Emission Reduction Activities in Private Households

Development of evaluation criteria and an application to the transport sector

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December 2012

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Off4Firms in a Nutshell

Off4Firms – Employer-led incentives for households' reductions in CO_2 emissions and energy consumption

Off4Firms is an applied research and innovation project aiming at reducing greenhouse gas emissions and energy consumption of private households. The project is led by ETH Zurich (Chair of Economics, Prof. Renate Schubert) and involves project partners from academia and business: Wageningen University, South Pole Carbon, Swiss Re, and EWZ. Partially financed by EIT Climate-KIC, the project runs from April 2012 until March 2014.

Being one of the world's largest emitters, households in aggregate bear an enormous potential for reducing emissions and energy consumption. Off4Firms starts from the premise that one effective way of triggering change in households is through household members' employers. Off4Firms creates a win-win situation for households and firms: both profit from employees saving energy and reducing CO_2 in their households. Employees benefit because they change their energy-related behaviour with the support of their employer. This change pays for – for example through lower energy costs. Companies, on the other hand, benefit from reputation gains as employers and in the public. In addition, under specific conditions – they may profit from offsetting their emissions by their employees' emission reductions.

Off4Firms develops a comprehensive programme for firms to use this great potential in an efficient way. This project enables firms to evaluate measures aiming at reductions in energy use and CO_2 emissions in their employees' private lives. Evaluation criteria are the effectiveness, cost efficiency, verifiability and acceptability of measures for the employees. Best practice measures will be identified and a tool kit will be provided, enabling the development of company-tailored CO_2 or energy reduction measures. These measures will be brought to scale by a dedicated business unit. In addition, the policy framework making such measures a win-win strategy for households and for firms will be depicted.

Abstract

This working paper focuses on the evaluation of household reduction activities, which could be fostered by household members' employers. First, a methodology for evaluating such household reduction activities is developed, including an Excel evaluation tool. Household reduction activities are evaluated according to the following four criteria: (1) the technical reduction potential, (2) the cost efficiency of the reduction, (3) the verifiability of achieved reductions, and (4) implementation barriers hindering the adoption of the reduction activities. In a next step, the evaluation methodology is tested by an exemplary evaluation of household reduction activities in the transport sector. Based on the evaluation, different types of household reduction activities can be compared. It turns out, for example, that highly efficient conventional diesel cars can achieve GHG emission reductions more cost efficiently than electric cars. It also shows that reduction activities involving the use of public transport are likely to have a low verifiability. Employers can use the results of the evaluation as a basis for deciding which household reduction activities they would like to incentivize.

1. Introduction

Households' energy consumption and its inherent CO_2 emissions are major causes for global climate change (Levine et al., 2007; Niederberger, & Spalding-Fecher, 2006). In the European Union and also in Switzerland around 30% of the energy demand is consumed in private households resulting in about 40% of the total CO_2 emissions (Eurostat, 2011b; SFSO, 2009). Given this large share, there is also a large reduction potential in energy consumption and CO_2 emissions in the household sector (Banfi et al., 2008; Wesselink, & Deng, 2009; Enkvist, Dinkel, & Lin, 2010; Farsi, 2010; Hofer, 2007; Levine et al., 2007; Meyers, Williams, & Matthews, 2010; Niederberger, & Spalding-Fecher, 2006; van Vuuren et al., 2009). In order to meet the EU climate targets, the EU Commission estimates that the CO_2 emissions in the residential and service sector have to be reduced by 37-53% until 2030 and by 88-91% until 2050 compared to 1990 levels (European Commission, 2011).

To reduce energy consumption and CO_2 emissions of private households significantly, many countries have introduced top-down governmental policy instruments (Geller et al., 2006; Harmelink, Nilsson, & Harmsen, 2008; Jochem, Mai, & Ott, 2010), such as feed-in tariffs, quota systems, tax rebates or carbon taxes (cf. Off4Firms deliverable D1.3 referenced as (Gerigk et al., 2012)). The measures are meant to drive households' energy demand down and to incite investments in energy efficiency. Yet, there seem to be several important barriers such as lacking awareness, large administrative hurdles, and missing information that impede the success of such activities (Epper, Fehr-Duda, & Schubert, 2011; Farsi, 2010; Jaffe & Stavins, 1994; Jakob, 2007; Jochem et al., 2010). Due to these barriers emission reductions and efficiency increases are below their full potential. Recently, some firms started offering incentives to their employees to reduce the CO_2 emissions and energy consumption in their private lives. They offer, for example, direct subsidies for energy efficiency investments at home, carry out workshops to inform employees about existing possibilities to reduce their energy consumption or CO_2 emissions or they organize energy saving competitions among their employees. Such measures may have a large potential as many households could be approached: in the EU as well as in Switzerland, less than 1% of all firms employ about 34% of the available workforce (European Commission, 2012; Kayser, 2010; SFSO, 2010). In addition, firms may have a stronger influence on their employees than comparable governmental and social norms) among a firm's employees. The project "Off4Firms" aims at investigating such effects in firms' schemes. This might be due to the relevance of social interactions (e.g., group dynamics, role models. A key issue is the identification of feasible and effective household reduction activities, initiated by firms and implemented by their employees' households.

In the following, an appropriate evaluation structure is defined that can be used *ex ante* for evaluating the different reduction activities and *ex post* for verifying the achieved reductions in energy consumption and GHG emissions. Having defined such an evaluation structure, an Excel evaluation tool is developed and tested by evaluating household reduction activities in the transport sector. The relevant data for this working paper is mainly collected from existing scientific literature as well as from technical reports. Additional data stems from qualitative interviews among 12 firms performed in 2010 as well as from a survey performed in 2012 among 200 employees of a large international firm.

2. Evaluation criteria for reduction activities

In this working paper we focus on household reduction activities. Household reduction activities enable households to reduce their GHG emissions and energy consumption compared to a household's baseline activity, i.e. the activity that would most probably be realized in absence of a reduction activity. An example of such a household reduction activity could be the purchase of a new and highly efficient car instead of the purchase of a new but less efficient average car, with the latter being the corresponding baseline activity. Households can reduce their GHG emissions and energy consumption in the sectors transportation, heating and cooling, and household appliances.

According to literature dealing with the evaluation of activities and projects in the areas of GHG emission reduction (Hayashi et al., 2010; Heuvelmans et al., 2005; Olsen, 2007; Sutter & Parreño, 2006), energy efficiency improvement (Banfi et al., 2008; Farsi, 2010; Kneifel, 2010; Michaelowa, Hayashi, & Marr, 2009; Short, Packey, & Holt, 1995; Worrell et al., 2003), and smart grid development (Baeriswyl et al., 2012; Efthymiou & Kalogridis, 2010; McDaniel & McLaughlin, 2009), four criteria appear relevant when evaluating households' reduction activities. First, (1) the technical reduction potential has to be determined. All other things equal, reduction activities with a high technical potential to reduce GHG emissions and energy consumption should be preferred. Furthermore, (2) the cost efficiency has to be identified, for instance, by calculating the specific abatement cost per unit of reduction for different reduction activities. Moreover, (3) the verifiability of the achieved reductions and the data privacy required by households have to be evaluated. Finally, (4) important implementation barriers have to be pointed out in order to design appropriate ways of overcoming them.

Evaluating households' reduction activities by means of the four criteria listed above enables us to compare various reduction activities in a meaningful way. Table 1 depicts a stylised evaluation matrix, which would enable the evaluation of various reduction activities in the sectors transportation, heating and cooling, as well as household appliances according to the identified five evaluation criteria. In the table it can be seen that an overall comparison of activities would require a weighting scheme for the five criteria. Depending on which criteria are most important for a decision-maker, specific activities will be more attractive than others.

Household reduction activities Evaluation criteria	Transportation				Heating and cooling				Household appliances			
	Activity 1	Activity 2	…	Activity N	Activity 1	Activity 2	…	Activity N	Activity 1	Activity 2	…	Activity N
1. Technical reduction potential												
2. Cost efficiency												
3. Verifiability of achieved reductions and data privacy												
4. Implementation barriers												

Table 1: Stylised evaluation matrix including the identified evaluation criteria and possible reduction activities

In the following we explain the five evaluation criteria more in detail. Where necessary we develop an appropriate evaluation methodology for each of the criteria. All evaluation criteria are used to develop an Excel evaluation tool, which automates and simplifies future evaluations of household reduction activities.

2.1. Technical reduction potential

In order to *ex ante* evaluate household reduction activities and *ex post* determine the reductions in energy consumption and GHG emissions technically achievable by the household activities, the technical reduction potential has to be calculated by comparing GHG emissions or the energy consumption of reduction activities on the one hand and baseline activities on the other hand, everything else being set equal. In the past, many studies have been performed to estimate the technical reduction potential of various reduction activities in different economic sectors, like transportation, industry, as well as residential and commercial buildings (Chung, Hui, & Lam, 2006; Wesselink, & Deng, 2009; Hofer, 2007; Kneifel, 2010; Pérez-Lombard, Ortiz, & Pout, 2007). However, none of the studies compares the technical reduction potential of different single activities (e.g. the technical reduction potential of hybrid cars is estimated instead of the technical reduction potential of different hybrid car models). Hence, it seems necessary to do our own calculations for the technical reduction potential of single reduction activities.

Calculation of the technically achievable emission reductions

For our evaluation purposes, technically achievable reductions are calculated from a default formula given in several methodologies for energy efficiency and GHG emission reduction monitoring (Adensam et al., 2008; IPCC, 2006; U.S. Environmental Protection Agency, 2007; UNFCCC, 2008 (EB 39)).

$$ER_i = \sum_{t=1}^{T} \left[C_{k,t} \cdot EF_{k,t} - C_{i,t} \cdot EF_{i,t} \right] \cdot (1 - rb) \tag{1}$$

ER_i	Total GHG emission reductions of activity *i*	[t CO_2e] [1]
i	Index for the evaluated reduction activity (*i* = 1,2,…,*n*)	[-]
k	Baseline activity of reduction activity *i (k* = 1,2,…,*m*)	[-]
$C_{k,t}$	Energy consumption of baseline activity *k* in year *t*	[kWh]
$C_{i,t}$	Energy consumption of reduction activity *i* in year *t*	[kWh]
$EF_{k,t}$	Emission factor in year *t* of the energy form used in the baseline activity	[t CO_2e/kWh]
$EF_{i,t}$	Emission factor in year *t* of the energy form used in the reduction activity	[t CO_2e/kWh]
rb	Rebound factor (*rb* > 0)	[-]
t	Index for year of consideration	[-]
T	Index for the total time span of the reduction activity	[-]

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[1] CO_2e is the abbreviation for CO_2 equivalents. GHGs differ in their individual global warming potential, that is, the harmfulness to the climate which they expose per molecule. In order to measure the climate impact with one single parameter, the harmfulness of each GHG is hence normed and expressed in CO2 equivalents.

According to formula (1), the technical emission reduction potential (*ER*) of a reduction activity i is the sum of all yearly differences between the emissions of a reduction activity (*i*) and the corresponding baseline activity (*k*) over the total time span (*T*) of the reduction activity. The energy consumption (e.g. consumption of heating oil, electricity consumption) of the baseline activity ($C_{k,t}$) and of the reduction activity ($C_{i,t}$) is converted to CO_2 emissions by an emission factor (*EF*). According to formula (1), the calculated energy savings and emission reductions are corrected by a rebound factor (*rb*). More will be explained in the following.

Baseline activity

The baseline activity is the activity that would most probably occur if the household reduction activity were not implemented (CDM Rulebook, 2012). If, for example, a household replaces its old car with a new environmentally friendly car (the reduction activity) the baseline activity would be the purchase and use of an average new car. To determine the baseline activity, market benchmarks can be used. This approach has, for instance, been introduced in the baseline and monitoring methodology AM0070 of the Clean Development Mechanism[2]. Focusing on the manufacturing of energy efficient refrigerators, this methodology sets the baseline according to a market benchmark for different refrigerator classes and designs (UNFCCC, 2010). In our evaluations, we use a benchmarking approach to define the baseline activities and to calculate the reductions in energy consumption and GHG emission of the household reduction activities. We define the baseline activities according to national average values, such as the average specific fuel consumption of new cars in Switzerland. Such average values can, to a large extent, be extracted from databases offered by different governmental bodies such as the Swiss Federal Statistical Office (SFSO) or the European Commission. In the Excel evaluation tool average values can be replaced by real values. The corresponding changes in the technical reduction potential are depicted in a diagram.

Emission factors

A household activity's technical reduction potential of GHG emissions further depends on the corresponding emission factors (*EF*). An emission factor is the conversion factor of different energy forms into GHG emissions. It typically has the dimension of kilogram CO_2 equivalents per kilowatt-hour. Activities improving energy efficiency do not alter the emission factor but reduce the energy consumed and thereby reduce emissions. Improvements originating from fuel switches have the potential of higher savings since not only the energy consumption but also the emission factor is lowered.

Emission factors differ for different primary energy sources and energy carriers. Primary energy sources like oil, coal, or natural gas have emission factors that can be calculated according to the carbon content of the energy source and the type of combustion. The determination of an energy carrier's emission factor is more

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[2] The Clean Development Mechansim (CDM) is one of three flexible mechanisms of the Kyoto Protocol. It allows countries with binding GHG emission reduction commitments under the Protocol to achieve their reductions by investing into GHG emission reduction projects in other countries that are not committed to reduce GHG emissions. In the CDM, methodologies define the definition of the baseline activity well as the monitoring procedures for specific types of projects (e.g. installation of photovoltaic panels) that reduce CO_2 emissions.

complicated. The emission factor of an energy carrier like electricity depends on the mix of primary energy sources used to produce the energy carrier as well as on the losses of production and distribution. The electricity mix of Switzerland, for example, is generated almost exclusively by hydro and nuclear power. It therefore has a rather low emission factor. Yet, the emission factor of consumed electricity can be higher due to electricity imports that are produced by non-renewable energy sources like oil or coal. In 2011 in Switzerland, for example, the emission factor of the electricity mix generated was 24gCO_2e/kWh, whereas the emission factor of the electricity mix consumed was 133gCO_2e/kWh (FOEN, 2012).

The two large databases "IPCC Emission Factor Database"[3] and the "United Kingdom's Emission Factor Database"[4] are often used to determine emission factors. They include data for emission factors of primary energy sources and energy carriers. Table 2 illustrates differences between the emission factors of the two databases and compares the factors with the values published by the Swiss Federal Office of the Environment (FOEN). It can be seen that only small differences exist for the primary energy sources. The UK's Emission Factor Database is the only database that provides emission factors that also include indirect emissions caused by the extraction and transformation of a fuel. Whereas the UK's Emission Factor Database only considers distribution losses in calculating the emission factor of consumed electricity, the factor from the FOEN also includes the emissions of the imported electricity.

