Accounting of energy savings in policy evaluation
How to get at least 8 different (correct!) results from the same data

Fabian Voswinkel, Fraunhofer ISI, Karlsruhe, Germany

ABSTRACT

Policy evaluations in energy efficiency are used for a variety of purposes. Each of which requires different methods to be used in quantitative accounting of savings. In broad categories, savings can be stated in annually recurring savings or in summed up values over larger time spans, with or without adjustments for effects. For that reason, it is far from trivial to define targets and methodological requirements for evaluation concisely.

This paper presents four quantitative accounting methods as used in the evaluation of the German federal Energy Efficiency Fund (EEF), which consists of a wide variety of policy measures. The stated accounting methods are the new annual savings, the cumulated annual savings, the periodically cumulated savings and the lifetime savings. They can yield results that are different by a possibly high factor depending on the investment's lifetime and other characteristics. And while each of the methods is justified to be used in a policy context, the accounting method should be clearly defined and described in the evaluation study in order for the reader to be able to interpret results the right way and make informed decisions.

In addition, values can be stated as gross values before or net values after effect adjustments for each of the four mentioned accounting methods. In this respect, the free-rider effect and its calculation methods are closely analysed. Summed up, evaluation, as it is performed in the EEF, can yield eight different results from the same input data. The paper presents both the theory of the accounting methods as well as their policy implications. Results are taken from a subsidised credit programme in support of investment in waste heat reduction and utilisation from the EEF.

The paper systematically shows how different methodologies can lead to very different results and illustrates how strong the influence of the evaluation methodology can be onto the political outcome and the stated degree of target achievement. It puts the presented methods into context using policy examples, which require each method's results.

1. Introduction

This paper starts with a thought experiment. In 2015, the German government ratified the Paris agreement and committed itself to reduce its yearly greenhouse gas emissions. To achieve this, it sets itself a reduction target for yearly energy consumption until 2020. In 2012, a financial incentive programme for cross-cutting technologies in industry has been implemented. In 2016, a programme for waste heat reduction in industry was added. In 2018, an evaluation of energy efficiency programmes is performed. It should give information about target achievement for the set target until 2020. How far have we come until now? How has the programme developed since it was first established? How will measures perform in the future, possibly after the end of the lifetime of the supported measures? How much energy and greenhouse gases have been saved by supported measures to date? But, how can we compare the two programmes that have started up in different years? Should we calculate savings until

the end of each measures' lifetime? And, finally yet importantly, is the policy even responsible for the savings so that the spending of tax money is justified?
It is obvious that not all of these questions can be answered with one single accounting method.

That is what this paper sets out to discuss on the example of the evaluation of the Energy Efficiency Fund (EEF), a broad-range funding scheme by the German Federal Ministry of Economic Affairs and Energy (BMWi) that was first started in 2011 and has since grown to almost half a billion Euros in 2018. The two programmes mentioned above, cross-cutting technologies and waste heat in industry are two of the larger policies financed by the EEF. The exemplary data in this paper are taken from the evaluation of the waste heat programme, a subsidised credit line administered by the development bank KfW. A more detailed analysis of the evaluation of the KfW waste heat programme including micro-level evaluation of energy savings concepts can be found in Voswinkel, Grahl and Rohde (2018, forthcoming).
The presented accounting methods are the **first-year savings**, the **cumulated annual savings**, the **periodically cumulated savings** and the **lifetime savings**. Next to these four methods, values can be stated in gross and net terms. Net effects describe the causality of the policy for the outcome. Hence adjustments for free-rider and other effects must be applied. This takes the number or different results up to eight, and they are, as the title indicates, all correct. However, while first-year savings and cumulated annual savings are yearly recurring savings, periodically cumulated and lifetime savings are not recurring. With lifetimes of e.g. 20 years, the value for lifetime savings can be 20 times as high as the cumulated annual savings. Although theoretically the units for recurring savings are stated as "per year", often times, statements are not clear and the numbers cannot be compared. Another problem in reality is the missing statement of final energy and primary energy savings. This information is often missing in evaluation reports and studies. This leads to a problem in evaluation practice. The methodology of savings accounting is often not explicitly stated in evaluation studies and reports either, a problem discussed in detail in this paper. This is particularly problematic due to differing methodological requirements in national or international reporting obligations. Hence, comparison between studies and between policies on national as well as international levels is very difficult (Broc, Guermont, & Deconninck, 2017). An incomplete statement of accounting methodology can lead the reader to interpret the policy from being very successful, if the number was calculated using the cumulated annual savings and is recurring yearly for the whole 20-year lifetime, to being very unsuccessful, if the number represents total savings until the end of this lifetime.

Part 2 presents the methodology with section 2.1 presenting the accounting methods and section 2.2 detailing the methodology for effect adjustments. Part 3 finally applies the methodologies to real life data from the evaluation of the waste heat programme to present results. Part 4 draws a conclusion.

2. Methodology

The energy efficiency support strategy of the government is based on targets to be achieved. An exemplary target is the exploitation of energy savings potentials. In the evaluation of the Energy Efficiency Fund (Fraunhofer ISI et. al, 2018, upcoming), the target achievement is based on predefined precise indicators. Hence, for example, an indicator for the mentioned target is the reduction of final and primary energy consumption. The quantitative indicators in the evaluation are bundled in three groups. The first (**group A**) being the target achievement containing gross savings values. **Group B** investigates the policy effectiveness, the degree to which the policy is causal for the outcome. This category makes use of effect adjustments described in Section 2.2, to generate net values. Finally **group C** monitors the economic efficiency of the policy. It relates savings data to financial inputs. Table 1 shows selected policy targets and the assigned quantitative indicators. Results are only presented for group A and B in section 3.

