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D1.1
Analytical Framework of Drivers and Barriers to Resource Efficiency

WP 1 – why have resources been used inefficiently

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Contributors: Rene Kemp, Marc Djik

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1 Introduction

There is still great potential to increase the efficiency of natural resource use in all sorts of human activities. Resource efficiency improvement can be obtained in many ways: through product changes, production process changes, recycling and product re-use systems and changes in consumer behaviour and choices. Eating less meat helps to save water and fossil fuels and leads to significant reductions in greenhouse gas emissions. Using energy-efficient lighting products helps to save electricity and indirectly fossil fuels being used to generate the electricity. Electricity can be produced without the use of fossil fuels but this leads to increased use of other materials needed to produce alternative energy technologies. The purpose of this report is to offer an introduction into the topic of resource use and offer a framework for describing, understanding and researching resource inefficiencies in different sectors and at the level of households and nations. In this report we develop an analytical framework that helps to understand why resources have been used inefficiently, and why from the perspective of individual actors this makes perfect sense. We take a sector- or industry-based approach which considers practices, cultural frames, policies, institutions and the interplay of supply and demand.

Increasing resource efficiency involves using a reduced quantity of resources to achieve the same or improved service or output (output/resource input), where both input and output are measured in some physical unit, e.g. km/litres of fuel. It is therefore an output/input measure of technical ability to produce "more from less".[1]

In this report, resource efficiency is a synonym for material efficiency. Mathematically, resource efficiency is the ratio between useful material output, *M*o, and material input, *M*i (Dahlström and Ekins, 2005, p. 173):

$$Mo/Mi = \text{material efficiency}$$

Material output is defined in physical terms, for example Kwh and passenger km. At the company levels the number of products produced can be used as a measure. Resource efficiency should be distinguished from resource productivity, which is the ratio between economic output, *Y*o, and material input, *M*i (Dahlström and Ekins, 2005, p. 173):

$$Yo/Mi = \text{material productivity}$$

A common indicator for material productivity is GDP / DMC, where DMC stands for Direct Material consumption.

The inverse of resource productivity is *resource intensity*: the resource use *M*i per unit of economic output *Y*o. Resource intensity can be calculated for labour, energy, and all material resources including land and water. Labor intensity would be measured as *L/Y*o, and energy intensity as *E*i/*Y*o. It can also refer to the production of some undesirable output (often resulting in pollution) by some other factor, for example, carbon dioxide output, *C*, per unit of energy input:

$$Co/Ei = \text{the carbon (emission) intensity of energy}$$

[1] Resource productivity, by contrast, has a component of economic value: it refers to the economic gains achieved through the use of resources (for example GDP/resource consumption). In this way it indicates the economic effectiveness of natural resource use.

which, assuming no abatement of carbon emissions, is the same as the carbon intensity of the energy inputs, *C*i/*E*i or the output of pollution or waste, *P*, per unit of material inputs:

*P*o/*M*i = the pollution intensity of material inputs or the output of pollution or waste, *P*, per unit of economic output (Dahlström and Ekins (2005, p. 174)[2]:

*P*o/*Y*o = the pollution intensity of output

The concept of resource efficiency is different from the concept of sustainable development. Sustainable development is not so much about resource use but about preserving eco-systems services and enhancing social and economic well-being. A decoupling of well-being from resource use is being advocated by the International Resource Panel, drawing attention to resource use as a pressure indicator. Resource use and environmental pressures are thus linked but not the same. Besides reducing environmental impacts, another important aspect of resource efficiency is that it delays the depletion of resources and reduces the vulnerability to supply shortages (BIO et al, 2012).

Most studies on resource inefficiency are rooted in either economic theories ('economic rationality') or psychological theories ('attitude change'). We will argue that both approaches underestimate both the complexity of the situation and the importance of social influences. Therefore, we seek a framework that moves beyond the dichotomy between these two distinct approaches and includes more of the social context of consumption: how consumers act in their environments and how their behaviour interacts with artefacts and physical infrastructures to trigger and shape resource flows. In other words, we pay more attention to how consumers themselves view and make sense of their own action, their responsiveness to prices and incentives and the importance of energy conservation vis-à-vis other considerations[3]. Secondly, we go beyond the idea of 'barrier to resource efficiency' as a concrete 'thing' that can be removed (such as a political rule, lack of subsidy, lack of information, absence of certain social norms), but instead we develop the notion of barrier as a 'web of constraints' stemming from the co-evolution of supply and demand resulting in practices, mind-sets and unequal development of technologies.

The structure of the report is as follows. Section 2 introduces the topic of resources by offering a categorisation of resources and definitions for resource efficiency, productivity and intensity. Section 3 offers a discussion of the importance of the social context. For two practical examples, light bulbs and passenger cars, the report shows how existing economic and psychological approaches can easily fall short of explaining resource inefficiency given the complex social context in with resource use takes place. In section 4 we review how innovation studies can help to explain resource inefficiency, through the attention to cause-and-effect chains, than social practice studies. In section 5, we develop an analytic micro-macro framework that integrates elements of company behaviour and user behaviour into a

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[2] There is a no generally agreed definition for resource efficiency. Remarkably, a recent EEA survey (EEA 2011a) on resource efficiency policies in 31 Eionet countries disclosed that only 5 countries defined "resources" and none defined "resource efficiency" (ITRE, 2012, p. 9. In the report Resource efficiency in European Industry (ITRE, 2012), resource efficiency is an overarching concept, which comprises resource intensity and resource productivity. Different from Dahlström and Ekins (2005) resource intensity is defined either per unit of physical output or economic output.

[3] Research suggests that energy conservation may be pursued as part of larger "home improvement" plans and relate to vague notions such as "being independent" or "making the house tight", which means that other issues than the payback period of an energy conservation option must be considered (Lutzenhiser, 1993).

dynamic innovation perspective, which is illustrated for the case of electric vehicles as a low-carbon product in Section 6. Section 7 discusses the markets for commodities and recycling as special markets subject to cycles of boom and bust. Section 8 examines the policy and governance element in resource efficiency choices. Section 9 summarises the most important findings about resource inefficiency. One important conclusion is that there is a web of constraints acting on material reduction, substitution and recycling.

2 Resources and resource efficiency

The production and use of goods and services is associated with the use of natural resources: water, land and a range of minerals or materials[4]. A common distinction of resources is in fossil fuels, construction minerals, metallic minerals, biomass, water and land. For biomass, minerals and fossil fuels, total global annual resource extraction and use increased from about 7 billion tons (7 Gt) in 1900 to about 55 billion tons (55 Gt) in 2000 (IRP, 2011, p. 17). The share of abiotic resources (minerals and fossil fuels) steadily increased and exceeds the share of biotic resources.

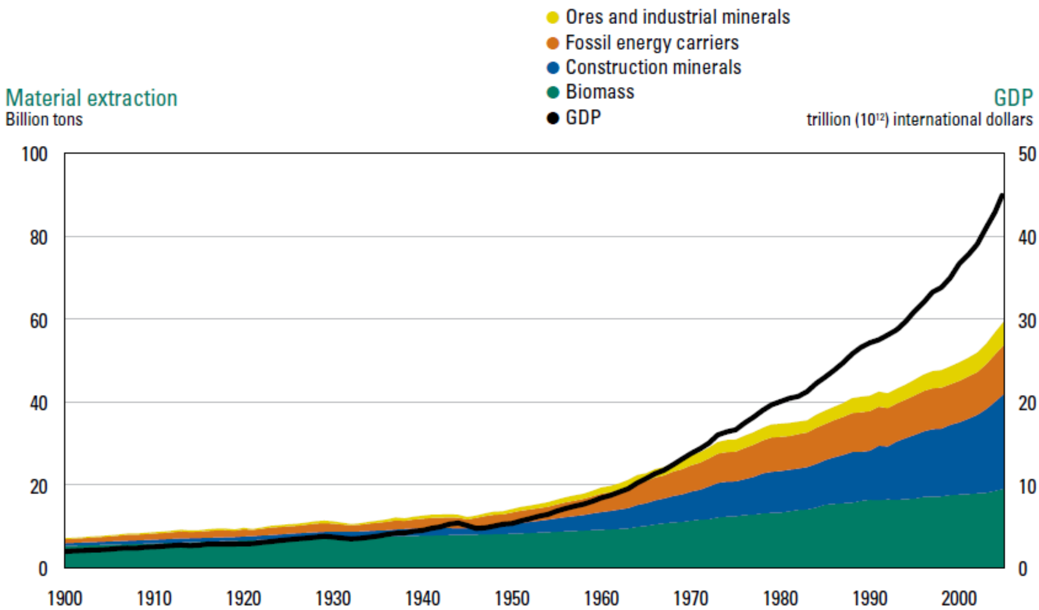

Figure 1. Global material extraction in billion tons, 1900–2005 (source: Krausmann *et al.,* 2009 published in UNEP 2011a, p. 11))

[4] A mineral is a "naturally occurring inorganic element or compound having an orderly internal structure and characteristic chemical composition, crystal form, and physical properties" (Bates and Jackson, 1980, p. 401). Metallic minerals are ore minerals and fossil fuels are fuel minerals (from http://www.uky.edu/KGS/rocksmn/definition.htm).

An overview of resource extraction *per capita* (what is being called the resource metabolism) is given in Figure 2, showing that resource use per capita per year doubled between 1900 and 2005 (from 4.6 tons in the year 1900 to 9 ton per capita in 2005).

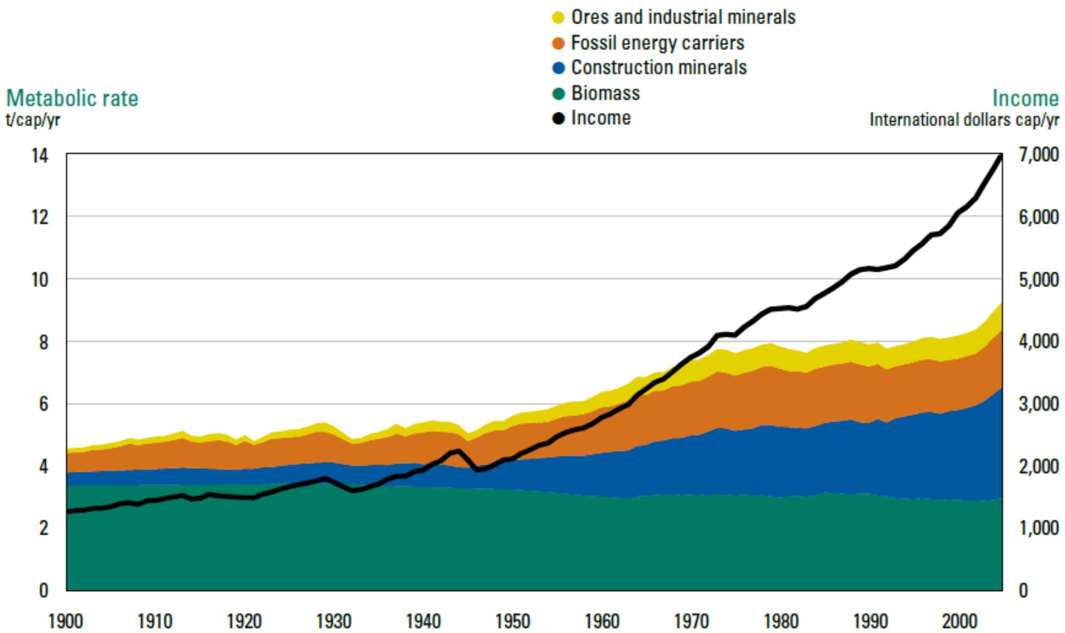

Figure 2. Resource use per capita, 1900–2005

Source: International Resources Panel (2011, p. 12) based on Krausmann *et al.,* 2009; based on SEC Database "Growth in global materials use, GDP and population during the 20th century", Version 1.0 (June 2009): http://uni-klu.ac.at/socec/inhalt/3133.htm)

Figures 1 and 2 show that the increase in resources is below the increase in GDP, which means that there has been a relative decoupling of resource use from GDP but not an absolute decoupling.

Per GDP, resource efficiency has improved but 90% of the material that is lifted from the earth does not appear in final goods (Schmidt-Bleek in Lettenmeier et al., 2009). Improvements in material productivity are below those for labour productivity and energy productivity: during the period 1970–2007, productivity of labour increased by 144% in the EU-15, while productivity of materials grew by 94% and productivity of energy increased by 73% (2009) (Bleischwitz, 2011).

In the past, the focus of environmental policy has been on emissions and waste and not on material flows. The Wuppertal Institute has been very vocal in criticising this, for the reason that material use is associated with environmental impact: "sooner or later every material input becomes an output in the form of waste, effluent or emissions (Lettenmeier et al., 2009, p. 5). Reductions in resource use and material consumption lead to reduced negative environmental impacts which will be lower than otherwise. Whether the overall environmental impact is going to fall in absolute terms depends on the magnitude of reduction in resource use. Recycling helps to reduce resource use but recycling requires energy which is associated with increased resource use (reducing the net positive effect). Recycling and reuse are essential strategies for phosphorous and critical materials[5].

At every point of the product chain there are losses in resources and energy. In the case of passenger cars, for instance, only 15% - 25% of the energy from the fuel put in the tank gets used to move the car, depending on the type of drive (motorway or city). The biggest source of energy loss is the engine (responsible for about 60% of energy losses, see Figure 3). Running the engine at idle moments (during stops) leads to energy losses of about 17%. Drive line losses amount to 5.6% and rolling resistance to 4.2%. Braking is responsible for 5.8%. Each of the losses has been the subject of innovation efforts (in the form of fuel injection systems, idle –off devices and direct-drive in wheel-technology). The aerodynamic drag also has been improved but the increase in weight resulted in an energy use penalty.

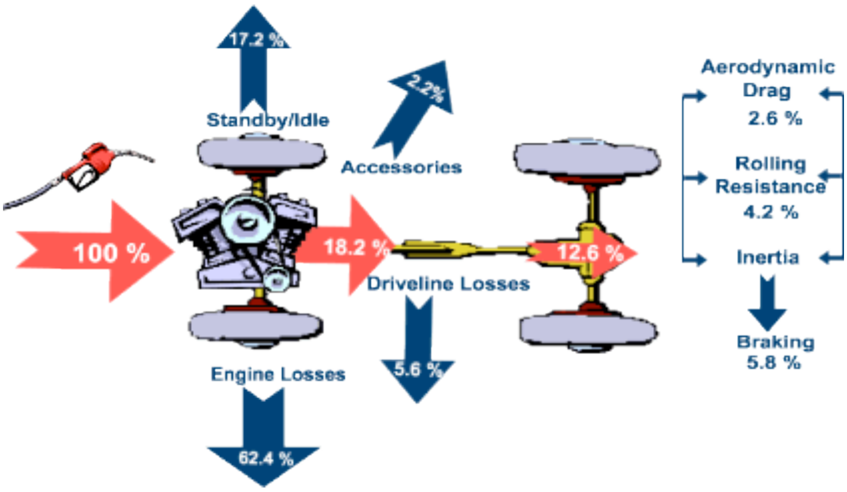

Figure 3. Energy losses in a vehicle

Source: http://www.consumerenergycenter.org/transportation/consumer_tips/vehicle_energy_losses.html

Full electric vehicles and hydrogen fuel cell vehicles have a higher energy efficiency but they involve critical materials (such as dysprosium) and give rise to waste problems that require attention at the end of their lifetime. The overall energy efficiency of 12.6 % of conventional vehicles (see Figure 3) is the first-law efficiency; energy losses in the production of fuels are not considered. A better indicator of energy efficiency is the exergy measure based on second-law efficiency. Ayres et al. (2003) calculated the exergy (secondary efficiency) of electricity-using technologies and appliances by correcting the energy efficiency for losses in power transmission and losses in power generation. The authors find that "the overall efficiency [in the conversion from electric power to `secondary work'] has remained almost constant during the past century, even though all individual applications have become more efficient, because the least efficient applications (low temperature heat and fractional horsepower motors) have sharply increased their share" (Ayres et al. 2003, p.1).

