Environmental rebound effect from transport innovation and implications for climate policy

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Introduction

A number of past innovations have been labelled as "eco-innovations" as they were expected to reduce the life cycle environmental burdens stemming from their use (EIO, 2012). In the context of transport, some examples of alleged eco-innovations are motor engines with increased fuel efficiency or the promotion of modal shifts towards greener transport modes (e.g. bicycle or public transport). Claims of environmental superiority, particularly from industry, are usually supported by the results of technology-oriented assessments, many of them based on traditional product life cycle assessment (LCA) (Dangelico and Pujari, 2010). However, the environmental performance of a given transport innovation is not solely the outcome of its technological characteristics, but rather the outcome of a co-production process. Such a co-production element was captured, in a very elemental form, through the so-called IPAT equation devised by Ehrlich and Holdren (1971). According to this equation, the environmental impacts (I) can be explained as the product of population growth (P), affluence (A) and technology (T).

The IPAT equation, however, can be interpreted through two opposite viewpoints. The first viewpoint understands the contributing elements (P, A and T) as independent, whereas the second sees them as interdependent (Chertow, 2000). When studying the environmental outcomes of innovations through the first approach (independency), one sees technology as an endogenous variable that needs to be modelled and then scaled-up through population and affluence, which are exogenous variables. This approach thus attributes the environmental burdens from a technology change (e.g. introduction of an innovation) solely to such change. Most LCA studies can be considered to fall within this viewpoint, either because both affluence and population are not part of the studied system (product level) or they are considered to be independent. On the other hand, when using the second approach (interdependency), all three variables become endogenous and need thus to be modelled to obtain the environmental score of a given innovation. This approach thus assumes that any change in the technology variable will induce a change in both population and affluence variables. Therefore, the environmental burdens attributed to an innovation will correspond to the combined contribution of these multiple changes. An exercise on how to calculate this combined contribution for a case study on diesel engines can be found in Font Vivanco et al. (2014b). Given that both approaches can be used to provide policy guidance, key questions are thus whether such interdependencies actually take place and how relevant are they.

The interdependency between technology and demand (a possible representation of affluence) has probably been the most studied among scholars. Concretely, it has been studied through the early theories of William Stanley Jevons (1865) or the "Jevons paradox", which was later on further developed into the so-called rebound effect (Brookes, 1990; Greening et al., 2000; Khazzoom, 1980; Saunders, 1992). In short, the rebound effect in the context of transport can be defined as the change in overall demand (transport as well as other products) from the liberated or bound consumption factors (e.g. income) caused by a technical change in a transport system (e.g. more fuel efficient vehicle). The rebound effect has been empirically confirmed by dozens of studies from various fields (e.g. transport, energy and ICT), and comprehensive and updated summaries of such findings can be found on Sorrell (2007) and Jenkins et al. (2011). However, its magnitude is still disputed due to the panoply of analytical approaches available and assumptions chosen by researchers.

Many single effects can be included within the rebound effect umbrella. Among these, methodological advances and data availability have favoured the study of microeconomic price effects, also known as direct and indirect price effects. These effects encompass static microeconomic changes in demand from changes in the effective prices of providing mobility. Within the environmental assessment field, the term "environmental rebound effect" (ERE) initially coined by Goedkoop (1999) is often used to differentiate rebound studies dealing with various environmental vectors instead of only energy use. The ERE concept entails a re-interpretation of the traditional energy rebound not only in how the rebound estimates are expressed (multiple environmental indicators) but also on the definition of the technical change, which leads to broader analytical possibilities (Font Vivanco et al., 2014a; Font Vivanco and van der Voet, 2014).

The existence of the (environmental) rebound effect presents many challenges for policies aimed at reducing absolute environmental impacts from consumption through technology improvements, such as climate policies. For instance, it can reduce or even completely offset environmental savings from alleged eco-innovations. It also questions the use of technology-oriented results (such as traditional LCA) for policy. The aim of this paper is thus to present macro-level quantitative estimates of environmental rebound effects for various transport eco-innovations and discuss the results in the context of climate policy. This research has been undertaken in the context of the Environmental Macro-indicators of Innovation (EMInInn) project, a collaborative EU FP7 project aiming at assessing the environmental impacts of innovations at the macro-level, as well as stimulating eco-innovation by strengthening the science-policy link.

