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LIFE CYCLE SUSTAINABILITY ASSESSMENT

Maximizing affluence within the planetary boundaries

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Abstract
Purpose Ordinary product LCA studies focus on measuring or minimizing environmental impact, but do not address if the product fits in a sustainable consumption pattern. This paper proposes a setup in which the planetary boundaries define the maximum impact, and the minimum requirements for a reasonable consumption level specify a lower impact level. Thus, a "safe operating space" remains.
Methods We use an IO table for EU-27 and the consumption pattern of the Bulgarian population extrapolated to the EU level as driving climate impact. The EU's policy targets are used as a planetary boundary for climate change.
Results The 2020 target is shown to be able to accommodate the Bulgarian-style consumption, with room for a much higher GDP. The 2050 target, however, is too narrow, and a slightly smaller consumption pattern is needed to reach the target.
Conclusions Although the approach is highly simplified and neglects many developments, the idea of using IO-tables and minimum consumption levels to backcast directions to be taken is expected to help policymakers. We acknowledge some important limitations of our approach, but accept these in the context of exploring future scenarios and how to get there, instead of predicting the future.

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1 Introduction

In environmental science, one can see two groups at work, one group studying the "cause", including the environmental burden of individual products (Rebitzer et al. 2004) and consumption on a societal level (Tukker and Jansen, 2006), and another group studying the "effect", including environmental mechanisms (Stoddard et al. 1999) and threshold values (Rockström et al. 2009). Although members of both groups frequently place their work in the context of sustainable development, the hallmark of this concept is that it covers both sides in a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission On Environment and Development, 1987). Sustaining the future productivity of the earth requires that the environmental pressure by anthropogenic activities does not exceed critical limits. Man should not simply minimize environmental impacts, but make sure they stay within the planetary boundaries, properly defined. Previous research (Rockström et al. 2009) suggests that for some impact types there is a large overshoot, while for other impact types the earth can handle more, and the planetary boundaries have not yet been reached.

This has important implications for mankind in a situation that the UN targets at eradicating extreme poverty and hunger (http://www.un.org/millenniumgoals/). The dilemma at face is that of sustainable development, in which affluence is supposed to be increased while the planetary boundaries must be respected to ensure affluence of future generations (World Commission On Environment and Development, 1987). A natural question is thus: can we imagine a "good life" (Costanza et al. 2007) that fits within the "planetary boundaries" (Rockström et al. 2009)?

2 Methods and data

The environmental pillar of sustainability can thus be translated in an absolute reference, based on planetary boundaries. As a consequence, it is not possible to decide on the environmental sustainability of isolated activities, products, or communities (Adhitya et al. 2011). While several society-wide analyses of consumption patterns have been carried out on the basis of environmentally extended input–output analyses (EIOA) (Tukker et al. 2010), such analyses typically do not address the planetary boundaries, and therefore cannot be considered as addressing the sustainability threshold of consumption.

For exploring ways to develop sustainable life styles, the following three modifications are needed on top of today's EIOA practice:

- First, we should introduce the planetary boundaries in the usual impact systems, such as carbon footprints (British Standards 2011), not measuring CO_2-equivalents as such, but always in relation to a critical value or target. With this modification upon the usual "sustainability analyses", it is possible to study if consumption patterns or scenarios of consumption fit within the limits of environmental sustainability.
- A second modification derives from the fact that certain categories of consumption are essential to sustaining human life. We must eat and drink, and in many places of the world, we need to dress ourselves, as well as we need housing and heating. Moreover, on top of the basic essentials for living, man enjoys a higher quality of life. We appreciate nice food, good wines, music, travel, and much more. Not all of this is required for a good life, but undoubtedly a good life is more than eating nutrients and drinking water. In allowing for "surplus consumption", we deviate from studies that address the ultimate carrying capacity of the earth (Franck et al. 2011).
- As a third modification, we change the usual "forward" analysis from consumption to impact into a "backward" analysis from impact to consumption. Thus, we introduce a backcasting approach (Holmberg, 1998) on top of a technology specification and the planetary boundaries, and try to find out which consumption patterns fit within these boundaries. This has conceptually been introduced in life cycle sustainability analysis (LCSA) by Guinée et al. (2011), but as far as we know it has never been put into practice.