Table 2: Comparison of emission factors from different databases

Fuel	**FOEN[5], [6]**	**United Kingdom's Emission Factor Database[7]**			**IPCC Emission Factor Database[8]**	
		Direct CO_2 emissions	Direct GHG emissions	Direct and indirect GHG emissions	Direct CO_2 emissions per TJ	Direct CO_2 emissions[9] per ton
Gasoline (100% fossil)	3.14 tCO_2/t	3.14 tCO_2/t	3.15 tCO_2e/t	3.78 tCO_2e/t	69.3 tCO_2/TJ	3.10 tCO_2/t
Diesel (100% fossil)	3.15 tCO_2/t	3.16 tCO_2/t	3.19 tCO_2e/t	3.86 tCO_2e/t	74.1 tCO_2/TJ	3.18 tCO_2/t
Heating oil light	3.14 tCO_2/t	-	-	-	-	-
Burning oil (Kerosene)	-	3.15 tCO_2/t	3.17 tCO_2e/t	3.82 tCO_2e/t	71.9 tCO_2/TJ	3.15 tCO_2/t
Natural gas	2.56 tCO_2/t	-	-	-	56.1 tCO_2/TJ	2.68 tCO_2/t
- CNG	-	2.72 tCO_2/t	2.72 tCO_2e/t	3.15 tCO_2e/t	-	-
- LNG	-	2.72 tCO_2/t	2.72 tCO_2e/t	3.68 tCO_2e/t	-	-
LPG	3.01 tCO_2/t	-	-	-	63.1 tCO_2/TJ	2.90 tCO_2/t
Ethanol	71.3 tCO_2/TJ	-	0.27 tCO_2e/TJ	38.9 tCO_2e/TJ	-	-
Swiss electricity generation	24 gCO_2e/kWh	-	42.59 gCO_2e/kWh	48.38 gCO_2e/kWh	-	-
Swiss electricity consumption	133 gCO_2e/kWh	-	45.78 gCO_2e/kWh	52.00 gCO_2e/kWh	-	-

In our evaluation we use the emission factors United Kingdom's Emission Factor Database for primary energy sources. For determining the emission factor of consumed electricity, we will use national data of specific European countries (e.g. the emission factors of the Swiss FOEN), because the international databases do not include imported electricity in their calculations.

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[3] http://www.ipcc-nggip.iges.or.jp/EFDB/main.php

[4] http://naei.defra.gov.uk/emissions/index.php

[5] (FOEN, 2011)

[6] (FOEN, 2012)

[7] (DEFRA, 2012)

[8] (IPCC, 2006)

[9] Calculated using the following unit conversion factors: Gasoline 44.74 GJ/t, Diesel 42.91 GJ/t, Burning oil 43.86 GJ/t, Natural gas 47.73 GJ/t, LPG 45.90 GJ/t (DEFRA, 2012)

Rebound factor

The rebound factor *(rb)* describes the increases in households' energy consumption caused by energy savings due to reduction activities and is measured as percentage of the savings. Rebound effects occur at a micro level (e.g. at the household level) and at a macro level (e.g. at the level of entire national economies). At the micro level, direct and indirect rebound effects are distinguished. A rebound effect is direct if the increase in households' energy consumption is caused by an increased use of a more energy efficient good, like a car. An indirect rebound effect accounts for an increase in energy consumption caused by the increased use or purchase of other goods. Direct and indirect rebound effects reduce the achievable GHG emission reductions of an activity (Greening, Greene, & Difiglio, 2000). Macro level rebound effects are nationwide. An example may be the spreading out of three-litre cars. This may result in a decreasing demand for gasoline, lowering the prices for gasoline, which gives an incentive for an increase in use. Direct, indirect and macro rebound effects together are called economy-wide rebound effect (Jenkins, Nordhaus, & Shellenberger, 2011; Santarius, 2012).

Due to the different levels and the complexity of rebound effects, there are large uncertainties in calculating the quantitative impact of rebound effects (Greening et al., 2000; Santarius, 2012; Shimoda et al., 2006). Direct rebound effects are estimated to amount to 10-30% of the energy savings in automotive transport and space heating (Greening et al., 2000; Santarius, 2012; Sorell, 2007), between 0-50% of energy savings in space cooling, less than 20% of the energy savings of consumer electronics (Greening et al., 2000; Sorell, 2007), and less than 10-40% of energy savings from water heating (Greening et al., 2000). Indirect and macro level rebound effects amount to 5-50% of the initial energy savings on average (Santarius, 2012). Global economy-wide rebound effects resulting from energy-efficiency policies are estimated to be 36-52% of the achieved savings for the transport sector and 44-61% for the residential/service building sector (Barker, Dagoumas, & Rubin, 2009). As a rule of thumb, an average economy-wide rebound effect of 50% is used, i.e. it is assumed that around 50% of the achieved reductions are compensated elsewhere (Santarius, 2012; Sorell, 2007). Yet, Sorell (2007) indicates that these 50% are too high for energy efficiency improvements in consumer electronic goods. Hence, for our evaluation we use an economy-wide rebound effect of 50% for the transport and the residential building sector. For household appliances a lower value of 30% is assumed. The chosen rebound effects are rather in the upper range of the estimates in literature and therefore lead to rather conservative results of the savings' calculations.

Total time span of the reduction activity

The total time span of the reduction activity (*T*) is the duration of a reduction activity. For defining the duration of the reduction activity, we distinguish between persistent and non-persistent reduction activities. A persistent reduction activity achieves GHG emission and energy consumption reductions even after a firm ceases to promote the reduction activity, whereas a non-persistent reduction activity only reduces GHG emissions and energy consumption while a firm incentivizes the activity. An example of a persistent reduction activity could be the purchase of an energy efficient refrigerator instead of the purchase of a less efficient one. Once the refrigerator is purchased, it will not stop consuming less electricity than the baseline refrigerator that would have been purchased otherwise. An example for a non-persistent reduction activity is carpooling, for which it is highly probable that employees stop doing it as soon as a firm stops promoting it (Abou-Zeid et al., 2012). The duration of a persistent reduction activity is the total lifetime of the activity, such as the total lifetime of an energy efficient refrigerator, whereas the duration of a non-persistent reduction activity is the time span of a firm measure promoting the reduction activity.

To compare the technical reduction potential of these two types of reduction activities, we use the yearly amount of achievable emission reductions. For persistent reduction activities also the expected total amount of achievable emission reduction over the total lifetime will be calculated to identify the reduction activities that have a large and long-lasting effect on GHG emissions and energy consumption.

2.2. Cost efficiency of the reduction activities

The cost efficiency of different reduction activities can be determined by calculating the specific abatement costs of the reduction activity incurred by a private household. The specific abatement costs are an approximation of the marginal abatement costs by calculating the average abatement costs per unit of GHG emission for a specific reduction activity. Positive specific abatement costs reflect higher costs of the reduction activity compared to the baseline activity, whereas negative specific abatement costs reflect monetary savings that result from the reduction activity. Households themselves as well as firms fostering households' energy consumption and GHG emission reductions are interested in activities achieving reductions at the lowest specific abatement costs. In case of negative specific abatement costs the subsidy scheme only has to overcome additional non-monetary barriers (cf. section 2.4) to foster a corresponding reduction activity.

A large variety of studies exists that try to estimate the specific abatement costs of reduction activities in different sectors (Wesselink, & Deng, 2009; Enkvist et al., 2010). Yet, due to different assumptions and models used for calculation, substantial differences can be found in the results (van Vuuren et al., 2009).

Calculation of a reduction activity's specific abatement costs

In our evaluation, the specific abatement costs (*ac*) of a household reduction activity are calculated according to formula (3). This formula refers to the total life-cycle costs of an activity j (TC_j) incurred by households: the total life-cycle costs correspond to the sum of discounted maintenance costs ($mc_{j,t}$), operation costs ($oc_{j,t}$), and revenues ($rev_{j,t}$) plus the initial investment costs (I_j) (Mansfield, 1999; Salvatore, 2006; Short et al., 1995). For the risk-adjusted interest rate (*r*) we assume a value of 4%[10] (Eichhammer et al., 2009; Evans, 2006).

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[10] Compared to current government bond rates in the EU (1.26% in the Euro area) and Switzerland (0.46%), 4% seems to be a rather high value(Trading Economics, 2012). Yet, it has to be mentioned that households perceived interest rate might be well above these 4% (usually 9% or higher) (Wesselink, & Deng, 2009)

$$TC_j = \sum_{t=1}^{T} \frac{mc_{j,t} + oc_{j,t} - rev_{j,t}}{(1+r)^t} \qquad (2)$$

TC_j	Total costs of activity *j*	[€]
j	Index for reduction activity *i* or baseline activity *k*: $j \in \{i,k\}$	[-]
$mc_{j,t}$	Maintenance costs of activity *j* in year *t*	[€/year]
$oc_{j,t}$	Operating costs of activity *j* in year *t*	[€/year]
$rev_{j,t}$	Total revenue of activity *j* in year *t*	[€/year]
r	Risk-adjusted interest rate	[-]
I_j	Investment costs of activity *j*	[€]
t	Index for year of consideration	[-]
T	Index for the total time span of the reduction activity	[-]

Given the total costs of the baseline (TC_k) and reduction activity (TC_i), the specific abatement costs (ac_i) can be calculated according to formula (3). Accordingly, the specific abatement costs (ac_i) are equal to the difference in total life-cycle costs (*TC*) of the reduction activity *i* and the corresponding baseline activity *k*, divided by the total achieved emission reductions of activity *i* (ER_i) calculated in formula (1).

$$ac_i = \frac{TC_i - TC_k}{ER_i} \qquad (3)$$

ac_i	Abatement costs of reduction activity *i*	[€/tCO$_2$e]
TC_i	Total costs of the reduction activity *i*	[€]
TC_k	Total costs of the baseline activity *k*	[€]
ER_i	Emission reductions achieved	[tCO$_2$e]

2.3. Verifiability of the CO$_2$ emissions and energy consumption reductions

Emission reductions and energy savings achieved in households have to be verified in order to be able to compare the effectiveness and efficiency of different activities (Ohndorf, 2010). The verifiability of a reduction activity describes how well its achieved GHG emission reductions or energy savings can be determined. A reduction activity's verifiability depends on the number of parameters that have to be verified in order to calculate the achieved GHG emission reductions or energy savings as well as the corresponding uncertainties in their verification. As a rule, high verifiability implies low uncertainties in verification and vice versa. Uncertainties in verification are caused by complex consumption patterns of a reduction activity, such as the discontinuous electricity consumption of a vacuum cleaner, by data privacy issues related to the collection of required data, by side effects on the monitored parameters, such as the influence of the weather on the energy consumption of a heating or cooling system, or by the accuracy of available measurement technology (JCGM, 2008; MacKenzie, & Ohndorf, 2012; Ohndorf, 2010).

In the field of household reduction activities, data privacy is sometimes assumed to play an important role in verifying achieved GHG emission reductions or energy savings. However, according to an Off4Firms survey among 200 employees of a large company[11], it is possible that on average no large differences in data privacy concerns exist for different energy consumption related data and that in general household energy consumption related data is perceived to be rather insensitive. Literature shows that in case of the existence of data privacy concerns, an appropriate incentive scheme could help overcome these concerns because personal information (e.g. information about the energy consumption) is seen as a commodity that individuals are willing to trade in against high enough benefits (Bolderdijk, Steg, & Postmes, 2012; Phelps, Nowak, & Ferrell, 2011; Posner, 1981).

Depending on the verifiability of a reduction activity, an appropriate monitoring and verification (M&V) methodology has to be determined. A lower verifiability usually results in higher M&V costs needed to achieve a certain quality of verification. Hereby, M&V costs mainly include costs for metering devices or metering services. Lowering the M&V costs typically implies the standardization of the M&V methodology and the use of average values for calculating energy savings and emission reductions instead of measuring them. In specific, average values have to be used on reduction activities for which the effects cannot be directly measured. Such average values can often be found in relation with labels and standards. Both, labels and standards exist for a variety of technologies (e.g. refrigerators, heating systems) implementable in private households. The EU energy label, for example, exists for televisions, refrigerators and freezers, washing machines, light bulbs, dishwasher, driers, air conditioners, and all sorts of vehicles and indicates the energy efficiency of the device compared to other devices of the same type (European Commission, 2010a). Examples of institutions issuing standards for different technologies applicable in private households are the International Organisation for Standardization (ISO)[12], the International Electrotechnical Commission (IEC)[13], the European Committee for Electrotechnical Standardization (CENELEC)[14], and the German Institute for Standardization (DIN)[15]. However, the assumptions underlying such values have to be considered carefully. Hence, emission reductions that are calculated based on average values typically involve higher uncertainties than directly measured reductions. The choice of verification methods depends on the availability of adequate average values as well as on decision-makers’ preferences concerning the trade-off between M&V costs and verification.

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[11] The participants of the survey had to indicate how sensitive they found different energy related data. Participants were asked about data on their monthly total electricity consumption; the type of electrical appliances they use at home; total time per day they use their electrical appliances at home; the exact time they use these electrical appliances at home; the type of car they have; how much they drive their car; the kind of heating system they have at home; the spending on oil/gas per year; if they have solar panels on the roof of their house; and if they use an energy efficient fridge and/or energy efficient washing machine at home. Participants could indicate their perception of data privacy on a Likert scale from 1-7, 1 being not sensitive at all.

[12] http://www.iso.org/

[13] http://www.iec.ch/

[14] http://www.cenelec.eu/

[15] http://www.din.de/

For most reduction activities different M&V methodologies may exist for determining the achieved GHG emission reductions and energy savings. The selection of the M&V methodology depends on the requirements of a corresponding regulator. The verifiability of a certain reduction activity may change according to the selected M&V methodology. In order to *ex ante* compare the verifiability of the different reduction activities without knowing the requirements for verification and certification, we base our evaluation on the number of parameters that have to be identified in order to calculate a reduction activity's technical reduction potential according to formula (1). We assume that a higher number of different parameters decreases the verifiability of the reduction activity.

In addition, we qualitatively evaluate the verifiability of the achieved emission reductions by discussing the following points:

- Variability in fuel consumption: This factor accounts for the patterns in fuel consumption of the reduction activity. It is assumed that a high variability in fuel consumption leads to a higher complexity of the needed M&V methodology and therefore to a lower verifiability.
- Number of side effects potentially influencing the achievable reductions: Side effects, such as the weather, could potentially influence the consumption pattern of a reduction activity and might make the verification of achieved reductions difficult.
- Accuracy of available measurement technology: The accuracy of available measurement technology is responsible for the degree of uncertainty in verification. It is assumed that a higher accuracy of available measurement technology also increases the verifiability of the corresponding reduction activity.
- Cost of available measurement technology: High costs for available measurement technology make it more difficult to use this technology at large scale to verify achieved reductions. We assume that increasing costs of available measurement technology decrease the verifiability of a reduction activity.
- Data privacy concerns: Data, which involves data privacy concerns, may make the process of M&V more difficult. We therefore assume that higher concerns about data privacy lead to higher costs for M&V and to a lower verifiability of the corresponding reduction activity.

2.4. Implementation barriers

Private households often refrain from energy efficiency activities even if the specific abatement costs are negative (i.e. there are abatement benefits). This occurrence is called the energy-efficiency gap (Brown, 2001; Jaffe & Stavins, 1994). The energy-efficiency gap implies that specific implementation barriers exist that hinder private households from realizing cost efficient reduction activities (Eichhammer et al., 2009; Jochem et al., 2010). Literature about implementation barriers in household energy efficiency is abundant (Brown, 2001; Carbon Trust, 2005; Hirst & Brown, 1990; Howarth & Andersson, 1993; Jaffe & Stavins, 1994; Jakob, 2007). In the following, possible implementation barriers are identified and described in more detail.