The DILER model

For the appraisal of the ERE at the macro-level, we use the Dynamic IPAT-LCA with Environmental Rebound effect (DILER) model. In short, this approach uses comparative product-level LCA values from the literature (reference [alternative to innovation] and alternative [innovation]) to model two macro-level ex-post scenarios: a counter-factual scenario in which the innovation was not introduced and a scenario in which the innovation diffused and caused an ERE. A graphical overview of the model is presented in Figure 1.

The dynamic IPAT-LCA model was proposed by Font Vivanco et al. (2014b) and is characterized by two main features. First, it scales up product-level LCA results to the macro-economic level by means of population growth and product demand data, based on the concept of the IPAT equation. Second, it adds temporal resolution to static LCA values by using technology change data.

The ERE model aims to describe how the consumption patterns of innovation users will change as a result of the cost changes from the use of the new product. In other words, how the liberated or bound income from cost changes will be re-spent or (un)allocated among the various consumption categories. For this, we use econometric estimates in the form of point elasticities. Concretely, the direct ERE is modelled through the own-price elasticity of demand (E_d), as generally done in the literature (Sorrell, 2007). That is, we model the changes in demand of the product subject to the technical change (a given transport innovation) by means of the responsiveness of users to the quantity demanded according to its price. For instance, if transport costs are 1% lower and E_d is -0.10, transport demand would increase by 0.10%. The indirect effect, that is, the remaining income that is spent on other consumption, is modelled through expenditure elasticities or Engel curves. This approach has been applied by Murray (2013), Chitnis et al. (2012b), Druckman et al. (2011) or Thomas and Azevedo (2013). In short, Engel curves describe how expenditure on a given consumption category varies with household income, and can be obtained by using expenditure statistics. In our case, we have used household mean consumption expenditure (HMCE) data for the EU27 member states and for the year 2005 by detailed classification of individual consumption according to purpose (COICOP) level (division, group and class) and income quintiles from Eurostat (2014a) (2014b). Engel curves can be expressed as proportional expenditure changes with respect to total income, also referred to as marginal budget shares (MBS). By calculating the MBS for each category of the consumption basket, we can model how changes in income will be (un)allocated among consumption categories.

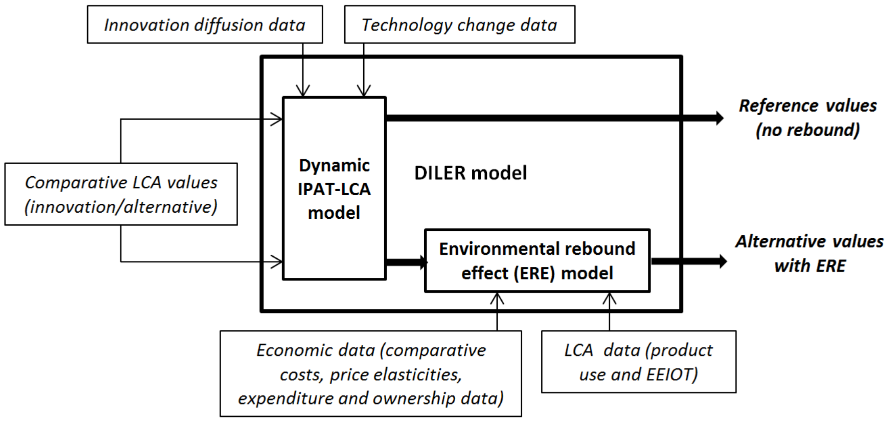

Figure 1. Graphic overview of the DILER model. Bolded boxes represent models, whereas non-bolded boxes represent data inputs. Bolded arrows represent endogenous modelled data flows, whereas non-bolded arrows represent literature data flows. LCA: life cycle assessment, EEIOT: environmentally extended input-output table.