The backcasting approach presented here combines three key elements. Planetary boundaries that define the maximum impact for a sustainable environment and the minimum levels of consumption that define a sustainable living standard are combined with a third element: the technological characteristics of the impacts of production and consumption, derived from an environmental input–output table (Duchin, 1992).

Our approach falls into the realm of backcasting LCA (BLCA; see Guinée and Heijungs (2011)), which we define as exploring ways—in a life cycle perspective—to meet normatively defined sustainability levels (planetary boundaries) through adapted affluence (as consumption levels), population growth, and/or technologies. This paper should be seen as a seminal contribution that addresses only the affluence.

The three elements mentioned above define a feasible region that is the solution space (a subset of the "safe operating space"; Rockström et al. 2009) of a sustainable society. All consumption patterns that fall in this space satisfy the minimum from a sustainable consumption point of view and the maximum from a sustainable environment point of view. As such, they define a sustainable living: meeting the needs of the present without compromising the demands of the future.

There are three options for this solution space: it can be empty (meaning that all minimum consumption patterns exceed the planetary boundaries), it can have a unique solution (meaning that precisely one consumption pattern fits within the planetary boundaries), or it can have several or a continuum of solutions (meaning that there is a choice). Situation 1 is bad, situation 2 is better, but situation 3 would be really great, as it implies that mankind can reshape its economic system into a sustainable direction.

We carried out the analysis described, with the EU-27 as study region.

Data on production and consumption were obtained from the supply-use table of the European Union for 2007 (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes), converted into a product-by-product input–output table. This table specifies the structure of the economy in terms of 59 product groups.

Environmental input–output tables contain emissions of pollutants by sector, assuming linear technologies, hence assuming that increasing or decreasing production levels will increase or decrease emissions proportionally. The analysis was restricted to three major greenhouse gas emissions: CO_2, CH_4, and N_2O. They were aggregated into CO_2-equivalents by means of the global warming potentials for 100 years (Solomon et al. 2007).

Another important source of greenhouse gas emissions is by direct consumption, mainly through the use of gas, petrol, and other fuels. These are more difficult to include in the model framework, as they should be connected to the consumption levels of specific product groups. In our model, we have introduced the simplification to keep the direct emissions by final users constant at the EU-wide level.

The maximum sustainable CO_2-equivalent impact was derived from the policy targets of the EU (UNFCCC, 2008). Two values are stated here: a 20 % reduction by 2020 and an 80 % reduction by 2050, compared to the 1990 value of 5,564 million tons. It should be observed that we use a policy target as if it were a planetary boundary. This is admittedly questionable. We do so because the policy target is more relevant for defining environmental policy, and is moreover sharply defined, in fact for the entire EU-27. There is much more disagreement on the true value of an ecologically inspired target value.

Minimum consumption levels have been based on the country in the EU with the lowest standard of living in 2007: Bulgaria. Consumption levels are the sum of those by households, by nonprofit organizations serving households, and by government. The ratio between the EU population (495,291,925) and the Bulgarian population (7,679,290) is used to upscale these minimum levels EU-wide; the scale factor is thus 64.5 (UNFCCC, 2008).

In an environmentally extended input–output model, consumption drives intermediate production, which in turns causes pollution. Our goal was to maximize affluence (U) with two types of constraints: the society-wide greenhouse gas emissions (b) should not exceed the planetary boundary (b_{max}), and the consumption level for each product group ($\mathbf{f}_{cons}$) should be at least as large as the subsistence minimum ($\mathbf{f}_{min}$). We tried to achieve this by choosing optimal production levels ($\mathbf{x}$) for each product group. Table 1 summarizes the model's variables; the mechanism of the model is illustrated for a two-product economy in Fig. 1. Affluence was defined as the GDP the economy generates. The mathematical form of the full model is displayed in Fig. 2. We applied a linear programming (LP) simplex algorithm (Dorfman et al. 1958) to explore the solution space.

