WORLD RESOURCES FORUM

Development of a Resource Efficiency Index of Nations

Illustrative calculations
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Development of a Resource Efficiency Index of Nations

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1 Introduction

The World Resources Forum (WRF) is the science-based platform for sharing knowledge about the economic, political, social and environmental implications of the extraction, use and management of natural resources. Its main activities are the annual flagship World Resources Forum conference, which is held every 2 years in Davos, Switzerland, and every 2 years in another part of the World.

The WRF secretariat is interested in the development of an integrated 'resource use' or 'resource-efficiency' index of nations, as a counterpart of the well-known Gross Domestic Product (GDP) that measures economic activity of nations. The WRF secretariat has granted the Institute of Environmental Sciences (CML) of Leiden University, the Netherlands, a budget for a small pilot project that should result in a discussion paper (and if possible some quantitative examples) of how such an integrated indicator could be formulated. This document was delivered in mid-2015 and presented during conferences of the International Society of Industrial Ecology in July 2015 in Surrey, and the World Resources Forum in October 2015 in Davos.

The pilot project also resulted in some illustrative calculations of resource indices. Lauran van Oers performed most of the calculations, whereas Arnold Tukker wrote most of this text. This document presents these results.

2 Calculation method

2.1 Introduction

The pilot project found that there are many ways to define resource categories, there are many ways to aggregate resources within categories, and there are many ways to aggregate (or weight) between resource categories. There is hence most probably no value-free or fully science-based approach to create an aggregated resource-use or resource-efficiency index of nations. Summarizing the situation:

a) Data inventory methods: **reasonable to high consensus**. MR EE IO and co-efficient methods are now quite widely used to make inventories of territorial and consumption based accounts for water, materials, land use and carbon. For pragmatic reasons, it is suggested that WRF for now will use one of the existing, major so-called MR EE IO research databases in which economic and resource extraction data are stored at global level.

b) Choice of resource categories and definition of resources: in the pilot project Carbon, Water, Land and Materials were pragmatically chosen as potential resources to be taken into account, but **more consensus is needed** on this choice. Particularly the inclusion of the Carbon footprint is questionable, being an impact indicator rather than a resource related indicator. Environmental relevance would be an argument in favour of integrating this indicator. Such a choice would implicitly lead to a broad definition of natural resources that considers climate stability as a resource.

c) Aggregation methods within resource categories:
   1. Carbon: **high consensus** on the aggregation method (GWP); but **low consensus** if a carbon footprint should be included in a resource use index of nations (see above).
   2. Water: **moderate consensus**. Simply adding up water use in m^3 irrespective of the region where it is used, as done by the Water footprint network, is not ideal since it neglects region-specific scarcity issues. The Water extraction index and its elaboration by Pfister et al. (2009), the Water stress index, is a watershed specific measure for the use of water from river and aquifers and seems the best candidate for a resource use index for water (see assessment conducted in Frischknecht et al. (2013) and application in Frischknecht et al. (2014) for Switzerland).
   3. Land: **moderate consensus**. Accounting for land use occupation in m^2 is hardly controversial (level 1 mentioned above), but if one wants to include some form of impacts of land use occupation things get different. First, there is a difference between land use occupation and land use change. Further, there are approaches that take into account the productivity of the land occupied (e.g. the ecological footprint method), but also approaches that assess according to the impact on e.g. biodiversity (see e.g. de Baan et al. (2012) for theoretical considerations and Frischknecht et al. (2014) for an application for Switzerland).
   4. Materials: **low consensus**. Like for land use, adding up materials by weight (level 1 above) as is commonplace in the MFA community is a rather simple exercise. But it has severe drawbacks, since neither scarcity nor the impacts related to materials is taken into account.

d) Weighting/aggregating across resource categories: **low consensus**. Some panel weighting methods have been developed, based on different approaches.

e) Economic reference indicator: **reasonable to high consensus**. GDP, with all its drawbacks, is the default economic reference indicator to be used. From the Beyond

GDP debate fairly well accepted indicators arose like the Human Development Index and the number of Happy Life Years.

2.2 Calculation of the carbon, water, land and materials footprint

The illustrative calculations had an ambition exactly as the words say: to give an **illustration** of what an integrated resource index of nations would look like and can be presented. It is absolutely not the aim to present a formal ranking based on a tried and tested methodology. So all findings presented have to be seen against this background, and be seen merely as an example of possible presentations of results once a tried and tested methodology is available.