Results

In this section, detailed results of the DILER model are presented for three case studies: diesel engines, direct fuel injection (DFI) systems and park-and-ride (P+R) facilities (see Figures 2, 3 and 4). The indicator chosen is global warming potential (GWP), expressed as CO_2 eq. The results are presented as point values with uncertainty ranges, which depend upon the quality of the data (e.g. geographical scope). For diesel and DFI systems, the results show that, even though these innovations entail GWP emission reductions at the product level (0.5% and 20% reduction, respectively), their introduction and diffusion entailed an increase in absolute emissions. Such increase was caused by the cost reduction of using these technologies, which induced a significant ERE. When all environmental savings are "taken back", we speak of a backfire effect (Saunders, 2000). The magnitude of the ERE was, however, more accentuated in the case of diesel engines (larger emission savings were "taken back"). Such difference can be partially explained by the fact that the cost reduction is larger in the case of diesel engines, with a 35% decrease against a 9% decrease for DFI systems. In terms of absolute income, the savings amount to 1,500€ and 240€ per user and year, respectively. For P+R facilities, we observe that absolute GWP emissions decreased. In this case, the emission reduction at the product level (57% decrease in CO_2 eq. emissions) was enhanced by a negative ERE. The ERE was induced by an increase in transport costs, concretely about 9% increase or 240€ per user an year.

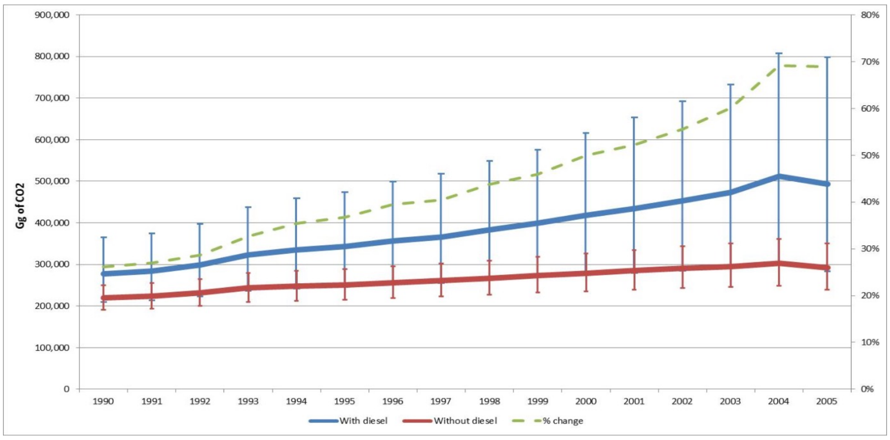

Figure 2. Calculated factual (with diesel engines) and counter-factual (without diesel engines) scenarios in Europe for the period 1990-2005.

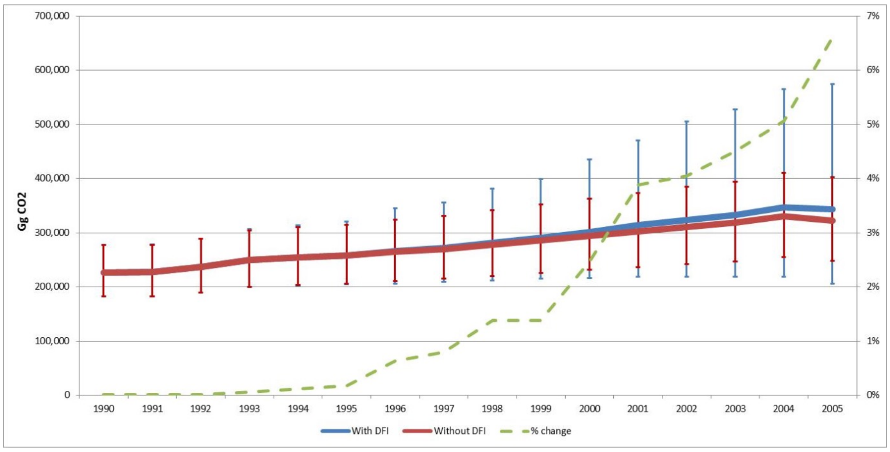

Figure 3. Calculated factual (with direct fuel injection [DFI]) and counter-factual (without DFI) scenarios in Europe for the period 1990-2005.