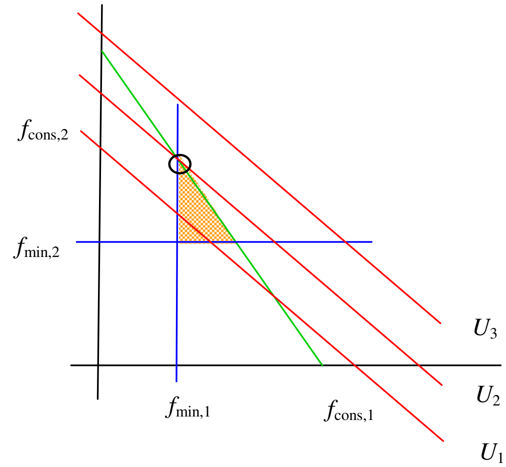

Fig. 1 Illustration of the model for a situation of a two-product economy. The *horizontal* and *vertical axes* specify consumption levels $f_{cons,1}$ and $f_{cons,2}$. The *blue lines* at $f_{cons,1}=f_{min,1}$ and $f_{cons,2}=f_{min,2}$ define minimum consumption levels. The *green line* defines the maximum consumption levels that just fit into the maximum impact level b_{max}. The *orange triangle* specifies the feasible consumption levels that satisfy all constraints. The *red lines* indicate consumption patterns of equal utility; $U_3>U_2>U_1$. The *small circle* indicates the point in the feasible region where U is maximal

3 Results

The EU's greenhouse gas target for 2020 is 4.5 billion ton CO_2-eq. The LP-model is solvable and yields a consumption patter that is for every product the group the minimum amount, except for "Activities of households as employers of domestic staff", for which the supply can go up till 430 trillion euro. Total attainable affluence in this situation was completely dominated by this product group, so the EU's GDP becomes 430 trillion euro. It is a typical feature of all LP-models that the optimum solution is in one of the "corners" of the solution space (Dorfman et al. 1958).

The target for 2050 is 1.1 billion ton CO_2-eq. Using this constraint, the LP-model is unsolvable. That is, the feasible region has size zero. However, with a slightly less strict target, approximately 28 % of the 1990 level, there is a small feasible region. The GDP is in that case equal to 1.4 trillion euro.

Figure 3 illustrates the results for the climate targets of 2020 and 2050.

Table 1 Overview of the symbols and their meaning in the model

Symbol	Quantity	Unit
$\mathbf{x}$	Production level by product group	million euro
U	Aggregated affluence (GDP)	million euro
$\mathbf{f}_{cons}$	Final consumption by product group	million euro
$\mathbf{f}_{min}$	Minimum consumption by product group	million euro
$\mathbf{A}$	Intermediate input matrix in coefficient form	million euro/million euro
$\mathbf{b}^t$	Greenhouse gas emission by product group in coefficient form	ton CO_2-eq/million euro
b_{max}	Maximum greenhouse gas emission	ton CO2-eq
b_{cons}	Direct greenhouse gas emission by consuming products	ton CO2-eq

Maximize

$$U = \sum_{i=1}^{59} x_i$$

subject to

$$\mathbf{Ax} + \mathbf{f}_{\mathrm{cons}} \geq \mathbf{f}_{\mathrm{min}}$$

and

$$\mathbf{b}^{\mathrm{t}}\boldsymbol{x} + b_{\mathrm{cons}} \leq b_{\mathrm{max}}$$

Fig. 2 Specification of the linear programming problem. See Table 1 for an explanation of the symbols

The EU-27's GDP in 2007 was about 12.4 trillion euro (UNFCCC 2008). Our simplified model suggests that the 2020 target is feasible with a much bigger economy, provided consumption patterns are changed. The 2050 target is, however, not possible, and a weaker target can only be reached with a much smaller economy (http://esa.un.org/unpd/wpp/index.htm).

4 Discussion

We immediately point out that the model does not pretend to prescribe or predict how the EU's economy should or will develop if a policy of sustainable development is implemented. Rather, we consider our study as an exercise in exploring the consequences and possibilities of pursuing a "good life" within the planetary boundaries, with an emphasis on the explorative character of the investigation. Our model is restricted in several important ways.

