Restore: An R of Sustainability that Can Tame the "Conundrum"

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Abstract: The environmental benefits of sustainability efforts can be rendered less effective due to economic feedback mechanisms. As a remedy against such rebound effects, a reinvestment strategy towards environmental causes has been suggested. Here, a practical implementation of such a reinvestment strategy is presented. It involves a) estimating the financial savings resulting from sustainability efforts, b) informing the participants that the environmental benefit of the efforts is reduced by economic feedback mechanisms and c) asking them to donate a fraction of the expected savings towards environmental causes. An easy-to-use methodology for estimating rebound effects of sustainability efforts is presented in order to quantify the efficacy of this approach. CO_2 emission offsets are used as an example of donations towards environmental causes. It is shown, that donating even a small amount (less than 1% of financial savings obtained from conservation or engineering savings) of donated carbon offsets can more than eliminate the estimated rebound effects. This then leads to the restore principle, that states that the environmental benefit of reducing activities with average environmental impact is dramatically improved if a fraction of the resulting financial savings is applied towards environmental causes. This approach is made practical by augmenting the common reduce, reuse, recycle motto with a fourth component: reduce, reuse, recycle and restore.

Keywords: Rebound; Donation; Voluntary Efforts; Carbon Offset; Restore

1. Introduction

"Reduce, reuse, recycle" is a commonly used motto that describes sustainability efforts that individuals, households and organizations are expected to perform. Such efforts are geared to either use less resources (conservation, sufficiency) or use resources more efficiently. In both cases, it is possible that participants experience financial savings as a result of implemented sustainability efforts. While this is it at first sight fortuitous (financial savings can be an excellent motivator for implementing sustainability efforts and has socioeconomic benefits[1]), it leads to the possibility that participants re-spend these savings, that then leads to a net reduction in environmental benefit of the sustainability efforts[2-5].

Such economic feedback mechanisms have been called rebound effects, backfire-effects, takeback effects or (informally) "conundrum"[6] and "paradox"[7]. Economic feedback mechanisms have been discussed in the 19^{th} century[8,9]; a modern treatment of the rebound problem has begun more recently[10-19]. Rebound effects are often defined as the relative engineering savings that are lost due to economic feedback mechanisms[12]. One commonly distinguishes between direct, indirect and economy-wide rebound effects[20]. Direct rebound effects correspond to a more efficient generation of a good or service that then, because of its lower price, leads to an increased demand for that good or service. Indirect rebound effects occur when a reduced price of a product (or a reduced use of it due to

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conservation measures) leads to an increase in real disposable income of the participants, who then re-spend some of these savings (income effect) or change their consumption pattern (substitution effect). Economywide rebound effects occur if efficiency or conservation measures change production and spending patterns throughout an economy. The current thought is, that rebound effects are relatively small in the area of energy efficiency and conservation measures[14, 12, 21]. It has, for example, been estimated that energy efficiency improvements in the UK result in rebound effects between 5% and 15%[12].

In this paper, an approach for estimating rebound effects based on two economic feedback mechanisms is used. First, savings that participants obtained from sustainability efforts are likely to be re-spend on other goods and services, thus reducing the net improvement of environmental impact (income effect). Secondly, the implementation of efficiency measures can be viewed as an economic activity with its corresponding environmental impact (this is called the embodied effect). Both of these effects are examples of indirect rebound effects. The motivation for focusing in this work solely on the income effect and the embodied effect is twofold: first, it has been shown for the case of UK households, that rebound effects are to a large extent due to indirect effects, primarily the income effect[12]. Secondly, this treatment dramatically simplifies the analysis, because the rebound effect estimates do not depend on behavioral data of the involved participants.

Several strategies have been proposed to compensate for rebound effects. One strategy for reaching a certain reduction of environmental impact is to simply target a more ambitious reduction goal in order to compensate for anticipated rebound effects. Another strategy, proposed by Wackernagel and Rees, is to remove the savings of below-cost efficiency gains from economic circulation by, for example, a tax and reinvest it in natural capital rehabilitation[22]. The “Restore” approach presented in this paper can be viewed as a practical implementation of such a reinvestment strategy, with the difference that the approach presented here is rooted in voluntary efforts that amount to only a fraction of savings that were obtained through efficiency gains. The restore strategy stands for applying a fraction of the financial savings that are realized through sustainability efforts towards actions or items that are environmentally beneficial. Examples of such items could be donations towards environmental non-profit organizations or the purchase of CO_2 emission offsets.