Financial costs

Financial costs barriers are often based on substantial up-front costs for many household reduction activities (Jakob, 2007). If households lack the necessary financial means or have no access to financing they often cannot realize investment cost-intensive reduction activities, even if they would be compensated through energy cost savings after the investment (Carbon Trust, 2005; Hirst & Brown, 1990). Due to low energy prices of saved energy, cost savings are often small, resulting in a low benefit-cost ratio of a reduction activity. In addition, households with high discounting rates strongly undervalue the future benefits of a reduction measure and are therefore not willing to invest large amounts of money in the present (Epper, Fehr-Duda, & Schubert, 2011; Jaffe & Stavins, 1994; Jakob, 2007).

Hidden costs

Hidden costs are all kinds of costs that are indirectly incurred by households. Additional implementation costs are hidden costs that may, for example, be caused by a large time effort to gather information on reduction activities. Hidden costs are also caused by all sorts of risks such as the risk of incompatibility of a reduction activity with the required service or available infrastructure (e.g. the short range of an electric car might force its owner to rent another car for travelling further distances), performance risks (e.g. a new heating system does not achieve the water flow temperature aimed for) or the risk of increasing or decreasing fuel prices (i.e. if prices of the fuel used by the baseline activity decrease, the cost savings achieved by the reduction activity also decrease) (Carbon Trust, 2005).

Market failures

There are several market failures that might additionally hinder the adoption of household reduction activities. Market failures arise from conditions in a market that decrease the efficiency in allocation of goods and services, i.e. the assumptions of an ideal market are violated. Misplaced incentives – commonly referred to as the principal-agent problem – are a first important market failure. The principal-agent problem describes a situation where an agent acts or decides on behalf of a principal without reflecting the principal's best interest. An example is architects, engineers, and builders minimizing upfront costs without considering the resulting life-cycle costs for the homeowners. Another example is the landlord-tenant relationship where the landlord is responsible for a building's energy efficiency and the tenant pays for the energy consumption. In addition to the principal-agent problem, also a fragmented market structure can inhibit a household reduction activity. An example is again the building industry, where separate firms may realize the design and engineering of a building (Brown, 2001; Jaffe & Stavins, 1994). An important constraint when selecting an appropriate household reduction activity is furthermore the availability to households of the required technology or fuel in a given country or region. Technologies or fuels that are common in some countries or regions might not be available in other countries or regions. For each of the analysed household reduction activities we therefore analyse whether or not the required technology or fuel is available to households.

Moreover, distortionary fiscal and regulatory policies might hinder the implementation of household reduction activities. Examples for distortionary fiscal policies may be a bad tax treatment of upfront investment costs or limited tax subsidies for energy efficiency investments. An example for a distortionary regulatory policy may be the high administrative requirements for building renovations. Due to external costs and benefits, which are not internalized in energy prices, a household reduction activity might be less beneficiary and thus not implemented. A common example is the low price of fossil fuels, which does not reflect the social costs that may be caused by the extraction, production, distribution and consumption of such fuels and which results in lower cost savings from reduction activities using other sources of energy. Insufficient and inaccurate information on household reduction activities by experts or political institutions, the slow revision of existing codes and standards, such as standards for energy efficient household appliances, as well as corruption are additional market failures that may hinder the implementation of household reduction activities (Brown, 2001; Hirst & Brown, 1990; Jaffe & Stavins, 1994; Jakob, 2007).

Behaviour

Finally, behavioural barriers are important. In many cases, behavioural barriers may have the strongest influence. Many households show inertia in adoption behaviour, refraining for long time from adopting new technologies and still using old and well-known technologies (Jaffe & Stavins, 1994). This inertia may at least partially be caused by either a lack of awareness and acceptability of new technologies or by continuing a traditional or common behaviour or habit (Abou-Zeid et al., 2012; Jakob, 2007; Jochem et al., 2010). Table 3 gives an overview of identified barriers potentially hindering the implementation of household reduction activities.

Table 3: Identified set of barriers potentially hindering the implementation of household reduction activities (Brown, 2001; Carbon Trust, 2005; Hirst & Brown, 1990; Howarth & Andersson, 1993; Jaffe & Stavins, 1994; Jakob, 2007)

Barrier categories	**Identified barriers**	
Financial costs	• Household budget constraints • Low benefit-cost ratio	• Lack of access to financing
Hidden costs	• Implementation costs • Risk of incompatibility	• Performance risks • Risk of increasing or decreasing fuel prices
Market failures	• Misplaced incentives (principal-agent problem) • Fragmented market structure • Availability of reduction activity to households • Distortionary fiscal and regulatory policies • External costs and benefits	• Insufficient and inaccurate information • Codes and standards • Corruption
Behaviour	• Inertia in adoption behaviour • Lack of awareness and acceptability	• Tradition and common behaviour

Evaluating of implementation barriers

The objective in evaluating barriers hindering private households from implementing reduction activities is twofold. On the one hand, identifying the relevant barriers allows for the design of appropriate incentive schemes that can overcome these barriers. On the other hand, we can show which reduction activities might be fostered the easiest. Hence, in our evaluation we identify for each reduction activity the relevant barriers out of the list of barriers shown in Table 3 by qualitative analyses.

2.5. Concluding remarks

In this chapter, four different evaluation criteria were discussed for evaluating reduction activities. As always, the results of the developed evaluation are dependent on the used assumptions. Sources for errors may be the selection of an inappropriate baseline activity, the discrepancy between chosen average values and measured values, or an inappropriate weighting of different indicators.

3. Exemplary evaluation of reduction activities in transportation

Private households typically are able to reduce GHG emissions and energy consumption in the areas of transportation, heating and cooling, and household appliances. In various studies the total technical reduction potential and the cost efficiency of different types of reduction activities was estimated (Bättig & Ziegler, 2009; Enkvist et al., 2010; Frauenhofer ISI, 2005; Hofer, 2007; Meyers et al., 2010; Wesselink, & Deng, 2009). There are considerable differences in the results of the different studies (van Vuuren et al., 2009), but the achievable technical reduction potential in transportation and heating and cooling seems large compared to the reduction potential of electric appliances (Frauenhofer ISI, 2005; Shimoda et al., 2006; Wesselink, & Deng, 2009).

Transportation accounts for a large share of the energy consumption and the CO_2 emissions caused by private households. In the EU and in Switzerland the transportation sector accounts for 33% (EU-27, 2009) and 35% (CH, 2011) respectively of the total final energy consumption and 23% (EU-27, 2007) and 39% (CH, 2011) respectively of the total CO_2 emissions. In Switzerland, 69% of these emissions are due to transportation with private vehicles (European Commission, 2010b; Eurostat, 2009; SFSO, 2011).

In the transport sector large amounts of GHG emissions can be reduced (Wesselink, & Deng, 2009; Frauenhofer ISI, 2005) Many of the GHG emission reductions can be realized cost-efficiently (Bättig, 2009; Enkvist et al., 2010; van Vuuren et al., 2009; Wesselink, & Deng, 2009). Wesselink, & Deng (2009), for instance, estimates the GHG emission reduction potential until 2030 in the EU-27 to be $99MtCO_2$ for electric passenger cars, $63MtCO_2$ for biofuel passenger cars, $259MtCO_2$ for fuel-efficient passenger cars, and $84MtCO_2$ for passenger aviation compared to a “frozen technology scenario”, which assumes no change in the technology mix from 2005 until 2030. Moreover, the specific abatement costs are estimated until 2030 in the EU-27 to be 252€/tCO_2 for electric passenger cars, 19€/tCO_2 for biofuel passenger cars, 45€/tCO_2 for fuel-efficient passenger cars, and -171€/tCO_2 for passenger aviation[16] compared to the “frozen technology scenario”.

In transportation, we assume that significant reductions can be achieved by the purchase of a highly efficient new car instead of a less efficient average car as well as by a switch from using a car or using public transport to using other less GHG emission intensive transport means such as cycling or walking. This chapter shows how reduction activities in private households can be evaluated with respect to the criteria discussed in chapter 2. The evaluation of the different reduction activities is implemented in Excel in order to develop an evaluation tool that can simplify future evaluations.

3.1. Purchase of new cars

In this section we want to evaluate the purchase of different car models. More efficient or less emitting cars available for private households are battery electric cars (BEC), hybrid electric cars (HEC), plug-in hybrid cars (PHEC), compressed natural gas cars (CNGC), bioethanol cars (BETHC), highly efficient conventional diesel cars (CDC), and highly efficient gasoline cars (CGC).

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[16] The negative specific abatement costs indicate monetary savings from improving GHG emission intensity in passenger aviation.

3.1.1. Baseline definition

In order to calculate the technical reduction potential and the cost efficiency of efficient car types, an appropriate baseline car has to be defined. According to the benchmarking approach defined in section 2.1, we define the baseline car according to characteristics of a car that would be most probably purchased by households in a given country and a given year. National average values on characteristics of newly purchased cars are therefore used to define the baseline activity. We assume that the baseline car would be used equally as the more efficient car and that the relative differences in fuel consumption are equal for the baseline and reduction activity car (e.g. both cars consume 10% more fuel when driving in a city).

Due to a lack of more exact data, the yearly emissions of the baseline car are in our evaluation calculated using the average specific CO_2 emissions of a new car and the average yearly distance driven by a car. In Germany the average new car emits 151.2 gCO_2/km (2010) and in Switzerland 155gCO_2/km (2011) respectively (European Environment Agency, 2011; SFOE, 2012). The average yearly distance driven by a car was 14'200km in Germany in 2010 (Kunert & Radke, 2011) and 13'086km in Switzerland[17] in 2010 (SFSO, 2012b) respectively. To estimate the total amount of achievable emission reductions by a new car, an average lifetime of the car of 8 years for Germany (2008) and Switzerland (2011) is used (ACEA, 2010; SFSO, 2012b).

To convert the costs of the Swiss baseline car from Swiss Francs to Euros, we use an exchange rate of 0.83€/CHF (Swiss National Bank, 2012). The total life-cycle costs of the baseline car are calculated by using the average investment costs, which were 25'893 Euros in 2011 in Germany (Dudenhöffer, 2012) and 30'420 Euros in 2011 in Switzerland (Comparis, 2012a). We calculate the operation costs of the baseline car according to the weighted average costs for the consumed fuel. The weights correspond to the shares of new gasoline and diesel cars, which are 51.3% and 48.7% in Germany[18] (Center Automotive Research, 2012) and 67% and 33% in Switzerland (SFOE, 2012) respectively. The average fuel consumption of new cars is 6.08liter/100km in Germany (Odyssee, 2010) and 6.93liter/100km in Switzerland (SFOE, 2012) respectively. A constant fuel price over the time span of the reduction activity is assumed. The average price of gasoline is currently at 1.61€/liter in Germany and 1.51€/liter in Switzerland, whereas the average price of diesel is currently at 1.52€/liter in Germany and 1.59€/liter in Switzerland (AvD, 2012). An average price of consumed electricity of 0.253€/kWh for Germany (Eurostat, 2011a) and 0.162€/kWh for Switzerland (ElCom, 2012) is used. Furthermore, we assume yearly car maintenance costs of 5% of the investment costs (ADAC, 2012a). To calculate the operation costs of natural gas and biofuel vehicles we use a natural gas price of 1.015€/kg for Germany and 1.62€/kg for Switzerland respectively and a price of bioethanol-85 of 1.115€/liter for Germany and 1.2€/liter for Switzerland respectively (Ethanol-tanken.com, 2012; gibgas, 2012; Topten International Group, 2012). Table 4 gives an overview of the used values and assumptions.

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[17] Calculated from total kilometers driven by private cars in 2010 (53'339 Mio km) and total number of private cars in 2010 (4'075'825 private cars) (SFSO, 2012b).

[18] The values are adjusted according to the assumption that only gasoline and diesel cars were sold in Germany in 2012. The 1.3% of alternative fueled cars sold in Germany in 2012 are excluded from these shares.

Table 4: Assumptions and chosen benchmark values used to calculate the technical reduction potential and the cost efficiency of the reduction activities involving the purchase of a new car.

Parameter	**Unit**	**Variable**	**Germany**	**Switzerland**
Average specific CO_2 emissions of newly purchased cars	gCO_2/km	e_{BL}	151.2	155
Average yearly distance driven by a car	km/year	D	14’200	13’086
Average lifetime of a car	years	T	8	8
Average price of newly purchased cars	€	I_{BL}	25’893	30’420
Average fuel consumption of a newly purchased car	liter/100km	C_{BL}	6.08	6.93
Share of gasoline cars newly purchased	%	$s_{gasoline}$	51.3	67
Average price of consumed gasoline	€/liter	$p_{gasoline}$	1.61	1.51
Share of diesel cars newly purchased	%	s_{diesel}	48.7	33
Average price of consumed diesel	€/liter	p_{diesel}	1.52	1.59
Average price of consumed electricity	€/kWh	p_{el}	0.253	0.162
Share of maintenance costs of total investment costs (assumption)	%/year	$s_{mc/I}$	5	5
Average price of natural gas	€/kg	p_{CNG}	1.015	1.62
Average price of ethanol-85	€/liter	$p_{ethanol}$	1.115	1.2

Using the benchmark values given in Table 4, we can calculate the yearly GHG emissions and total costs of the baseline activity. The baseline car emits 2.147 tCO_2 per year in Germany and 2.028 tCO_2 per year in Switzerland respectively. The total life-cycle costs of the baseline car add up to 43’713 Euros in Germany and 50’041 Euros in Switzerland respectively. Table 5 gives an overview of the baseline car characteristics in Germany and Switzerland.

Table 5: Characteristics of the baseline activity for Germany and Switzerland

Country	**Yearly GHG emissions of baseline activity**	**Yearly operation costs of baseline activity**	**Total costs of baseline activity**
Unit	*tCO_2/year*	*€/year*	*€*
Calculated variable	$E_{BL,t}$	$oc_{BL,t}$[19]	TC_{BL}[20]
Germany	2.147	1’352	43’713
Switzerland	2.028	1’393	50’041

3.1.2. Technical reduction potential

In the following we calculate the technical reduction potential for different reduction activities in transportation according to the methodology defined in section 2.1. We assume that the achieved emission reductions in the transport sector are compensated by an economy-wide rebound effect of 50% (cf. section 2.1). Moreover, it is important to consider differences in emissions of the production of the car and the consumed fuel. It can however be seen that the emissions caused by the production of the car (without the battery) are more or less equal for all car types and that the emissions caused by the production of a battery for hybrid and electric cars is similar to the emissions caused by the production of fossil fuels (Althaus & Gauch, 2010). In our calculations we therefore only consider emissions that are directly caused by the use of the vehicle and emissions that are caused by producing electricity for electric and plug-in hybrid cars.