The calculations had to be done in a day or so, and therefore we took some important shortcuts. This led to the following approach (see also the explanation in Box 2.1 of the production- versus consumption based or 'footprint' approach and how footprints are calculated with a MR EE IO such as EXIOBASE):

a) Data inventory methods: we used pragmatically EXIOBASE, a Multi-regional input output database that contains data for 43 countries and 5 rest of continents, as a basis. This database was readily available for us, CML being one of the main developers of it in the EU FP7 projects CREEA and DESIRE.
b) Choice of resource categories and definition of resources. We pragmatically used the carbon, water, land and material footprint as the 4 main resources to be covered. This was because the team had for the 43 countries and 5 other global regions for these indicators the footprints already calculated in the context of the booklet 'The Global Resource Footprint of Nations' (Tukker et al., 2014).
c) Aggregation methods within resource categories again were pragmatically based on what had been calculated already by Tukker et al. (2014):
    1. Carbon: the indicator used is GWP.
    2. Water: the indicator used is m^3 blue water extraction (despite, as said, neglects region-specific scarcity issues).
    3. Land: the indicator used is land use occupation in m^2 (despite, as said, this neglects the quality of land used)
    4. Materials: the indicator used is ton materials extraction (despite, as said, this takes neither scarcity nor the impacts related to materials into account).
d) Weighting/aggregating across resource categories: we used some readily available weighting sets, to be discussed in the next section.

The economic reference indicator was not used – we simply aggregated hence the resource footprints as such, and did not compare this with socio-economic performance of a country.

2.3 Weighting the carbon, water, land and materials footprint

For weighting the carbon, water, land and materials footprint, the following approaches were used.

First, next to the absolute footprints per country in ton CO_2 equivalent, m^3 blue water use, km^2 land use, and ton materials use, the footprints were normalized on the basis of the total global carbon, blue water, land and material footprints as available in EXIOBASE. These normalized footprints indicate for which percentage each country contributes to the global footprint. This is a dimensionless number, which allows for multiplication with weighting factors.

Box 2.1: Production versus consumption-based assessments

An Input-Output table shows a country's total economy, usually divided in a few dozen industry and service sectors. For each economic sector the IOT shows how much produce a specific sector buys from other economic sectors, and how much output the specific sector sells to each of the other sectors, expressed in monetary value (e.g. Euro), The table hence shows e.g. deliveries of the glass, steel and plastic production sectors to the automotive sectors, and also the output of the automotive sector, used by other industries and households. By doing this for all countries in the world, and adding trade information, a global Multi-regional IOT is formed. For each economic sector in each country, further so-called extensions are added: the emissions, the direct resource extraction, the direct water extraction, the land use, and so on. Figure B2.1 gives a hypothetical MR EE IO for three countries, with the country IOTs in red, final consumption per country in orange, trade in pink, and extensions in dark green.

The extensions (the dark green block, i.e. emissions, land use and resource use) are at this point per *sector* and per *country*: in total this is the total pollution and resource extraction within the boundaries of this country, or the so-called **territorial/production based emissions**. However, it is well possible that region a) in figure B2.1 produces a lot of material goods like electronics, exports this to region c) for final consumption, while region c) exports services to region a). In that case, The result is that the *consumption in country c)* leads to a lot of *emissions and resource extraction in country a)*. But since we have now an input-output matrix that gives all economic transactions in this 3 country world, it is possible for each final consumption category in country a), b) or c) – say 1 Mio Euro of bread - to track back which sector in which country contributed how much added value to this 1 Mio Euro of bread (e.g. say 300.000 Euro by the retail sector, 200.000 Euro by the bakery sector, 200.000 Euro by the wheat production sector/farmers, next to all kind of smaller contributions of e.g. the electricity production sector and the fertilizer sector). But since the MR EE IOT gives also for each sector in each country the emissions and total turnover, it is possible to calculate per sector the emissions per unit turnover. This together allows to estimate how the emissions and resource uses per sector and country (the production based approach) can be re-distributed over the final consumption categories in the different countries (which is the consumption based approach).

Mathematically, this approach was first proposed by Leontief, who later won the Noble prize for this work. Using this now well-known standard calculation approach based on the so-called Leontief inverse, a MR EE IO allows calculation of the emissions and primary resource extraction related to a final demand by category per country as follows (c.f. Miller and Blair, 2009):

$$\mathbf{x}^E = \mathbf{Dx} = \mathbf{D}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{f}$$

Where f = final demand, A is the matrix of direct input co-efficients, D is the matrix of direct impact coefficients, and x^E is the total requirement of environmental factors.