In this paper, the purchase of carbon offsets is used as an example of a reinvestment towards environmental causes. The use of carbon offsets simplifies the comparison of different net emission scenarios; in principle many other avenues for donating towards causes that have a clear environmental benefit are possible.

2. Results

Let sustainability measures stand for either conservation measures (use of less resources) or efficiency measures (changes to more resource-efficient technologies). The rebound effect is a quantity for describing how the actual changes in resource usage or emissions due to a sustainability measure differ from the expected changes:

$$R = \frac{\text{expected changes - actual changes}}{\text{expected changes}} \quad (1)$$

The rebound effect is in this paper expressed in terms of CO_2 emissions; in principle it could stand for other quantities (such as changes in general greenhouse gas emissions, or environmental impact, fossil fuel use etc.). In what follows, the nomenclature is similar (but not identical) to the recent work of Chitnis *et al*.[12].

The expected changes are also called engineering savings (ΔH); the actual changes are also called total impact (ΔQ):

$$R = \frac{\Delta H - \Delta Q}{\Delta H} \quad (2)$$

The total impact ΔQ is approximated as the sum of four effects: the engineering savings (ΔH), the embodied effect (ΔM), the income effect (ΔG) and a restore effect (ΔT):

The engineering effect ΔH stands for the changes in CO_2 emissions due to a sustainability measure without considering additional behavior changes or economic feedback mechanisms.

The embodied effect ΔM describes emissions that originate from the activities involved in implementing a sustainability measure. Insulating a home, for example, leads typically to a lower use of household electricity use and lower greenhouse gas emissions. These reductions in emissions are, however, somewhat countered by emissions that occur as a result of implementing this particular efficiency measure (such as driving activities of contractors who perform the installation or the energy needed to create the insulation material etc.).

The income effect ΔG describes the effect of an increased real disposable income of a household or organization due to financial savings resulting from sustainability measures. This increased real disposable income can then lead to new spending that would not have occurred otherwise, prompting economic activities that have their own environmental impact, thus reducing the net environmental benefit.

The restore effect (ΔT) describes additional mitigation efforts that are a result of the financial savings obtained from sustainability measures.

Taken together, one can write:

$$\Delta Q = \Delta H + \Delta M + \Delta G + \Delta T \quad (3)$$

leading to

$$R = -\frac{\Delta M + \Delta G + \Delta T}{\Delta H} \quad (4)$$

Note that ΔH and ΔT are typically negative quantities (a reduction in environmental impact), and ΔG and ΔM are non-negative quantities (leading to an increase in environmental impact).

We can estimate the engineering savings in emissions corresponding to a certain sustainability effort to be the product of the financial savings $\Delta C_{sus} < 0$ multiplied by the corresponding emission intensity s:

$$\Delta H = \Delta C_{sus} s = -V s \quad (5)$$

with $V = -\Delta C_{sus} \geq 0$ representing the direct financial savings resulting from a sustainability measure (not counting costs to implement the measure).

The economic activity of implementing the efficiency measure has its own environmental impact, called the embodied effect. We estimate the embodied effect by using the Kaya identity[23]:

$$\Delta M = K s_0 \quad (6)$$

with $K \geq 0$ being the capital cost of implementing the efficiency measure and s_0 being the economy-averaged CO_2 intensity.

The restore component ΔT is proportional to the amount D of currency units donated towards environmental causes. As an example, we use here carbon offsets as an example of such mitigation efforts:

$$\Delta T = -\frac{D}{p} \quad (7)$$

with $p > 0$ being the price of environmental donations (for example carbon offsets in units of US$ per metric ton of CO_2).