[5] Critical materials are materials for which there are risks of supply shortage because of time lags in the adjustment of supply to demand or because of strategic behaviour on the part of governments who are using restrictions on export and production as a trade weapon (EU, 2010). The EU has identified 14 critical materials with a particular high risk of supply shortage in the next 10 years (for an overview see Appendix A)

The continuing rise in resource use per capita suggests that fundamental shift in process efficiency is necessary (power generation and fuel production) in order to make significant improvements in resource efficiency. Instead of using fossil fuels, we may use renewables for power generation. As a capital investment, solar PV and wind power are material intensive per unit of capacity but the use or solar PV and wind power leads to a reduction in resources. An inherent disadvantage of renewable energy technologies however is that the energy return on (energy) investment or ERO(E)I is lower than that of fossil fuels (which are packed with energy). ERO(E)I is the energy output obtained in a process divided by the energy input or cost needed to extract, produce, deliver and use the output (Murphy and Hall, 2010). Oil from easily reachable fields has an EROEI of over 100, coal has a constant EROEI of about 80 since the 1950s (van den Bergh, 2012). The shift towards less economic fields (such as those in deep seas), has resulted in a significant drop of the global average EROEI of oil, despite technological progress in exploration, drilling and transport technologies, but the EROEI of 40 still compares favourably with the EROEI of biofuels: the EROEI from sugarcane (corn-based) ethanol varies between less than 1 and 10, and biodiesel 1.3 (van den Bergh, 2012). The EROEI of nuclear fission varies between 5 and 15, that of hydropower is above 100 (but has limited application), wind is 18, solar PV is about 7, solar (flat plate) thermal collectors 1.9 and solar concentrated heat power 1.6 – all far below the EREOI of 80 for coal.

Favourable physical characteristics are one reason for the dominance of fossil fuels, the co-evolution of supply and demand is another reason. When we say the co-evolution of supply and demand, we mean the competition amongst producers, product offerings, sunk costs at the supply side and at the demand side the cultural and behavioural embedding of particular products in people's life, which puts new technologies at a disadvantage and creates constraints for governments to act against particular products. We will now take a closer look at the social context in which demand and supply are embedded.

3 The social context of resource use and why it matters

3.1 Light bulbs

Why is energy for domestic lighting not used more efficiently? For decades the incandescent light bulb has been the dominant lighting technology in domestic housing. The fairly standard screw-based socket provides mechanical support and electrical connections. The energy efficiency of the traditional bulb is between 5 and 10%, relatively low. The fluorescent lamp (mostly tubes), by comparison, has an efficiency of 65%. This latter type of lamp was already introduced by 1938, are widely applied in offices and other large buildings, but not in domestic housing, mostly because their tube shape and colour of the light are not appreciated at home.

Picture 1: A classical light bulb

By 1980 Philips introduced a compact fluorescent lamp, a tube folded in the shape of a light bulb, which was the first energy saving bulb ('spaarlamp' in Dutch), which was further refined since then. It has an efficiency of about 40%

Picture 2: A compact fluorescent lamp

Another energy efficient alternative to the standard light bulb is the halogen lamp. The latest version has an energy efficiency of about 30%. Halogen lamps were used on the Times Square Ball from 1999 to 2006. However, from 2007 onwards, the halogen lamps were replaced with LED lights

Picture 3a: A halogen lamp, 3b: Times Square Ball

The burning time of standard light bulbs is about 1.000 hours; for halogen lamps about 2.000 hours, whereas a compact fluorescent lamp has an average burning time about 10.000 hours.
Because of the higher energy efficiency and burning time, the compact fluorescent lamp and halogen lamp have lower 'operating' cost, although the purchase price is higher. On a balance the higher purchase price of the compact fluorescent lamp is earned back within two to three years. Nevertheless, consumers have preferred to apply standard light bulbs for domestic lighting, typically supported by the argument that the colour of the light of the compact fluorescent lamp was not 'cosy' enough.
Some governments have started to 'overrule' the consumers' preference through the introduction of bans on low-efficient incandescent light bulbs, often driven by the aim to decrease greenhouse gas emissions and/or increase energy efficiency. Australia has started to phase out the light bulbs already from 2008 onwards. The measure was supported by the argument that it is 'expected to save 28 million tonnes of

greenhouse gas emissions between 2008 and 2020' and 'expected to save the Australian economy around $380 million per year by 2020 and result in net savings of more than $50 per year for each household'.
The Dutch minister Jacqueline Cramer (DG Environment) announced on 21 May 2007 during a company visit at Philips in Eindhoven that the sales of all incandescent light bulbs would be banned in The Netherlands. This plan was enforced by law on 1 September 2012. Existing stocks were allowed to be sold but the production of 100, 75 and 60 Watt-bulbs was prohibited from 1 September 2009 onwards. The European Union decided in December 2008 that after 1 September 2012 a range of types of incandescent light bulbs would be banned from the market in Europe. A similar plan exists in California, USA. From 1 September 2016 onwards not any type of light bulb is allowed to be sold in the EU. Most types of halogen lamps are allowed until at least 2016.
The most logical alternative for the incandescent light bulb is the compact fluorescent lamp. Halogen lamps will probably remain, especially in spot lights that require a more concentrated bundle of light and also in 'ambiance lighting', where the colour of halogen lamps is usually preferred over compact fluorescing lamps. Currently the market share of halogen lamps is nevertheless threatened by the emergence of LED lighting, which is even more energy efficient. Also, LED applications are being developed in screw-based sockets and these become an alternative to the compact fluorescent lamp. LED lamps have an even higher efficiency (about 50%) and burning time than fluorescent lamps, although they have even stronger problems with the colour of the light, in sense of not found not cosy enough in the eyes of consumers.
Critics have pointed to the presence of (toxic) mercury in a compact fluorescent lamp, which may be released when the lamp breaks. Moreover, the heat production of light bulbs will now be compensated by the domestic heating systems (in the case this is turned on), which will partly downsize the gains in CO_2-emission. Also, the production of compact fluorescing lamps requires a significant amount of (extra) CO_2 (compared to the light bulb), suggesting that despite the low efficiency, a light bulb is even better for the environment (Stanjek, 1991).
What does the above story learn about the barrier? At first sight, the aspect of cosiness of colour appears the bottleneck and thus the barrier. A deeper analysis however reveals that the slow diffusion is due to both demand side factors (the preference for a certain type of light and consumers minding more about purchase cost then operational cost), and supply side factors (suppliers not actively promoting energy-saving lightning and the slowness of attractive product offerings). Policy acted as a driver through the introduction of a ban of light bulbs but perhaps could have done this earlier; it also could have taxed energy-efficient products. In the Netherlands, the strong position of Philips in compact fluorescent lamps, probably stimulated the Dutch government to be an early mover to ban incandescent light bulbs, creating a promising business opportunity for the firm.
The example shows that the interplay of factors (and thus the whole issue of barriers) is dynamic. Consumer acceptance was growing together with product offerings, the ban in one country facilitated the introduction of bans in another country and the introduction of a product ban in one country (The Netherlands) owed much to the Netherlands being the home country of a company with a strong position in energy-efficient lighting (Philips). The announcement and enforcement of the bans in various countries encouraged businesses to further develop compact fluorescent and other low-efficient alternatives, leading to a broader range of alternative lamps (some of them solving the cosiness issue), many fitting the standard screw-based socket, which limited hassle and cost for consumers to replace bulbs.

3.2 Passenger cars

Passenger cars are another product whose fuel economy could have been higher. A quick glance at the automobile market may suggest a steady progress in the eco-efficiency of cars over the last few decades. The conventional internal combustion engines (ICE) in automobiles have improved in energy efficiency and emissions and hybrid-electric vehicles (HEV) have been sold more than 3 million times worldwide now. At the same time, however, the car market is clearly under influence of a general trend of more comfort and convenience. This trend, together with higher safety requirements, has led to an increased demand in size and luxury-level of cars (Van den Brink and Van Wee, 2001). As Shove (2003) indicates, attributes typically start out as an extra capacity or luxury, but can soon become normality, thus shifting consumer preferences and expectations. As a consequence, the price of an average new car in the Netherlands has doubled from some €13,500 in 1970 to €26,000 in 2009[6]; more importantly, the fuel consumption has not seen any substantial decrease between 1980 and 2005 (see Figure 4 below).

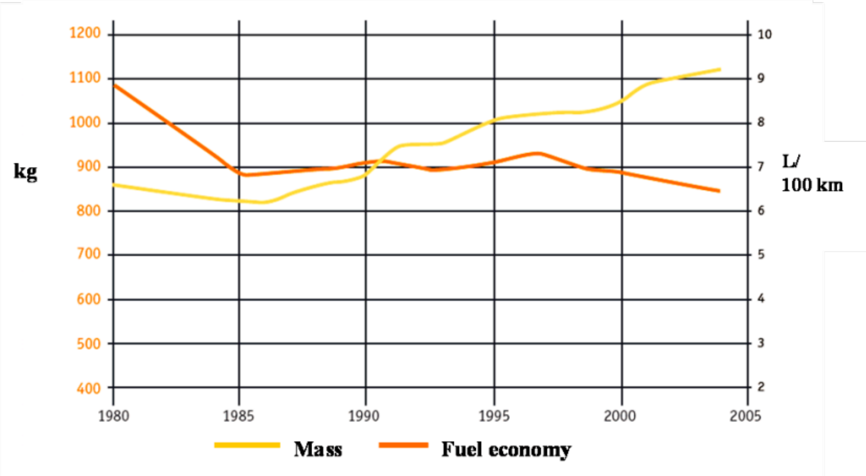

Figure 4: Trends in average car mass and fuel consumption

This example shows that for consumers other characteristics than fuel economy are important. For diesel drivers, engine capacity, volume, acceleration and speed are more important than the fuel efficiency of the engine (as can be seen from Figure 5 based on analysis of newspaper stories about cars).

[6] These figures represent the catalogue price as it is paid by buyers from the private household sector in 2009 Euros (adjusted for inflation). It ignores environmental subsidies but includes net catalogue price, private motor vehicle tax, and VAT.

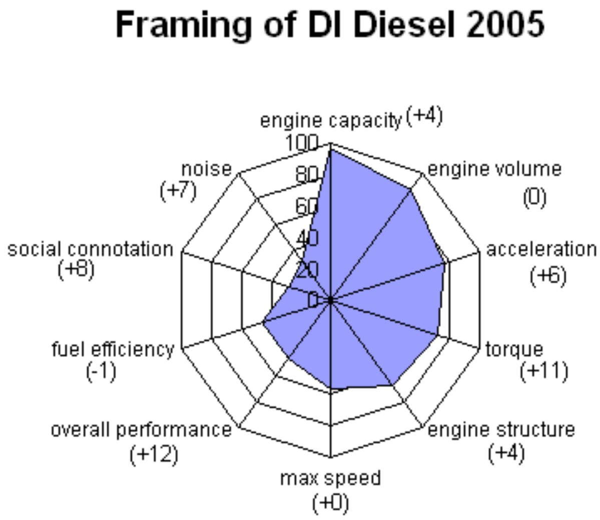

Figure 5: Consumer frames for Dutch diesel drivers (The spider diagram indicates the attention for attributes; the outer values indicate the appraisal scores for each feature.) Source: Dijk 2011

The valuation of characteristics will differ between people and people may be categorised into consumer groups on the basis of the ranking of product characteristics. For full electric vehicles (FEVs), which have a higher potential resource efficiency than diesel and hybrid electric vehicles, users are typically people who are highly concerned with the environment, taking environmental values into consideration and striving to comply with an environmental lifestyle (Jansson, 2011; Moons and De Pelsmacker, 2012). They appreciate the full-electric car above all because of its eco-friendliness, and are proud of its eco-friendly image. These user types would be ready to use an electric car, when an opportunity rises. Dijk's study (2011) suggests that this group is not very large, around 2-3% of those who buy new vehicles.

Studies about the socio-demographic background of current users of electric cars find that it is used by people in slightly elder age groups with relatively high levels of education (Hunter et al., 2004; Shen and Saijo, 2008; Moons and De Pelsmacker, 2012.)

In the study of Graham-Rowe et al. (2012) consumers expressed their expectations of how others would view them for using an electric car. The answers resulted in the identification of three consumer groups. A group of people which primarily value the functionality of the car, a group for who environmental concerns are important and a group of technology aficionados. The most positive image was granted for the third group, that is FEV drivers who derive social identity gains from adopting – or being seen to adopt – a radically novel type of cars. This was an identity with which the people in the study were most happy to be associated with. The functionalists were seen as sensible and boring, showing that people associate cars with certain identities.

Overall, there is still more research needed to understand the heterogeneity among car drivers and the user segments that will be most receptive for eco-efficient cars. Even more than light bulbs, the example of passenger cars shows that, more than one concrete barrier, a range of factors work against cars with a high fuel economy: cultural factors, individual preferences for certain functionalities, aesthetics and the product offerings from suppliers (which depend on perceived demand from consumers as well as supply-side capabilities and interests). The salience of energy efficiency may change thanks to the obligatory use of clearly visible energy labels in car show rooms, higher fuel prices and new product offerings. The use of battery drive systems in sport cars may help to give electric cars more of a masculine image. At the end of the paper, we will consider the stimuli for electric cars and constraining factors in a more detail.

3.3 Why the social context of consumption matters

The cases of light bulbs and passenger cars suggest that successful diffusion of eco-innovation relates considerably to the consumer perspective or rather the heterogeneity of consumers (sub-frames), business perspectives and regulation. Therefore, we need to examine the social context of consumption, how consumers act in their environments and how their behaviour interacts with artefacts and physical infrastructures to trigger and shape resource flows.

Luzenhiser (1993) provides a thorough review of social and behavioural aspects of energy use. He stresses that the role of human social behaviour has been largely overlooked, both in economic approaches ('economic rationality') and psychological approaches ('attitude change') to energy use. Efforts in the economic strand have focused almost entirely on the physical characteristics of buildings and appliances, and on the aggregate effects of rising energy prices. The behaviour of the human "occupants" of buildings is seen as secondary. By assuming human behaviour to be a relatively insignificant aspect of consumption these models overlook the central role of human action in shaping energy use. The variability in residential consumption reported in the literature, however, suggests that there is hardly a "typical" level of consumption for any energy end-use. Utility billing records, for example, show considerable variation in energy use among customer accounts -even when they live in same type of house and concern demographically similar families. Stern & Aronson (1984) observe that 'tremendous variation … exists in the needs and practices of energy users, so that analyses based on an average situation are likely to be wrong in many or most particular cases' (Stern & Aronson, p.182). This suggests that certain efficiency solutions may be more appropriate in some settings than in others. Explanations that take into account behavioural differences between households are clearly required. Psychological approaches have mainly been based on the simple Fishbein-Ajzen model that explains behaviour on the basis of attitudes, later also on subjective norms and behavioural control. Studies have reported significant relationships between attitudes and subsequent conservation action (Becker et al. 1981; Seligman et al. 1979), but others have found that situational factors predominate (Stutzman and Green 1982; Wilhelm and lams 1984). Since these studies typically work with a rather narrow framework of a set of factors that potentially affects an action, Stern & Oskamp (1987) propose a more complex multidimensional view of resource psychology - one that is more interested in contexts of action and sees attitude-behaviour processes as embedded in larger systems of beliefs, events, institutions, and influential "background factors" (e.g. income, education, family size, and temperature). Stern et al. (1986) point to the importance of nonfinancial social and behavioural factors in the successful use of financial incentives. Their review points to a number of reasons why persons who are targeted with incentives may fail to act in ways that economic analyses suggest are in their self-interest. These include: lack of accurate information, confusion, restricted choice, too much time and/or too much effort required (high "information costs"), lack of trust in information sources, lack of cash, and the relative invisibility of conservation impacts. Persons also pursue a variety of nonfinancial goals that conflict with their "investor role," for example when concerned about "comfort and/or appearance," when acting as "members of groups," and when "avoiding hassles" (i.e. taking the minimum action necessary to solve immediate problems). This led Stern et al. to conclude that "The stronger the financial incentives are, the more important the nonfinancial factors -especially marketing- become to a program's success" (p. 162). But little attention has been given to differential social responses to price changes (Lutzenhiser, 1993). Luzenhiser (1993) identifies a cluster of other studies pointing to the fact that, because social humans are symbol-users and the household is a primary centre of social activity, it is also a symbolic realm of energy use (Monnier, 1983). Items of hardware have collective meanings apart from their utilitarian significance. Appliances must conform to status expectations (Hackett and Lutzenhiser, 1990), and relative energy-efficiency is only one of many issues salient to social actors (Gordon and Dethman, 1990). This means that buildings, energy improvements, and alternative energy sources such as solar collectors must fit into the symbolic realm of families and communities (Wilk and Wilhite, 1984; Lutzenhiser and Hackett, 1993).