Figure B2.1: An MR EE IO for three countries

Second, different weighting sets were applied, using mainly 'off the shelf' information and methods. It concerns:

1. 'All equal'. This weighting set assumes that the environmental problems caused by carbon, water, land and materials are equally important.
2. 'Distance to target'. Here, first targets for the maximum desirable carbon, water, land and materials footprints were identified. These are compared with the actual carbon emissions and water, land and materials use. A footprint that overshoots its target highly (e.g. a factor of 2), gets a high weight (in this case, a weight of 2)[1].
3. 'Panels'. In the past, expert panel studies have been done that allocated weights to categories like carbon emissions, water use, land use and materials use. We averaged the outcome of these studies and used the averages as weights.
4. 'Damage costs'. There have been studies that expressed the damage costs or shadow prices of a kg of CO_2 emission, m^3 water extraction, m^2 land use and ton material extraction in Euro. We pragmatically used a fairly comprehensive handbook written for the Dutch government on this as a basis.

Weighting methods 1-3 have to be applied to the normalized carbon, water, land and materials footprint. Weighting method 4 prices the absolute levels of carbon emissions and water, land and materials use, and hence has to be applied on the non-normalised footprints. Box 2.1 gives backgrounds to the weighting methods 2-4.

Box 2.1: Backgrounds behind calculated weighting factors

Distance to Target

The 2007 average footprint per capita was taken from Tukker et al. (2014). The target per capita in 2050 was calculated using an expected future population between some 9-10 billion (Gerland et al., 2014). For **carbon**, the UNEP Emissions Gap report states to stay within the 2 ^oC limit greenhouse gas emissions should be in an 18-25 Gt CO_2-eq range by 2050 (UNEP, 2014), leading to a 2 ton per cap target in 2050. For **blue water**, the recent planetary boundary paper of Steffen et al. (2015) suggests an availability of 4000-6000 billion m^3 at global level, or some 500 m^3 per capita by 2050. For **land use**, it is assumed there is no or hardly potential to expand this without major biodiversity consequences (van Vuuren and Faber, 2009; UNEP, 2014). The current land use of around 88 Mio km^2 has to be shared by more people in 2050, we use there 0.01 km^2/cap as maximum. For materials use, recently Bringezu (2015) suggested mainly on the basis of historical extraction levels (hence not damage levels) a goal of 5 ton per person for raw material consumption.

Data per capita to calculate DtT weighting factors	**GWP**	**Material extraction**	**Water Consumption Blue - Total**	**Land use**
	ton CO_2 eq/cap	ton/cap	m^3/cap	km^2/cap
Impact world now	5.72	9.89	250.15	0.013
Target world 2050	2	5	500	0.010
(Impact world now)/(Target world year 2050)	2.86	1.98	0.50	1.33
In % of total	**42.9%**	**29.7%**	**7.5%**	**19.9%**

Panels

[1] Note that this in principle gives not yet a full weighting. Implicitly it is assumed, that overshooting the target for e.g. water with a factor 2, is equally bad as overshooting the target for e.g. climate with a factor of 2.

Huppes and van Oers (2011a and 2011b) reviewed weighting methods, including a number of panel reports. Three panel weighting sets are given in the table below, and simply averaged by adding numbers up and dividing them by 3.

	GWP	**Material extraction**	**Water Consumption Blue - Total**	**Land use**
EPA Science Advisory Board	16	5	3	16
BEES Stakeholder Panel	29	10	8	6
NOGEPA extended	25	6	4	8
Total	70	21	15	30
Average	23	7	5	10
In % of total	**51%**	**15%**	**11%**	**22%**