The income effect ΔG occurs due to the re-spending of the increased real disposable income that results from implementing the efficiency measure. This additional income ΔY can be estimated as the financial savings due to the direct financial savings (V) minus the capital cost of implementing the efficiency measure (K) minus the cost of the environmental donations (D).

$$\Delta G = \Delta Y s_0 = (V - K - D) s_0 \quad (8)$$

Using equations 4, 5, 6, 7 and 8 we can write for the rebound effect R:

$$R = -\frac{K s_0 + (V - K - D) s_0 - \frac{D}{p}}{-V s} \quad (9)$$

$$R = \frac{s_0}{s} - \frac{D}{V} \frac{s_0 p + 1}{s p} \quad (10)$$

We define the restore fraction f to be the ratio of the environmental donations D and the direct financial savings V:

$$f = \frac{D}{V} \quad (11)$$

leading to

$$R = \frac{s_0}{s} - f \frac{s_0 p + 1}{s p} \quad (12)$$

If the product of the average carbon intensity and the price of carbon offsets is a small quantity (and this turns out to be the case; $s_0 p \ll 1$) one can approximate the rebound effect as follows:

$$R \approx \frac{s_0}{s} - \frac{f}{sp} \qquad (13)$$

Alternatively, one can express the environmental donations D as a fraction f^{θ} of the net financial savings (direct financial savings minus the cost of implementing the sustainability measure):

$$D = f^{\theta} (V - K) \qquad (14)$$

leading to an equation that is slightly more complicated compared to equation 12:

$$R = \frac{s_0}{s} - f' \left(1 - \frac{K}{V}\right) \frac{s_0 p + 1}{sp} \qquad (15)$$

Let us analyze several special cases of equation 12:

Case I: no environmental donations ($D = 0, f = 0$**)**: For the common case of no environmental donations ($D = 0$), this leads to the remarkably simple expression for the rebound effect:

$$R = \frac{s_0}{s} \qquad (16)$$

In this case, the estimated rebound effect only depends on the ratio of the economy-averaged CO_2 intensity and the CO_2 intensity of the reduced items. The estimated rebound effect is only then smaller than one hundred percent, if the CO_2 intensity corresponding to the reductions is greater than the economy-averaged CO_2 intensity. The economy-averaged CO_2 intensity s_0 has for the United States been estimated to be 0.43 kg CO_2 per US$. The CO_2 intensity of electricity is in this work estimated to be 7.35 kg per US$ (see Materials and Methods). Using these two emission intensity values in combination with equation 16, one obtains for the case of reductions in electricity usage an estimated rebound effect of relatively small magnitude:

$$R = 0.43/7.35 = 5.9\% \qquad (17)$$

Case II: elimination of activities with average environmental impact ($s = s_0$**)**: In this case, equation 12 simplifies to

$$R = 1 - f\frac{s_0 p + 1}{s_0 p} \qquad (18)$$

For $s_0 p \ll 1$ one can approximate:

$$R \approx 1 - \frac{f}{s_0 p} \qquad (19)$$

Case III: complete reinvestment ($f = 1$**)**: For the case of reinvesting all direct financial savings towards environmental offsets, one obtains for equation 12:

$$R = \frac{s_0}{s} - \frac{s_0 p + 1}{sp} \qquad (20)$$

$$R = -\frac{1}{sp} \qquad (21)$$

Case IV: eliminated rebound effect ($R = 0$**)**: Using equation 12, setting the quantity R to zero and solving for the fraction f_0 of environmentally reinvested direct financial savings that is needed to eliminate the rebound effect leads to:

$$f_0 = \frac{s_0 p}{s_0 p + 1} \qquad (22)$$

For the case of $s_0 p \ll 1$ one can approximate:

$$f \approx s_0 p \qquad (23)$$

Example: What fraction of direct financial savings have to be reinvested into carbon offsets in order to eliminate the estimated rebound effect? In the United States, the price of carbon offsets is (for example) US$10 per metric ton of CO_2 (or p = 0.01 US$/kg) and the economy-averaged CO_2 intensity has been estimated to be s_0 = 0.43kg/US$ (Materials and Methods). This leads to $s_0 p = 0.01 \times 0.43 = 0.0043$. Applying equation 22, one obtains the following fraction f_0 of direct financial savings that, if applied towards carbon offsets, leads to a rebound effect value of zero: $f_0 = 0.0043/(1 + 0.0043) = 0.00428 = 0.428\%$

The resulting estimated rebound effect as a function of fraction f of reinvested financial savings is given by equation 12 and is schematically depicted in **Figure 1.** The left side of the graph corresponds to the typical situation of greater-zero rebound values and no reinvestment strategy. The right side of the graph corresponds to a high fraction of environmentally reinvested direct financial savings, in which case the rebound effect is negative. The break-even of a zero rebound effect is given by equation 22.