Table 1: Select targets and indicators. Source: Schlomann, et al. 2017, own representation

Policy Target	Indicator
A. Target achievement	
Contribution to the achievement of climate protection targets	Greenhouse gas reduction (t CO_2-eq.)
Exploitation of energy savings potentials	Reduction of final and primary energy consumption (MWh_{final} and $MWh_{primary}$)
B. Effectiveness	
Net values for quantitative indicators after adjustment for effects (free-rider, spill-over)	
C. Economic Efficiency	
Funding efficiency (perspective: funding body)	GHG - funding efficiency (t CO_2-eq./EUR of funding] Energy-funding efficiency (MWh_{final}/EUR of funding]

2.1. Savings accounting

This section presents four savings metrics: the first-year savings, the cumulated annual savings, the periodically cumulated savings and the lifetime savings. They are then put into perspective with an example of the policy implications. Figure 1 illustrates the savings methods for a generic highly efficient appliance with a lifetime of 5 years and yearly savings of 10 energy units, with one new appliance installed each year. The numbers are small for illustration purposes. All presentations of accounting methods will reference Figure 1.

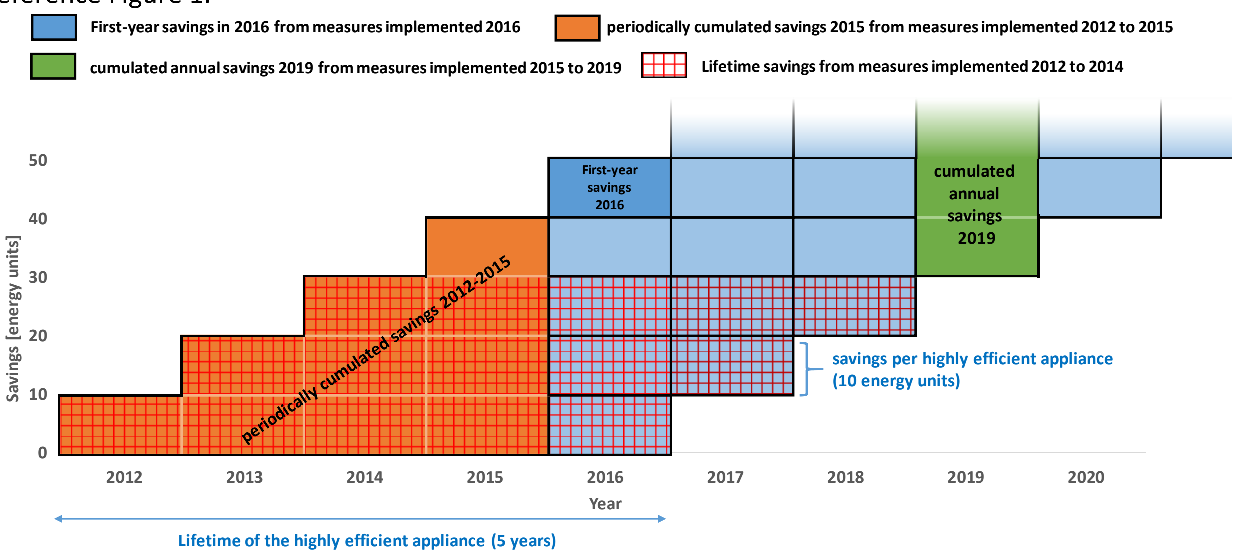

Figure 1: Accounting methods illustrated for a generic appliance with lifetime of 5 years and yearly savings of 10 energy units.

Apart from the graphical illustration, savings metrics will be stated in formal terms. Table 2 lists all items in the equation with a short description.

Table 2: List of formal equation items

t=0	Current evaluation year (end of the year)	$S_{i,t}$	First year savings in year *t* from measures from year *i*.
N	Calculation period (e.g. 2012 to 2014 → N=3)		
T	Lifetime of the measure	C_t	Cumulated annual savings
i	index for the year when the measure was implemented	P_t	Periodically cumulated savings

j	index for the year for which the energy savings are accounted		L_t	Lifetime savings

First-year savings

This method is the basis for all of the others. It sums up the yearly savings of all measures that were implemented in a given year. In formal connotation, the first-year savings are stated as $S_{i,t}$. Savings from measures implemented in year *i* that are realised in year *t*. In Figure 1 above, the first-year savings $S_{2016,2016}$ are marked in dark blue in the upper block of year 2016. For the generic appliance, that means that the measure was implemented in year i=2016 and in its first year (year t=2016) delivered savings of 10 energy units. $S_{i,t}$=10 e.u.

First-year savings can be a suitable measure for the evaluation of the development of a policy over time by comparing savings between years, in case the policy promotes always the same type of actions that have similar lifetimes. For policies that promote several types of actions with very different lifetimes, the mix of measures and their corresponding lifetimes can vary strongly from year to year. In this case, looking at trends in the first-year savings could lead to misinterpretations. For example, it is possible to have high first-year savings, but which are stemming from a mix of actions that has a shorter average lifetime, thereby potentially delivering less savings overall.