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[19] $oc_{BL}=[(s_{gasoline}\cdot C_k\cdot p_{gasoline})+((1-s_{gasoline})\cdot C_k\cdot p_{diesel})]\cdot D/100$

[20] Calculation according to formula (2)

Electric, hybrid, and plug-in hybrid cars

The technical reduction potentials are calculated for the car models Lexus CT 200h Hybrid, Toyota Prius 1.8 Hybrid, and Mitsubishi iMiEV, which are considered to be the most environmentally friendly HEC and BEC currently available (VCS, 2012). Additionally, we calculate the technical reduction potential for the new Toyota Prius Plug-in Hybrid. The specific CO_2 emissions are 87gCO_2/km for the Lexus CT 200h Hybrid and 89gCO_2/km for the Toyota Prius 1.8 Hybrid respectively (VCS, 2012). The specific CO_2 emissions of the gasoline engine of the Toyota Prius 1.8 Plug-in Hybrid are 49gCO_2/km (ADAC, 2012b). The specific GHG emissions of the iMiEV and of the electric motor of the Plug-in Prius are calculated by their specific electricity consumption and the national emission factor for consumed electricity, which is 566gCO2eq/kWh in Germany (Umweltbundesamt, 2012) and 133gCO2eq/kWh in Switzerland (FOEN, 2012) respectively. The specific electricity consumption is on average 13.5kWh/100km for the iMiEV (VCS, 2012) and 5.2kWh/100km for the Plug-in Prius (ADAC, 2012b) respectively. For the iMiEV, this results in specific CO_2 emissions 76.41gCO_2/km for Germany and 17.96gCO_2/km for Switzerland respectively. For the Plug-in Prius, the specific CO_2 emissions caused by the electricity production add up to specific CO_2 emissions of the gasoline engine. This results in specific CO_2 emissions of 78.43gCO_2/km (29.43gCO_2/km specific CO_2 emissions of consumed electricity) for Germany and 55.92gCO_2/km (6.92gCO_2/km specific CO_2 emissions of consumed electricity) for Switzerland.

In the following we exemplify the calculation of the technical reduction potential for a Mitsubishi iMiEV in Germany. The calculation of the technical reduction potential of the other car types is analogous, differing only by the consumed type of fuel.

- Specific emissions (e_{iMiEV}) of a Mitsubishi iMiEV in Germany:

$$e_{iMiEV,t} = C_{iMiEV} \cdot EF_{electricity,t} = 0.135\frac{kWh}{km} \cdot 566\frac{gCO_2}{kWh} = 76.41\frac{gCO_2}{km}$$

- Yearly emissions (E_{iMiEV}) of a Mitsubishi iMiEV in Germany:

$$E_{iMiEV,t} = e_{iMiEV,t} \cdot D_t = 76.41\frac{gCO_2}{km} \cdot 10^{-6}\frac{tCO_2}{gCO_2} \cdot 14200\frac{km}{year} = 1.085\frac{tCO_2}{year}$$

- Yearly technical reduction potential of an iMiEV compared to the baseline car:

$$ER_{iMiEV,t} = (E_{averagenewcar,t} - E_{iMiEV,t}) \cdot (1-rb) = \left(2.147\frac{tCO_2}{year} - 1.085\frac{tCO_2}{year}\right) \cdot (1-0.5) = 0.531\frac{tCO_2}{year}$$

- Total technical reduction potential of an iMiEV compared to the baseline car:

$$ER_{iMiEV,t} = ER_{iMiEV,t} \cdot T = 0.531\frac{tCO_2}{year} \cdot 8years = 4.248tCO_2$$

Calculating the technical reduction potential similarly for the other three car models, it can be seen that the Mitsubishi iMiEV has the largest technical reduction potential with 0.531tCO_2/year in Germany and 0.897tCO_2/year in Switzerland respectively. The high technical reduction potential of the Mitsubishi iMiEV calculated for Germany is interesting, as electric cars are usually thought to only achieve considerable emission reductions if powered by green electricity. Moreover, also the Toyota Prius 1.8 Plug-in Hybrid has a comparably high technical reduction potential. The technical reduction potentials of Toyota Prius 1.8 Hybrid and the Lexus CT 200h Hybrid are smaller but still considerable. The results are shown in Table 6.

Compressed natural gas and bioethanol cars

We calculate the technical reduction potential of the two car models VW Passat Variant 1.4 TSI EcoFuel as an example for a midsize natural gas car and the Ford Mondeo 2.0 Flexifuel Trend as an example for a midsize biofuel car. Both car models can be seen as one of the most efficient compressed natural gas cars (CNGC) and bioethanol cars (BETHC) respectively. The VW Passat has specific CO_2 emissions of 94gCO_2/km for a Swiss natural gas mix, which consists of 80% natural gas and 20% biogas, and 119gCO_2/km for the German natural gas mix, which consist of 100% natural gas (ADAC, 2012b; VCS, 2012). For comparison, specific CO_2 emissions of natural gas cars in Switzerland range between 63-125gCO_2/km (VCS, 2012). The Ford Mondeo emits 32gCO_2/km assuming that 85% of the ethanol are produced from renewable bio matter (e.g. from wooden waste in Switzerland) or 169gCO_2/km if the Ethanol-85 is not renewable (ADAC, 2012b; VCS, 2012).

The results show that due to the comparably high specific emissions, the VW Passat achieves rather small emission reductions with 0.229tCO_2/year and 0.399tCO_2/year for Germany and Switzerland respectively. The Ford Mondeo can only achieve emission reductions if the bioethanol-85 is renewable. Otherwise, its specific CO_2 emissions are above the average CO_2 emissions of a newly purchased car in Germany and Switzerland. If the bioethanol is renewable the Mondeo achieves large emission reductions of 0.846tCO_2/year and 0.805tCO_2/year in Germany and Switzerland respectively.

Highly efficient conventional diesel and gasoline cars

A large variety of new and efficient conventional diesel cars (CDC) or conventional gasoline cars (CGC) exist. For the calculation of the technical reduction potential the two most efficient midsize diesel and gasoline cars available are taken as calculation example. These are the Skoda Octavia/Combi 1.6 TDI-CR Greenline (diesel) and the VW Jetta 1.2 TSI BM Techn. (gasoline). The Skoda Octavia emits 99gCO_2/km and the VW Jetta 123gCO_2/km respectively (ADAC, 2012b; VCS, 2012). This results in achievable emission reductions of 0.371tCO_2/year and 0.366tCO_2/year for the Skoda Octavia in Germany and Switzerland respectively and of 0.200tCO_2/year and 0.209tCO_2/year for the VW Jetta in Germany and in Switzerland respectively. Therefore, highly efficient diesel cars seem to have a higher technical reduction potential than highly efficient gasoline cars. Table 6 depicts an overview of the results of the calculation for the selected reduction activites and for Germany and Switzerland.

Table 6: Technical emission reduction potential of different car models in Germany and Switzerland.

Car type	**Country**	**Specific car emissions**	**Yearly emissions of red. activity**	**Yearly emission reductions**	**Total emission reductions**
-	*Unit*	gCO_2/km	tCO_2	$tCO_2/year$	tCO_2
-	*Calculation*	e_i	$E_{i,t}$	$ER_{i,t}$	ER_i
Lexus CT 200h Hybrid	Germany	87	1.235	0.456	3.647
Toyota Prius 1.8 Hybrid	Germany	89	1.264	0.442	3.533
Mitsubishi iMiEV	Germany	76.41[21]	1.085	0.531	4.248
Toyota Prius 1.8 Plug-in Hybrid Life	Germany	78.43	1.114	0.517	4.133
VW Passat / Var. 1.4 TSI EcoFuel	Germany	119	1.690	0.229	1.829
Ford Mondeo 2.0 Flexifuel Trend	Germany	32	0.454	0.846	6.771
Skoda Octavia/Combi 1.6 TDI-CR Greenline	Germany	99	1.406	0.371	2.965
VW Jetta 1.2 TSI BM Techn.	Germany	123	1.747	0.200	1.602
Lexus CT 200h Hybrid	Switzerland	87	1.139	0.445	3.559
Toyota Prius 1.8 Hybrid	Switzerland	89	1.165	0.432	3.455
Mitsubishi iMiEV	Switzerland	17.96[22]	0.235	0.897	7.173
Toyota Prius 1.8 Plug-in Hybrid Sol	Switzerland	55.92	0.732	0.648	5.186
VW Passat / Var. 1.4 TSI EcoFuel	Switzerland	94[23]	1.230	0.399	3.193
Ford Mondeo 2.0 Flexifuel Trend	Switzerland	32	0.419	0.805	6.438
Skoda Octavia/Combi 1.6 TDI-CR Greenline	Switzerland	99	1.296	0.366	2.931
VW Jetta 1.2 TSI BM Techn.	Switzerland	123	1.610	0.209	1.675

3.1.3. Cost efficiency

In order to compare the cost efficiency of the different reduction activities, we calculate the specific abatement costs according to formula (2) and (3) in section 2.2 for Germany and Switzerland and test the assumptions with a sensitivity analysis. For the calculations, an interest rate of 4% (cf. section 2.2) is assumed and the costs of household reduction activities in Switzerland are converted from the Swiss Franc to Euros using an exchange rate of 0.83€/CHF (Swiss National Bank, 2012).

Electric, hybrid, and plug-in hybrid cars

We calculate the specific abatement costs for the four car models Lexus CT 200h Hybrid, Toyota Prius 1.8 Hybrid, Mitsubishi iMiEV, and Toyota Prius 1.8 Plug-in Hybrid. The investment costs are taken from national car databases (ADAC, 2012b; Toyota Switzerland, 2012; VCS, 2012). The Lexus CT 200h Hybrid consumes 3.8liter/100km, the Toyota Prius 1.8 Hybrid 3.9liter/100km, the Mitsubishi iMiEV 13.5kWh/100km and the Toyota Prius 1.8 Plug-in Hybrid 2.1liter/100km and 5.2kWh/100km (ADAC, 2012b; Toyota Switzerland, 2012; VCS, 2012). The Lexus CT200h and both Prius models run on gasoline. We calculate the operation costs using the current average gasoline prices as well as the current average electricity prices for Germany and Switzerland (compare Table 4). Again, we exemplify the calculations of the specific abatement costs for a Mitsubishi iMiEV in Germany.

- Maintenance costs:

$$mc_{iMiEV,t} = s_{mc/I,t} \cdot I_{iMiEV} = 0.05\frac{1}{year} \cdot 34990 Euros = 1750\frac{Euros}{year}$$

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[21] 13.5[kWh/100km]*566[gCO2e/kWh]*0.01[km/100km]=76.41[gCO2e/km]

[22] 13.5[kWh/100km]*133[gCO2e/kWh]*0.01[km/100km]=17.96[gCO2e/km]

[23] According to Swiss natural gas mix, which is a blend of 80% natural gas and 20% biogas (VCS, 2012)

- Operation costs:

$$oc_{iMiEV,t} = C_{iMiEV} \cdot D_t \cdot p_{el,t} = 0.135\frac{kWh}{km} \cdot 14200\frac{km}{year} \cdot 0.253\frac{Euros}{kWh} = 485\frac{Euros}{year}$$

- Total life-cycle costs:

$$TC_{iMiEV} = \sum_{t=1}^{T} \frac{mc_{iMiEV,t} + oc_{iMiEV,t} - rev_{iMiEV,t}}{(1+r)^t} + I_{mc_{iMiEV}} = \sum_{t=1}^{8} \frac{1750 + 485 - 0}{(1+0.04)^t} + 34990 = 50358 Euros$$

- Specific abatement costs:

$$ac_{iMiEV} = \frac{TC_{iMiEV} - TC_{averagenewcar}}{ER_{iMiEV}} = \frac{50358 Euros - 44097 Euros}{4.354 tCO_2} = 1438\frac{Euros}{tCO_2}$$

The results for the specific abatement costs of the three car models in Table 7 show, that under the given assumptions the Toyota Prius 1.8 Hybrid has the lowest specific abatement costs in both countries. The negative specific abatement costs imply that the reduction activity results in monetary benefits in comparison to the baseline activity. These benefits are due to the comparably low total costs, which mostly result from the lower investment costs and maintenance costs. The specific abatement costs of the other car models are comparably high. A reference value for the specific abatement costs may be taken from the Swiss Climate Cent Foundation, which in 2011 paid a total of 374 million Euros (450 million Swiss Francs) for a total of 2.6 million tons of inland CO_2 emission reductions (Swiss Climate Cent Foundation, 2012). This results in abatement costs of 144 €/tCO_2.

Compressed natural gas and bioethanol cars

For natural gas and biofuel cars the abatement costs are calculated for the VW Passat Variant 1.4 TSI EcoFuel and the Ford Mondeo 2.0 Flexifuel Trend respectively. The investment costs are again according to national car databases. The VW Passat consumes 4.2kg/100km natural gas and the Ford Mondeo 9.2liter/100km bioethanol-85 (ADAC, 2012b; VCS, 2012).

The cost efficiency calculation for the VW Passat and the Ford Mondeo result in comparably high abatement costs (cf. Table 7). The very high abatement costs of the VW Passat are mainly due to its high investment costs and the low technical reduction potential, whereas the high abatement costs of the Ford Mondeo are mainly caused by its high operation costs.

Highly efficient conventional diesel and gasoline cars

The cost efficiency is calculated for the diesel powered Skoda Octavia/Combi 1.6 TDI-CR Greenline and the gasoline powered VW Jetta 1.2 TSI BM Techn. The list price in Germany and Switzerland of the Skoda Octavia is 22’810 Euros and 27’000 Euros respectively and of the VW Jetta 21’875 Euros and 24’942 Euros respectively. The Skoda Octavia consumes 3.8liter/100km diesel and the VW Jetta 5.3liter/100km gasoline (ADAC, 2012b; VCS, 2012).

Given that the investment and maintenance costs are lower than the investment and maintenance costs of the baseline activity (cf. Table 4), the two car models have clearly negative abatement costs depicted in Table 7, which means that the purchase of such vehicles instead of the baseline vehicle results in clear monetary benefits for the corresponding households.

Table 7: Cost efficiency of the reduction activities calculated according to formulas (1) and (2) for Germany and Switzerland.

Car type	**Country**	**Investment costs**	**Fuel consumption**	**Maintenance costs**	**Operation costs**	**Total costs of reduction activity**	**Specific abatement costs**
Unit	-	*€*	*liter/100km,* *kWh/100km* *kg/100km*	*€/year*	*€/year*	*€*	*€/tCO2*
Variable	-	I_i	C_i	$mc_{i,t}$	$oc_{i,t}$	TC_i	ac_i
Lexus CT 200h Hybrid	DE	29’200	3.8	1’460	869	44’879	320
Toyota Prius 1.8 Hybrid	DE	26’500	3.9	1’325	892	41’424	-648
Mitsubishi iMiEV	DE	34’990	13.5	1’750	485	50’034	1’488
Toyota Prius 1.8 PHEC	DE	36’200	2.1/5.2	1’810	667	52’876	2’217
VW Passat Variant 1.4	DE	31’650	4.3	1’583	620	46’477	1’511
Ford Mondeo 2.0	DE	26’800	9.2	1’340	1’457	45’629	283
Skoda Octavia/Combi 1.6	DE	22’810	3.8	1’141	820	36’011	-2’598
VW Jetta 1.2	DE	21’875	5.3	1’094	1’212	37’397	-3’943
Lexus CT 200h Hybrid	CH	34’777	3.8	1’739	751	51’540	421
Toyota Prius 1.8 Hybrid	CH	33’449	3.9	1’673	770	49’898	-42
Mitsubishi iMiEV	CH	38’172	13.5	1’909	286	52’949	405
Toyota Prius 1.8 PHEC	CH	43’077	2.1/5.2	2’154	525	61’114	2’135
VW Passat Variant 1.4	CH	36’894	4.3	1’845	912	55’451	1’694
Ford Mondeo 2.0	CH	33’864	9.2	1’693	1’449	54’991	769
Skoda Octavia/Combi 1.6	CH	27’000	3.8	1’350	791	41’412	-2’944
VW Jetta 1.2	CH	24’942	5.3	1’247	1’047	40’389	-5’763

Sensitivity of the calculations

In the following we test the sensitivity of a reduction activity’s specific abatement costs to changes in the assumptions used for the calculation. For each of the used assumptions different values (in Figure 1 depicted as a percentage change to the original value) were inserted in the above calculations to determine the corresponding change in specific abatement costs. Figure 1 shows the result for the Toyota Prius 1.8 Hybrid in Switzerland. It can be seen that the specific abatement costs are highly sensitive to possible[24] percentage changes in the investment costs and the fuel consumption of the baseline activity, i.e. they are highly significant to changes in the cost difference between reduction activity and baseline activity. According to formula (2) and (3), this implies in reverse that the abatement costs are also strongly significant to changes in the investment costs and the fuel consumption of the reduction activity. A change in the ratio between maintenance costs and investment costs, in the assumed yearly interest rate, in the yearly distance driven, in the expected lifetime of the vehicles, as well as in the gasoline price has a lower but still considerable influence on the specific abatement costs. The rebound effect has a high effect on the achievable emission reductions but a comparably low effect on the specific abatement costs. If the rebound effect for example is 0% instead of 50% the achievable emission reductions are twice as large, which results in specific abatement costs being reduced to 50% of the initial value (compare formula (3)). A 100% decrease of the rebound effect therefore leads to a 50% decrease in specific abatement costs. At the same time, a 50% decrease in specific abatement costs can *ceteris paribus* also be caused by a change in investment costs of the baseline of only 0.2%.