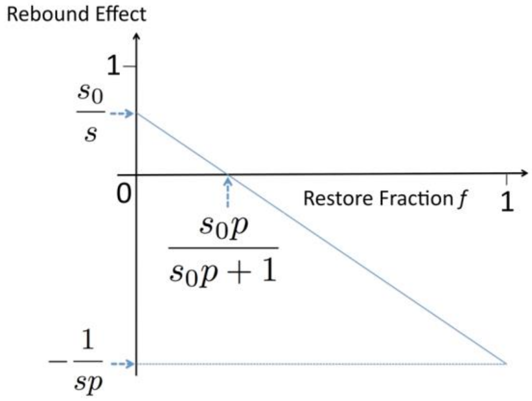

Figure 1; Schematic graph of the amount of the estimated rebound effect as a function of the fraction of financial savings (obtained through conservation or efficiency efforts) that is reinvested into carbon offsets. Negative y-values correspond to situations in which the estimated rebound effect is more than eliminated. Notice how the point corresponding to a zero rebound effect does not depend on the CO2 intensity of the conserved items but only on the economy-averaged CO2 intensity and the price of carbon offsets.

In **Figure 2**, an application of the developed theory is shown for two extreme cases of a) purely electricity-related savings on one hand (a high CO_2 emission per dollar value), and b) savings obtained from conservation of items with average CO_2 emission per dollar value. Surprisingly, the more dramatic elimination of the rebound effect as a function of the fraction of savings that is reinvested into carbon offsets is obtained for reductions of items with average CO_2 intensity.

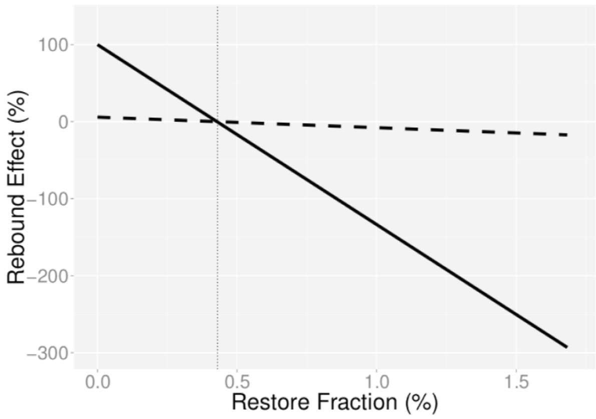

Figure 2; Theoretically predicted amount of the rebound effect as a function of the relative amount of savings resulting from sustainability measures that is reinvested into carbon offsets. Solid line: the savings correspond to conservation of items with average CO2 intensity; dashed line: the savings corresponding to the conservation of electricity. The vertical line indicates the value of the restore fraction of 0.43% that in both cases leads to an eliminated rebound effect**.**

The derived results lead to the formulation of the **restore principle**:

Reductions of activities with average environmental impact lead to a dramatically improved environmental benefit if a fraction of the resulting financial savings is applied towards environmental causes.

The restore strategy or restore approach entails for conservation or efficiency measures to (roughly) estimate the resulting direct financial savings, followed by donating a fraction of these estimated financial savings towards environmental causes as a safeguard against rebound effects.