Cumulated annual savings

Most policies operate over a period of several years, but savings from implemented measures are recurring at least until the end of the appliance's lifetime. Behavioural impacts related to learning processes as well as follow-up investments due to market transformation effects may last a lot longer. The cumulated annual savings are the sum of all the annual savings achieved in a given year, independently of the year when the related measures were implemented, as long as the appliance's lifetime has not yet ended. The cumulated annual savings in year 2017 for a policy that started in 2016 are all savings in 2017 from measures implemented in 2016 plus those from measures implemented in 2017. In long running policies that are evaluated after the lifetime of the first implemented measures have ended, those measures are not part of the cumulated annual savings anymore. In formal terms, the cumulated annual savings are given by C_t in equation 1 where N is the calculation period (e.g. 2016 to 2017 -> N=2):

$$C_{t=0} = \sum_{i=-N}^{t=0} S_{i,t=0}$$

In the illustration in Figure 1, the cumulated annual savings in 2019 are shown in green in the upper blocks of 2019. In this example the area represents yearly savings added up from measures implemented in 2015 to 2019. 2015 as the first implementation year can be read from the left bound of the row of the lowest square marked in green. Measures implemented before 2015 are already past their lifetime. For illustration purposes, additional rows for measures from 2017 and onwards are not shown in the figure.

In the German Energy Efficiency Fund, policy targets are defined in terms of cumulated annual savings in a given year. The waste heat programme aims at achieving greenhouse gas emissions savings of one million tonnes CO_2-equivalent per year in the year 2020 (BMWi, 2017). The cumulated annual savings are yearly recurring savings. In order to interpret this value for a long-run analysis, assumptions have to be made about the savings effects of the policy after a supported appliance's lifetime. It is unclear whether they will continue to deliver savings or will be replaced with a less efficient technology again afterwards. In another scenario, the policy may have contributed in a shifting market after the appliance's lifetime so that a less efficient technology is not available anymore. However, this discussion is subject to further research and not part of this paper.

Periodically cumulated savings

The periodically cumulated savings are a method for a status quo statement capturing a particular timeframe. It presents the total amount of savings that have been realised over a given period (noted N in Table 2). In the illustration in Figure 1, they are given in orange in the left half. They add up all savings generated in the first year of analysis with the savings of each following year until the year of analysis. In formal terms they are equal to the sum of all cumulated annual savings until the year of analysis.

$$P_{t=0} = \sum_{j=-N}^{t=0} C_j$$

Periodically cumulated savings can be used if targets are e.g. defined as a carbon budget. The IPCC estimates that the world has a carbon budget of about one trillion tonnes of carbon that can be emitted into the air in total since the industrial revolution in the mid to late 19th century to meet the 2°C target. As of the year 2011, about 52 percent of that budget has already been used (IPCC Working Group III, 2014). To quantify the amount of carbon that the policy has prevented from being emitted, periodically cumulated savings are a suitable metric. It is a non-recurring metric stating absolute terms. It furthermore does not account for any future savings. The EU Energy Efficiency Directive (EED) sets an energy savings target for 2020 stated in total values. Article 7 requires member states to set national targets and report their degree of target achievement. In that report, savings have to be stated states in periodically cumulated values (European Union, 2012, Annex V).

Lifetime savings

Lifetime savings are different from periodically cumulated savings by accounting for future savings from already implemented measures till the end of their lifetime under the assumption that the appliance remains in operation until the end of its lifetime. Its calculation does not need any non-technical assumptions as to how savings will progress in the future except the above mentioned assumption of retention of operation so that the lifetime of the savings is equivalent to the lifetime of the appliance. It states all savings that a measure will have throughout its entire lifetime independent from the time of analysis. The lifetime savings of all measures implemented until the time of analysis are added up. Figure 1 illustrates lifetime savings as the rasterised area in the lower part. They show the lifetime savings from measures implemented over 2012-2014. The measure does include future savings, although only of those measures that have already been implemented over the period under evaluation. In formal terms, it is given by L_t with T being the weighted average lifetime of the measures in the programme (assuming this average remains the same over time, i.e. no change in the mix of implemented measures).

$$L_{t=0} = \sum_{i=-N}^{t=0} \sum_{j=-N}^{T+i} S_{i,j} \qquad for\ N \leq T$$

Lifetime savings are most suitable for a technology evaluation. They facilitate comparisons of technology options with different lifetimes and therefore different overall savings. In comparison, measures with a longer lifetime will be evaluated more favourably by this metric. It is suitable for evaluation of past, present and future savings of a given measure. In the end of a policy, lifetime savings allow for a more holistic evaluation of the savings attributable to the policy. Lifetime savings are stated in absolute non-recurring terms and used in budgetary views of emissions or energy consumption. Since lifetime savings are including future savings, it is most important to unmistakably and transparently state the accounting metric. As comparisons between lifetime savings and other metrics are not possible and can be misleading towards an overestimation of a programme's success.