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[24] An increase or decrease of, for example, 10% seems possible for the investment costs and the fuel consumption of the baseline activity.

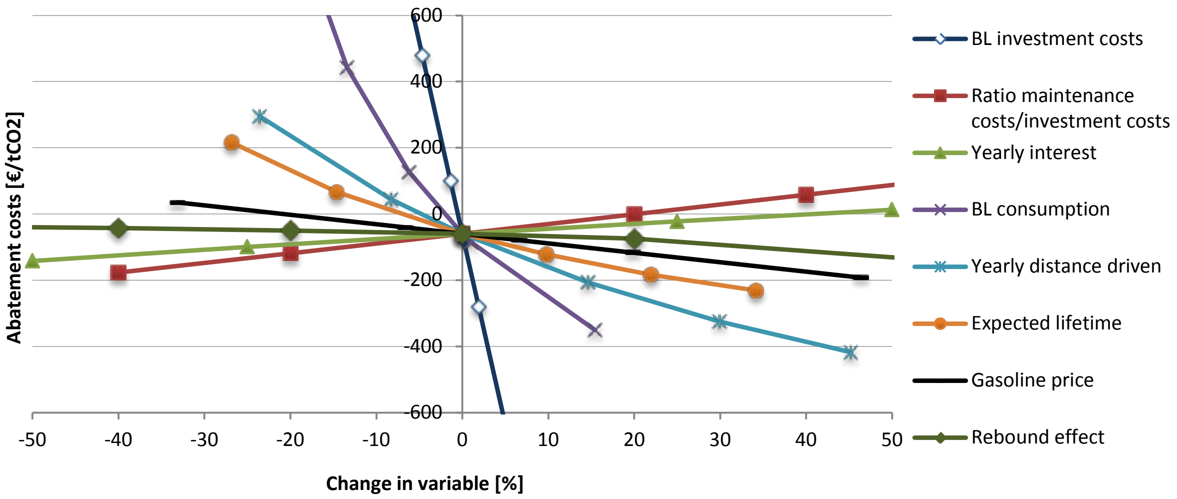

Figure 1: Sensitivity analysis for the cost efficiency calculation of the Toyota Prius 1.8 Hybrid in Switzerland. The intersection depicts the most probable abatement costs of the reduction activity (composed by the authors)

The sensitivity analysis shows that the results of the cost efficiency calculation are sensitive to many of the made assumptions. The absolute values for the different specific abatement costs should therefore be used carefully. However, given the investment costs and fuel consumption of the different reduction activities the ranking of reduction activities according to the specific abatement costs stays the same also when changing the assumptions. Therefore the specific abatement costs can be used to compare the cost efficiencies of the different reduction activities.

3.1.4. Verifiability

According to section 2.3, we compare the different reduction activities by determining the number of parameters used to calculate the corresponding technical reduction potentials. In addition, we qualitatively discuss the verifiability of the different reduction activities. Table 8 gives an overview of the number of parameters used to calculate the technical reduction potential.

GHG emissions of the baseline activity

In order to calculate the emission reductions achieved by a certain reduction activity, the GHG emissions of the corresponding baseline activity have to be determined. In our calculations we used a benchmark value for the specific GHG emissions of the baseline car purchased by an average household. Such benchmark values are available for different countries and are commonly updated on an annual basis. In addition, we used the average distance driven per car in order to calculate the total GHG emissions of the baseline activity from its specific GHG emissions.

GHG emissions of the reduction activity

For calculating the GHG emissions of the different car models, the specific GHG emissions of the car models were used. Only for the electric motor of the Mitsubishi iMiev and the Toyota Prius Plug-in Hybrid we calculated the GHG emissions by the cars' specific electricity consumption and the corresponding emission factor for a normal electricity mix. Table 7 gives an overview of the used parameters. The total number of parameters is the sum of all parameters identified calculating the GHG emissions of the baseline and reduction activity.

Table 8: Number of parameters that were determined in order to calculate the technical reduction potential by the reduction activity compared to the given baseline activity

Car type	**Car model**	**Specific emissions**	**Distance**	**Amount of fuel consumed**	**Type of fuel consumed**	**Emission factor of fuel**	**Total number of parameters**
Baseline car	-	1	1	-	-	-	-
Lexus CT 200h Hybrid	1	1	-	-	-	-	**4**
Toyota Prius 1.8 Hybrid	1	1	-	-	-	-	**4**
Mitsubishi iMiEV	1	-	-	1	1	1	**6**
Toyota Prius 1.8 PHEC	1	1	-	1	1	1	**7**
VW Passat Variant 1.4	1	1	-	-	-	-	**4**
Ford Mondeo 2.0	1	1	-	-	-	-	**4**
Skoda Octavia/Combi 1.6	1	1	-	-	-	-	**4**
VW Jetta 1.2	1	1	-	-	-	-	**4**

As a result it can be seen that the most parameters had to be determined for the Mitsubishi iMiEV and the Toyota Prius 1.8 PHEC. The verifiability of these two car models is therefore likely to be lower than for the other car models.

Verifiability of the achieved GHG emission reductions

We identify four different approaches of M&V applicable to the here evaluated reduction activities:

- On-board trip computers: The GHG emissions of the reduction activity could be verified by using on-board trip computers, which record the fuel consumption of the vehicle. This measure might however result in additional costs if such on-board trip computers are not standard in a car model or require an additional device that saves the recordings. In addition, this approach would require the identification of the type of fuel consumed and the corresponding emission factor.
- Credit card system: The fuel consumption of the car could be monitored with high accuracy, by letting households use a special credit card for payments. The credit card billing would reveal the households' fuel consumption and also the type of fuel consumed (Davenport & Hershey, 2003; Leu, 1994). To calculate the total GHG emissions, the identification of the corresponding emission factor would be required.
- Refuel/recharge receipts: A cheaper method could be the collection of all receipts from the refuel/recharge stations, which would equally give information about the amount and type of fuel consumed. The emission factor would have to be identified additionally. The drawback of this measure however is a larger effort that is required from the vehicle owners and the risk of lost receipts.
- Average values: Average values available from national statistical institutions could be used to determine the achieved GHG emission reductions similarly to the calculations in this evaluation. A prerequisite for this approach however, is the availability of appropriate and up-to-date average values as well as a large enough number of households realizing a certain reduction activity, i.e. a number that is large enough for allowing the assumption that the differences in consumption behaviour of participating households are averaged out. Given the variability in fuel consumption is in

general high among households and depends on their driving behaviour. A large number of households realizing the same reduction activity would be needed (compared, for example, to implementing energy efficient refrigerators) in order to use national average values for certification of achieved GHG emission reductions. An additional factors that might lead to errors in the calculations is the different fuel types available in different countries or regions.

3.1.5. Implementation barriers

Implementation barriers for reduction activities involving different car types are evaluated according to the methodology presented in section 2.4. Accordingly, for each type of car the implementation barriers are identified. Table 9 in the end of the subsection gives an overview of the identified barriers. The sum of the observable implementation barriers can be used as a first indicator on how difficult it might be to implement a given reduction activity.

Electric, hybrid, and plug-in hybrid cars

Financial barriers seem to be an important reason why private households refrain from purchasing electric, hybrid, or plug-in hybrid cars. The price of almost all car models is well above the average price of a newly purchased vehicle (Kahn Ribeiro et al., 2007; VCS, 2012). According to the previously calculated abatement costs, it can be seen that especially for BEC and PHEC models the benefit-cost ratio is too small. Additional implementation costs for installation of a recharge station at home might even diminish the benefit-cost ratio. Moreover, the risk of incompatibility with the required services is an important barrier. Especially BEC but also PHEC need a good recharge station infrastructure. Long charging times are an additional barrier. BEC have a rather short driving range of around 150km per battery load (Hidrue et al., 2011; van Vuuren et al., 2009; VCS, 2012) and BEC, HEC, and PHEC are not available for many different service levels (e.g. no hybrid van exists yet) (ADAC, 2012b; VCS, 2012). All evaluated car models are available to households in Switzerland and Germany. The Toyota Prius 1.8 Plug-in Hybrid is only available as the “Life” version in Germany and as the “Sol” version in Switzerland. However, the two versions have similar characteristics (ADAC, 2012b; VCS, 2012). For BEC and PHEC there is a risk of increasing electricity prices, which can make these reduction activities worse off compared to the baseline activity. The low benefit-cost ratio is partially caused by low prices for fossil fuels (Hirst & Brown, 1990). This is due to a lack of internalized external costs. Inertia in adoption behaviour as well as a tradition or common behaviour are no implementation barriers because the household already decided to purchase a new car. A last important barrier is a potential lack of acceptability. Due to the rather low number of available BEC, HEC, and PHEC models, households might not find a car model with the preferred design.

Compressed natural gas and bioethanol cars

Most of the car models that run on natural gas or bioethanol are a special version of a similar car model that runs on gasoline or diesel. A comparison of the prices between the different versions of the car models shows that CNGC models have clearly higher investment costs than the versions running on gasoline or diesel. CNGC also have higher investment costs than the baseline car. The higher investment costs of CNG cars can be explained by the fact that CNG must be stored under high pressure in larger and heavier fuel tanks (Kahn Ribeiro et al., 2007). For bioethanol cars the differences in investment costs are not as clear (VCS, 2012). Therefore we assume no budget constraints that prevent households from buying a BETHC. Due to the high price of CNG cars and due to the high fuel consumption of bioethanol cars (ranging between 6.8 and 9.4liter/100km) the benefit-cost ratio of both car types is rather low.

For both car types there is a risk of incompatibility with the given infrastructure. Both, CNG and bioethanol cars require their own refuelling infrastructure (Kahn Ribeiro et al., 2007) and cars are not purchased if the corresponding refuelling infrastructure is not well established. Moreover, due to the low number of available bioethanol cars not all required services such as vehicle size or type of drivetrain might be available (ADAC, 2012b; VCS, 2012). Due to the comparably large number of CNG car models, we assume that most services are available for CNG cars. For both cars, there is a risk of increasing fuel prices. The energy cost savings are small because of low prices for gasoline and diesel. Finally, also a lack of acceptability may be a strong implementation barrier if the preferred car model or brand offers no CNG or bioethanol option. For bioethanol cars an additional cause for a lack of acceptability might be concerns about the sustainability of using biofuels for transportation (Althaus & Gauch, 2010; Kahn Ribeiro et al., 2007; Luo, van der Voet, & Huppes, 2009; WBGU, 2008, also compare Figures 2 and 3 in the Annex).

Highly efficient conventional diesel and gasoline cars

For highly efficient conventional diesel and gasoline cars no major financial implementation barriers exist. Both car types can be related to investment costs comparable or even lower than those of the baseline activity. In addition, the lower fuel consumption results in cost savings (ADAC, 2012b; VCS, 2012). Yet, also for this type of car the rather low gasoline or diesel prices result in rather low cost savings. Increasing fuel prices are *per se* no risk, as the reduction activity would still be the preferable option compared to the baseline activity. Consequently, other implementation barriers, such as unavailable services or a lack of acceptability seem to be relevant because the average specific CO_2 emissions of newly purchased cars are still well above the specific CO_2 emissions of highly efficient conventional diesel and gasoline cars. Also for highly efficient conventional diesel and gasoline cars the inertia in adoption behaviour as well as a tradition or common behaviour are no implementation barriers, as the household already decided to purchase a new car.

Table 9: List of relevant implementation barriers for reduction activities in transportation, “1” indicates that this barrier applies to the reduction activity and “-” indicates that the barrier doesn’t apply to the reduction activity (BEC: battery electric car, HEC: hybrid electric car, PHEC: plug-in hybrid car, CNGC: Compressed natural gas car, BETHC: Bioethanol-85 car, CDC: Conventional diesel car, CGC: Conventional gasoline car)

	Monitored parameter	**BEC**	**HEC**	**PHEC**	**CNGC**	**BETHC**	**CDC**	**CGC**
Financial cost barriers	Household budget constraints	1	1	1	1	-	-	-
	Low benefit-cost ratio	1	-	1	1	1	-	-
	Lack of access to financing	-	-	-	-	-	-	-
Hidden cost barriers	Additional implementation costs	1	-	1	-	-	-	-
	Risk of incompatibility							
	- New recharge infrastructure	1	-	1	1	1	-	-
	- Short driving range	1	-	-	-	-	-	-
	- Unavailable services (e.g. size, 4x4)	1	1	1	-	1	1	1
	Performance risk	-	-	-	-	-	-	-
	Risk of increasing fuel prices	1	-	1	1	1	-	-
Market failures	Misplaced incentives (principal-agent problem)	-	-	-	-	-	-	-
	Fragmented market structure	-	-	-	-	-	-	-
	Availability to households	-	-	-	-	-	-	-
	Distortionary fiscal and regulatory policies	-	-	-	-	-	-	-
	Unprized external costs and benefits	1	1	1	1	1	1	1
	Insufficient and inaccurate information	-	-	-	-	-	-	-
	Codes and standards	-	-	-	-	-	-	-
	Corruption	-	-	-	-	-	-	-
Behavioural barriers	Inertia in adoption behaviour	-	-	-	-	-	-	-
	Lack of acceptability	1	1	1	1	1	1	1
	Tradition and common behaviour	-	-	-	-	-	-	-
Sum of applicable implementation barriers		**9**	**4**	**8**	**6**	**6**	**3**	**3**

Table 9 gives an overview of the findings and shows the total number of implementation barriers applicable to the different reduction activities. It shows that hybrid electric cars and highly efficient conventional diesel and gasoline cars can be related to less implementation barriers than the other car types.