3. Discussion

3.1 Overview

The used methodology for estimating the rebound effect captures only a part of the various economic feedback mechanisms and makes simplifying assumptions about how monetary savings resulting from sustainability efforts are being spent. The made simplifying assumptions are motivated by the goal of providing a practical easy-to-use framework for estimating rebound effects and are justified by a recent report that income effects are of greater magnitude compared to direct rebound effects or substitution effects[12]. Also, the approach has several advantages: first, the estimated rebound effect is easily computable in an unambiguous way; second, the quantity does not depend on behavioral data; third, the presented estimate of the rebound effect is likely to be in many cases a lower estimate that may serve as a ”compromise treatment” for cases where rebound effects would otherwise be ignored or be impractical to obtain; fourth, the combination of these points can make possible that rebound percentage values are routinely computed (not only by experts but also by “practitioners in the field”) and are used as a tool for guiding decisions in environmental economics. Such simple-to-compute lower estimates of the complex rebound concept are likely to be of lasting usefulness, in particular in situations where the rebound effect is not the central focus of a project. This is the justification for giving the approximation to the rebound effect provided in equation 12 the distinct name rebuy fraction. The concept of the restore strategy is not intrinsically tied to a particular approach for estimating rebound effects; instead a rebound estimation approach that is an extension or an alternative to the one presented in this paper may be utilized, provided the methodology does not correspond to an unfavorable trade-off between accuracy and practicality.

The magnitude of the estimated rebound effect terms of CO_2 emissions is relatively small (6%) for a high-CO_2-intensity expenditure (electricity) and dramatically high (100%) for an expenditure of average CO_2 intensity (equation 16, case I). This underscores, that unless a reinvestment strategy is being implemented, general reduction efforts should focus on the conservation of items with high CO_2 intensity such as energy; the savings in CO_2 emissions due to a reduction of expenditures with average CO_2 intensity is thus doubtful, given the assumption that the saved money is spent on other trade items with again average CO_2 intensity. Note that the estimated rebound effect of 6% for savings in electricity is within the range of rebound effects of energy efficiency measures in the UK which were estimated to be in the range of 5%-15%[12]. The rebound effect resulting from electricity conservation has been estimated to be between 4.5 and 6.5% for Australia[21].

The work presented in this paper suggests that in addition to estimating environmental impact, it is important to estimate financial savings obtained from sustainability efforts. Expanding the motto “reduce, reuse, recycle” to “reduce, reuse, recycle and restore” captures this shift in emphasis. A graphical depiction of the restore concept is shown in **Figure 3.** This depiction shows that for many sustainability efforts, a fraction of the realized financial savings can be used to contribute to the restore component or other Rs of sustainability.

Figure 3; Graphical depiction of the reduce, reuse, recycle motto in combination with a reinvestment strategy into a restore component. The short arrows correspond to a part of the financial savings obtained from conservation or efficiency efforts that is rein-

vested towards environmental causes.

3.2 Opportunities

If mitigation efforts are fueled by savings, which are achieved by performed sustainability actions, multiple objectives are achieved simultaneously: First, the overall prevalence of voluntarily donating towards environmental causes will likely be higher compared to the current situation. As mentioned before, carbon offsets are only used as an example of one possible type of such donations. Second, the work presented in this paper suggests that closely integrating mitigation early into all our sustainability efforts will lead to lower net emissions compared to reduction efforts alone. Third, "offset-cynicism" (viewing carbon offsets as indulgences[24]) may originate from the approach of viewing mitigation as the last step of a waste hierarchy that may in this fashion lower the incentive to reduce emissions in earlier steps. The approach presented here is quite different: increased reductions (decreased emissions) lead via a fraction of savings to increased (instead of decreased) offsets. The indulgence argument is in this way not applicable to offsets that were purchased within the restore framework. Fourth, "rebound-cynicism" (implying that many conservation efforts are essentially futile) is being addressed by showing that the restore approach can reduce or eliminate rebound effects. Even reductions of items with average CO_2 intensity (that would without a restore strategy lead to an estimated rebound effect of 100%) can lead to an eliminated rebound effect. In other words, conservation efforts have a new additional role as a driver for donations towards environmental causes. Fifth, the restore strategy can be viewed as a safeguard against (perhaps involuntary) "green-washing". As shown earlier, the magnitude of the rebound effect is highly dependent on the nature of the reductions: the rebound effect is relatively small for electricity (6%) and dramatically high (100%) for items with average CO_2 intensity. In practice, it may be for organizations and households difficult to clearly separate effective from ineffective conservation efforts. The right side of **Figure 2** demonstrates that in both cases the rebound effect is more than eliminated, if the restore strategy has been applied. Sixth, the fraction of financial savings reinvested towards environmental causes is, at least approximately, taken out of economic circulation and does not contribute to rebound effects. Seventh, it is for individuals and organizations easier to track fluxes of money as compared to fluxes of CO_2, especially if indirect emissions are taken into account. Balancing the rebound effect does not depend on knowledge of the CO_2 intensity of the involved items (equation 22), thus simplifying a practical implementation. Eighth, the approach presented here represents a "future-proofing" of sustainability efforts for a scenario in which removal of greenhouse gases from the atmosphere may become a necessity[24, 25] and for a scenario in which rebound effects are even more prevalent than today[12]. Ninth, a main driving force for conservation efforts are financial savings. By using only a (voluntary) fraction of such savings towards environmental causes, this driving force is preserved.