2.2. Effect Adjustment

The doubling of the four methods presented in the previous section to eight correct results are finally due to effect adjustments leading to gross and net values. The distinction accounts for the causality of savings. To what degree has the policy caused the savings compared to which savings would have occurred in the absence of the policy? This "what-would-have-been" scenario is called the baseline or counterfactual. In evaluations, it is normally not possible to know what would have happened in the absence of the policy. That is why the counterfactual has to be estimated (Violette & Rathbun, 2017). Net values are the gross values subtracted by the counterfactual. The question whether gross values or net values are more appropriate for target achievement is controversial in the policymaking process. In terms of justification for the spending of public money for the policy, it is important to state what savings have actually been generated by the policy. Free-riders are in this view wasted investments and therefore not counted, so net effects are taken as benchmark. However, the underlying goals and targets of policies, the transformation of the economy towards climate neutrality and a reduction or halting of climate change are not distinguishing between the actual causes of the savings, any amount of emissions that is saved is doing its part. Hence, gross values are just as well appropriate for evaluation. The conflict line can therefore very well lie between the underlying goals on a global level and the micro level of policy implementation and financing. Different evaluations therefore give priority to one or the other value. The range of different accounting methods and gross or net values can give policymakers the opportunity to employ the value that best fits their political agenda. Therefore, a thorough methodological statement is key to a transparent policy evaluation. The Energy Efficiency Fund states both gross and net values for each result so satisfy requirements of different branches of politics. For the calculation of net results, there is a wide range of effects that can be considered ranging from free-rider effects, through spill-over effects and interaction effects to rebound effects, to name a few. The waste heat programme employs adjustments for two effects, the free-rider effect and the spill-over effect. The former calculates the percentage of all savings that would have occurred also if the programme had not existed. They are subtracted from the gross values. The spill-over effects are savings that are occurring as a result of the programme but are not directly covered by it. For example the usage of the programme of one branch of a company makes the management interested in energy efficiency so investments in further measures are implemented. Spill-over effects are added to the gross data. Due to limited data availability and difficulties in quantitative calculation methodologies, other effects are not explicitly calculated in the waste heat programme evaluation. The overarching evaluation of the entire energy efficiency fund additionally accounts for interaction effects between the single policies subtracting savings that have been accounted in more than one policy from the added up savings of the fund.

Summing up, net values are calculated by subtracting free-rider effects from gross values and adding spill-over effects according to the following equation with S being savings, *so[%]* the spill-over effect in percent and fr[%] being the free-rider effect in percent. Figure 2 illustrates the adjustments.

$$S_{net} = (1 + so[\%] - fr\ [\%]) * S_{gross}$$

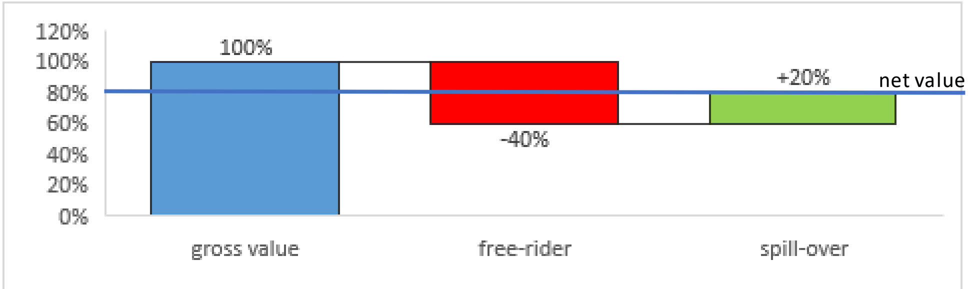

Figure 2: Net savings value calculation

Free-rider effects

A frequently calculated effect in energy efficiency policy evaluation is the free-rider effect. It counts what part of the measures would have been implemented by the participant in the absence of the policy. Formally, free-rider effects can be distinguishes as three groups. Strong free-riders, weak free-riders and deferred free-riders (Olsthoorn, Schleich, Gassmann, & Faure, 2018), (Violette & Rathbun, 2017). Strong free-riders were planning the investment already before knowing of the incentive programme and only signed up to benefit from it. Weak free-riders on the other hand, had not initially planned the investment but decided upon it after receiving the information about investment possibilities from the policy. They then also apply for the financial incentive. Hence, for weak free-riders, the information aspect of a policy is important, but on the financial incentive, they are free-riding. Finally deferred free-riders had already planned to implement the measures, but at a later point in time. Hence, for the time the investment has been pulled forward, savings accrue to the policy, for the rest of the time they can be considered free-riders. The deferred free-rider effect can be both weak and strong.

In the following, the methodology for calculation of free-rider effects used in the waste heat programme is presented. It is a survey-based approach. Violette and Rathbun (2017) give a good account of other methods, including randomised control trial and quasi-experimental methods.

In the survey based approach, free-rider effects are determined in three steps. The first step calculates the basic free rider effect. It does not yet feature a distinction between strong and weak free-riders and of deferred free-ridership. However, it distinguishes if the complete measure would have been implemented without the policy or only a reduced scale with lower savings. The base question asked in the survey is "Would you have also implemented the measure without financial incentives?" with the options "1: no", "2: yes, on the same scale", "3: yes, on the same scale, but later" "4: yes, but on a lower scale", "5: yes, but on a lower scale and later", "6: n/a". While answer 1 means no free-rider effect, answer 2 means 100% free-rider effect. Answers containing "later" are relevant for deferred free-riders as described further below. Answers 4 and 5 indicate that the measure would have been implemented on a lower scale. Hence, they are only part free-riders. In conjunction with a second question, the degree of free-ridership is determined. For those who answered that their main motivation for using the incentive scheme was the financial incentive, it is assumed that their investment would have been considerably lower due to financial limitations or higher sensitivity to pay-out variations. In this case, the free-rider effect is assumed to be 25%, hence the investment without the scheme would have been 75% lower. Otherwise, a free-rider effect of 50% is assumed. A sensitivity analysis for both showed that a one percentage point change in the assumptions resulted in a difference in total free-rider effect of under 0.1 percentage points.