3.1.6. Results

The evaluation of the eight different car models for Germany and Switzerland showed interesting results. The purchase of the Mitsubishi iMiEV (0.531tCO_2/year in Germany, 0.897tCO_2/year in Switzerland), the Toyota Prius Plug-in Hybrid (0.517tCO_2/year in Germany, 0.648tCO_2/year in Switzerland), and the Ford Mondeo Flexifuel (0.846tCO_2/year in Germany, 0.805 tCO_2/year in Switzerland) can achieve comparably high emission reductions in both countries. The largest emission reductions can be achieved by the purchase of a Mitsubishi iMiEV (battery electric car) in Switzerland and by the Ford Mondeo 2.0 Flexifuel Trend (bioethanol-85 car) in Germany. The gasoline car VW Jetta achieves the lowest emission reductions with 0.200tCO_2/year in Germany and 0.209tCO_2/year in Switzerland respectively.

The Toyota Prius Hybrid, the Skoda Octavia Greenline and the VW Jetta have negative specific abatement costs indicating a monetary benefit resulting from their use compared to the use of the baseline car. The VW Jetta achieves emission reductions at the lowest specific abatement costs with -3’943€/tCO_2 in Germany and with -5’763€/tCO_2 in Switzerland. All other car models have high positive specific abatement costs ranging from 279€/tCO_2 for the Ford Mondeo Flexifuel in Germany to 2’157€/tCO_2 for the Toyota Prius Plug-in Hybrid in Germany.

The total number of parameters used for the calculation of the achievable emission reductions is larger for BEC and PHEC. This is due to the fact that the specific GHG emissions of the two cars depend on the electricity used to recharge the battery of the cars. Therefore, the GHG emissions of the two cars cannot directly be calculated by their specific GHG emissions. For the electric motor of both cars, the specific electricity consumption, the type of electricity and the corresponding emission factor have to be identified. It is therefore likely that the verifiability of BEC and PHEC is lower than the verifiability of emission reductions caused by the other car types.

The fewest implementation barriers can be related to highly efficient conventional gasoline and diesel cars. Due to concerns about sustainable land and resource use, additional constraints especially exist for biofuel cars (e.g. bioethanol-85 car) (Althaus & Gauch, 2010; Kahn Ribeiro et al., 2007; Luo et al., 2009; WBGU, 2008).

3.2. Choice of transportation means

In this section, we analyse reduction activities that achieve GHG emission reductions and energy savings due to a switch to other less GHG emission intensive transport means or due to the reduced use of GHG emission intensive transport means. We thereby focus on transportation means used for commuting to work, as it is extremely difficult to analyse households' transportation behaviour during leisure time.

3.2.1. Baseline definition

We assume the baseline scenario for a reduction activity involving a choice of another type of transportation to be the continued use of a certain type of transportation for commuting to work. Significant CO_2 emission reductions can be achieved by the following reduction activities:

- Switching from the use of a car or motorcycle to the use of public transport, to cycling or to walking
- Using a car more efficiently by carpooling
- Switching from public transport to cycling or walking
- Reducing the use of the baseline activities by the introduction of home office days

As there are barely any values on the specific CO_2 emissions or fuel consumption of motorcycles we do not calculate the emission reductions that result from the switch away from using a motorcycle. Yet, it can be assumed that the emissions per person kilometre (Pkm) of a motorcycle are lower than the emissions per Pkm of a car and higher than the emissions of public transport. Consequently, the following two baseline activities are defined: the continued use of an average car[25] and the continued use of public transport for commuting to work. Table 10 depicts the here analysed reduction activities with their corresponding baseline activity.

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[25] In section 3.1 the baseline was the purchase of an average newly commissioned car. In this section the baseline is the use of an average car used in a specific region or country. These two different types of average cars should not be confused.

Table 10: Overview of the analysed reduction activities and their corresponding baseline activity

Reduction activity	Corresponding baseline activity
Switch from using a car to using public transport	Continued use of an average car
Switch from using a car to cycling	Continued use of an average car
Switch from using a car to walking	Continued use of an average car
Increased efficiency by carpooling	Continued use of an average car
Reduced use of car by home office days	Continued use of an average car
Switch from using public transport to cycling	Continued use of public transport
Switch from using public transport to walking	Continued use of public transport
Reduced use of public transport by home office days	Continued use of public transport

For both countries considered in this exemplary evaluation, we assume a total number of 225 working days per year and a maximum daily walking distance of 10km (corresponds to about 2 hours of walking: 1 hour walking to work and 1 hour back home after work). The specific CO_2 emissions of an average car (i.e. an average of all used cars and not only an average of newly commissioned cars) used per Pkm travelled are 140.7gCO_2/Pkm in Germany and 147gCO_2/Pkm in Switzerland respectively (Allianz pro Schiene, 2011; Keller et al., 2011). Finding no reliable benchmark values, we assume a specific fuel consumption of an average car to be 8litres/100km in Germany and 9 litres/100km in Switzerland. Moreover, we assume that 60% of all cars in Germany and 70% of all used cars in Switzerland are gasoline cars, whereas 40% are diesel cars in Germany and 30% in Switzerland respectively. The average car occupation is 1.2 persons per car in Germany and 1.12 persons per car in Switzerland (BMVBS, 2008; SFSO, 2012a). In Germany employees commute on average 17 kilometres per day whereas in Switzerland employees commute on average 15 kilometres per day to work (SFSO, 2011; Vimentis, 2011; Zeit Online, 2012). For the specific emissions of public transport we assume an average of the specific emissions from trains, trams and trolley busses in the corresponding countries. This results in 69.3gCO_2/Pkm in Germany and 7.1gCO_2/Pkm in Switzerland respectively (Allianz pro Schiene, 2011; Keller et al., 2011; VCD, 2008). Moreover, we calculate with a total duration of the reduction activity of one year, assuming that firms incentivize their employees to realize the reduction activity by a yearly financial bonus. We assume the reduction activities to be non-persistent (cf. section 2.1) reduction activities, i.e. the employees are only realizing the reduction activities if they are fostered by the firm (Abou-Zeid et al., 2012).

There are many different options for the use of public transport. An employee either has the choice of purchasing a general public transport pass, a regional public transport pass or the single tickets. Considering an average daily distance that employees commute to work of around 15 kilometres, a regional public transport pass might on average be appropriate. For a yearly regional transport pass we assume a price of 1000 Euros (Deutsche Bahn, 2012; SBB, 2012). Furthermore, we use the fuel prices already given in Table 4.

Table 11: Assumptions and chosen benchmark values used to calculate the technical reduction potential and the cost efficiency of the reduction activities involving a change in demand for certain transport means.

Parameter	Unit	Variable	Germany	Switzerland
Number of working days per year (assumption)	days	t_w	225	225
Maximum daily walking distance to work (assumption)	km/day	$d_{walking}$	10	10
Specific emissions of average car used (not newly purchased car)	gCO_2/Pkm	e_{car}	140.7	147
Specific fuel consumption of average car used (assumption)	liter/100km	c_k	8	9
Share of gasoline cars in use (assumption)	%	$s_{gasoline,used}$	70	80
Average car occupation	people/car	occ_k	1.2	1.12
Average daily distance to work	km/day	d_w	17	15
Specific emissions of public transport (assumption)	gCO_2/Pkm	e_{pt}	69.3	7.1
Specific emissions of train	gCO_2/Pkm	-	59.8	1.3
Specific emissions of tram	gCO_2/Pkm	-	78	10
Specific emissions of trolley bus	gCO_2/Pkm	-	70	10
Duration of incentive scheme (assumption)	Years	T	1	1
Investment costs public transport pass (assumption)	Euro	I_{pt}	1000	1000

Using the benchmark values and assumptions given in Table 4 and Table 11, we can calculate the GHG emissions and total costs of the two baseline activities “continued use of an average car” and “continued use of public transport” for Germany and Switzerland. Therefore, the use of an average car for commuting to work emits 0.538 tons of CO_2 per year in Germany and 0.496 tons of CO_2 per year in Switzerland whereas the use of public transport for commuting to work emits 0.265 tons of CO_2 per year in Germany and 0.024 tons of CO_2 per year in Switzerland respectively. The use of an average car for commuting to work results in total costs of 466€/year in Germany and 446€/year in Switzerland whereas the use of public transport for commuting to work results in 1000€/year in Germany and in Switzerland. Table 12 gives an overview of the baseline car characteristics in Germany and Switzerland.

Table 12: Characteristics of the two baseline activities for Germany and Switzerland

Baseline activity	Country	Yearly GHG emissions of baseline activity	Yearly operation costs of baseline activity	Total costs of baseline activity
Unit	-	*tCO_2/year*	*€/year*	*€*
Calculated variable	-	E_k	oc_k[26]	TC_k[27]
Continued use of an average car	Germany	0.538	484	466[28]
	Switzerland	0.496	464	446
Continued use of public transport	Germany	0.265	1000	1000
	Switzerland	0.024	1000	1000

In the following we analyse the different reduction activities depicted in table 11 according to the four evaluation criteria developed in chapter 2.

3.2.2. Technical reduction potential

The technical reduction potential is determined according to section 2.1 using the baseline activity, average values and assumptions given above in subsection 3.2.1. In the following the calculations are shown as an example for the yearly emission reductions of different types of reduction activities realized in Germany.

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[26] $oc_{BL}=[(s_{gasoline, used} \cdot C_k \cdot p_{gasoline})+((1-s_{gasoline, used}) \cdot C_k \cdot p_{diesel})] \cdot D/100$

[27] Calculation according to formula (2)

[28] According to formula (2), the operation costs are depreciated over one year resulting in lower total costs than the actual operation costs

- Switch from a car to public transport:

$$ER_{car-pt,t} = \left(e_{car,t} - e_{pt,t}\right) \cdot d_{w,t} \cdot t_w \cdot (1-rb) = \left(140.7\frac{gCO_2}{Pkm} - 69.3\frac{gCO_2}{Pkm}\right) \cdot 10^{-6}\frac{tCO_2}{gCO_2} \cdot 17\frac{Pkm}{day} \cdot 225\frac{days}{year} \cdot (1-0.5) = 0.137\frac{tCO_2}{year}$$

- Switch from a car to walking:

$$ER_{car-w,t} = e_{car,t} \cdot d_{walking} \cdot t_w \cdot (1-rb) = 140.7 \cdot 10^{-6}\frac{tCO_2}{Pkm} \cdot 10\frac{Pkm}{day} \cdot 225\frac{days}{year} \cdot (1-0.5) = 0.158\frac{tCO_2}{year}$$

- Increased efficiency by carpooling among 3 employees:

$$ER_{carpooling,t} = \left(occ_{carpooling,t} - occ_{BL,t}\right) \cdot e_{car,t} \cdot d_{w,t} \cdot t_w \cdot (1-rb) = (3-1.2) \cdot 140.7 \cdot 10^{-6}\frac{tCO_2}{Pkm} \cdot 17\frac{Pkm}{day} \cdot 225\frac{days}{year} \cdot (1-0.5) = 0.484\frac{tCO_2}{year}$$

- Reduced use of a car by home office:

$$ER_{homeoffice,t} = e_{car,t} \cdot d_{w,t} \cdot t_{homeoffice,t} \cdot (1-rb) = 140.7 \cdot 10^{-6}\frac{tCO_2}{gCO_2} \cdot 17\frac{Pkm}{day} \cdot 45 days \cdot (1-0.5) = 0.054\frac{tCO_2}{year}$$

The results for all reduction activities in Germany and Switzerland in Table 12 show that carpooling with 3 employees involved achieves high emission reductions of 0.484 tCO_2 per year in Germany (0.753 tCO_2 per year with 4 employees involved) and 0.466 tCO_2 per year in Switzerland (0.714 tCO_2 per year with 4 employees involved) respectively. Considerable emission reductions can also be achieved by a switch from using a car to using public transport (0.137 tCO_2 per year in Germany, 0.236 tCO_2 per year in Switzerland), by a switch from using a car to using a bicycle (0.269 tCO_2 per year in Germany, 0.248 tCO_2 per year in Switzerland), and by a switch from using a car to walking (0.158 tCO_2 per year in Germany, 0.165 tCO_2 per year in Switzerland). Due to the higher specific emissions of public transportation, also a switch from public transport to cycling and walking in Germany can achieve considerable emission reductions. Home office days result in comparably low GHG emission reductions. Table 13 gives an overview of the yearly achievable emission reductions.

Table 13: Achievable emission reductions by a more efficient or reduced use of transport means to work or a switch to other transport means.

Reduction activity (RA)	**Country**	**Specific emissions of RA**	**Yearly emissions of reduction activity**	**Yearly emission reductions**
Unit	-	*gCO_2/Pkm*	*tCO_2*	*tCO_2*
Calculation	-	$e_{i,t}$	$E_{i,t}$	$ER_{i,t}$
Switch from car to public transport	Germany	69.3	0.265	0.137
Switch from car to bicycle	Germany	0	0.000	0.269
Switch from car to walking	Germany	0	0.222[29]	0.158
Increased efficiency by carpooling (3 persons in car)	Germany	140.7	0.538	0.484
Increased efficiency by carpooling (4 persons in car)	Germany	140.7	0.538	0.753
Reduced use of car by home office (1 day per week)	Germany	140.7	0.431[30]	0.054
Switch from public transport to bicycle	Germany	0	0.000	0.133
Switch from public transport to walking	Germany	0	0.109	0.078
Reduced use of public transport by home office (1 day per week)	Germany	69.3	0.212	0.027
Switch from car to public transport	Switzerland	7.1	0.024	0.236
Switch from car to bicycle	Switzerland	0	0.000	0.248
Switch from car to walking	Switzerland	0	0.165	0.165
Increased efficiency by carpooling (3 persons in car)	Switzerland	147	0.496	0.466
Increased efficiency by carpooling (4 persons in car)	Switzerland	147	0.496	0.714
Reduced use of car by home office (1 day per week)	Switzerland	147	0.397	0.050
Switch from public transport to bicycle	Switzerland	0	0.000	0.012
Switch from public transport to walking	Switzerland	0	0.008	0.008
Reduced use of public transport by home office (1 day per week	Switzerland	7.1	0.019	0.002

3.2.3. Cost efficiency

In the following we calculate the specific abatement costs that are incurred by households according to formula (2) and (3) in section 2.2. However, compared to the before analysed reduction activities, which considered the purchase of an efficient car instead of a baseline car, many of the here evaluated reduction activities do not necessarily involve investment costs, maintenance costs or operation costs. An employee, for example, who decides to use public transport instead of a private car, can save the fuel costs the car would have consumed but needs to buy a pass or tickets for public transportation.

An employee who wants to cycle to work has the option of buying a new bicycle for that purpose or the option of using an already owned bicycle. We calculate with assumed investment costs of 200 Euros. This value might appear to be very low for buying a good bicycle. However, once purchased, the bicycle can also be used in future years to commute to work. At last we assume that an employee would need one pair of good shoes per year to walk to work, which we assume to result in investment costs of 100 Euros. In addition, we estimate the yearly maintenance costs (e.g. the costs for the replacement of a broken tire) of the bicycle to be 100 Euros. In case of carpooling employees can share the operation costs of one car but no additional costs arise. Home office days are assumed not to result in additional costs but shorten the total yearly distance commuted to work.

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[29] We assume a maximum daily walking distance of 10km. The rest of the average distance to work has to be traveled by the baseline means of transport.

[30] Home office days reduce the number of days an employee has to travel to work and therefore also the total yearly distance traveled to work. One home office day per week results in 180 working days instead of 225 working days (225 – 5/225*1=180).