3.3 Limitations

One limitation of the presented calculations is that the used constants for emissions per US$ GDP and emissions per kWh electricity correspond to CO_2 emissions and do not include non-CO_2 greenhouse gases. It should be straightforward to overcome this limitation by using a different set of emission constants.

Care should be taken to keep the restore approach "light-weight", in order to avoid the situation that undue bureaucracy causes a "backfire-effect" of participants avoiding sustainability efforts altogether. Just as it is non-trivial to estimate rebound-effects, it can be non-trivial to estimate the true long-term savings of reducing, reusing and recycling. That is why a voluntary approach of simply "tipping nature" when experiencing efficiency-related savings maybe of similar or even higher effectiveness compared to a fully quantified approach. Ideally, such an approach will become as pervasive as restaurant tipping[26].

Implementing the restore strategy in practice might need strategies to counter our common urge to take savings for granted and use them towards new expenditures. This is likely to be easier in organizations as compared to households, because in organizations, once possible environmental reinvestment strategies have been identified, they can be incorporated into formal operating procedures. The restore approach is likely to be easier to implement, if savings are not incremental but instead are reductions in cost that are substantial, unexpected, quantifiable and realizable. Suggestions for applying the restore strategy are given for the cases of reducing, reusing and recycling.

3.4 Applications - "Reduce"

Vendors of new, more efficient products could additionally certify their products for something that does not exist yet: a "rebound-buster" certification, that corresponds to the possibility that a small fraction of the savings that the consumer is likely to experience is applied towards carbon offsets or environmental donations. Facilitators of energy reductions such as energy auditors or grant givers could make it routine to estimate the savings that participants are likely to experience and ask for a fraction of those estimated savings to be applied towards carbon offsets. Power and utility companies could have a unique role by facilitating conservation efforts of their customers while simultaneously administrating the fractional application of realized savings towards environmental causes. Organizations with sustainability teams could grant them the authority to use a fraction of the financial savings that they helped to create through sustainability efforts towards environmental donations.

3.5 Applications – "Reuse"

The restore strategy is particularly difficult to implement in practice with respect to "reuse". As a reminder, the shown results indicate that the reuse of an item (with average CO_2 intensity) by the same person or organization, does not lead to reduced CO_2 emissions, given the assumptions that the initial savings are being spent elsewhere without delay on different items (with again average CO_2 intensity). The situation is more complicated if items are being reused by someone else (for example as a result of a donation). A helpful approach would be viewing a more frugal use of an item only then as clearly environmentally beneficial, if the prolonged use is accompanied by environmental offsets that are a fraction of the estimated savings (counting only those savings that the involved parties would be able to re-spend).

3.6 Applications – "Recycle"

The economics of recycling is complex and dependent on the municipality. If municipalities experience recycling programs initially as costs, these costs can, in some cases, be seen as savings, if contrasted to the costs of increased landfill usage that would occur if no recycling program existed. Responsible municipalities could now decide on a fraction of those savings that can be applied towards (for example) carbon offsets. Secondly, it is for organizations not uncommon to obtain a part of their revenue from contractors who recycle some of the waste or surplus material. Such recycling contractors and their customers could independently implement the restore approach, thus leading to an increased net environmental benefit of the recycling process.