The second step adjusts for deferred free-riders. Here, the free-rider effect is only counted for the time starting at the initially planned implementation of the measure sometime later than the actual implementation. In the base question, those who responded with answers 3 or 5 ("yes, on the same scale, but later" or "yes, but on a lower scale and later") are taken as deferred free-riders. An important information for this calculation is how much later, the company would have implemented the measure. However, exact questions relating to a particular investment in surveys are very prone to a number of biases. Therefore, reliable responses about how much later the investment would have been made cannot be expected from the survey. Therefore a literature based approach was used to assign a specific average time to “later”.

Wilson and Eilertsen (2010) conducted a survey study among a large group of company to assess general budget planning cycles. While investments that affect operation for a longer timeframe are planned further in advance, than shorter measures, they found that capital budget planning cycles are between three and five years on average. In the waste heat programme, the overall implementation from applying to the funding scheme to the physical implementation of the measure takes 1,5 years on average. Subtracting these 1,5 years from the three to five years of budget planning, the planning period is 1,5 to 3,5 years. It can be expected that for that survey item in the policy evaluation, a particularly pronounced social desirability bias occurrs (Fisher, 1993). Those who have participated in the incentive programme have given thought to energy efficiency investments and may perceive that it is socially desired that they do not implement the measure only because of the funding, but because of other intrinsic motivations. They may state that they would have merely acted later to let look like it was not about the money but about ideals and that the time had just not arrived yet. Due to that bias, the planning period is rounded up slightly to between two and four years. Since the waste heat concepts have an average lifetime of ten to twenty years, an advance planning period of two years per 10-year lifetime, or 20% is assumed. In a sensitivity analysis excluding the bias showed an overall free-rider effect that was only 0,3 percentage points higher than including it. Therefore the assumption was maintained.

To this point, all free-riders are taken as strong free-riders. The third step determines the weak free-riders. Therefore, a further question is asked in the survey: “Was it difficult in the internal decision-making process to request the incentive scheme?”. For those who answer, “no, not difficult”, weak free-ridership can be assumed. That is because the the barriers to investments are low and as soon as they got the information about the energy efficiency investments, they could have invested also without the financial investment. The free-rider effect determined in the previous steps is multiplied by a factor that corresponds to the part of the overall programme expenditure that accrues to the information part. However, in practice the information part of the programme cannot be separated and affects the overall programme participation, weak free-riders are multiplied by 50%. A sensitivity analysis has shown that a one percentage point change in this assumption leads to a 0,15 percentage points change in total free-rider effects.

Another common form of free-rider calculation are randomised control trials (RCTs) or quasi-experimental designs (Violette & Rathbun, 2017). They have the advantage of using control groups in their data collection to eliminate uncertainties and assumptions needed for the survey-based approach in this paper. On the other hand, they often require a higher work load and budget from programme administrators. Another difficulty are data protection laws in many countries. Control groups, different to treatment groups are not participants of the programme and have hence not signed to agree to take part in a survey. The purchase of appropriate customer data can also be very costly for the programme administrator or evaluator. However, since both methods rely on physical measurements after the implementation of the measure, they cannot be applied to the evaluation of the waste heat programme because energy savings are based on the estimates made by the energy consultants before the measures are implemented.

Spill-over effect

Spill-over effects describe how many savings have been caused by the policy inside and outside of the participating company that are not direct savings stemming from the programme focus. For example, additional energy efficiency investment the company is performing because they became interested in energy efficiency due to the policy. Spill-over effects are added to the gross values.

Due to the large variety of possible paths, that spill-over effects manifest themselves in, it is challenging define and to quantify them. For the evaluation of the Energy Efficiency Fund, a survey-based methodology was developed that employs a series of five questions. The questions try to find out, how the programme has influenced the prioritisation of energy efficiency in the company and in its business environment. All questions are scored on a five-point Likert scale from 4 (strongly agree / very probable) to 0 (strongly disagree / very improbable). All point scores are then multiplied by a weighting factor. The result is used as a percentage of spill-over effects. The scaling is set to allow a maximum spill-over effect of 26%. This result is based on a study by Rosenberg, Vine and Pettit (2011) quantifying the spill-over effects of a household lighting incentive scheme in California using different methods. They conclude that the spill-over effect for this programme is between 23 and 40%. However, spill-over effects in industry cannot be expected to be as high as in households because communication about internal matters between companies operating in a competition environment is lower than for individuals. Furthermore, waste-heat measures are more complex and require more thorough planning than lighting which can lower the spill-over effect. Hence, the maximum is set slightly over the lower bound of the actual effect in the California lighting scheme. The calculated spill-over effect values are averaged over all respondents and applied to the whole sample. This is necessary because of incomplete returns of surveys and sufficient because the evaluation of target achievements requires programme-wide results rather than individual participant results. The respondents were fairly representative for the whole sample, as all sectors and company sizes were present in about the same ratios as in the whole sample.