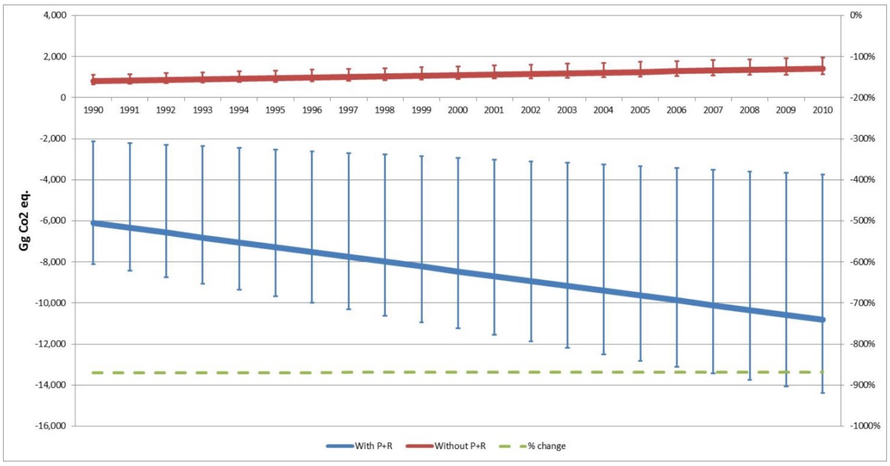

Figure 4. Calculated factual (with park-and-ride [P+R]) and counter-factual (without P+R) scenarios for the global warming potential indicator in Europe for the period 1990-2010.

Additionally, the ERE model alone was also applied to specific passenger car models for three types of electric technologies: plug-in hybrid electric (PHE), full battery electric (FBE) and hydrogen fuel cell (HFC). Figure 5 presents the comparative results between original LCA scores and LCA scores including the ERE. For the PHE car, the ERE is marginally positive as a result of a moderate decrease in transport costs, which is not sufficient to cause a backfire effect. For the FBE and HFC cars, the significant increase in transport costs cause a remarkable negative ERE, thus enhancing environmental savings. The increase in costs is partially explained by the current immaturity of FBE and HFC technologies and the lack of a market niche, which drive purchasing costs up.

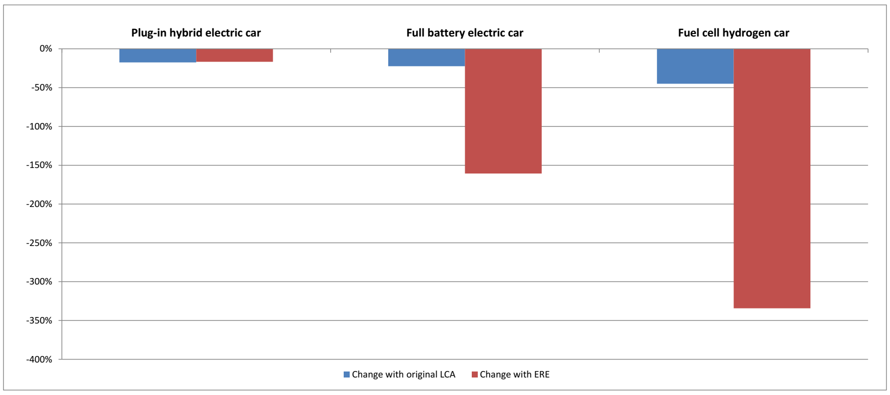

Figure 5. Comparative results between original LCA scores and LCA scores considering the environmental rebound effect (ERE) (in CO_2 eq.) for various electric propulsion technologies for passenger cars.

Discussion and conclusions

Apart from the six transport (eco-)innovations studied in this paper, four other (catalytic converters, high speed rail, car sharing schemes and bicycle sharing systems) were also assessed in the context of the EMInInn project. Overall, from the ten innovations studied, only half would still support claims of environmental superiority once considered the ERE. In these cases, the ERE was either insignificant (no cost differences), positive but small (slight decrease in costs) or negative (increases in costs). For the rest, the ERE caused a backfire effect and therefore all environmental gains were lost, causing a worsening in terms of GHG emissions as they diffused through the economy. These results highlight the need to consider price-related and other causal effects when assessing the environmental performance of innovations introduced in the market in other to achieve climate policy goals.