The model deals only with greenhouse gases. This has the advantage that we can restrict the model to a single-objective function. Multi-objective optimization is a trivial extension, but less easy to visualize. So, a main argument in favor of this simplification is the illustrative nature of our approach. Moreover, we believe that the situation for the other types of impact is not worse, because global warming targets are often regarded as the most difficult ones to meet (Wheeler 2008).

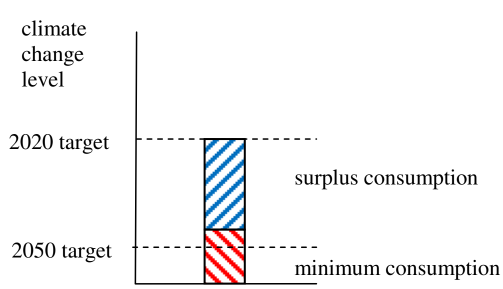

Fig. 3 Results of the simulations. Under the assumptions made, the minimum consumption does not fit within the climate target for 2050, but allows for a substantial surplus consumption within the climate target for 2020

A more serious limitation is that our model assumes a static population and technology. It is projected that the EU's population will decrease the next few decades (http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/themes). This would mean that an even better life pattern might fit within the defined greenhouse gas target. This tendency is reinforced by the hope that dematerialization (Schmidt-Bleek 2008), eco-innovation (Fussler and James 1996), and eco-efficiency (Huppes and Mansanobu 2007) will allow for a greater degree of welfare within the defined boundaries. On the other hand, economic growth in general leads to higher consumption levels, and efficiency gains may lead to paradoxical increases of pollution due to behavioral mechanisms. In our static and linearized production and consumption model, such phenomena have not been modeled. The structural matrices of the IO-model represent a highly idealized model. As a result, we do not believe in the results in terms of black-white demarcation. We, however, think that the overall message is more or less valid: the Bulgarian pattern will fit in the 2020 targets and even has room for extra welfare, while the 2050 target will be more of a problem.

A crucial element in our model is the definition of the welfare function *U*. Here, we have defined it as the total GDP that is generated by the economy, which is equivalent to the sum of the production volumes of every sector. Because an LP-algorithm, whenever it finds a solution, always finds a corner-solution, we will come up with a consumption pattern with all product levels at the minimum, and only one at a higher level. This is obviously a service-type one, a product which has the lowest impact per unit of GDP created. The most-debatable assumption is that all surplus operating space would be devoted to the most eco-efficient extra activities. Instead, it is much more likely that the surplus will be used for a mix of different activities: some more holidays, some more mobility, some more luxury food, etc. We have not taken the effort to model such more sophisticated welfare-optimizing behavior, also because our purpose is merely to find out if there is anyhow room for surplus welfare. Our findings suggest this is the case for 2020, but not for 2050. Our extreme way of producing additional welfare in the operating space that is left over would generate quite some extra GDP. Again, this is only an exploration of an extreme scenario, not a prediction of the course of development.

Altogether, as a result of these limitations, we do not suggest that our findings are in any sense precise predictions. They should merely be seen as explorations of a tendency of our current economic system, extrapolated in a linear and static way. We consider them as setting an agenda on moving sustainability analyses further, by including minimum consumption levels and maximum impact levels, and by tying up with the principle of backcasting.

Referring to the IPAT equation (Ehrlich and Holdren 1971), we have only adapted A (affluence) while keeping P (population) and T (technology) constant. Above, we already discussed the possible decline of A and T. Thus, there seems to be reason for some optimism, allowing for a higher A in 2020 and for an A that fits in the 2050 target. Our explorations can serve to stimulate two lines of development: more realistic models that cover more mechanisms (Guinée et al. 2011), and a fundamental debate on the trade-offs in the environmental, economic, and human dimensions of sustainability.

5 Conclusions

We have shown that a simplified model suggests that a reasonably good life is almost possible, although with an affluence much smaller than the richer countries have nowadays. This conclusion is based on an environmentally extended input–output model for the EU-27, with the poorest (i.e., Bulgarian) consumption pattern extrapolated to the EU-27, and the environment restricted to greenhouse gases, the EU target for 2050 serving as a planetary boundary.

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