3.7 Outlook

More ideas from the sustainability community of how to incorporate the restore strategy into the daily life of households and organizations will be needed.

The results show, that reinvesting the relatively small fraction of less than 0.5% of financial savings obtained from conservation or efficiency efforts can eliminate the estimated rebound effect. Given that the used estimate of the rebound effect is in many situations likely to be an approximate lower bound estimate of all rebound effects, and expecting only a partial participation, a practical reinvestment fraction of 1% or higher seems reasonable. This is reminiscent of the 1% For The Planet approach, in which firms voluntarily donate 1% of their revenue to environmental causes (http://www.onepercentfortheplanet.org). The fact that the needed fraction of reinvested savings for substantially reducing or eliminating rebound effects is so small can serve as an encouragement that voluntary efforts can be effective.

It will be a critically missed opportunity if we fail to closely integrate donations towards environmental causes into sustainability efforts that represent savings. One can argue that these opportunities are now greater than ever, because efficiency gains due to new technologies are often substantial.

4. Conclusions

This paper has introduced a practical methodology for estimating economic feedback mechanisms that can reduce the effectiveness of sustainability efforts. A possible strategy, called restore, for reducing or eliminating rebound effects is presented. This environmental reinvestment strategy amounts to a close integration of mitigation into all sustainability efforts, especially those that lead to financial savings. It is shown that reinvesting a relatively small amount of financial savings resulting from sustainability efforts towards environmental causes can substantially reduce or eliminate rebound effects. The conclusion is, that the common reduce, reuse, recycle motto will be more effective if it is augmented by another component: reduce, reuse, recycle and restore.

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6. Materials and Methods

Four different constants have been used:

The CO_2 intensity of an average trade item in the U.S. has been approximated as national CO_2 output per dollar gross domestic product (0.43 kg CO_2 per US$ GDP, 2009 data, http://mdgs.un.org/unsd/mdg/Metadata.aspx?IndicatorId=0&SeriesId=776, accessed Nov 8th, 2012).
The name of the data series is Carbon dioxide emissions (CO_2), kg CO_2 per $1 GDP (PPP) (UNFCCC). This corresponds to a value of 2325 US$/t. Note that this CO_2 intensity does not account for other greenhouse gases.

For the CO_2 intensity of electricity, a conversion factor of 6.8956×10^{-4} metric tons CO_2 per kWh has been used (Environmental Protection Agency http://www.epa.gov/cleanenergy/energy-resources /refs.html, eGRID2010 Version 1.1, U.S. annual non-baseload CO_2 output emission rate, year 2007 data, accessed Oct 12, 2012). Note that this value does not include other greenhouse gases and is by the factor of 1.1756 greater than the base-load emission values. (Non-baseload emission values are higher because less efficient power stations are being utilized in peak usage times). Which of those two values is the more appropriate number depends on the type of energy reduction being implemented; the conclusions of the paper should, however, not be affected by this choice.

As retail price for electricity a value of 0.0997 US$ per kWh has been used (United States, 2011 average price for commercial customers)[27]. This leads to a CO_2 intensity (direct emissions) of 0.68956 kg/kWh / 0.0997 US$/kWh = 6.916 kg/US$. In other words, for the purchase of one U.S. dollar of electricity, the power company has 6.916 kg CO_2 in direct emissions. The common theme of this paper is, however, to also include indirect emissions that arise as throughput through the economy (not only employee commute, but also employee salaries that lead to employee vacation travel etc.). In other words, in order to compare the CO_2 intensity of electricity fairly to the non-electricity-related values used in the paper, another component has to be added. Based on the Kaya identity, an approximation to this indirect economy throughput component the “default” emission value of 0.43 kg CO_2 per US$ GDP is used[23]. This leads to a combined (direct and indirect) CO_2 intensity of (6.92+0.43) kg/US$ = 7.35 kg/US$.

As a price for reducing or offsetting one metric ton of emitted CO_2, a value of 10 US$ per metric ton of CO_2 has been used based on the offset price offered by Carbonfund.org (http://www.carbonfund.org, accessed Nov 7th, 2012).

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