The calculations of the total costs, which are needed to calculate the specific abatement costs according to formula (3), are special for the reduction activities that involve a switch to walking, carpooling, and home office. In the following we show the calculations for Germany as an example.

- Total costs of walking to work in cases where the distance to work is larger than the possible walking distance:

$$TC_{walking} = I_{walking} + \frac{\left(d_w - d_{walking}\right)}{d_w} \cdot TC_{BL} = 100 Euros + \frac{17-10}{17} \cdot 466 Euros = 292 Euros$$

- Total costs of carpooling assuming 3 employees using one car together:

$$TC_{carpooling} = \frac{1}{n_{Persons}} TC_{BL} = \frac{1}{3} \cdot 466 Euros = 155 Euros$$

- Total costs of for employees that benefit from one home office day:

$$TC_{homeoffice} = \left(1 - \frac{d_{homeoffice}}{5}\right) \cdot TC_{BL} = \left(1 - \frac{1}{5}\right) \cdot 466 Euros = 373 Euros$$

For a switch from public transport to walking or for reducing the use of public transport by home office days, the calculations of the total costs furthermore depend on whether or not the employee uses a public transport pass or buys single tickets. In case of the former no cost savings can be achieved by reducing the use of public transport, because the transport pass has to be bought anyway, whereas in case of the latter the employee can buy less tickets and therefore also saves costs.

The calculation of the specific abatement costs shows that almost all reduction activities achieve emission reductions more cost-efficiently. Only a switch from using a car to using public transport is not cost efficient because the operation costs of a car are likely to be lower than the investment costs for a public transport pass or public transport tickets. The cost efficiency of a reduction of the use of public transport depends on whether or not an employee buys single tickets for public transport. A switch from public transport to walking can be cost inefficient, if an employee already owns a public transport pass. The purchasing costs of the public transport pass can be seen as fixed costs of the employee, which do not change if public transportation is used less. If the distance to work is longer than the maximum walking distance the employee still has to use public transport and needs a public transport pass.

The very low negative and the very high positive specific abatement costs that can be observed for some reduction activities are due to very low achievable emission reductions, which are only a small share of one ton of CO_2 emission reductions. Consequently, the specific abatement costs (i.e. cost savings) become very large when extrapolated to one ton of CO_2 emission reductions.

Table 14: Specific abatement costs of reduction activities involving a change of the demand for a certain reduction activity

Car type	**Country**	**Investment costs**	**Maintenance costs**	**Operation costs**	**Total costs of reduction activity**	**Specific abatement costs**
Unit	-	*€*	*€/year*	*€/year*	*€*	*€/tCO2*
Variable	-	I_i	$mc_{i,t}$	$oc_{i,t}$	TC_i	ac_i
Switch from a car to public transport	DE	1’500	0	0	1’000	3’912
Switch from a car to a bicycle	DE	200	100	0	296	-630
Switch from a car to walking	DE	100	0	199	292	-1’099
3 persons join for carpooling	DE	0	0	161	155	-641
4 persons join for carpooling	DE	0	0	121	116	-464
Reduction of car use by 1 home office day	DE	0	0	388	373	-1’731
Switch from public transport to a bicycle	DE	200	100	0	296	-5’311
Switch from public transport to walking						
- Employee buys public transport tickets	DE	512	0	0	512	-6’262
- Employee with public transport pass	DE	1’100	0	0	1’100	1’283
Reduction of public transport use by 1 home office day						
- Employee buys public transport tickets	DE	800	0	0	800	-7’545
- Employee with public transport pass	DE	1’000	0	0	1’000	0
Switch from a car to public transport	CH	1’000	0	0	1’000	2’263
Switch from a car to a bicycle	CH	200	100	0	296	-684
Switch from a car to walking	CH	100	0	155	249	-1’313
3 persons join for carpooling	CH	0	0	155	149	-680
4 persons join for carpooling	CH	0	0	116	111	-496
Reduction of car use by 1 home office day	CH	0	0	371	357	-2’201
Switch from public transport to a bicycle	CH	200	100	0	296	-58’746
Switch from public transport to walking						
- Employee buys public transport tickets	CH	433	0	0	433	-70’944
- Employee with public transport pass	CH	1’100	0	0	1’100	12’520
Reduction of public transport use by 1 home office day						
- Employee buys public transport tickets	CH	800	0	0	800	-83’464
- Employee with public transport pass	CH	1’000	0	0	1’000	0

3.2.4. Verifiability

Similar to the evaluation of the verifiability of the emission reductions achieved by the purchase of a new and highly efficient car, we also evaluate the verifiability of emission reductions achieved by reduction activities reducing the demand for GHG emission intensive transportation means. For this *ex ante* evaluation we follow the calculations performed under section 3.2.2 to identify parameters that have to be determined in order to calculate the GHG emission of the corresponding baseline and reduction activities.

GHG emissions of the baseline activity

We start with the calculation of the GHG emissions of the two baseline activities: the use of a car for going to work and use of public transport for going to work. To determine the GHG emissions caused by one employee using a car for going to work it is necessary to know the type of car used and its specific GHG emissions. As the baseline car can also be used for other purposes than commuting to work, it seems reasonable to determine an employee’s distance to work and directly calculate the GHG emissions by the use of the specific GHG emissions of the car model. In order to determine the total distance to work per verification period[31] (e.g. per year) the number of days an employee came to work as well as the corresponding daily travel distance have to be

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[31] The verification period is the time interval of verification. If, for example, a firm can certify the achieved emission reductions on an annual basis, the verification of achieved emission reductions would have to be done annually.

measured. Lastly the car occupation should be known in order to verify that the baseline does not already involve carpooling.

The verification of the GHG emissions caused by using public transport to work can be more complex. For employees using different types of public transportation (e.g. train and tram), the different types of public transportation have to be determined and for each type of used public transportation the corresponding specific GHG emissions and the corresponding total distance commuted have to be determined. In addition, the number of working days has to be known.

GHG emission of the reduction activities

Calculating the GHG emissions that are caused by a switch from using a car to using public transportation requires the determination of the types of public transport used and the corresponding specific GHG emissions and total distances travelled. In Table 15 we consider 3 different types of public transport. The total distances travelled have to be determined again, as they might be different compared to the baseline activity.

In order to verify GHG emission reductions that are achieved by employees using a bicycle for commuting to work or walking to work, the total distance cycled or walked has to be determined. For both reduction activities, it can be the case that not the complete distance to work is cycled or walked. In such a case, the distance for which the baseline activity is still used and the corresponding GHG emissions have to be determined according to the already determined characteristics of the baseline activity. In our calculations we assumed that at average employees are able to cycle the complete distance whereas they can only walk parts of the distance to work. The results in Table 15 correspond to these assumptions.

In case of carpooling, the used car model and its specific GHG emissions have to be verified. In addition, the total distance travelled, which might change due to picking up other employees, has to be determined. For each of the employees pooled together in one car, the corresponding baseline activity has to be determined. This results in an increasing number of parameters to verify with an increasing number of employees pooled together in one car (cf. Table 15).

In case of reducing the use of a car by the introduction of home office days, the resulting change in the total distance travelled has to be determined. The GHG emissions of the reduction activity can in the following be calculated by using emission characteristics of the baseline activity. Table 15 gives an overview of the number of identified parameters.

Table 15: Number of parameters that were determined in order to calculate the technical reduction potential by the reduction activity compared to the given baseline activity in Germany and Switzerland. For public transportation the number of parameters that have to be determined depend on the number of different types of public transport used. In our calculations we assumed the use of 3 different types of used transport. For carpooling the number of parameters is given per participating employee and in brackets also in total.

Reduction activity	**Car model**	**Type of public transport**	**Specific emissions**	**Distance**	**Number of working days**	**Number of persons in the car**	**Total per employee**
Baseline: Car used to go to work	1	-	1	1	1	1	
Switch to public transport	-	3	3	3	-	-	**14**
Switch to a bicycle	-	-	-	1	-	-	**6**
Switch to walking	-	-	-	2	-	-	**7**
Carpooling (3 persons)	1	-	1	1	-	1	**6.3 (19)**
Carpooling (4 persons)	1	-	1	1	-	1	**6 (24)**
Home office	-	-	-	1	1	1	**8**
Baseline: Public transport used to go to work	-	3	3	3	1	-	
Switch to a bicycle	-	-	-	1	-	-	**11**
Switch to walking	-	-	-	2	-	-	**12**
Home office	-	-	-	1	1	-	**12**

Table 15 shows that large differences exist in the number of parameters needed to calculate the technical reduction potential. A large number of parameters has to be determined in case of using different types of public transport either in the baseline or in the reduction activity. In the case of carpooling, for each of the participating employees the baseline activity has to be determined. This results in a large total number of parameters but in a reasonable low number per participating employee.

Verifiability of the achieved GHG emission reductions

Unlike the reduction activities involving the use of a new highly efficient car instead of a new average car, it seems very complex to directly measure the achieved GHG emissions of the here evaluated reduction activities. The reason for this is that employees might still stick to the baseline activity during leisure time (which is not possible in case of a new car, because the baseline car is not available to households).

To verify the achieved emission reductions it seems reasonable to determine the distance that each of the participating employees commutes to work and verify the days the participating employees commuted to work by a certain type of transport.

3.2.5. Implementation barriers

In the following section 2.4, we identify applicable implementation barriers hampering households from realizing the analysed reduction activities. Table 16 gives an overview of the identified barriers.

Switch to public transport, to a bicycle and to walking

According to our calculations in section 3.2.3 it can be seen that a switch to public transportation can involve a low benefit-cost ratio, as the public transport pass may be more costly than the operation costs saved by not using a car. A switch to public transport can also be related to a decrease in personal flexibility, which means that the employee is not free to choose when to go to work or go home but has to follow the time schedule of public transportation (Abou-Zeid et al., 2012).

The availability to households is a major constraint for the selection of an appropriate household reduction activity in this field. An important distinction can be made between employees who commute over large distances and employees who commute over very short distances. On the one hand, incentivizing employees commuting over large distances to walk or cycle to work is unreasonable because the maximum distance an employee can walk or cycle to work is restricted. On the other hand, employees who live very close to their place of work should not be incentivized to use a car or public transport for commuting. It is important to consider these differences appropriately when fostering such reduction activities.

The fact that work-related expenses caused by using a car or using public transport for commuting are deductible from taxes may also hinder households from switching to public transport, increasingly using bicycles or walking to work (although also the use of a bicycle can be deducted from taxes) (Comparis, 2012b; Online Focus, 2008). Rather low prices of fossil fuels and electricity are caused by unpriced external costs and additionally decrease the benefit-cost ratio of the reduction activities. Finally, employees might refrain from changing their common behaviour and habits and thus do not switch to more efficient means of transportation (Bamberg, Ajzen, & Schmidt, 2010; Carrus, Passafaro, & Bonnes, 2008; Eriksson, Garvill, & Nordlund, 2008). In the case of public transport this might be enforced by a misperception about public transport service attributes (e.g. travel time, delays) leading to a lack of acceptability (Abou-Zeid et al., 2012). Employees might additionally refrain from walking and cycling due to concerns about a decrease of their travel safety. In some countries, no or inadequate infrastructure exists for using bicycles or walking (Kahn Ribeiro et al., 2007; Mohan, 2002; Rietveld, 2001).

Carpooling and reduced use of transport due to home office days

Similar to a switch to public transport, carpooling may decrease the flexibility of employees, because they have to meet the other participating employees at a certain time in order to use the same car to go to work or to go home. Misplaced incentives apply because employees refrain from working from home if the employer does not tolerate it. A distortionary fiscal policy is the ability to deduct costs of using public transport or a car for commuting to work (Comparis, 2012b; Online Focus, 2008). This distortionary fiscal policy decreases the incentive for employees to work from home. Unprized external costs decrease the benefit-cost ratio of carpooling and home office days. Finally, carpooling may also not be realized due to the common behaviour and habits of employees (Bamberg et al., 2010; Eriksson et al., 2008).

Table 16: List of relevant implementation barriers for reduction activities in transportation, “1” indicates that this barrier applies to the reduction activity and “-” indicates that the barrier doesn’t apply to the reduction activity (Pt: Switch from using a car to using public transport, B: Switch to bicycle, W: Switch to walking, CP: Carpooling, HO: Home office)

	Monitored parameter	**Pt**	**B**	**W**	**CP**	**HO**
Financial cost barriers	Household budget constraints	-	-	-	-	-
	Low benefit-cost ratio	1	-	-	-	-
	Lack of access to financing	-	-	-	-	-
Hidden cost barriers	Additional implementation costs	-	-	-	-	-
	Risk of incompatibility					
	- Time dependence	1	-	-	1	-
	Performance risk	-	-	-	-	-
	Risk of increasing fuel prices	-	-	-	-	-
Market failures	Misplaced incentives	-	-	-	-	1
	Fragmented market structure	-	-	-	-	-
	Availability to households	1	1	1	-	-
	Distortionary fiscal and regulatory policies	1	1	1	-	1
	Unprized external costs and benefits	1	1	1	1	1
	Insufficient and inaccurate information	-	-	-	-	-
	Codes and standards	-	-	-	-	-
	Corruption	-	-	-	-	-
Behavioural barriers	Inertia in adoption behaviour	-	-	-	-	-
	Lack of acceptability	1	1	1	-	-
	Tradition and common behaviour	1	1	1	1	-
Sum of applicable implementation barriers		**7**	**5**	**5**	**3**	**3**

As a result it can be seen that especially a switch to public transport involves some considerable implementation barriers. All other reduction activities involve a lower number of implementation barriers.

3.2.6. Results

The estimated technical reduction potential from activities reducing the demand for GHG emission intensive transportation are in general lower than the technical reduction potential of the reduction activities involving the purchase and use of a highly efficient car. The highest emission reductions are achieved by carpooling. The more employees are pooled together the higher become the achievable emission reductions. A switch away from public transport can achieve very low emission reductions. This is due to the already rather low GHG emissions of public transport. Especially in Switzerland, a switch away from public transport therefore does not strongly contribute to climate change protection.

Due to the comparably low costs incurred by employees from switching from the use of a car or public transport to cycling, walking, carpooling or working from home, these reduction activities can achieve emission reductions very cost efficiently. Only a switch from using a car to using public transportation leads to positive specific abatement costs, as the costs of a public transport pass or public transport tickets are likely to exceed the operation costs of a car.

Considerable differences exist in the number of parameters that have to be identified for the calculation (and verification) of achievable (achieved) emission reductions. In our evaluation considerably more parameters had to be identified for the use of public transport because we assumed a mix of three different types of public transport. For each of the public transport types the specific GHG emissions and the corresponding distance travelled had to be identified. Reduction activities involving the use of public transport are therefore likely to have a lower verifiability.

The evaluated reduction activities can be related to less financial barriers than activities involving a purchase of a new car. Especially behavioural barriers seem to be important for this type of reduction activity. Also distortionary fiscal policies that enable employees to deduct the costs of using a car or public transport from taxes seem to play a role. Additional barriers for an implementation are that many of the reduction activities are only appropriate either for employees with large commuting distances or employees with rather short commuting distances. Furthermore, cycling and walking may entail a reduction of travel safety for participating employees.