Statements about internal factors include “The incentive scheme has contributed to us targeting investments in energy efficiency more directly now” (multiplier 1.5) and “The incentive scheme has contributed that we give more priority to energy efficiency in general” (multiplier 1.5). External factors are evaluated using the question “How probable is it that you recommend in your professional environment to invest in energy efficiency?” (multiplier 1.5).

3. Results

This section presents results for the target achievement of the waste heat programme for all participants accepted since the start of the programme in May 2016 until December 2017. The presentation is structured in the same way as the methodology detailed in the previous section.

In the timeframe, KfW granted credit subsidies totalling 56 million Euros. The programme has supported total investments in waste heat energy efficiency of 215 million Euros. A verification of real investments is done by proof of implementation after completion. Data for this analysis are taken from granted values taken from waste heat concepts elaborated by the companies’ energy consultants before physical implementation. Physical measurements of savings after implementation are not performed. Adjustment for free-rider and spill-over effects leaves the triggered investments at 181 million Euros. Results are presented in detail for the indicators “total greenhouse gas emissions reductions” followed by a brief presentation of other indicators from group A and B (gross and net target achievement). The decision for the presentation of greenhouse gas emissions was made due to the policy target of the waste heat programme being defined as annual savings of 1 million tonnes of CO_2-equivalent until 2020. CO_2-factors have been defined for the entire Energy Efficiency Fund to make results comparable. All methodological considerations of this paper are applied to final energy savings, primary energy savings as well as CO_2-emissions savings.

First-year savings

The programme has led to new annually recurring savings of 52,300 tonnes of CO_2-equivalent in the year 2016 and 221,100 tonnes in 2017. New annual savings can be used to show the development of the programme, as this programme is about a single type of measures. Therefore the average lifetime of savings can be assumed to be constant over the years. Averaging monthly savings in 2016 to account for the fact that the programme only started in May of that year, the growth stands high at 182% due to the time needed for the word to spread and market diffusion of the new policy. For net values that are effectively caused by the programme, adjustments for free-rider and spill-over effects are applied.

For the calculation of free-rider effects, the largest group in the survey replied that they would have made the investment also without the programme, but on a lower scale. One main result of the policy can therefore be seen as savings performance improvement. After the first step of free-rider effect calculations, the effect stands at about 50% and therefore in the upper middle ground of other programmes in the Energy Efficiency Fund using the same methodology. However, applying step two and three of the calculation to distinguish between weak and strong free-riders as well as deferred free-riders starkly decreases the percentage of free-rider effects. A large portion of survey participants can be grouped as weak free-riders based on their answers as described in section 2.2. The final free-rider effect for the programme hence stands at 32% taking it to the lower middle ground.

Spill-over effects are based on a series of questions as detailed in the methodology section in section 2.2. The weighting factors for each questions are scaled to permit a maximum spill-over effect of 26%, using Rosenberg et al. (2011) as a benchmark. The calculations for the conducted survey point towards a spill-over effect of 16%.

The net value is therefore the gross value subtracted by 32% and added by 16%. First year net savings are therefore 43,900 tonnes of CO_2-equivalent in 2016 and 185,900 tonnes in 2017. Table 2 shows first-year savings in gross and net values as well as adjustment factors.

Table 3: First-year savings of GHG emissions (t CO2-eq./year) in gross and net terms

First-year savings	**gross**	**free-rider effect**	**spill-over effect**	**net**
GHG emissions reduction (t CO_2-eq./year)		**-32%**	**+16%**	**-16%**
2016	52,300	-16,600	8,200	43,900
2017	221,100	-70,000	35,000	185,900

Cumulated annual savings

The second method is cumulated annual savings, the sum of all first-year savings under the assumption that savings remain constant over the lifetime of measures. Cumulated gross annual savings from 2016 to 2017 stand at 273,400 tonnes of CO_2-equivalent. Effect adjustments result in cumulated annual net savings of 229,800 tonnes of CO_2-equivalent in the years 2016 and 2017.

Since the policy target in the waste heat programme is defined in terms of tonnes of yearly emissions reductions saved until 2020, this metric is used for the evaluation of target achievement and for projections to the target year 2020. For the projection, the evaluation assumes a constant number of yearly participants and constant average savings. That assumption appears realistic judging from the strong growth the programme has shown since its start in 2016. Word of mouth effects for further growth of the programme are expected to be exhausted by 2017. In 2020, gross savings of 936,700 tonnes of CO_2-equivalent are projected. The defined target value of the policy was yearly savings of 1 million tonnes (BMWi, 2017) until the year 2020. Hence, the projection corresponds to a degree of target achievement of roughly 94%. Adjusting for effects, net savings are projected to be 786,900 tonnes corresponding to a net target achievement of 79%. Figure 3 shows the projection for 2020 for both gross and net values.