Shadow prices

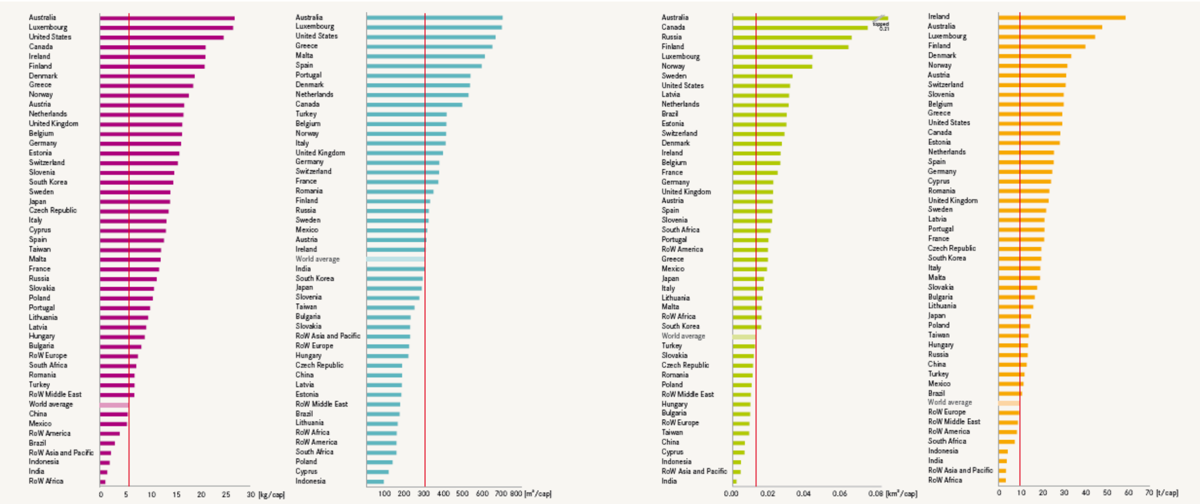
Finally, de Bruyn et al. (2010) developed a handbook with shadow prices for Dutch government. This gives then the following shadow prices or damage costs for carbon, water, land and materials. Note that materials are assumed to have no shadow prices, assuming that scarcity and damage costs are already included in the prices to be paid for materials.

	euro/kg CO_2 eq	euro/kg resource eq	euro/m^3 blue water	euro/m^2.annum
shadow prices (original units)	0.025	0	1	0.094

3 Results

We first present the footprints per capita that were the basis for the calculations in Figure 3.1. This figure has been directly copied from Tukker et al. (2014). EXIOBASE contains 43 countries specifically next to and 5 Rest of Continents – chosen on the basis of the contribution of GDP of the world. The countries specifically shown represent about 90-95% of the global economy.

Figure 3.1: Carbon, water, land and materials footprint per capita per country



But as indicated before, most weighting methods use normalized carbon, water, land and material footprint scores, i.e. expressed in fractions of the global total carbon, water, land and material pressures. For equal, panel and DtT weighting we hence use the dimensionless normalized total carbon, water, land and material footprint per country as a starting point for weighting, and the total global normalized carbon, water, land and material footprint being 1. These were multiplied with the weighting sets in Table 3.1 – all weighting factors together being 100%, resulting in a dimensionless ‘Integrated use index’ per country, with again adds up to 1 for the world.

For external costs, the real total carbon, water, material and land footprint per country were taken, and multiplied with the shadow prices presented in Table 3.1. By this, we also could calculate the total shadow price for all carbon emissions, materials use, water use and land use in the world, and then of course calculate which fraction each country would contribute to the total shadow price in the world. This, again, results in a dimensionless ‘Integrated use index’ per country, with again adds up to 1 for the world.

Finally we could calculate which % carbon, materials, water, and land contribute to the total global shadow price/damage costs, also presented in table 3.1. Interestingly, we see that the weighting implies by the shadow costs we took from literature, gives a very high emphasis on land use, neglects materials, and does not emphasize carbon or water.

