1). The benchmark quota can be for example an estimate of the per capita sustainable renewable resource amount or a value representing a 'business-as-usual' scenario (see Appendix A).

The suggested metric, termed EcoTime, uses as input prior estimates of the environmental burdens incurred during production of a given product or service (Fig. 1, steps 1 and 2). The estimations can be the result of a detailed LCA or any other similar approach. Any specific methodology for these calculations has its limitations but our methodology focuses on a way to represent the output of such analysis agnostic of the discussion on the best way to perform the tallying of the natural costs. The resource consumption is compared to a benchmark quota (Fig. 1 step 3), which depicts either the resource's renewability or some other scenario, e.g. its per capita 'business-as-usual' consumption. The quota chosen is based on the target use of EcoTime: if for instance the quota chosen is a per capita average consumption of the resource, then the resulting EcoTime is the time cost compared to an average person's consumption; if the quota is the renewability of the resource, then the EcoTime is an effective time cost relating to the sustainable usage of that resource (Fig. 1 step 4).

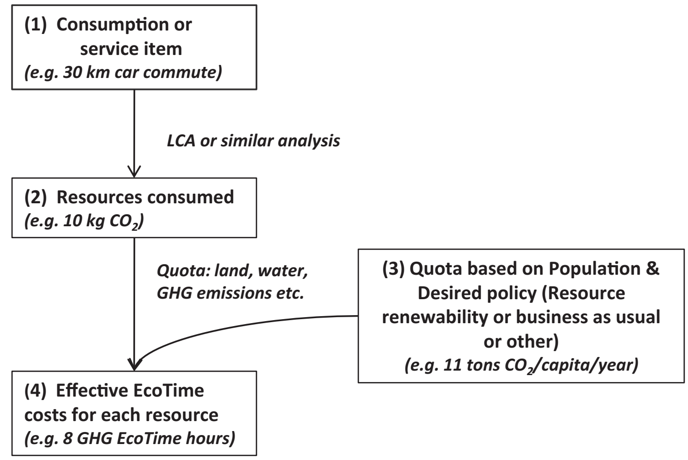

Fig. 1. EcoTime methodology flowchart: items used or activities (1) are analyzed in terms of the resources consumed (2) through life-cycle analysis or any other quantitative method and then compared to a renewable benchmark quota (3). Quotas are derived from resource renewability (renewable quota), or from alternative scenarios such as 'business-as-usual' or other policy. This results in an effective time cost for each resource (4), defined as the EcoTime of that item or activity in that resource. A numeric example using the characteristic GHG emission of a 30 km car commute and 'business-as-usual' developed country per capita GHG emission quota is given in parenthesis.

As a simplified illustrative example consider a 30 km car commute to work. For a moderate car efficiency scenario this incurs a carbon footprint of about 10 kg CO_2 (Fig. 1, step 2) (Lenzen, 1999). Assuming a 'business-as-usual', developed world average emission of 11 ton per capita per year (Fig. 1, step 3) this is equal to about one thousandth of the yearly quota. With 8800 h per year this will be represented in the EcoTime methodology as 8 GHG emissions EcoTime hours (Fig. 1, step 4). In this example the costs of car production and similar indirect aspects are also included (Lenzen, 1999). The value in terms of time gives a concrete evaluation on the intensity of this activity in the personal fraction of natural resources utilization. In other words, the EcoTime units of time intrinsically contain a reference/benchmark that enables assessing the magnitude of impact in a specified context. This solves the problem that to many people the environmental impact in absolute values of kg CO_2 or squared meters are tough to put in the context of the available world resources.

Table 1 presents the carbon footprint of three representative activities: daily use of a computer, a 30 km car drive, and a one way flight from NY to London. For each activity we use a previously estimated value for its carbon footprint (see Appendix B section 1) and we calculate their associated EcoTime based on an 11 ton/year/per-capita quota ('business-as-usual'). Using a laptop for 10 h incurs a GHG emission of 0.11 kg, which for a 'business-as-usual' quota of 11 ton per year per capita represents a fraction of $0.11/11000 = 1 \times 10^{-5}$ of a year, or about 5 min. A one way trip from London to New York has an EcoTime value of 1.5 months, a high impact activity (Lenzen, 1999). The exact impact of a flight depends on many conditions such as type of aircraft used, number of passengers or what type of climatic forcings are effectively taken into account (Chester and Horvath, 2009) (see also Appendix