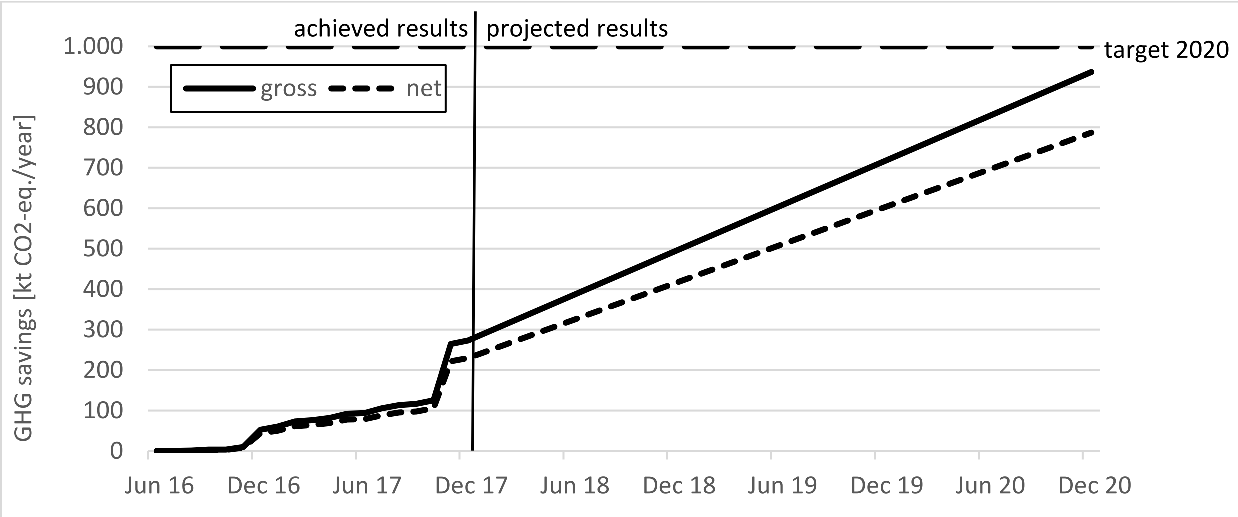

Figure 3: target projections for 2020 of cumulated annual GHG savings in gross and net terms

Periodically cumulated savings

The third measure are periodically cumulated values. They can be used for the impact on carbon budgets with information about future savings originating in the programme. They show absolute non-recurring savings up to the time of evaluation. Due to the rather short running time of the policy at the moment of writing this paper, the discrepancy of the absolute periodically cumulated savings and the annually recurring cumulated annual savings is less pronounced. Though the gap widens with the number of years the policy has been active. Periodically cumulated savings can be used for the evaluation of the impact on carbon budgets without accounting for future savings of implemented measures.

From June 2016 to December of 2017, the waste heat programme has produced total emissions savings of 325,700 tonnes of CO_2-equivalent. After adjusting for effects, the periodically cumulated net savings are 273,700 tonnes.

Lifetime savings

The fourth measure are lifetime savings. Because they evaluate overall programme performance rather than individual performance, an average lifetime of all measures implemented in the programme is used. The average lifetime in the waste heat programme evaluation is 15 years. Because the evaluation period is shorter than the lifetime, all measures in the evaluation are still in their lifetime. In this case, lifetime savings are equal to the cumulated annual savings multiplied by the average lifetime. Lifetime savings can be used for the evaluation of the impact on carbon budgets including information about future savings of implemented measures. They show lifetime-cumulated savings of measures implemented from the start of the programme until the time of evaluation.

The programme has led to gross lifetime savings of 13,973,900 tonnes of CO_2-equivalent. After adjusting for free-rider and spill-over effects, the net value amounts to 9,396,400 tonnes.

Summary results

Table 4 summarises results for three indicators in group A (for gross values) and B (for net values). First-year savings have shown a strong increase from 2016 to 2017. This increase is more pronounced in terms of greenhouse gas emissions and primary energy. Final energy savings have also increased strongly, however a little less. That has to do with a strong rise in electricity-related measures in 2017 that feature a higher discrepancy between final energy and primary energy for the applied primary energy factor of 2.4 for Electricity and 1.1 for fuels. For interpretation of results in table 4, it should be mentioned that particularly net effects are calculated with the above-mentioned pragmatic approach using a survey approach. Several assumptions take part in this calculation.

Table 4: Summary evaluation results

Average Lifetime: 15 years	**gross**	**free-rider**	**spill-over**	**net**
Indicator Group A (gross) / B (net)		**-32%**	**+16%**	**-16%**
GHG emissions reduction (t CO_2-eq.)				
First-year savings 2016	52,300	-16,600	8,200	43,900
First-year savings 2017	221,100	-70,000	34,800	185,900
Cumulated annual savings	273,400	-86,600	43,000	229,800
Periodically cumulated savings	325,700	-103,100	51,200	273,700
Lifetime savings	4,100,700	-1,298,500	644,600	3,446,800
Final energy savings (MWh_{final})				
First-year savings 2016	209,800	-66,400	33,000	176,400
First-year savings 2017	721,800	-228,600	113,500	606,700
Cumulated annual savings	931,600	-295,000	146,400	783,100
Periodically cumulated savings	1,141,400	-361,400	179,400	959,400
Lifetime savings	13,973,900	-4,424,800	2,196,700	11,745,800
Primary energy savings ($MWh_{primary}$)				
First-year savings 2016	216,100	-68,400	34,000	181,600
First-year savings 2017	1,030,100	-326,200	161,900	865,900
Cumulated annual savings	1,246,200	-394,600	195,900	1,047,500
Periodically cumulated savings	1,462,300	-463,000	229,900	1,229,100
Lifetime savings	18,692,900	-5,919,100	2,938,500	15,712,300

4. Conclusion

Initially, this paper posed a row of questions that policy evaluations in energy efficiency are trying to answer. Most policies define targets that can be defined in different terms. Yearly or total carbon or energy savings to name just a few. These two examples already illustrate how different accounting methods can generate strongly different numbers that serve different purposes. However, the exact methodologies differ and a detailed description is often not delivered. The examples show how minimum documentation of the data and clear presentation of the metrics and periods taken into account are essential to avoid misinterpretations of the results. Authors as well as reviewers of evaluation reports and studies should therefore be sensitive to methodological uncertainties.