The way consumers practically use products has received special attention in the social practices approaches (Shove, 2003; Shove et al., 2012). This approach suggests that practices like cooking and showering represent recognizable, relatively stable entities. By a practice they mean a routinized type of behaviour which consists of several elements interconnected to one other: forms of bodily activities, forms of mental activities (framing, meaning, norms), artefacts and resources and ways of using them. It is something that actual and potential practitioners can either participate in or withdraw from. Practices are constituted through performance, which in their terminology means integrations of symbols, materials and procedures. To emphasize that practices tend to participate in their own reproduction, Shove et al. (2012) have developed the concept 'circuit of reproduction', meaning that practices (as an entity) and performances interact (through feedback) in a less or more complicated way.

The notion of 'practice' is developed from the notion of 'habit'. Shove (2012) argues that much of the consumption that matters for environmental sustainability is habitual, recurrent and ordinary, and, accordingly, strategies designed to steer behaviour in pro-environmental directions have to grapple with this habitual aspect. Most attempts to do so treat habit as an obstacle to change, and as a type of behaviour that is automatic, frequent and set within a stable context. In such analyses habits are behaviours that people pick up, have and occasionally lose. Shove turns this topic around by approaching it from the habit's point of view. If we assume that rather than acquiring habits we are acquired by them, familiar questions appear in a very different light and new ones arise. How do habits locate suitable carriers? How do habits, viewed as practices that require recurrent, consistent reproduction, relate to other less demanding pursuits? How is the rhythm of society defined by the sum total of habits? Can policy makers do anything to help sustainable habits capture large swathes of the population and edge other more damaging habits out of the way?

Shove explores in her research the questions of how new conventions become normal, and what the consequences are for sustainability (Shove, 2003). She works on the supposition that domestic consumption practices are not just a combination of objects and systems of provision, but also intimately linked in reproducing what people are referring to as normal or, for them, ordinary ways of life. More research is necessary to understand how meanings and practices of a range of consumption areas (for resource efficiency especially food, transport, domestic energy use) are taken for granted and how they may change. A focus on practices helps to comprehend the behavioural component behind impacts. Practices may be positive or negative from a material consumption point of view. An example of a positive practice is people separating their waste and bringing this to a waste collecting point. Separation of household waste is well–established in Europe, thanks to special collecting schemes and instruments such as pay-per-bag taxes, leading to reductions in non-separated waste (Husaini et al., 2007). A Norwegian study offered further details into people's motivation and behaviour around sorting. 93% of the people surveyed said they sort their waste to some extent. In Norway, sorting is viewed mandatory and viewed as a contribution to the environment. 73% perceive it as a duty and 16% of the people interviewed found it a pleasant activity (Bruvoll et al., 2002). The study also revealed that 60% of the households clean waste glass with warm water and that often people use their car to bring the separated waste to a waste collecting depot. Both types of practices give rise to negative environmental impacts, showing that we have to consider different practices around the issue of household waste separation. Another telling statistic is that even when people consider sorting a duty, the majority prefers automatic sorting and on average is willing to pay 20$ per year for this.

3.4 Why the social context of production matters

So far the focus of attention in this report has been on consumers and practices. But producer decisions are made in a social context too: that of the organisation, the links with suppliers and users, the strategies of competitors and the wider context of culture and (government-imposed) standards for business operation. Some firms are more inclined to improvements in resource efficiency than others. Dijk and Montalvo (2012) find that the willingness of car manufacturers to develop hydrogen vehicles correlates with their technological and organizational competences to do so. The business case for innovation is interpreted differently by firms. Their attitude towards government intervention also differs: some firms (such as Philips in the case of energy-efficient lightning) welcome regulation; others deeply resent it and engage in lobbying to alter the details of the regulations to which they will be held. In resource-intensive firms (firms for whom material costs are significant), resource efficiency receives a good deal of attention for normal business reasons of saving costs. This does not hold true for companies for whom material costs are a small part of the costs (less than 5%). Rising costs of resources may lead them to give attention to ways of reducing costs from resource use but they may also opt to pass on such costs through higher prices to consumers.

Few companies make resource efficiency an issue for marketing and product choices. The main reason for this is that consumers are not very interested in the resource use element of products. In the case of food and bottled water, there has been a discussion about food miles, but not for other products. There is one case where resource use really got the attention which is the product design principle of cradle-to-cradle, a concept popularised in 2002 by William McDonough en Michael Braungart in their book *Cradle to Cradle: Remaking the Way We Make Things,* which received an enormous amount of attention in the media (television, newspapers). One of the reasons why it got so much attention is that the slogan “waste is food” and the use of biodegradable (and recyclable) materials speak to people. It inspired various companies to incorporate it in their business decisions but sales of C2C products have been discouraging. The carpet company Desso is struggling to make a business model out of it and the same holds true for van Gansenwinkel, a Dutch waste management company interested in becoming a producer of products based on secondary materials. Puma Cradle-to-Cradle Sportswear Line will launch a Cradle-to-Cradle sportswear line of products which are biodegradable or recyclable.[7] It will be interesting to see what those products will do in the market place. So far sales of C2C products have been disappointing.[8]

[7] http://www.environmentalleader.com/2013/02/13/puma-launches-cradle-to-cradle-sportswear-line/

[8] The C2C received several criticisms, which appear well-founded. One criticism is that the C2C concept ignores the use phase of a product. Secondly, consumption of C2C products in a world that is based on fossil fuels is unlikely to achieve a radical decoupling of environmental degradation from GDP. It is also clear that absolute decoupling requires something more than a few C2C products. In the words of Bio Schmidt- Bleek: *I can feel very nice on Michael's seat covers in the airplane. Nevertheless I am still waiting for a detailed proposal for a design of the other 99.99 percent of the*

Environmental NGOs are in favour of products whose resource use is lower than that of comparable products but they do not make the resource consumption (e.g., the weight of products) a prime target of their actions. There is one exception which is conflict-minerals (typically tin, tungsten, tantalum and gold) mined in the midst of armed conflict. Some companies such as Sony Ericsson have integrated conflict mineral management in their supply chain management (Tahara, 2010).
In virtually every company there is potential for resource efficiency improvements. According to a study of DEFRA, around 2% of UK profits in the manufacturing sector are lost through resource efficiency, a figure which corresponds with the cost reduction of 2.3% of annual turnover that was obtained in the DEMEA programme in Germany (EIO, 2012). The Hungarian "Money back through the window" programme finds average savings of 134,000 euro with no investment and 180,000 with payback under 3 years, which is close to the average savings of 210,000 euro per company found in the DEMEA programme). These cost reductions are real cost reductions obtained by the companies and not estimated cost reductions based on research-based resource efficiency potentials. Now an important question for POLFREE is whether or not companies can and will achieve these cost reductions without the help of special audits by external experts. In the DEMEA and Hungarian programme, special auditors went into the companies to do a potential analysis and make suggestions for resource efficiency improvements. The consultants identified in plant material losses, they did a quantitative material flow analysis and offered suggestions for measures to reduce material use. They were also involved in the implementation of the measures and helped companies with finding financial aid. For the consultancy services, companies paid 33% of the costs for analysing, advising, coaching and training if total costs were below 15,000 and 50% if the costs were between 15,000 and 17,550 euro (being the maximum sum allowed by the programme) (EIO, 2012). The audits appear a critical element in achieving the cost reductions, which begs the question whether they are able to achieve resource efficiency benefits without external audits, whether they want to have such audits and how much they are willing to pay for having such audits.
Consumer choices and producer choices are interrelated in various ways. The social practice approach has less attention for the broader interaction of consumption with business strategies, environmental change, regulation, etc. Such dynamic interactions are more the topic of innovation studies, and therefore we turn to these now.

4 Cause-and-effect chains as barriers to resource efficiency

4.1 The classical meaning of 'barrier' toward resource efficiency

Research on energy efficiency has established that actors from all societal domains, i.e. business, government and private households, fail to take full advantage of cost-effective energy-conservation measures (DeCanio, 1998). Investments in energy efficiency measures are lacking. The resulting gap between the actual levels of investment in energy efficiency and the level which would be cost-beneficial for the owner is called 'efficiency gap' (Brown, 2001). A range of 'barrier models' seek to explain the

Airbus 30 after his principles. http://en.wikipedia.org/wiki/Cradle-to-cradle_design It is also remains to be seen that C2C will achieve more than strategies of low consumption, about which Braugart says that they are not necessary. .

existence of the efficiency gap. Weber (1997) offers a review of barrier models regarding efficient use of energy. He suggests a typology of four groups of barriers:

- Institutional barriers: barriers caused by political institutions, i.e. state government and local authorities
- Market barriers or market failure
- Organizational barriers
- Behavioural barriers

Weber distinguishes three features of a barrier: (1) the objective obstacle; (2) the subject hindered; and (3) the action hindered:

- *what is the obstacle?* Persons, patterns of behaviour, attitudes, preferences, social norms, habits, needs, organisations, cultural patterns, technical standards, regulations, economical interest, financial incentives.
- *to whom is it an obstacle*? Consumers, tenants, workers, clerks, managers, voters, politicians, local administrators, parties, trade unions, households, firms, NGO's, etc.
- *for reaching what*? Buying more efficient equipment, retrofitting, decreeing an energy tax, establishing a public traffic network, improving operating practices, etc.

In barrier models, institutional obstacles typically include (as the 'what') political rules, a party or pressure group, a certain department or policy act; these may be (as the 'for whom') a barrier for a single citizen, a social group, organization or whole nation; to reach (as the 'reaching what') more efficient equipment or retrofitting. Weber notes that institutions can hardly be changed by individuals and develop slowly.

Market conditions strongly depend on institutional constraints and prerequisites. In barrier models market obstacles typically include monopolies, lack of information or subsidies; subjects obstructed are mainly individuals and firms.

Models of organizational barriers define firms as social systems influenced by goals, routines, organizational structures, etc. Obstacles in organizations may result from asymmetry of information, a trade-off with non-energy-specific goals or missing responsibility with regard to energy consumption (Cebon, 1992).

Behavioural barrier models focus on individuals with their values and attitudes towards energy conservation. Obstacles regarding behavioural barriers may be lack of attention towards energy consumption, lack of perceived control, etc.

There is a set of implicit assumptions in barrier models which is worth discussing to see the limits of them. They assume that improved efficiency is the result of particular 'positive' action (e.g. buying more efficient equipment); they typically not include stopping with 'negative' actions or adaptation of behaviour. They do not question the purpose or perspective concerning a certain 'positive' action; they just include the action 'technically', implicitly favouring technical solutions. They implicitly assume an objective ideal level of efficiency, and ignore the social shaping of norms. Accordingly, they speak of energy efficiency 'potential' in objective and normative terms, which may be reasonable from a management perspective but this ignores the social practices and perspectives of individuals with total energy use being an unintentional side-effect.

All in all one can question the independence market barriers and behavioural barriers (as distinguished in the typology of Weber 1997), since they interact to such a high extent in practice. A market barrier for the adoption of energy efficiency measures in household equipment is, for instance, that energy issues lack salience in the planning of the household budget since the total cost of energy have a relatively small share in the overall household expenditures. This is particularly true when it comes to buying new equipment. Energy efficiency is not something the consumer purchases as such, but only a characteristic of the bought product (Brown, 2001). Furthermore, it seems that it is not even an important attribute. As Howarth and Andersson (1993) show, consumer behave irrational when it comes to energy efficiency, since they tend not calculate the lifecycle costs of a product, but focus on the (higher) purchase price of energy-efficient products. This shows how fluent the border between market and behavioural factors can be.

In summary, the models on ‘barriers to resource efficiency’ tend to treat barriers in fairly concrete terms and to overcome the barrier typically involves a specific action that needs to be done. This may be true for some cases, but often barriers are part of a complex pattern of interaction (as we saw between market and behavioural barriers), of cause-and-effects in a sector, in which reasonable actions of individual actors, unintentionally add up to aggregate problems. Also, underlying perspectives of relevant stakeholders- firms, consumers - are often kept exogenous to the study, *a priori* speaking of the subject being ‘hindered’ towards more resource efficiency. In the eyes of the stakeholder this may not be the case at all. Subsequently, the social context tends to be treated in a somewhat mechanic way (identify obstacle, delete obstacle, subject will act more efficiently), which will not be as simple as that in practice.

4.2 A typology for resource efficiency and its implications for diffusion

Resource efficiency innovations may be an improvement of what exists, a new product or service or a new system. From the point of view of diffusion (i.e. the ease of it) this makes a significant difference, and therefore it is important to distinguish the various types of eco-innovations. O’Brien and Miedzinski (2013) distinguish four types of eco-innovation based on two dimensions: scope and degree of implemented change, see Figure 6.

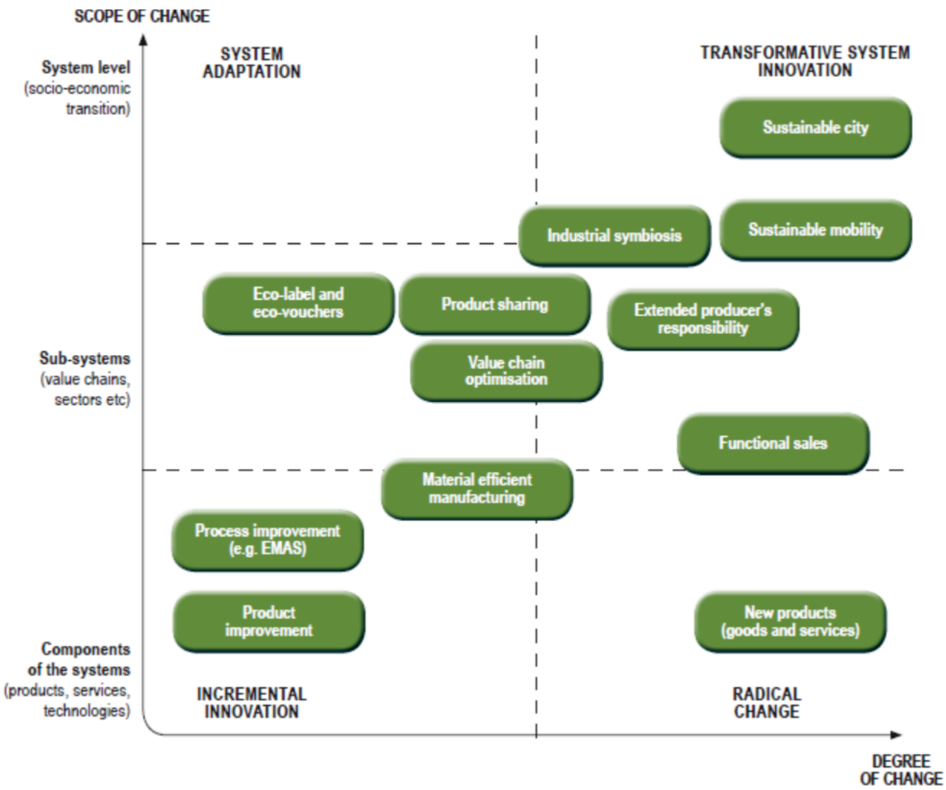

Figure 6: From product improvement to transformative system innovation (Source: O'Brien and Miedzinski, 2013)

A different ways of categorising eco-innovation is the scheme of Kemp (2011), based on a distinction on whether the eco-innovation disrupts or sustains the supply chain and involves an incremental or radical change in technology.[9] The scheme is being used to map eco-innovations of the EACI programme in 4 quadrants.

[9] The scheme of Kemp draws on the scheme of Abernathy and Clark (1985). The terms "disruptive" and "sustaining" come from Christensen. They are not the same as radical or revolutionary. A radical/revolutionary technology may be sustaining when it does not disrupt markets. An example is direct fuel injection in internal combustion engines.