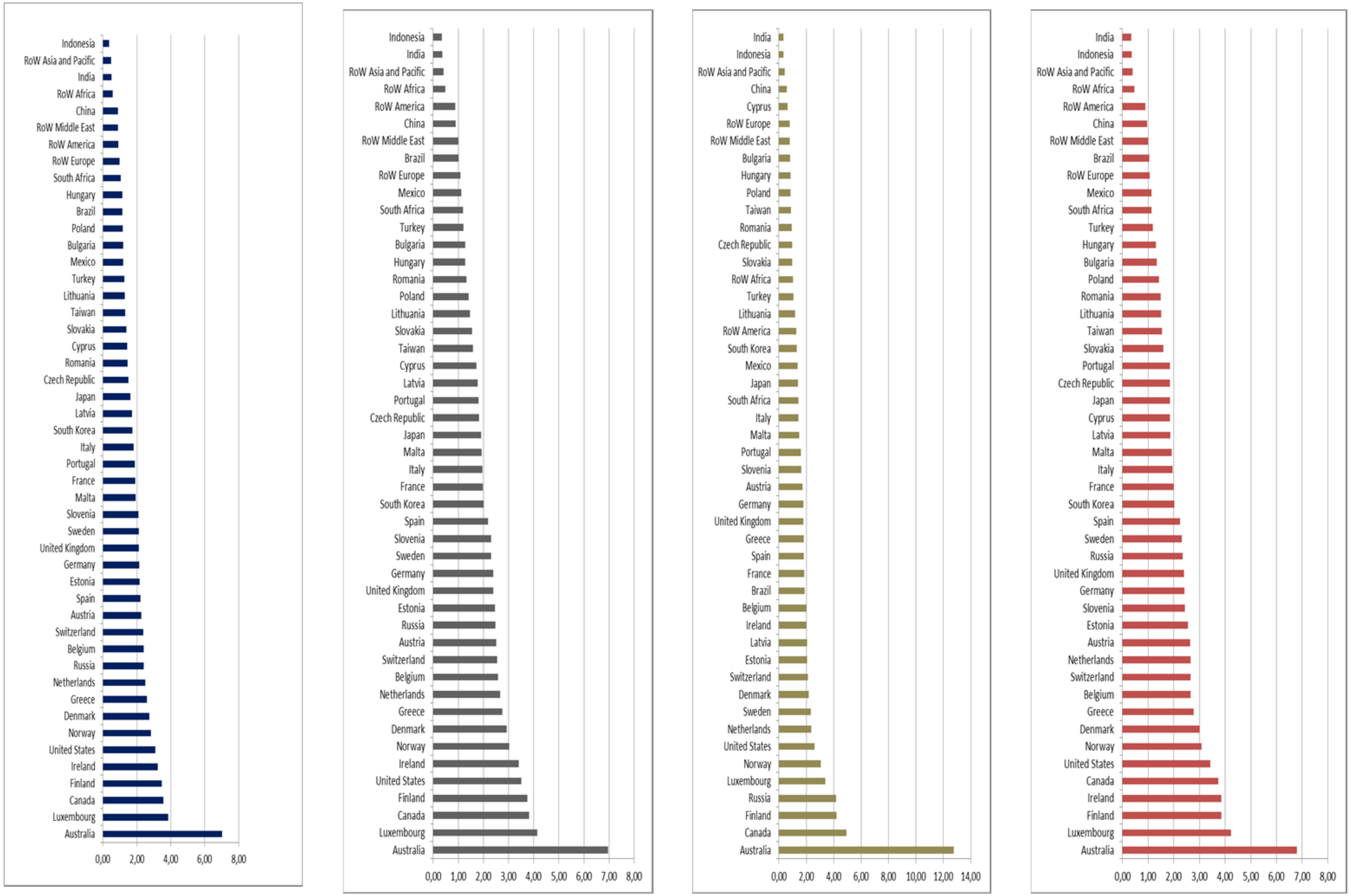
Table 3.1: Weighting factors used

	Carbon	**Materials**	**Water**	**Land**
Equal weight	25%	25%	25%	25%
Weighted panels	51%	16%	11%	22%
DtT	42.9%	29.7%	7.5%	19.9%
Shadow prices	25 Euro/ton CO_2-eq.	0 Euro/ton	1 Euro/m^3	940 Euro/ha
Shadow prices (total)	8.7%	0.0%	15.3%	76.0%

At this point we have for each country a resource index, calculated via equal weighting, panels, DtT and shadow costs, that expresses the contribution of that country as a % of a dimensionless 'integrated global resource pressure' that is set at 100% for the world.

We now simply can compare the contribution of a country to the integrated resource pressure of the world with its share of the population of the world – a country which has an equal share in problems and population then simply scores 1 (its citizens contribute on average to the global resource problem). For each country in our database, figure 3.2 now gives this index. It is clear that, like for the individual footprints, rich countries can create per capita resource pressures which are factors higher as of the global average citizen. Also, the top and lowest scoring countries are surprisingly similar across the different weighting methods, despite the crude approach of this exercise. It is likely that the weighting method used to combine the carbon, materials, land and water footprint may be less relevant for the outcome as the rather simple approaches to calculate the materials, land and water footprints themselves, all based on simply adding tons of materials, ha of land, and m^3 of water, without taking into account impact of the materials, quality of the land, or scarcity of water in the region where it is extracted.

Figure 3.2: Resource index of nations – weighted resource pressures by country as % of global total compared with share as % of the global population of that country. The population in a country scoring 1 would have an average contribution per person to weighted resource pressures. Weighting methods used from left to right: all equal, panels, shadow costs, distance to target



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