As rebound effect models are complex and time-consuming, innovations that need policy attention can be identified with the help of a benchmarking tool. The idea behind such a tool is to classify various innovations according to those variables that contribute the most to the rebound effect. According to the findings of our research, two variables that are highly correlated with the ERE magnitude are the change in absolute income and the relative environmental impact intensity (EII) of the innovation. Changes in absolute income are the result of price differences and innovation diffusion, and are positively correlated with the ERE magnitude. By relative EII it is understood the environmental impacts per euro spent on a given innovation with respect to those from general consumption. If the EII from other consumption categories are larger than those from the innovation, every marginal income unit liberated or bound will have greater capacity to offset or enhance environmental savings.

Once the most challenging innovations are identified, there are many policy options to mitigate the ERE. These options can be classified in two broad categories, according to whether they target transversal increases in environmental efficiency or shiftings in consumption patterns. Economic instruments such as a carbon tax, transversal technology improvements or changes in lifestyles through product standards or identity signaling are just some examples of the spectrum of options available. A collection of examples can be found in Maxwell et al. (2011). However, much is still ignored about the full range of policy options available or their possible outcomes, being an area of research with great potential.

Lastly, many other causal effects relevant for climate policy can be studied in the context of the environmental assessment of innovation. For instance, self-selection, market or technology spill-over effects (Huppes et al., 2011). Also other types of rebound effects, such as non-economic effects (e.g. those related to time or socio-psychological costs (Font Vivanco and van der Voet, 2014))or macroeconomic effects. Within EMInInn, upcoming research aims to quantity such macroeconomic rebound effects with a computable general equilibrium-based model. By increasing the current knowledge base, more informed policy advice is expected.

Comment [FVD1]:

References

Brookes, L., 1990. The greenhouse effect: the fallacies in the energy efficiency solution. Energy Policy 18, 199-201.
Chertow, M.R., 2000. The IPAT Equation and Its Variants. Journal of Industrial Ecology 4, 13-29.
Dangelico, R., Pujari, D., 2010. Mainstreaming Green Product Innovation: Why and How Companies Integrate Environmental Sustainability. J Bus Ethics 95, 471-486.
Ehrlich, P.R., Holdren, J.P., 1971. Impact of Population Growth. Science 171, 1212-1217.
EIO, 2012. Methodological report, in: Observatory, E.-I. (Ed.).
Eurostat, 2014a. Mean consumption expenditure by detailed COICOP level (in PPS), http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hbs_exp_t121&lang=en.

Eurostat, 2014b. Structure of consumption expenditure by income quintile (COICOP level 2), http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=hbs_str_t223&lang=en.
Font Vivanco, D., Freire-González, J., van der Voet, E., Kemp, R., 2014a. The remarkable environmental rebound effect of electric cars: A microeconomic approach. Environmental Science and Technology (submitted).
Font Vivanco, D., Kemp, R., van der Voet, E., Heijungs, R., 2014b. Using LCA-based Decomposition Analysis to Study the Multidimensional Contribution of Technological Innovation to Environmental Pressures. Journal of Industrial Ecology 18, 380-392.
Font Vivanco, D., van der Voet, E., 2014. The rebound effect through industrial ecology's eyes: A review of LCA-based studies. International Journal of Life Cycle Assessment (accepted for publication).
Goedkoop, M.J., 1999. Product service systems, ecological and economic basics.
Greening, A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption –the rebound effect– a survey. Energy Policy 28, 389-401.
Huppes, G., Ishikawa, M., Kramer, G.J., 2011. Challenges for Industrial Ecology in Practice and Theory. Journal of Industrial Ecology 15, 677-679.
Jenkins, J., Nordhaus, T., Shellenberger, M., 2011. Energy emergence: rebound and backfire as emergent phenomena. Breakthrough Institute.
Jevons, S., 1865. The Coal Question. Can Britain Survive? Reprinted by Macmillan 1906.
Khazzoom, J.D., 1980. Economic implications of mandated efficiency in standards for household appliances. Energy Journal 1, 21-40.
Maxwell, D., Owen, P., McAndrew, L., Muehmel, K., Neubauer, A., 2011. Addressing the rebound effect, a report for the European Commission DG Environment.
Saunders, H.D., 1992. The Khazzoom-Brookes postulate and neoclassical growth. The Energy journal, 131-148.
Saunders, H.D., 2000. A view from the macro side: rebound, backfire, and Khazzoom–Brookes. Energy Policy 28, 439-449.
Sorrell, S., 2007. The rebound effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. Project Report.