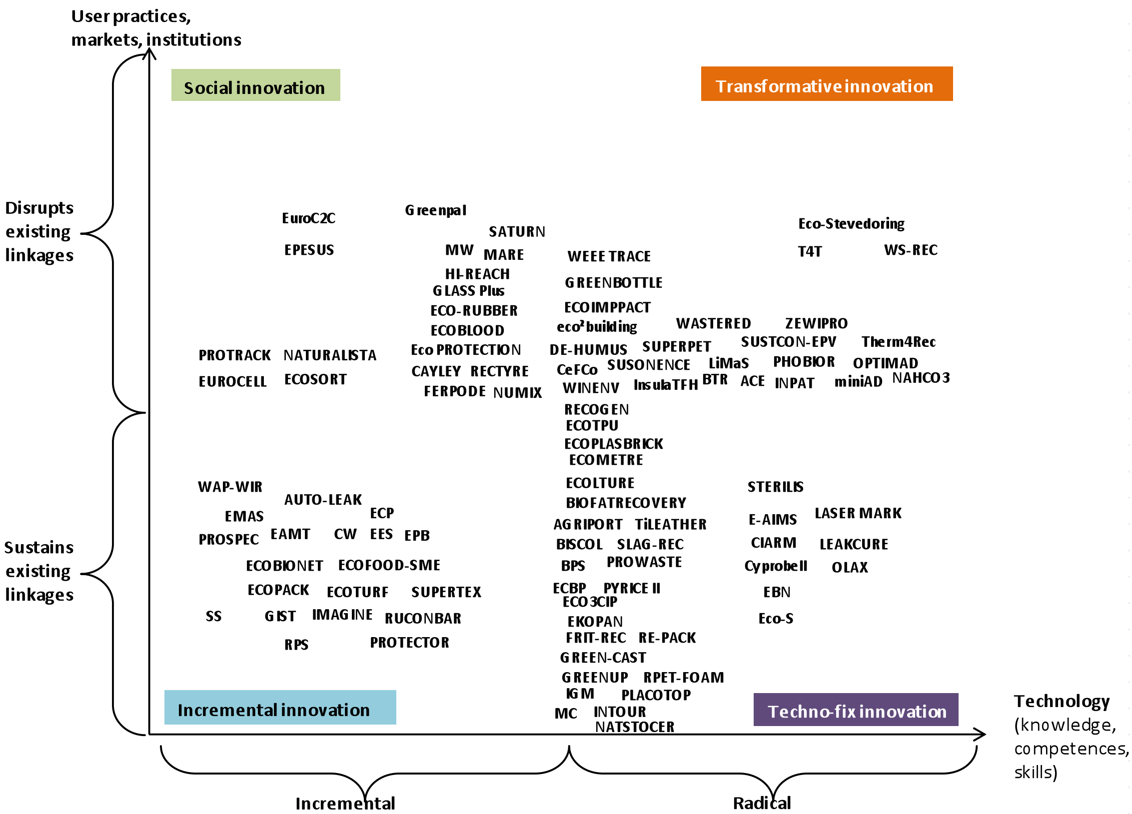

Figure 7: Categorising eco-innovations in the EACI programme

The scheme shows that an innovation may be radical in a technological sense and radical from the point of view of user practices and markets. When an innovation is radical from a technological point of view only, we have a techno-fix innovation. Innovations which are radical from both a technological and market point of view are called a transformative innovation. An example of a transformative innovation is "green bottle": an environmentally superior packaging for liquid consumable products (produced with the help of special moulding machines). Initially, the market for milk was targeted but the retail milk market in the UK is so competitive that supermarkets wanted to buy the product for 7-9 pence (creating an almost unreachable cost target for the innovator), which led GreenBottle to search for other markets (GHK, 2013). Wine, fruit juice, water and personal care products have been being identified as interesting targets. Instead of targeting retailers, the company will target product owners such as Unilever and Coca Cola companies committed to environmental goals and sustainability. The innovation is disruptive from a market point of view (which is dominated by very large companies such as Tetra Pack) but not disruptive from a consumer point of view. An innovation which is radical from a consumer point of view is organized car sharing and carpet leasing. To reach resource efficiency improvement of factor 4-10 across the economy, far-reaching systems change will be needed as well as reductions in consumption (consumption is at the root of resource use). The closing of material loops is an example of a system change that is needed. [10]

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[10] System changes are the most revolutionary (far-reaching) type of change, which have been studied by transition researchers (Geels, 2005; Geels and Kemp, 2006; Geels and Schot, 2007; Smith and Stirling, 2010). They take a long time (2 generations or more) and are the results of processes of co-evolution (Rotmans et al., 2001; Geels 2005).

From the point of view of diffusion it makes a big difference whether or not the innovation requires changes at the supply and demand side and the institutional and regulatory context. When a technology requires complementary assess and institutional changes in the operating context, diffusion will be slow. Many socio-technical innovation studies have adopted the notion of path dependency, and many studies show how systemic mechanisms or network externalities provide advantages to an established regime technology. Path-dependence has been studied in formal models (for example in Arthur, 1989) to show that increasing returns to adoption (positive feedback) lead to the lock-in of incumbent technologies, preventing the take up of potentially superior alternatives (see Figure 8 below). In a later publication, Arthur (1994) specified the feedback loop by referring to four major classes of increasing returns: economies of scale, learning effects, adaptive expectations and network economies[11].

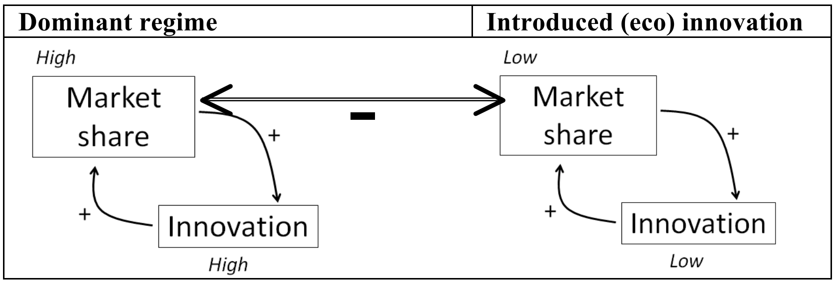


Figure 8: Key dynamics between competing innovations

These mechanisms may suggest that products from an established regime will always have a relative advantage in comparison to products from new regime-disruptive niches, due to scale and learning benefits, and will therefore hardly be overthrown in the absence of mandated (i.e., regulated) changes. In this respect various studies refer to the path dependent character of technological change (e.g. Arthur 1989, David 1985).

Despite the tendency of particular product regimes to serve as the basis for product development and behavioural choices, the record of history shows that regimes also get overthrown or transformed, and therefore that path dependence should be seen as a tendency, but not the whole story. Other mechanisms or factors therefore must play a relevant role in product market developments; ones that do not necessarily favour the established technology and practice. Major ones found in other studies are:

- The attention for particular product characteristics may change due to changes in preferences, social connotation of products and changes in the economic environment (e.g., a change in the oil price).
- Policy interventions may alter the relative costs or benefits for the one technology compared to another one (see Ostlund, 1994)
- Technology spill-over from other sectors may help the technology to go down the learning curve quickly
- Resource scarcity of materials used and other problems in the established technology may drive up prices (Cowan and Gumby, 1996)

[11] The strength of the various mechanisms, or causal chains, differs from the one or the other, also from sector to sector. Some loops are more rapid, such as prices that may fall in the course of a few years, whereas other loops are slow or discontinuously changing, such as the improvement of technological quality of new options.

These findings have implications for the definition 'barrier' towards eco-efficiency. Barriers may be relatively concrete or more systemic, having to do with non-alignment of existing technologies, regulations, user patterns, business models, infrastructures and cultural discourses. Diffusion can be expected to be slow when (1) significant changes at the supply and demand side are needed, (2) social connotation of product technologies is not favourable, (3) firms are making little profits with a new technology, (4) prevailing prices and economic conditions favour the established technology and (5) there is no strong constituency speaking on behalf of the innovation, making it difficult for policy makers to introduce supporting measures for the innovation. If these conditions hold, both suppliers and consumers can be expected to opt for low-cost, incremental resource efficiency improvement options.
According to Ashford and Hall (2011), the most crucial problem in achieving sustainability is lock-in or path dependency which stems from: "(1) the failure to envision, design, and implement policies that achieve co-optimization, or the mutually reinforcing, of social goals, and (2) entrenched economic and political interests that gain from the present system and advancement of its current trends" (p. 270).

5 The interaction of supply and demand and the micro-macro link

The slow or fast diffusion of a resource efficiency innovation is a story of supply and demand. At the supply side, manufacturers produce established and new products. At the demand side we find heterogeneous consumers of different income and lifestyles, equipped with preferences, beliefs and ways of thinking, who may be grouped into consumer segments (see Figure 6).

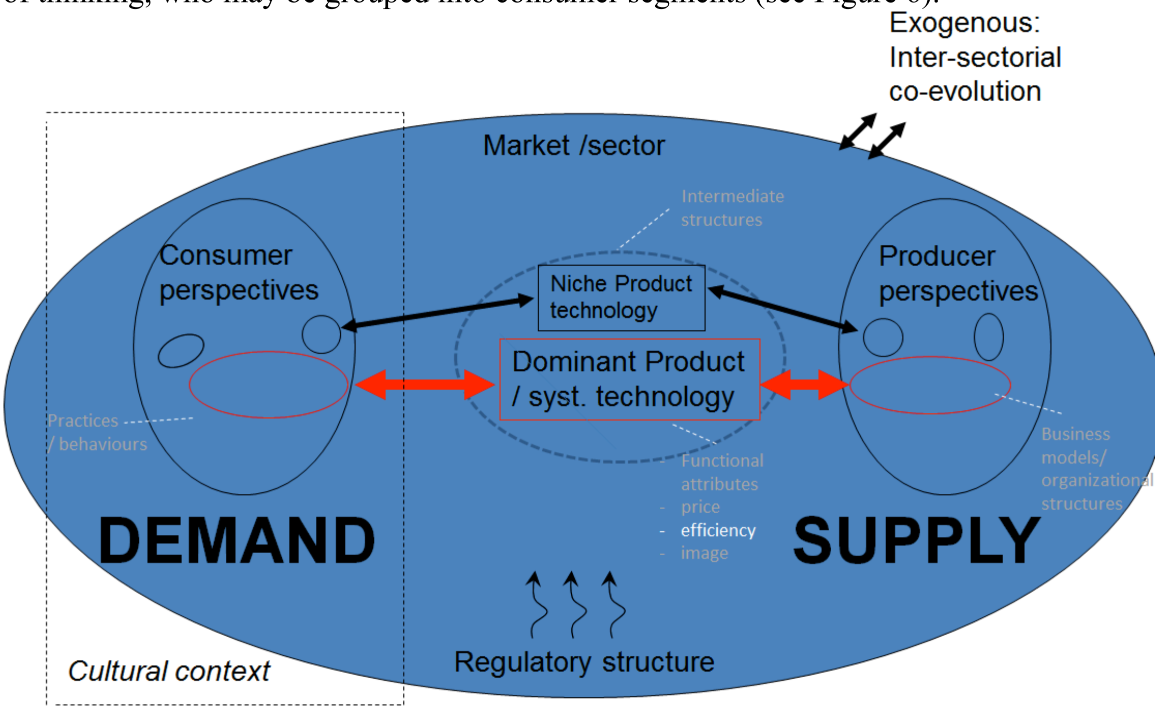


Figure 9: An analytical framework for sectoral innovation and eco-innovation: key variables and relations (with the socio-technical regime in red)

Market prices are important, but certainly not the whole story behind supply and demand. The greater the technological uncertainty, the greater the influence of non-organisational factors (Tushman and Rosenkopf, 1992). Markets are socially embedded and historically determined. Underlying supply and demand we find socio-economic actors, with ways of interpreting, expectations, capabilities, habits, etc Both at the supplier and at the consumer side various forms of learning take place. These forms of learning are interrelated, in the sense that at the very beginning suppliers have to inform consumers about the innovation, but then suppliers themselves gradually learn how to evaluate demand as an innovation diffuses. Learning entails the availability of new skills and knowledge, new social connotations, changing future expectations, new supplier-user relationships, and changes in the regulatory framework. Consumers, by their different ways of interpreting, using and talking about technologies, further contribute to their social shaping. This is part of what some call the domestication process of product into daily life (Lie and Sorensen 1996). Thus, both the technological hardware and the relevant social context change in a complex co-evolution process with evolutionary traits of variation, selection and retention. Diffusion of resource efficiency innovations is governed by endogenous and exogenous changes. Endogenous dynamics may consist of the following six processes identified by Dijk and Kemp (2010).

- *Increasing returns to scale*: cost per unit fall as firms take advantage of economies of scale, allowing them to profitably sell products at lower prices, which stimulates sales and further scale economies
- *Learning about the market*: growing sales lead to better knowledge about the heterogeneity of demand (who prospective buyers are, their willing to pay for specific features, what is valued and less valued); knowledge which may be used for R&D and new product offerings, which will give rise to better products and more targeted marketing effort that will stimulate sales
- *Learning by users*: Potential users must learn about the new technology—its existence, characteristics and consequences for the adopting unit. The information transfer is endogenous to the diffusion process (Rogers, 1983): the more people have adopted it, the better known the solution is and the more it is recognized as a proven, valid solution.
- *Cultural taste formation*: a product may become culturally desirable (fads). Cultural dynamics may stimulate sales (in the case of positive stories and connotation) or discourage them (in the case of negative stories and associated meanings)
- *Learning-by-doing*: production experiences lead to improved skills and discovery of cost-efficiencies in production, allowing manufacturers to reduce prices and increase sales and production.
- *Competition* resulting in more supply, wider distribution, greater variety in product offering and lower costs and prices.

These endogenous processes play concurrently and involve both actor-level factors and micro-macro feedback loops. Endogenous processes interact with exogenous changes such as changes in oil prices, regulation[12] and technological change in other sectors. Figure 10 illustrates the various mechanisms that are operating, showing the complexity that is involved in it.

[12] Regulation is both an exogenous and endogenous factor. Once a resource efficient product is well developed, its producers can ask for supportive action in the form of regulation (as happened in the case of the energy efficient lightning and renewable energy in Germany).