This paper presented four accounting methods and calculation approaches for determining the causality of the policy for the savings. Policy implications have been discussed and applied to the KfW waste heat programme in Germany.

In conclusion it can be said that the metric to use strongly depends on the way targets are formulated. Particularly for emissions reduction targets, both carbon budgets and yearly carbon savings are common metrics. Hence, the decision between yearly values (first-year savings and cumulated annual savings) and/or total values (periodically cumulated savings and lifetime savings) has to be made. Additionally, for yearly values, the question has to be posed whether target achievement or the policy development is in the focus of analysis. In total values, either a decision about the inclusion (lifetime savings) or exclusion (periodically cumulated savings) of future savings has to be made or both values can be given including thorough documentation of methodology. And finally, the question about gross and net savings remains. While net savings may be more appropriate for financial accounting of invested money, gross values may serve better for the evaluation of target achievement on the higher level of why the policy was implemented in the first place, i.e. the reduction of climate change.

An interesting field of future research is, how these different metrics are applied in real life policies and what justifications are given for using gross or net values or each of the methods by courts of auditors, ministries or programme implementers.

Acknowledgements

This paper is based on a research project funded by the German Federal Ministry for Economic Affairs and Energy (BMWi). In this project, the results and experience of the analysis and evaluation of the first year of the funding period were compiled by the working group, adelphi, German Energy Agency (dena), Fraunhofer ISI and University of Stuttgart under the direction of dena.

I would like to thank the representatives at the ministry and all project partners for the support of this study and for the important discussions during the period of project work.

The considerations have furthermore been included in a case study about the German Energy Efficiency Fund as part of the project EPATEE, which analyses evaluation studies worldwide. Results can be found on www.epatee.eu. EPATEE has received funding from the European Union's Horizon 2020 Research and innovation programme under grant agreement No 746265.

References

Adan, H., & Fuerst, F. (2016, October). Do energy efficiency measures really reduce household energy consumption? A difference-in-difference analysis. *Energy Efficiency*, pp. 1207-1219.

BMWi. (2017, 08 25). Änderung der Richtlinie für die Förderung der Abwärmevermeidung und Abwärmenutzung in gewerblichen Unternehmen. Retrieved 01 12, 2018, from http://www.bmwi.de/Redaktion/DE/Downloads/A/abwaermerichtlinie.pdf?__blob=publicationFile&v=12

Broc, J., Guermont, C., & Deconninck, C. N. (2017). Impacts and cost-effectiveness of majora energy efficiency policies for existing buildings. What do we exactly know and what can we learn? *Proceedings of the ECEEE 2017 Summer Study*, pp. 1747-1758.

Eichhammer, W., Boonekamp, P., Labanca, N., Schlomann, B., & Thomas, S. (2008). Distinction of energy efficiency improvement measures by type of appropriate evaluation method. *Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services*.

European Union. (2012). Energy Efficiency Directive. *Official Journal of the European Union*.

Fisher, R. J. (1993). Social Desirability Bias and the Validity of Indirect Questioning. *Journal of Consumer Research*.

Fraunhofer ISI et. al. (2018, upcoming). Endbericht der Evaluation des Energieeffizienzfonds. *BMWi*.

IPCC Working Group III. (2014). Climate Change 2014 - Mitigation of Climate Change. (C. U. Press, Ed.) *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Olsthoorn, M., Schleich, J., Gassmann, X., & Faure, C. (2018). Free riding and rebates for residential energy efficiency upgrades: A multi-country contingent valuation experiment. *Energy Economics*.

Rosenberg, M., Vine, E., & Pettit, T. (2011). Quantifying Energy Savings from Market Effects: The Case of High Bay Lighting. *Proceedings of the IEPEC 2011 Conference*.

Schlomann, B., Hirzel, S., Nabitz, L., Heinrich, S., Jessing, D., Paar, A., . . . Antoni, O. (2017). From Targets to Impacts: Eight Steps for Evaluating Energy Efficiency Policies. *Proceedings of the 2017 IEPEC Conference*.

Schlomann, B., Rohde, C., & Plötz, P. (2015). Dimensions of energy efficiency in a political context. *Energy Efficiency*.

Violette, D. M., & Rathbun, P. (2017). Chapter 21: Estimating Net Savings - Common Practices. In NREL, *The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures.* Golden, Colorado.

Voswinkel, F., Grahl, A., & Rohde, C. (2018, forthcoming). Less hot air for a less hot climate - Evaluating the German waste heat reduction programme. (ECEEE, Ed.) *Proceedings of the ECEEE Industry 2018 Berlin Conference*.

Wilson, J., & Eilertsen, S. (2010). How did strategic planning help during the economic crisis? *Strategy & Leadership, 2*.