3.3. Results and qualitative rating of reduction activities in the transport sector

In the following the overall results of this exemplary evaluation are shown for the reduction activities in Germany and Switzerland. In addition to the results of section 3.1 and 3.2, we qualitatively rate the different reduction activities. The qualitative rating for the technical reduction potential, the verifiability, and the implementation barriers is determined by the median and standard deviation. For the qualitative rating of the cost efficiency we use the abatement costs of Swiss inland CO_2 emission reductions realized by the Swiss Climate Cent Foundation as a reference value. These abatement costs are 144€/tCO_2 (Swiss Climate Cent Foundation, 2012). Table 17 defines the qualitative rating scheme used in Table 18 and Table 19.

Table 17: Method of qualitative rating of the different reduction activities

Evaluation criteria	**“+”**	**“++”**	**“+++”**
Technical reduction potential	*ER* < (Median – St. dev.)	(Median – St.dev) < *ER* < (Median + St.dev)	*ER* > (Median + St.dev.)
Cost efficiency	*ac* > 144€/tCO_2	0€/tCO_2 < *ac* < 144€/tCO_2	*ac* < 0€/tCO_2
Verifiability	*N* > (Median + St.dev.)	(Median – St.dev) < *N* < (Median + St.dev)	N < (Median – St. dev.)
Implementation barriers	*N* > (Median + St.dev.)	(Median – St.dev) < *N* < (Median + St.dev)	N < (Median – St. dev.)

Table 18 and Table 19 give an overview of the results for the estimated emission reductions, specific abatement costs, total number of parameters needed for the emission reduction calculations, and total number of applicable implementation barriers.

Table 18: Results and qualitative rating of the different reduction activities according to the results from the different evaluation criteria, an explanation of the qualitative rating can be found in table 17.

Car type	**Country**	**Emission reductions**		**Abatement costs**		**Verifiability**		**Barriers**	
Unit	-	*tCO₂/year*		*€/tCO2*		-		-	
Overall mean	All	0.322		-		7		5	
Overall median	All	0.259		-		6		5	
Overall standard deviation	All	0.248		-		3		2	
Purchase of new cars									
Lexus CT 200h Hybrid	DE	0.456	++	320	+	4	++	4	++
Toyota Prius 1.8 Hybrid	DE	0.442	++	-648	+++	4	++	4	++
Mitsubishi iMiEV	DE	0.531	+++	1’488	+	6	++	9	+
Toyota Prius 1.8 Plug-in Hybrid Life	DE	0.517	+++	2’217	+	7	+	8	+
VW Passat / Var. 1.4 TSI EcoFuel	DE	0.229	++	1’511	+	4	++	6	++
Ford Mondeo 2.0 Flexifuel Trend	DE	0.846	+++	283	+	4	++	6	++
Skoda Octavia/Combi 1.6 TDI-CR Greenline	DE	0.371	++	-2’598	+++	4	++	3	+++
VW Jetta 1.2 TSI BM Techn.	DE	0.200	++	-3’943	+++	4	++	3	+++
Choice of transportation means									
Switch from car to public transport	DE	0.137	++	3’912	+	14	+	7	+
Switch from car to bicycle	DE	0.269	++	-630	+++	6	++	5	++
Switch from car to walking	DE	0.158	++	-1’099	+++	7	++	5	++
Carpooling (3 persons in car)	DE	0.484	++	-641	+++	6.3	++	3	+++
Carpooling (4 persons in car)	DE	0.753	+++	-464	+++	6	++	3	+++
Home office for car user (1 day per week)	DE	0.054	++	-1’731	+++	8	++	3	+++
Switch from public transport to bicycle	DE	0.133	++	-5’311	+++	11	+	5	++
Switch from public transport to walking	DE	0.078	++			12	+	5	++
- Employee buys public transport tickets				-6’262	+++				
- Employee with public transport pass				1’283	+				
Home office for p. t. user (1 day per week)	DE	0.027	++			12	+	3	+++
- Employee buys public transport tickets				-7’545	+++				
- Employee with public transport pass				0	++				

Table 19: Results and qualitative rating of the different reduction activities according to the results from the different evaluation criteria, an explanation of the qualitative rating can be found in table 17.

Car type	**Country**	**Emission reductions**		**Abatement costs**		**Verifiability**		**Barriers**	
Unit	-	*tCO₂/year*		*€/tCO2*		-		-	
Overall mean	All	0.322		-		7		4	
Overall median	All	0.259		-		6		3	
Overall standard deviation	All	0.248		-		3		2	
Purchase of new cars									
Lexus CT 200h Hybrid	CH	0.445	++	421	+	4	++	4	++
Toyota Prius 1.8 Hybrid	CH	0.432	++	-42	+++	4	++	4	++
Mitsubishi iMiEV	CH	0.897	+++	405	+	6	++	9	+
Toyota Prius 1.8 Plug-in Hybrid Sol	CH	0.648	+++	2’135	+	7	+	8	+
VW Passat / Var. 1.4 TSI EcoFuel	CH	0.399	++	1’694	+	4	++	6	++
Ford Mondeo 2.0 Flexifuel Trend	CH	0.805	+++	769	+	4	++	6	++
Skoda Octavia/Combi 1.6 TDI-CR Greenline	CH	0.366	++	-2’944	+++	4	++	3	+++
VW Jetta 1.2 TSI BM Techn.	CH	0.209	++	-5’763	+++	4	++	3	+++
Choice of transportation means									
Switch from car to public transport	CH	0.236	++	2’263	+	14	+	7	+
Switch from car to bicycle	CH	0.248	++	-684	+++	6	++	5	++
Switch from car to walking	CH	0.165	++	-1’313	+++	7	++	5	++
Carpooling (3 persons in car)	CH	0.466	++	-680	+++	6.3	++	3	+++
Carpooling (4 persons in car)	CH	0.714	+++	-496	+++	6	++	3	+++
Home office for car user (1 day per week)	CH	0.050	++	-2’201	+++	8	++	3	+++
Switch from public transport to bicycle	CH	0.012	++	-58’746	+++	11	+	5	++
Switch from public transport to walking	CH	0.008	+			12	+	5	++
- Employee buys public transport tickets				-70’944	+++				
- Employee with public transport pass				12’520	+				
Home office for p. t. user (1 day per week)	CH	0.002	+			12	+	3	+++
- Employee buys public transport tickets				-83’464	+++				
- Employee with public transport pass				0	++				

As already discussed in the results subsections 3.1.6 and 3.2.6, the above Tables 18 and 19 show that there are large differences between the results of the different reduction activities for the four different evaluation criteria. The qualitative rating depicts these differences graphically. It can be seen that no differences in the results exist between Germany and Switzerland.

In both countries, the highest emission reductions can be achieved by the purchase of the Mitsubishi iMiEV, the Toyota Prius 1.8 Plug-in Hybrid, the Ford Mondeo 2.0 Flexifuel Trend or by pooling 4 persons together in one car for commuting to work. However, the high positive abatement costs of the Mitsubishi iMiEV, the Toyota Prius 1.8 Plug-in Hybrid, and the Ford Mondeo 2.0 Flexifuel Trend point to the fact that higher costs are incurred by households deciding to purchase such car models. GHG emission reductions can be achieved more cost-efficiently by the purchase of the Toyota Prius 1.8 Hybrid, the Skoda Octavia/Combi 1.6 TDI-CR Greenline, and the VW Jetta 1.2 TSI BM Techn. Moreover, the switch to cycling or walking as well as carpooling and the participation in home office days can achieve significant GHG emission reductions cost-efficiently.

The verifiability of emission reductions achieved by the purchase of a new electric or plug-in hybrid vehicle is assumed to be lower than for other car types. This is due to the fact that these two vehicle types require the determination of the emission factor of the corresponding electricity mix consumed, which is different between countries. For all other car types, the emissions can be directly calculated using the specific emissions of the car model (usually given in g/km) because the emission factor of the consumed fuel (e.g. diesel) is the same in all regions. Moreover, especially the verifiability of reduction activities involving the use of public transport is low, because for each type of used public transport (e.g. train, tram) the corresponding emissions have to be determined. Finally, a comparably low number of implementation barriers could be identified for the purchase of highly efficient conventional diesel and gasoline cars, for carpooling, and for home office days.

Considering all four evaluation criteria together, participation in carpooling as well as the purchase of a Skoda Octavia/Combi seem to be the most promising reduction activities because significant emission reductions can be achieved cost-efficiently at a reasonably high verifiability of the achieved reductions and a low number of implementation barriers that have to be overcome.

4. Conclusion

In this working paper, we developed a methodology for evaluating household reduction activities that could be fostered by household members' employers. The different household reduction activities are evaluated according to the following four different criteria: the technical reduction potential, the cost efficiency of the reduction, the verifiability of achieved reductions, and implementation barriers hindering the adoption of the reduction activities. The results of the evaluation can be used as a decision basis for employers to decide on which household reduction activities they would like to incentivize. To simplify future evaluations an evaluation tool was in addition developed in Excel (for more information consult www.off4firms.com). The developed evaluation tool gives households and the decision maker the flexibility to compare household reduction activities either according to benchmark values or according to firm or household specific values. In addition, the baseline activities can be adjusted according to different requirements of a possible regulator or decision maker.

The exemplary evaluation of household reduction activities in the transport sector showed that the developed evaluation methodology is capable of generating results according to which household reduction activities in different sectors and of different type can be compared to each other. Based on this methodology, the technical reduction potential of a hybrid car can, for example, be compared with the technical reduction potential of a geothermal heating system. Firms planning to implement an incentive scheme, which fosters household reduction activities, can use the results to compare different household reduction activities. They can focus essentially on the criterion which they find most important. If, for example, a firm is willing to invest a lot of money into an incentive scheme and has the main goal of reducing as much GHG emissions as possible, it can solely focus on the results of the first evaluation criteria – the technical reduction potential. Another firm might base its decision on all four evaluation criteria. The firm could therefore decide to incentivize employees to purchase a Toyota Prius Hybrid or a Skoda Octavia Greenline. Both car models can achieve considerable emission reductions at negative abatement costs, at a verifiability of achieved emission reductions that is similar to the verifiability of other car types, and at a rather low number of relevant implementation barriers. Furthermore, the firm may decide on incentivizing carpooling among employees who use a car for commuting to work. According to the results in this working paper, carpooling has a comparably high reduction potential, low specific abatement costs, a comparably high verifiability as well as a low number of implementation barriers. To foster an additional reduction activity, which addresses employees using public transport, the firm could foster the use of bicycles for commuting to work.

The exemplary evaluation performed in this working paper turned out to be useful for selecting appropriate household reduction activities and seems to be a good basis for evaluating and comparing reduction activities in the other sectors heating and cooling as well as household appliances. However, the selection of appropriate benchmark values and the definition of an appropriate baseline activity are a weak point in the evaluation: a change in the used values can considerably change the results of the evaluation. We therefore recommend investing more effort in the identification of solid benchmark values and also in determining the effects of certain changes in the benchmark values.

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Annex

Life-cycle analyses of different car types according to different sustainability indicators

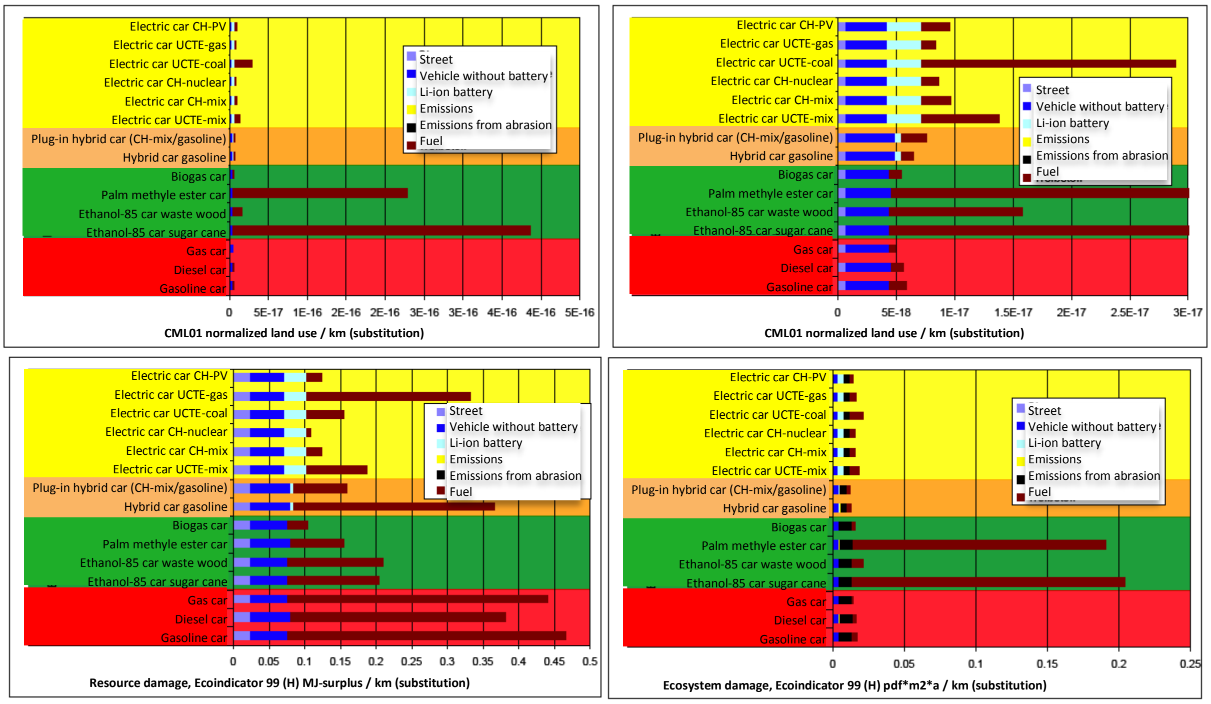

Figure 2: Life-cycle analyses of different car types according to land and resource use and the corresponding degradation of the ecosystem. The values for land use are shown in two different scales (Althaus & Gauch, 2010)

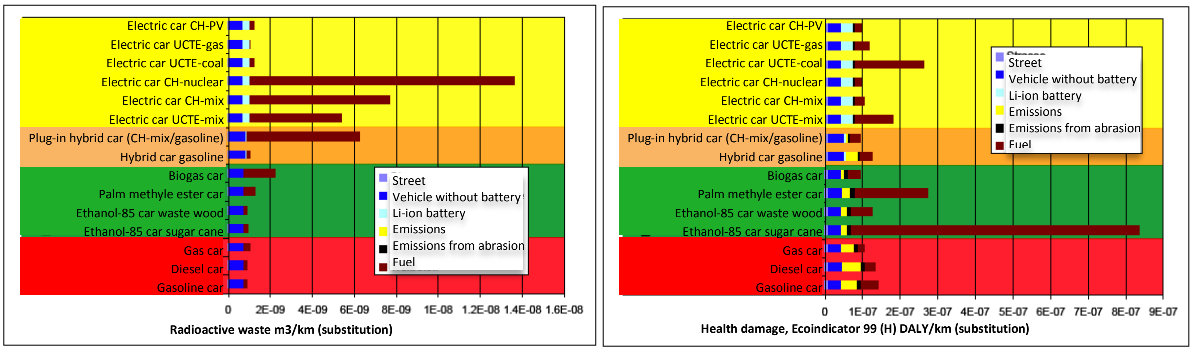

Figure 3: Estimated amount of radioactive waste and estimated overall damage of human health for different car types (Althaus & Gauch, 2010)

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