Sectoral dynamics (endogenous)

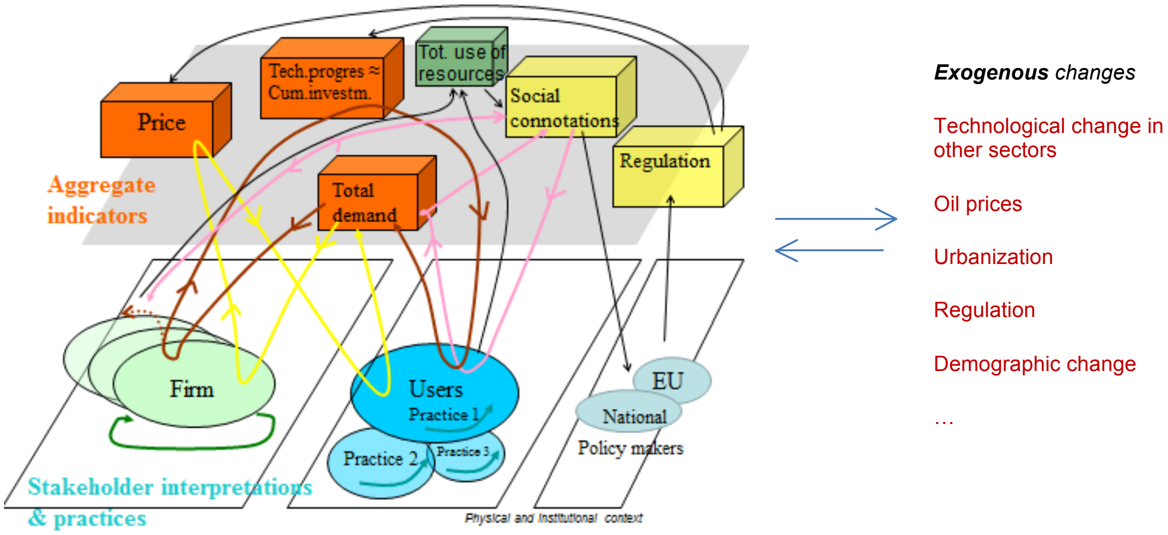
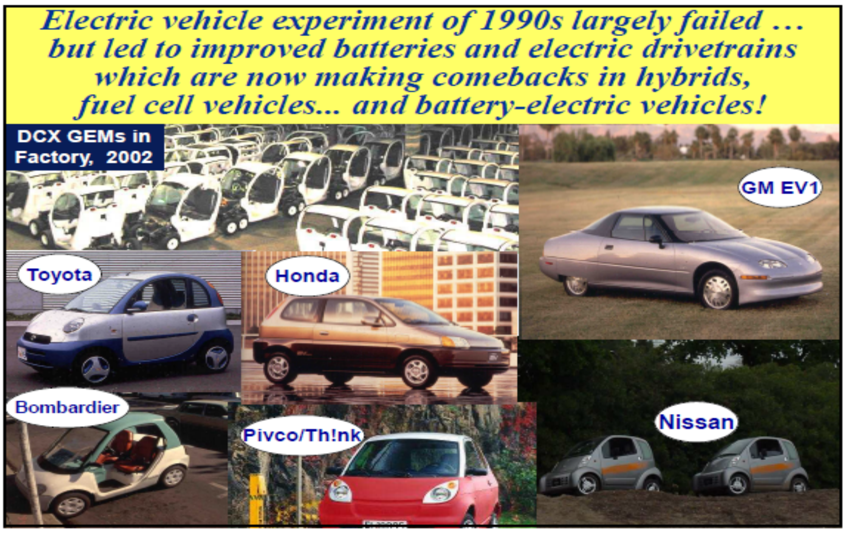


Figure 10: Endogenous dynamics consisting of five processes: increasing returns-to-scale (yellow), learning-about-the-market (brown), learning by users (blue), cultural taste formation (pink), learning-by-doing (green). Also, the role of environmental externalities and regulation is indicated (in black).

Some economic models of innovation have been able to highlight the economic mechanisms well but typically have difficulties to incorporate a changing social and ecological context and competition between products. In this POLFREE project we seek to advance in this direction of integration by highlighting social practices of users as well as causal mechanisms that play a role (interaction effects, co-evolution, rebound effects, causal links) between the users, manufacturers, intermediary structures, the state of the natural environment and regulation. This will help to deepen the study of resource-inefficiency and to come up with novel strategies to stimulate resource efficiency.
The interaction of supply and demand and micro-macro link is different in each sector. For example, the market of recycling (discussed in section 8) differs from the market of consumer goods in terms of the big influence of raw material markets, the need for collection and separation and the buyers being companies instead of consumers. Each market has its own unique aspects. In the case of homes and real estate, split incentives between owners and renters act as a barrier on energy efficiency improvement.

6 An example of negative and positive interaction effects in the market of a low-carbon consumer good: electric vehicles

In this section we examine an example case of complex dynamics: the development and diffusion of full electric vehicles (FEVs). Diffusion of electric vehicles has been very slow. In the early 1990s, a few small companies outside the (high volume) car industry were dominating EV-developments. These niche players adopted a different design for the car body, which depended less on economies of scale and allowed them to be profitable by selling only a few hundred vehicles. Large automakers opted for a low-risk, low-cost strategy of converting existing models into FEVs. For these companies, it has been both more attractive and safer to invest in innovation in the existing ICE technology than in technological options that carry the risk of low consumer acceptance. This yields a pattern in which car manufacturers continuously refine the dominant design in order to improve environmental performance of ICEs (see also Dijk and Yarime 2010).



Picture 4: Various types of EV in the 1990s (source: Sperling 2009)

The only success story of the application of an electric engine is the Prius car, combining a gasoline and electric engine with a short full-electric range, which has sold worldwide more than 4 million times. In the first quarter of 2012, the Prius was the world's third best-selling car, with 247,230 vehicles sold, coming behind only the Toyota Corolla (300,800) and Ford Focus (277,000) (see http://business.time.com/2012/05/29/toyota-prius-niche-car-no-more/).

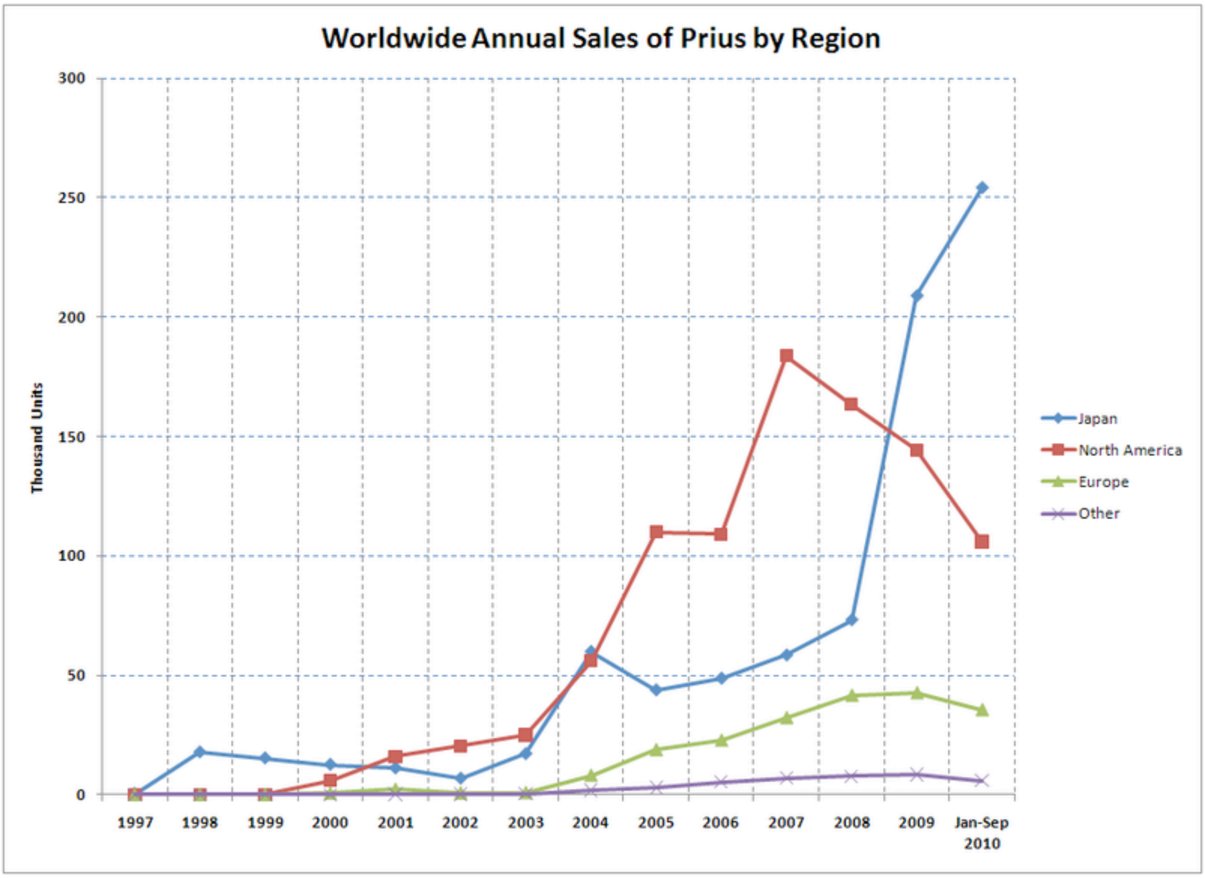


Figure 11: Worldwide sales of the Toyota Prius (Source: http://www.greencarcongress.com/2010/10/worldwide-prius-cumulative-sales-top-2m-mark-toyota-reportedly-plans-two-new-prius-variants-for-the-.html#more)

The momentum for electric mobility has been weak for many decades, but around 2000 this started to change. In the past 10 years almost all major car manufacturers are developing cars with electric propulsion: FEV, plug-in HEV, fuel-cell vehicles (FCV); some (Nissan and Renault) moved from a defensive to a more offensive strategy. The European Commission has stimulated the development of alternative powertrain technologies through R&D programs (mainly via the 7th Framework), and England, Italy, Germany, and Japan introduced subsidies for the purchase of FEVs. Denmark and Israel championed the incentives for FEVs by exempting them of the taxes paid for ICEs. There were also local action plans for electric mobility and various fleetowners became interested in full electric cars (an example is the car2go electric car sharing initiative in Amsterdam). All of this creates a positive momentum of EVs.
At the same time a number of factors still work against electric vehicles"

- High battery costs and short range (only for FEV)
- The current dominance of cultural attachment to *owning* rather than renting vehicles;
- The commitment of car manufacturers to (environmentally improved) internal combustion engine (ICE) vehicles;

- Increasing sales and preference for cheaper ICE cars in emerging markets such as China, as compared to more expense hybrid vehicles;

Figure 12 sketches how different developments in infrastructure, policy, demand and congestion may affect electric mobility (Dijk et al. 2013). The plus (+) and minus (-) signs that accompany the arrows in the Figure indicate influences that promote (+) or detracting (-) the development of different powertrain technologies. It does not include every possible effect, but focusses on what the authors consider to be the most important relations. As the Figure suggests, compared to ICEV, the electric configurations are expected to benefit from the following developments: higher oil prices, better recharging systems, new business propositions such as mobility leasing with battery swapping, urban policies to restrain car traffic and promote clean and silent cars, better systems of intermodality and the cultural acceptance of electric mobility and organised car sharing.
Some of the developments feed each other: car restraining policies can be expected to stimulate intermodality which feeds on car sharing and electric mobility. There are also *balancing developments*: the availability of cleaner ICE vehicles will slow down the diffusion of electric vehicles. Car restraining policies and motorised two-wheeler will reduce congestion and public and private investment in intermodality.

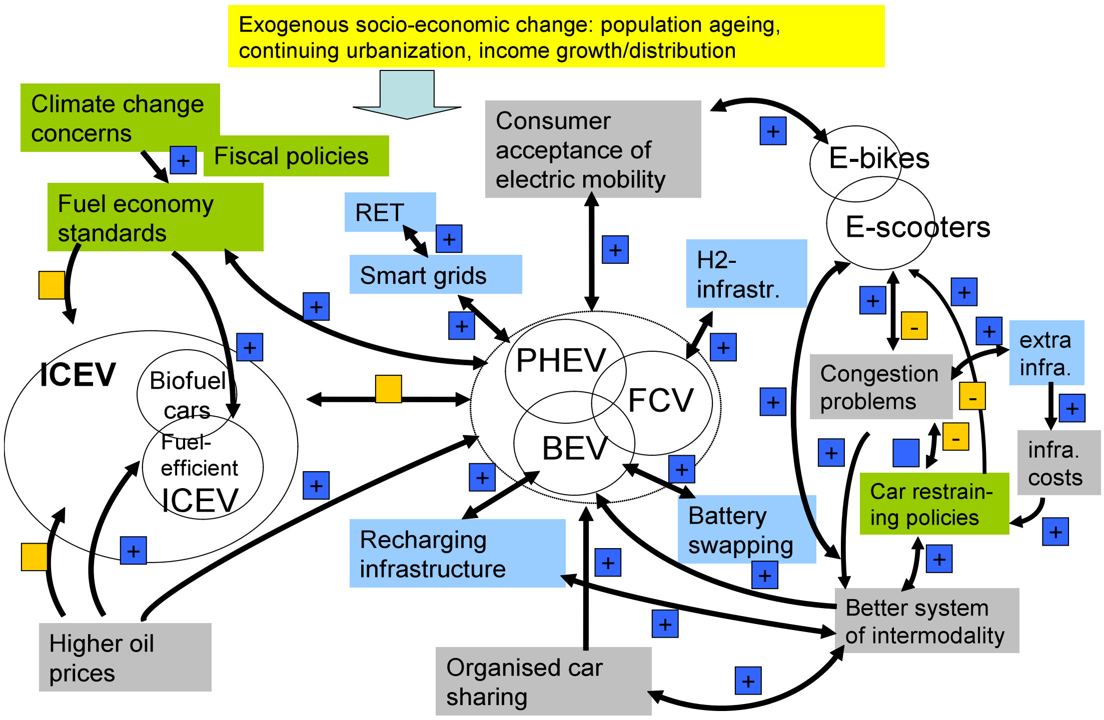


Figure 12: Factors Promoting (+) or Detracting (-) the Adoption of Different Powertrain Technologies and Vehicles (source: Dijk et al., 2013)

The trajectory of electric mobility (electric, plug-in hybrid, hybrid) is not driven by single factors such as price or technological change, but typically involves co-evolution between multiple developments. There has been a spell of activity in electric mobility, especially after 2005, which has to do with the following developments:

1. Climate protection policies and targets that included electric propulsion as a source of reduction of CO_2;

2. FCVs and (especially after 2005) BEVs becoming an icon for zero-carbon vehicles;
3. The peak oil expectation and the unpredictability of future prices which brought attention to vehicles that do not depend on oil;
4. The success of the Toyota HEV Prius in the past decade, showcasing electric drive;
5. Progress in battery technology spurred by consumer electronics sector, helping to lower the costs of EVs;
6. New offers of EVs based on battery leasing and mobility packages such as the one of Better Place, which aroused consumer curiosity and widened consumer choice;
7. The realization by fleet operators and, to a certain extent, by individual consumers that EVs may have lower overall driving costs than ICEs.
8. The economic recovery programmes in the US and Europe which favoured clean technologies, including EVs;
9. Car manufacturers adopting a diversification strategy, including hybrid and pure EVs in their portfolio.

All this suggest that a trajectory of electrification of cars is advancing, as a result of progress in batteries, carbon reduction policies, new value propositions by business, as well by as an increasing positive image of electric drive amongst consumers and policy makers. It remains to be seen, however, whether these developments will lead to a transformation of the regime of individually owned cars, with a more prominent place for hybrids (HEV and PHEV), or whether it will entail a transition to a new regime in which a majority of pure electric cars are used in close combination with other transport modes. Both scenarios are possible.

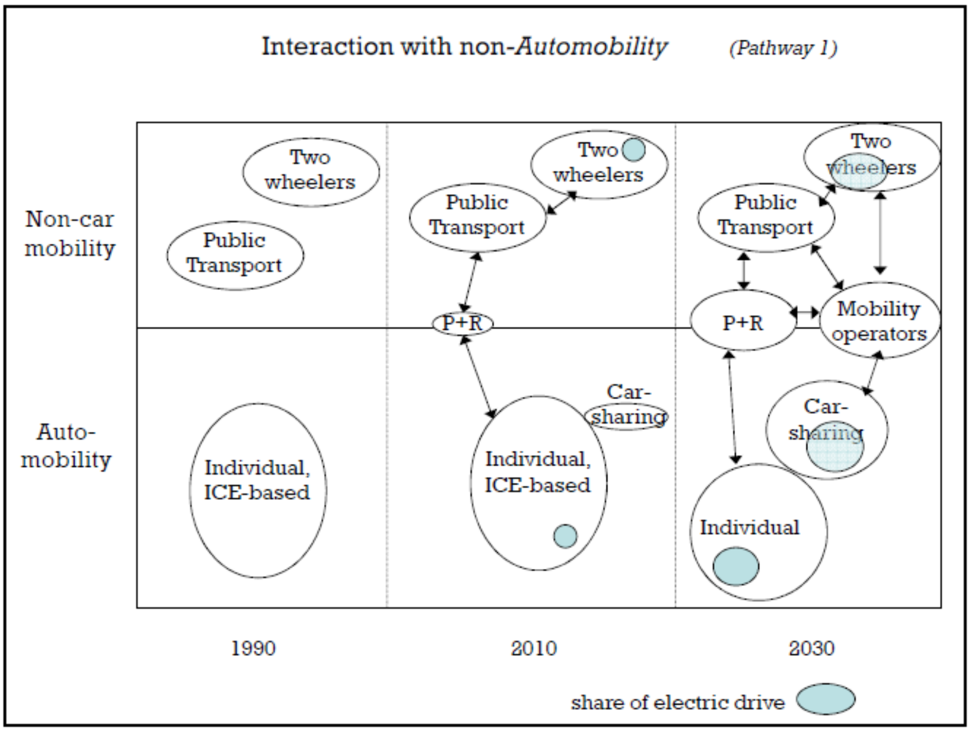


Figure 13. The possible diffusion of electric drive in different mobility segment (source: Dijk et al, 2013)

The resource use of full electric vehicles is a complicated matter as it depends not only on the materials that are being used during production but also on how electricity is produced, the lifetime of the batteries, whether the batteries are being recycled, whether the FEV is used in combination with other modes of transport, and the resource use implications of the money that is being saved and subsequently spend. In the EMInInn project a methodology has been developed to combine LCA analysis with aspects of use (described in Font Vivanco et al., 2013). The greatest reduction in material consumption is when people will be using cars less, for instance when commuting by (electric) bike or scooter. Something like this is happening in the Netherlands, with the help of special promotion programmes and incentives.

7 The markets for commodities and secondary materials

The markets for commodities and secondary materials are special markets in that price developments are subject to cycles of boom and bust. Especially commodity markets are characterised by great price volatility, as shown by Figure 14. The price volatility for commodities stems from the following factors:

- Mine production cannot adapt quickly to meet demand (e.g. it takes 9 to 25 years to develop a large copper project).
- High tech metals are often by-products of mining and processing major industrial metals, such as copper, zinc and aluminium, which means that their availability is largely determined by the availability of the main product (European Commission, 2010).
- Price setting behavior of oligopolistic suppliers and price manipulation by financial speculants. [13]

[13] Between 2003 and 2008, institutional investors increased their investments in commodities markets from 13 billion euro in 2003 to between 170 and 205 billion euro in 2008 (EC, 2011, p. 2). Price speculation is not the driving force behind this but price manipulation is possible for products whose supply cannot be quickly increased.

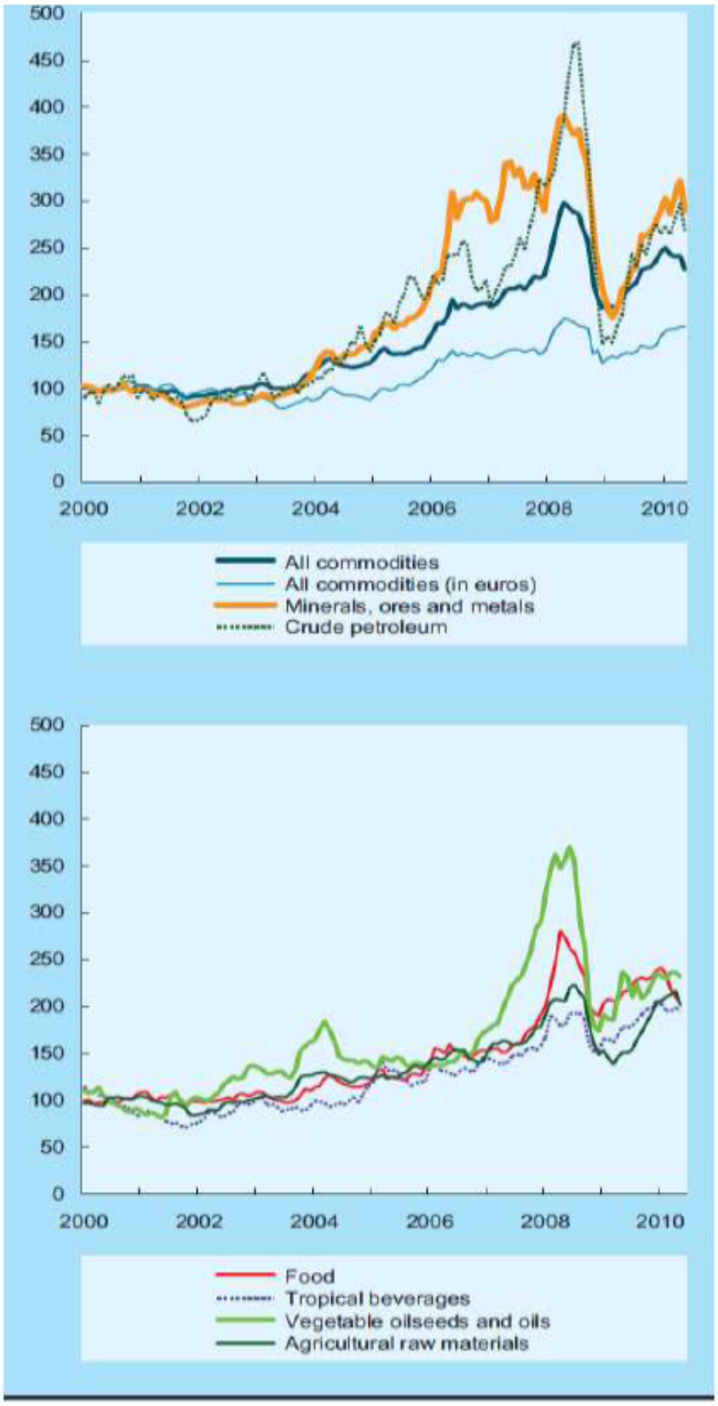


Figure 14 Monthly Commodity Price Indices by Commodity Group, 2000-2010, (2000=100) (Source: Nissanke, 2011 based on UNCTAD (2010b), Chart 1.2 p. 8)

There is also price volatility at the markets for secondary materials as we can see in Figures 15 and 16.

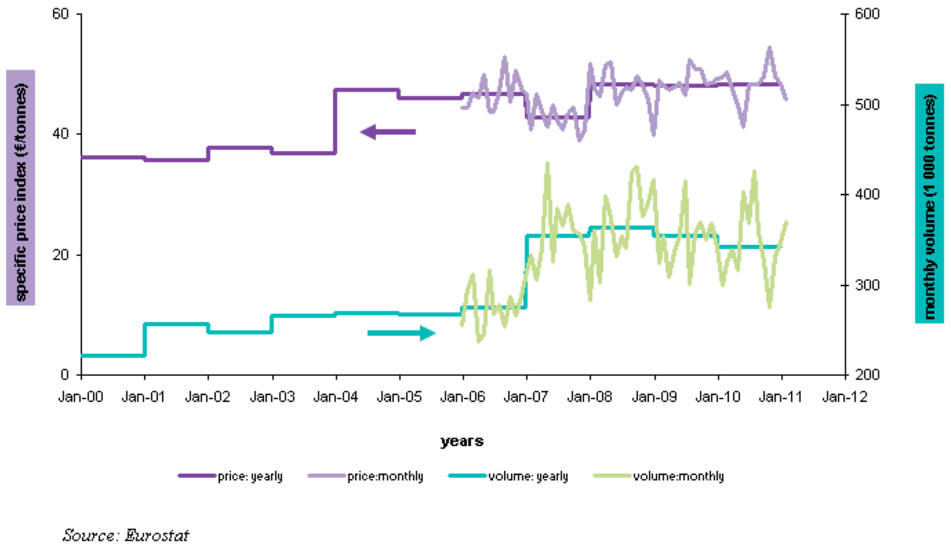


Figure 15. Price indicator and trade volume for glass waste in EU-27 (source: http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Recycling_%E2%80%93_secondary_material_price_indicator)

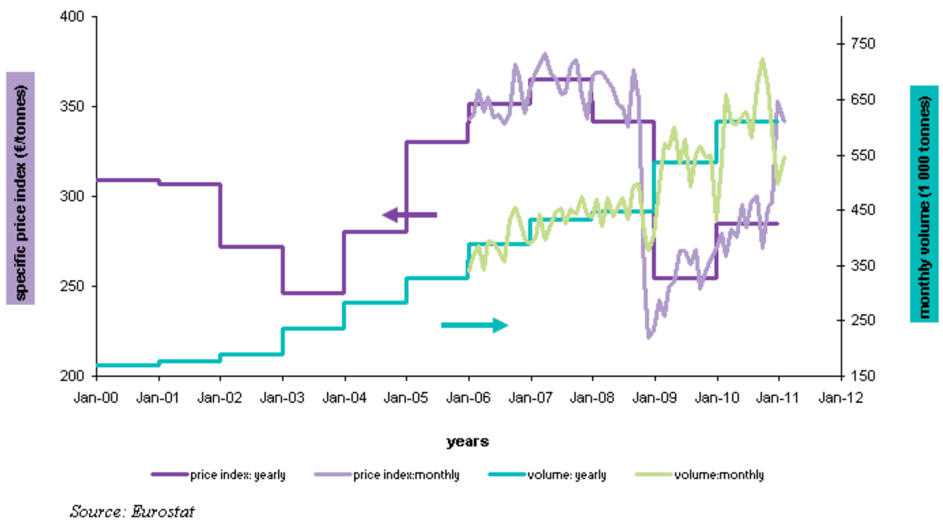


Figure 16. Price indicator and trade volume for plastic waste in EU27 (source:http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Recycling_%E2%80%93_secondary_material_price_indicator)

The markets for glass and plastic waste are very much different from each other, as shown by the differences in prices and traded volumes. Glass is a heavy and low-cost material and most trade takes place in-between neighbouring countries. Markets for paper waste and plastics waste are more international. The price of plastic waste depends on the supply and demand of plastic waste material but also on crude oil prices. Since 2004 the price for plastic waste increased to levels above 350 €/tonnes. From a high of about 375 €/tonnes in October 2008 it fell to about 230 €/tonnes in January 2009 (a price fall of almost 40%). Since then, the price recovered to 300 €/tonnes by the end of 2010. Interestingly, trade volumes recovered more quickly than prices[14]

The economics of recycling depend on the prices for virgin materials, the costs of collection and separation, waste management policies and the way in which products are designed. Landfilling tariffs and bans together with end-of-life regulations give waste a positive economic value, thus facilitating energy recovery, material recycling and re-use of product components. Recyclers require a steady stream of waste and a steady demand (two conditions which are difficult to manage). Incineration overcapacity and low costs for landfilling can undermine waste management systems (such as recycling): "Overcapacity makes it harder for local authorities to source third party waste to 'top up' their incinerator if they were to reduce their own 'residual' waste arisings. This, in turn, leads to excess capacity that results in artificially low gate fees that discourage reduction, re-use, recycling, composting and anaerobic digestion" (http://ukwin.org.uk/2012/08/28/2011-sita-discussion-of-european-incineration-overcapacity/). Same as the markets for raw materials, recycling markets are subject to cycles of boom and bust. The reasons for this have to do with volatile international markets for commodities and discontinuities in waste policies. All this makes recycling an uncertain business and undermines investment and innovation..

Recycling rates vary enormously. Steel and cupper have end-of-life recycling rates of more than 50% (see Figure 17). For most metals the EOL RR is below 1%. The rates have to do with whether the materials are easily recoverable and the value of recovered materials in the market place (UNEP, 2011b, p. 18). Lead in batteries and steel in automobiles are easily recoverable and for this well-established markets exist. When materials are used in small quantities in complex products (e.g. tantalum in electronics) the rates tend to be low (UNEP, 2011b, p. 18).

Various policies exist to promote. The most important type of policy is mandatory recycling rates. Another important policy is deposit-refund schemes. A deposit-refund system consists of an extra fee applied on the price of a product or its packaging which can be refunded once the product is returned. Bfore the expansion of one-way bottles in western economies deposit-refund was the norm (e.g. in 1947 in the US, refillable bottles had a 100% market share (Vaughn, 2009). For containers of gas for heating and cooking a deposit-refund still exists (Fitzsimons et.al 2011). A widely recognized problem for deposit-refund systems is that they impose high handling costs on the agents that carry out the take-back. Storing in particular has very high opportunity cost because a lot of space is occupied by empty containers, which are a less profitable business than other consumer products (Walls, 2011).

In Europe there are very few examples of large scale deposit-refund systems which arise voluntarily; much of the experiences instead are responses to legislation and government intervention. Ways in which government intervenes are numerous. In Denmark refillable containers are mandatory, while in Finland the fiscal leverage is used to achieve certain targets in reuse. Germany built its policy by supporting an already well structured deposit-refund system, through reuse quota which sets targets to be met, and a mandate to charge a deposit if the producer takes part to a licensed collection system. Waste management policies in the Netherlands are designed to make the disposal of recyclable wastes prohibitively expensive or illegal. The existing deposit return systems for refillable bottles are maintained by implied threat of legislative intervention (Fitzsimons et al. 2011) .

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[14] (based on http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Recycling_%E2%80%93_secondary_material_price_indicator).

Mandatory deposit-refund systems may trigger innovation at the supply side. The introduction of reverse vending machines (vending machines that recognise bottles which belong to the deposit-refund scheme, and automatically collect, stack and refund the bottles) is a clear example of this. Systematic information about consumer attitudes towards deposit-refund schemes is difficult to find. Culture seems to play a significant role. It is not just a coincidence that countries who have implemented deposit-refund schemes (Scandinavian and Continental European) are also the countries with a stronger recycling tradition and with a historically build and solidified participation to such schemes. Finland's case here is the perfect example. Their low population prevents the recycling industry from achieving significant economies of scale in recovery of waste. Efficiency and prevention have historically been the focus in Finland's waste disposal. This helped consolidate a strong culture in favor of recycling; just regarding the deposit-return scheme (which is not mandatory but encouraged through tax exemptions), the return rate in 2001 was of 95%, a level comparable to Denmark's and Germany's which have stricter mandatory rules on deposit-refund (Hiltunen, 2004).

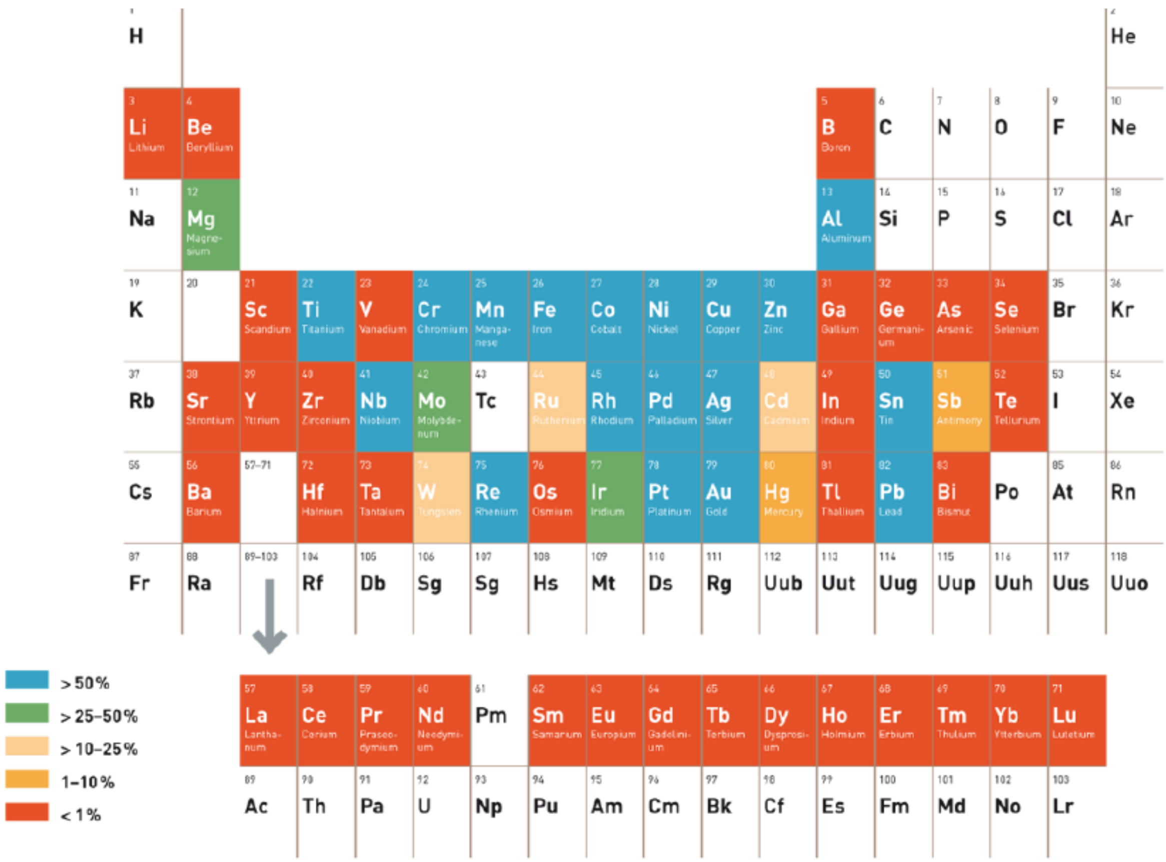


Figure 17. End of life recycling rates for metals (source: UNEP, 2011b, p. 19)

Between member states there are enormous differences in waste management in general. In Germany and Austria no bio-degradable municipal waste is landfilled. An overview of recycling of municipal waste can be found in Figure 18. Between 2001 and 2010 levels of municipal waste recycling increased in almost all European countries, with Austria and Germany having the highest recycling rates (above 60%).

Figure 18. Municipal waste recycling rates in 32 European countries, 2001 and 2010 (source: EEA, 2013, p.13)

Differences in landfilling have to do with national policies such as bans for landfilling for certain types of waste (e.g., biodegradable waste or non-pretreated municipal waste) and the costs of landfilling which depend on landfill taxes. In general, countries using a broad range of instruments have a higher municipal waste recycling rate than countries using very few or no instruments (EEA, 2013, p.6).

There is no legally binding EU limit on landfilling of municipal waste but the EU's Landfill Directive (EU, 1999) stipulates that all EU Member States reduce the amount of biodegradable municipal waste landfilled (EEA, 2013, p. 22). The Landfill Directive was passed in 1999 and lays down a set of long-term and intermediate targets for reducing the amount of biodegradable municipal waste landfilled. It says that by 2006 countries must reduce to 75 % of the amount they generated in 1995, with targets of 50 % by 2009 and 35 % by 2016 (EEA, 2013, p. 22).

The above discussion shows that the markets for primary materials and secondary materials are related with each other. Recycling markets depend on separation, sorting and collection of goods containing materials for recycling, prices for secondary materials and government regulations and taxes. They also depend on the costs of energy because recycling uses energy. The markets for energy, primary and secondary materials, waste, water and land are related with each other in complex ways and one of main goals of the POLFREE project is to study the interrelations with the help of models. Strong links exist between power generation, fossil fuel prices, water consumption (and land use in the case of biofuels). Price increases in materials affect the costs of renewable energy technologies. The costs of materials depend on the elasticity of supply and prices of secondary materials which in turn depend on separating and sorting systems and government policies.

Recycling also depends on the way in which products are designed. So far few products are designed in ways that ease disassemble and reuse. It was hoped that the extended producer responsibility would lead manufacturers to redesign their products but this hoped-for effect did not occur. The trend towards the use of composite materials in products in fact complicates recycling, because they can't be easily separated. An example is milk and juice cartons that come with circular pour spouts and caps built into the side, making recycling nearly impossible. The only way to recycle these is for users to cut the plastic spout from the rest of the container before placing them both in a recycling bin (from http://www.atissuejournal.com/2010/03/31/design-for-disassembly/). But even if the products were designed differently, based on design for disassembly principles (which are well-established), there is no guarantee that this will happen. One reason for why products are not designed in ways that allow for easy disassembly and recycling is that designers and people in the waste sector belong to different worlds with altogether different concerns (Ordonez and Rahe (2013). The practice of waste incineration also works against it. There is no purpose in designing products for disassembly if they end up in the waste incinerator. This is all part of what we have called the web of constraints.

A challenge for the POLFREE project is to integrate aspects of product design, behaviour (which differs among people and nations), government policies, institutions and co-evolution in the analysis of interdependent markets for materials. Another challenge is to examine the international aspect of primary materials and secondary materials. For secondary materials trade restrictions exist for export. The EU forbids the export for disposal operations outside the EU except for EFTA countries [15]. Raw materials are to be freely traded but "increasingly countries are pursuing strategic policies to secure access to raw material deposits worldwide, while at the same time restricting access to their domestic raw material markets at the expense of raw materials importers. This is for instance the case for highly specialised metals and minerals, such as rare earths, lithium and platinum group metals (platinum, palladium and rhodium). These materials are needed for the development of technologically sophisticated products, which are critical for low-carbon / 'green' technologies" (from http://www.wto.org/English/res_e/publications_e/wtr10_forum_e/wtr10_18may10_e.htm)
Typical measures include[16]:

- Export taxes and restrictions such as: export duties, export quotas, non-automatic export licences;
- Discriminatory taxation systems to prevent the export of raw materials or to favour domestic sales;
- Dual pricing or price-fixing of energy and raw materials;
- Strategic raw materials sourcing through state owned enterprises;
- State aid or unfairly subsidised export credits;

[15] Regulation (EC) No 1013/2006.
[16] Source: http://www.wto.org/English/res_e/publications_e/wtr10_forum_e/wtr10_18may10_e.htm

- Restriction of investments, including through unfair use of the definitions such as strategic sectors and national security;
- State interference on local commodities exchange to lower prices for domestic industry.

The same source also reports that “in 2007, the European Commission identified around 450 export restrictions on raw materials, which were applied by roughly one-third of WTO members”. Complaints can be filed at the World Trade Organization which has been set up for the purpose of safeguarding free trade. It is not clear how trade restrictions for raw and secondary materials affect resource efficiency and productivity but they appear a relevant issue and it is proposed therefore to incorporate this into the modelling analysis within the POLFREE project.

8 Policy and multilevel governance as determinants of resource efficiency

In the EU, we don’t have specific policy frameworks for resource efficiency with targets and regulations. Many environmental policies can be considered de facto resource efficiency policies:

- Energy efficiency product regulations and labels
- Climate policies that seek to reduce fossil fuel use and greenhouse gas emissions
- Compulsory recycling targets
- Landfill taxes and bans
- Extended producer responsibility for recycling and re-use.

Resource efficiency is a flagship initiative of the European Commission, which has produced a road map to a resource efficient Europe (EC, 2011). In the roadmap various visions for 2020 are being formulate. One vision is that “*by 2020 waste is managed as a resource. Waste generated per capita is in absolute decline. (...) More materials, including materials having a significant impact on the environment and critical materials, are recycled. Waste legislation is fully implemented. Illegal shipments of waste have been eradicated. Energy recovery is limited to non recyclable materials, landfilling is virtually eliminated and high quality recycling is ensured* (EC, 2011, p. 8).

In terms of governance, it is being said that “transforming the EU into a more resource efficient economy will require concerted action across a wide range of policies” (EC, 2011, p. 19).

The following actions are being announced in the roadmap to a resource efficient Europe:

The Commission will (EC, 2011):

- Launch an "EU Resource Efficiency Transition Platform"(2012), building upon the work of existing platforms;
- Set up a Resource Efficiency Finance Round Table, including representatives from private and institutional banks (such as the EIB, EBRD), insurance companies and venture capital companies, to identify opportunities to develop adapted finance and use innovative financial instruments for resource-efficiency (2012);
- Develop an EU Skills Panorama and a European Sector Council on skills for green and greener jobs;
- Continue work on indicators, including the quality of the data, taking stock of existing assessment frameworks, such as iGrowGreen, with a view to inclusion in the mid-term review of the Europe 2020 strategy (2013);

- Propose a new lead indicator on natural capital and environmental impacts of resource use (end of 2013);
- Continue its efforts under the "GDP and beyond" road map to measure societal and economic progress more comprehensively, inter alia by continuing the development of the system of environmental accounts, further integrating environmental externalities into national accounting and developing a composite index on environmental pressures;
- Consider how best to include resource efficiency considerations in the impact assessments of future policy proposals.

Member States should:

- Develop or strengthen existing national resource efficiency strategies, and mainstream these into national policies for growth and jobs (by 2013);
- Report their progress on resource efficiency as part of their national reform programmes.

Much is expected from targets, indicators, platforms for coordination and innovation. No policy actions are being proposed in terms of regulations for achieving an absolute reduction in resource use. Most likely at some point in time policy recommendations will emerge but it remains to be seen how potent the proposed policies will be.
The EU plans to engage in a “raw materials diplomacy” towards non-EU trading partners, especially in Africa, and wants to reinforce the “Raw Materials Trade Strategy”. Ideas for how to do this are described in the Communication “Tackling the Challenge in Commodity Markets and on Raw materials”, where it is being said that the Commission considers that the EU should:
continue to develop bilateral thematic raw materials dialogues with all relevant partners, and strengthen ongoing debates in pluri – and multilateral fora (including e.g. G20, UNCTAD, WTO, OECD); carry out further studies to provide a better understanding of the impact of export restrictions on raw materials markets, and foster a dialogue about their use as a policy tool.
further embed raw materials issues, such as export restrictions and investment aspects, in ongoing and future EU trade negotiations in bilateral, plurilateral and multilateral frameworks.
pursue the establishment of a monitoring mechanism for export restrictions that hamper the sustainable supply of raw materials, and will continue to tackle barriers distorting the raw materials or downstream markets with dialogue as the preferred approach, but using dispute settlement where justified.
encourage in OECD activities the inclusion of relevant non-OECD members in the work on raw materials, and explore further multilateral and plurilateral disciplines including consideration of best practices.
use competition policy instruments to ensure that supply of raw materials is not distorted by anti-competitive agreements, mergers or unilateral actions by the companies involved.
(EC, 2011, p. 18)
Again, much is expected from dialogue, certification and greater transparency. Instrument aspects for delivery are not worked out.
Between countries there exist differences in policy styles, differences in the political-institutional context in which policy decisions are made and differences in actions and instruments (see Figure 19).

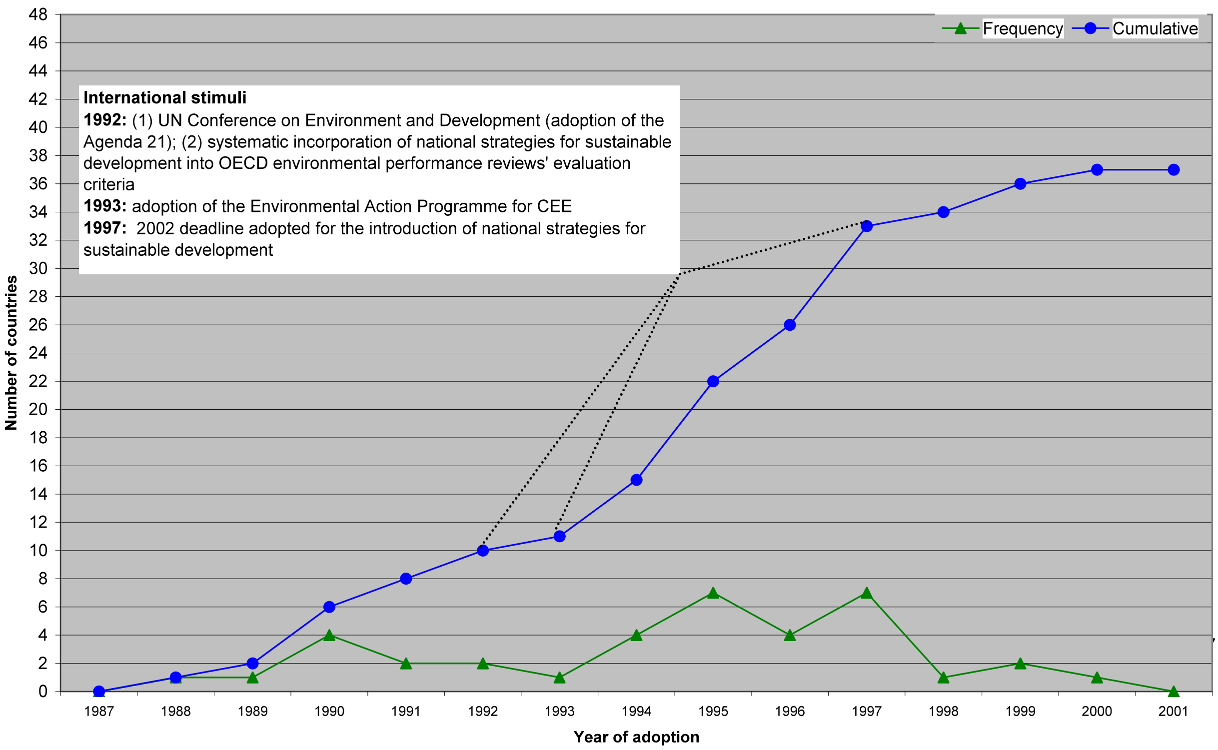
Policy style	Political-institutional context of action	Actions and instruments
• Form of target setting • Flexibility in applying the instruments • Timing of the measures • Orientation towards consensus • Legislation, bureaucratisation • Calculability	• Competence and the influence of the regulating body(s) • Role of other policies their integration • Relation between regulators and regulatees • Role of non-governmental environmental institutions	• Dominant instrument in the mix • Degree of determining behaviour • Punctual versus strategic approach

*Figure 19. Policy patterns (*source: IPTS, 2007, p. 8, based on Jänicke, 2000)

Haverland (1999) studied policy approaches in Germany, the Netherlands and the UK to reduce packaging waste. Germany opted for an ordinance, keeping in with the regulatory tradition, The Netherlands as a consensus-seeking nation for a covenant and the United Kingdom for industrial codes of practice (determined by industry). Of the three countries, the UK had the least formalized and ambitious approach, leaving it to industry to take action (Haverland, 1999). Such differences extend to other areas and are highly persistent, acting as constraints on policy.

Even when national develop different approaches to dealing with environmental problems, we can also observe an element of policy diffusion, with nations adopting similar policy instruments and strategies. For example, the Dutch Environmental Policy Plan of 1989 served as a model for similar initiatives in other European countries and also for the European Union’s Fifth Environmental Action Programme (Holgers et al., 2002). For CEE transitional countries the Polish “National Environmental Policy” of 1991 became the model for adoption. Diffusion of policy innovations also depends on international stimuli (see Figure 20). For example, international norms, like the “Toronto goal” and later the UN Framework Convention on Climate Change have stimulated national emission reduction goals which induced further national efforts to adopt concrete policy measures—like energy/carbon taxes—to ensure goal achievement (Ibid, p. 18). These examples show that international organisations and trans-national advocacy networks can act as agents of policy diffusion.

Figure 20: Spread of National Environmental Policy Plans and Strategies for Sustainable Development in OECD-Countries



and Central and Eastern Europe (source: Busch and Jörgens, 2002, quoted in Tews et al. (undated)

A comparison across policy initiatives learns that policy diffusion is relatively quick for national environmental policy plans and strategies for sustainable development and eco-labels but slow for redistributive policies such as energy and carbon taxes (see Figure 21). First ideas for emission trading were developed in 1968 by a Canadian policy scientist. Elements of emission trading were introduced in a number of programme in the US but the first real application was the sulphur dioxide cap-and-trade programme in 1990 in the US, which was part of the acid rain programme. The first time use proved the viability of the instrument but diffusion has been relatively slow. Emission trading was much discussed during the UN Kyoto protocol and give rise to several initiatives for carbon trading, the most important one being the EU ETS system introduced in 2005, operating in the 27 EU countries, the three EEA-EFTA states (Iceland, Liechtenstein and Norway) and Croatia, and currently in its third stage.

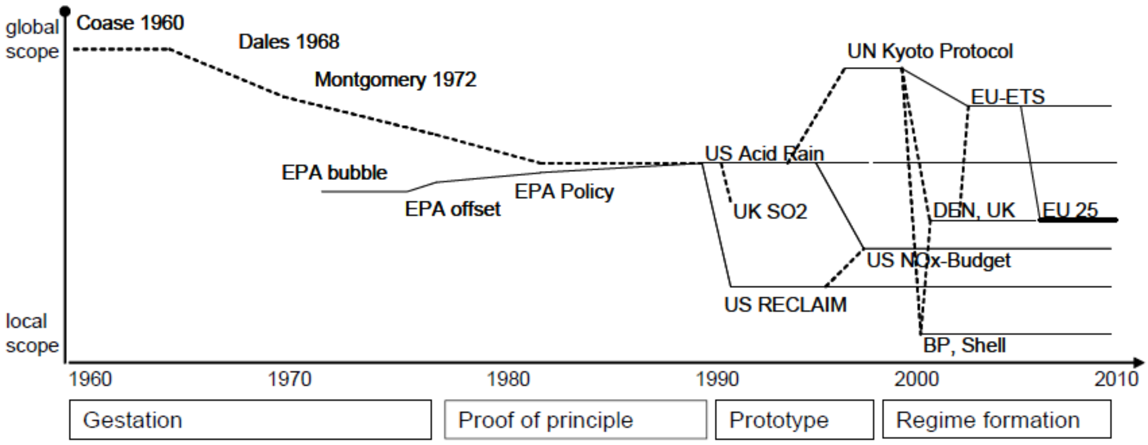


Figure 21. The emissions trading's innovation journey (source: Voss et al., 2007, p. 332)

The diffusion of energy/carbon taxes has been particularly slow in new Member States (Tews et al.). Another relevant finding from the literature on policy diffusion is that policy innovations which fit with existing structures can be expected to be spread faster than those which conflict with traditional regulative structures and policy styles (Kern, Jörgens and Jänicke 2001: 11-13).

A key insight from the policy literature is that government does not act independent from society. Issues about which certain societal groups care strongly will receive more attention from government than those on which society does not care about a lot. The reality of the moment is that resource efficiency is not something that society cares about a great deal. Waste management policies were driven by opposition to landfill sites, which led policy makers to search for waste streams that were easy targets for policy. Packaging waste was an easy target in that the waste was relatively homogenous, offering low-cost opportunities for re-use and recycling.
For resource efficiency policies a convincing rationale is needed. One rationale is that the EU as a big net importer of materials and energy suffers from security of supply risks which are especially troublesome for energy and a list of 14 critical raw materials (listed in Appendix A). A second possible rationale is that resource efficiency helps to save money and generates jobs. A third rationale is that resource efficiency is

a necessary component of sustainable development. These rationales are not controversial but the EU lacks strong constituencies speaking on behalf of them.

For consumers, resource efficiency is very much a non-issue. People are attracted by the idea of cradle-to-cradle, but in general resource efficiency is not a salient attribute of a product for consumers, and neither is energy efficiency despite information campaigns about cost savings from reduced energy use. Resource efficiency is well-institutionalised in resource intensive companies who have developed capabilities and programmes for reducing material consumption primarily for cost-saving reasons (for resource-intensive firms resource use is an important cost factor). For product choices, thus far resource efficiency is a minor goal for innovation and the crucial issue is how to make resource efficiency into an important consideration for consumers. People care about people, about animals and they care about the quality of air and water; they don't care about resources as such (leading them to disregard how much they consume and what is done with a product at the end of its product life). Unless a clear and appealing rationale for policies for resource efficiency can be found and formulated, policy action is going to be difficult. Resource efficiency has to resonate with societal values and pressing concerns. An interesting case of resource efficiency becoming a salient issue is the "Days without meat" campaign in Belgium and the Netherlands.

Discovering that the production of meat requires a large amount of resources and gives rise to large amounts of greenhouse gas emissions, a 22 year old woman in Belgium started a campaign to eat less meat. Alexia Leysen had read that 1 kg of beef required 9 kilos of food, 1500 liter of water and that meat consumption causes more greenhouse gas emissions than the entire transport sector is emitting". She started a campaign to eat less meat during a period of 40 days,[17] which received a great deal of attention from newspapers and television and resulted in 14,647 people agreeing to eat less meat during 40 days (between Febr 13 and March 30 2013). The campaign relied on the use of metrics ("every vegetarian day reduces your ecological footprint with 11 m2, saves 1000 liter of water and 2 kg of GHG emissions") and benefited from celebrities that supported the initiative and from media attention (including national television). The issue of resource use became framed as a personal issue, of making a difference to the world and being a responsible person. People were invited to make a difference through statements such as "the supermarket is our Nahrir square". At a special website people could indicate their participation. Resource efficiency was being linked to identity creation, a storyline of making a difference and challenging yourself (achievement). There was no discussion of money being saved by eating less meat. Meat consumption was not portrayed as something diabolic. Also modest reductions were considered positive.

It is an example of a successful campaign the results of which in terms of reduction in resource use still have to be evaluated. It shows the potential power of normative and affective factors, and demonstrates that people have normative/social values (Etzioni, 1992, pp. 49-50). It seems unlikely that resource consumption in general becomes a deep moral issue.

Environmental economists have long debated the pros and cons of different policy instruments (overview articles are Jaffe et al. (2002), Ekins and Ven (2006), Vollebergh (2007) and Kemp and Pontoglio (2011)). Much of the discussion is about whether market-based instruments are better suited to promote innovation in pollution abatement and prevention than regulation is.[18] The focus of the discussion is on

[17] The duration is equal to the fasting period or Lent (as an old cultural frame and practice).
[18] An important conclusion is that the impacts of a policy instrument may depend more on design features than on the type of instrument chosen (Kemp and Pontoglio (2011). Relevant aspects of design are: stringency; predictability; differentiation with regard to industrial sector or the size of the plant; timing; the credibility of policy commitments to

instruments, and less on the capacity of policy makers to craft useful policies for sociotechnical change, the politics of policy making processes, ideological beliefs, interaction effects between different instruments and how environmental issues are linked with issues of trade, health, governance, law and finance (cf. Ashford and Hall, 2011). For POLFREE it is proposed to give special attention to those issues, for example, by examining the following questions[19]:

- How was it possible for government to introduce powerful policies (what circumstances made this possible, how were the policies framed to gain acceptance, how were powerful actors enrolled and resistance overcome)?
- How to avoid minimalist solutions?
- How to build capacity for standard setting for resource efficiency and energy transitions?
- How to deal with uncertainty, conflicting claims and evidence?
- How to generate positive external economies and self-propelling processes of change?

9 Main conclusions

1. Resource efficiency innovations can be incremental, radical or systemic. They can be technological and social or a combination thereof. They can disrupt or sustain value chains and user practices.

2. Innovations in resource efficiency can be measured on the basis of price and performance indicators and described in terms of the perceptions and meanings of actors. For understanding resource efficiency choices it is important to consider the objective and subjective nature of an innovation and waste reduction opportunity. If companies start to see waste as a waste of resources they can be expected to act differently than when they see it just as waste.

3. Resource efficiency is an attribute of technological systems or products, but what matters is whether it is a significant attribute *in the eyes* of consumers and firms. At the moment, for few consumers and firms resource efficiency is an attribute of great importance; other characteristics (functional ones and status and identity aspects not having to do with greenness or resource efficiency) are usually more important. As an illustration of this point, the overwhelming majority of consumers are not asking questions such as:

   - *How much materials have been moved to create the product?*
   - *What materials are being used in my smart phone?*
   - *How much kilometers did product components travel before reaching me (product miles)?*
   - *What is the resource efficiency of my product?*
   - *Will the materials of this product be recycled?*
   - *What can I do to make sure that materials are not wasted?*

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future standards; possibilities for monitoring compliance and discovering non-compliance; enforcement (inspection and penalties for non-compliance) and combination with other instruments of policy.

[19] Answers to some of the questions are given in Mytelka et al., (2012).

4. Households do engage in waste separation and viewing separation as something responsible. Something similar is true for companies. A challenge for resource efficiency policy is to make resource efficiency culturally salient, besides making it more economically attractive.

5. The perspectives of producers on innovation whose environmental impact is lower than of present alternatives are also far from homogeneous. Some firms are more inclined to make improvements in resource efficiency than others. The willingness of firms depends on internal factors but also depends importantly on external factors: resource prices, waste management costs (which depend on waste policies), customer wants and competition from other companies across the world.

6. The example of the incandescent light bulb shows that regulation is not something autonomous but part and parcel of the social context in which demand and supply are embedded. The introduction of it was helped by a big European company (Philips) being in favour of the ban. When regulations affect citizens directly, they are usually against it. The London congestion charge is an example in which (market-based) regulation was originally strong resented, but widely appreciated when eventually implemented and showing effects.

7. Resource efficiency has an impact mostly through the factor of 'cost' in business models of firms. Various studies have indicated that companies can reduce material costs through measures which are not expensive and have payback times of less than 3 years. Whether companies will utilise such opportunities is unclear. It requires attention, analysis and low transaction costs (as well as low opportunity costs) on the part of companies.

8. It is common to consider resource inefficiency from the viewpoint of concrete barriers. Two examples of a barrier are lack of attention and split incentives between owner and renter of a building. The examples of energy-efficient lightning and fuel-efficient cars show that the slow diffusion has to do with consumer preferences but also with product offerings and slow introduction of policies to discourage the use of incandescent light bulbs. Instead of the notion of barriers we think it is better to think in terms of a "web of constraints" acting as a blocking mechanism. Likewise, instead of a single driver we should think in terms of multiple drivers creating a positive inducement mechanism when they support each other. Positive stimuli interact with negative ones.

9. In our analysis of barriers, we propose to given attention to the following questions:
    - *why does the barrier exist* (where we look for deeper explanations than "high costs" or 'habits' through an examination of webs of constraints)
    - *why is it a barrier for some and not for others* (getting us into the heterogeneity of the population of potential adopters),
    - what *attempts* have been made to *eliminate barriers*, with what success, giving us insights into the hardness of constraints and the identification of interventions that make a difference, and
    - *how are the barriers affected by the evolution of various developments upstream and downstream and in neighbouring fields.*

10. Our barriers analysis should help us to better understand interaction effects between various factors, to consider actor-based heterogeneity and to examine contextual factors (ultimate factors having to do with culture and global chains besides proximate factors).

11. Diffusion of a product and its development are interrelated. User feedback helps manufacturers to improve products, which will stimulate diffusion. A large customer base makes it attractive to invest a great deal of money in further product development and new product offerings.

12. Diffusion of innovation is governed by exogenous changes such as energy price changes and endogenous changes. Endogenous changes that create momentum are: increasing returns to scale (cost reductions in the manufacturing due to economies of scale, allowing manufacturers to profitably sell products at lower prices), learning about user needs and the market, learning by users, endogenous taste formation (when a product become culturally desirable), learning-by-doing (production experiences lead to improved skills and discovery of cost-efficiencies in production) and competition between manufacturers resulting in more supply, wider distribution, greater variety in product offering and lower costs and prices.

13. In case of competitive effects, the diffusion of one technology goes at the expense of another technology. Gains in resource efficiency using existing technological approaches may delay the development and introduction of alternative novel technologies. In case of synergetic effects, the diffusion of one technology stimulates the diffusion of another one.

14. An important way to reduce material consumption is through recycling. In Europe, recycling and energy recovery is actively supported by national and local authorities through the use of recycling targets, extended producer responsibility, special infrastructures for collection and through waste management policies (landfill prices and bans). It is possible to go further into this direction but there are limits as to how far government can go in this direction. Manufacturers are not happy to be made responsible for the recollection of their products. In several countries, deposit-fund systems have been abolished because of opposition from supermarkets and manufacturers.

15. A second complicating factor is that recycling markets are subject to cycles of boom and bust, which undermines private investment and innovation in separation and recycling systems. We have some good functioning recycling markets but also markets characterised by distortions. Examples of market distortions are: the non-internalisation of external costs, discontinuities in waste policies, different classifications of waste and import and export restrictions. EU companies are unlikely to succeed with ambitious resource efficiency action as long as international market distortions prevail.

16. Policy makers need a convincing rationale to intervene actively for resource efficiency. One rationale is that resource efficiency helps to lower environmental impacts and is a necessary component of sustainable development. A second possible rationale is that resource efficiency helps to save money and to generate jobs. These rationales are not controversial but the EU lacks strong constituencies speaking on behalf of them.

17. Regulation has proved important for achieving recycling, improving the fuel efficiency of cars and promoting energy-efficient lighting. It is unlikely that an absolute reduction in resource use will be achieved without regulation of products and mandatory targets for recycling. In the EU, incandescent light bulbs are being banned from the market, but the downside of this is that it reinforces a widely prevalent view among European citizens of a European bureaucracy which is interfering with people's life. Regulation of companies and mandatory targets for recycling suffer less from this problem. When

evaluating policy approaches, we should consider the constraints acting upon the use of them and investigate possibilities for making them attractive, without reducing their efficacy.

18. Policy makers need arguments to actively intervene. An interesting question is: How was it possible for government to introduce powerful policies (what circumstances made this possible, how were the policies framed to gain acceptance, how were powerful actors enrolled and was resistance overcome)?

19. In our policy analysis we should give attention to the interaction effects between policy instruments and pay attention to issues of trade, health, governance, law and finance. The following questions appear good questions for our prospective analysis of policies:

- How to avoid minimalist solutions?
- How to build capacity for standard setting for resource efficiency and energy transitions?
- How to deal with uncertainty, conflicting claims and evidence?
- How to generate positive external economies and self-propelling processes of change?

20. A challenge for the project is to integrate aspects of product design, behaviour (which differs among people and nations), government policies, institutions and co-evolution in the analysis of interdependent markets for materials. Another challenge is to examine the international aspect of primary materials and secondary materials in terms of who is trading with who, and the restrictions being posed on trade.

21. A last observation is that the markets for energy, primary and secondary materials, waste, water and land are related with each other in various ways. Strong links exist between power generation, fossil fuel prices, water consumption (and land use in the case of biofuels). Price increases in materials used in RET may negatively affect the costs of RET (as a temporary effect or structural effect). The costs of materials depend on the elasticity of supply (which is low for rare earth materials) and prices of secondary materials which in turn depend on separating and sorting systems and government waste policies. The interactions between the markets for primary and secondary materials and quantitative effects of policy measures can only be studied comprehensively with the help of E3 models. A challenge for the project is to incorporate webs of constraints (having to do with institutions, ways of thinking, practices and the interaction of supply and demand) into the (modeling) analysis.

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Appendix A Critical materials for the EU

Raw materials	Main producers (2008, 2009)	Main sources of imports into EU (2007, or 2006)	Import dependency rate	Substitutability	Recycling rate
Antimony	China 91%	Bolivia 77%	100%	0,64	11%
	Bolivia 2%	China 15%			
	Russia 2%	Peru 6%			
	South Africa 2%				
Beryllium	USA 85%	USA, Canada, China, Brazil (*)	100%		
	China 14%				
	Mozambique 1%				
Cobalt	DRC 41%	DRC 71%	100%	0,9	16%
	Canada 11%	Russia 19%			
	Zambia 9%	Tanzania 5%			
Fluorspar	China 59%	China 27%	69%	0,9	0%
	Mexico 18%	South Africa 25%			
	Mongolia 6%	Mexico 24%			
Gallium	NA	USA, Russia (*)	(*)	0,74	0%
Germanium	China 72%	China 72%	100%	0,8	0%
	Russia 4%	USA 19%			
	USA 3%	Hong Kong 7%			
Graphite	China 72%	China 75%	95%	0,5	0%
	India 13%	Brazil 8%			NA
	Brazil 7%	Madagascar 3%			
		Canada 3%			
Indium	China 58%	China 81%	100%	0,9	0,30%
	Japan 11%	Hong Kong 4%			
	Korea 9%	USA 4%			
	Canada 9%	Singapore 4%			
Magnesium	China 56%	China 82%	100%	0,82	14%
	Turkey 12%	Israel 9%			
	Russia 7%	Norway 3%			
		Russia 3%			
Niobium	Brazil 92%	Brazil 84%	100%	0,7	11%
	Canada 7%	Canada 16%			
Platinum group metals	South Africa 79%	South Africa 60%	100%	0,75	35%
	Russia 11%	Russia 32%			
	Zimbabwe 3%	Norway 4%			
Rare earths	China 97%	China 90%	100%	0,87	1%
	India 2%	Russia 9%			
	Brazil 1%	Kazakhstan 1%			
Tantalum	Australia 48%	China 46%	100%	0,4	4%
	Brazil 16%	Japan 40%			
	Rwanda 9%	Kazakhstan 14%			
	DRC 9%				
Tungsten	China 78% (6,1)	Russia 76%	73%	0,77	37%
	Russia 5% (6,5)	Bolivia 7%			
	Canada 4%	Ruanda 13%			

Source: EC (2011, p. 21)