# Less hot air for a less hot climate: evaluating the German waste heat reduction programme

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## Abstract

The German industry sector amounts to almost one third of final energy consumption and shows large potentials for energy efficiency. Research has shown that waste heat reduction and utilisation bears great savings potential. Hence, one of the more large-scale programmes is the waste heat programme for subsidised credit financed by the German Federal Ministry of Economic Affairs and Energy (BMWi) and administered by the development bank KfW. It is open for companies of any size with a special support scheme for SMEs.

To successfully adapt the programme to changing conditions, thorough evaluation is imperative. This paper draws on primary data from the evaluation of the programme. It gives insight both into individual waste heat concepts, as well as into the impact on macro-level emissions reduction targets. The methodology for the impact evaluation is thoroughly described and applied on evaluation results.

Policies are structured according to a line of priorities starting with waste heat avoidance. The remaining waste heat should then be used according to the waste heat cascade: 1. direct integration of waste heat into processes 2. integration of waste heat into other operating processes 3. external utilisation, and 4. generation of electricity from waste heat. The effectiveness of waste heat utilisation depends on numerous influencing factors such as the quantity of waste heat, temperature level and time availability.

In the evaluation, waste heat concepts showed to be very heterogeneous in structure and quality. Surveyed administrative staff stated that stricter requirements for the structure standardisation of the presented concepts would help to streamline the application process, which would reduce waiting times and reduce barriers for companies to participate. Target achievement analysis concludes that with a constant number and structure of participant companies, the target of yearly savings of 1 million tonnes of $CO_2$-eq. until 2020 can be achieved with an exceedance of 90 %.

While free-rider effects are an issue in such a large-scale programme, survey results show an increased awareness for energy efficiency pointing towards the existence of positive spill-over effects into further investments inside or outside of the company.

## Introduction

As part of the ambitious *Energiewende*, German governmental bodies have established a series of policy measures to reduce final energy consumption. The waste heat reduction programme aims to incentivise investments in reduction and usage of waste heat by means of a subsidised credit line by the development bank KfW. It supports investments within Germany in modernisation, expansion or new construction of plants for the avoidance or use of waste heat. Since May 2016, low-interest loans and subsidies as part of the "KfW Energy Efficiency Program – Waste Heat Utilization and Prevention in Commercial Enterprises" have been available for these measures. The KfW programme is financed by the German Federal Ministry for Economic Affairs and Energy (BMWi) as part of the "Waste

Heat Utilisation Offensive" of the National Energy Efficiency Action Plan (NAPE). It also is one of the large-scale programmes of the energy efficiency fund, financed from a special budget of the BMWi.

Companies can receive a repayment subsidy of 30 % of the additional investment expenditure related to energy efficiency in waste heat reduction and utilisation. In the case of external use of waste heat, the repayment subsidy in most cases amounts to 40 % of the eligible investment costs. Small and medium-sized enterprises (SMEs) receive an additional bonus of 10 % on the eligible investment costs. The programme aims to make a significant contribution to saving energy and reducing $CO_2$ emissions. This support programme is set apart from others, like the cross-cutting technologies programme in industry, in being available not only to SMEs but also for large companies to support waste heat recovery measures.[1] The maximum aid ceiling is set by EU state aid rules. In 2017, a direct aid scheme was implemented next to the subsidised credit line. However, the evaluation and this paper focusses on the latter.

While the need for a thorough evaluation of large-scale programmes in energy efficiency is generally accepted, the evaluation methodology differs widely. This paper focusses on the evaluation methodology developed for the energy efficiency fund, a funding instrument for a long array of policies consisting, among others, of the waste heat programme. Applicant firms for the subsidised credit are required to present a comprehensive and detailed waste heat savings concept developed by a licensed energy consultant. Based on this concept, KfW decides on the acceptance of the application.

The evaluation of the programme employs both an in-depth analysis of a sample of 50 savings concepts presented to KfW as well as impact evaluation of the entire policy. In a first step, a grading system for the savings projects was developed based on quantitative (e.g. energy savings, emissions savings) as well as qualitative criteria (formal criteria, plausibility, comprehensibility). Consecutively, an ex-post impact evaluation was performed based on deemed savings from the savings concepts. However, at this stage of the project, an evaluation after the physical implementation of the measure is not performed. The impact evaluation follows a set of predefined indicators including total energy savings, emissions savings as well as subsidy effectiveness. A client survey was conducted for complementary information on data adjustment factors and client satisfaction, the latter not being part of this paper. This information is used for a transparent calculation of effect adjustments, namely free-rider effects and spill-over effects. Finally, recommended actions are formulated by the evaluators both for the overall policy design as for the requirements to the savings concepts.

Evaluation results are presented based on primary data from the KfW waste heat programme. They aim to characterise similarities and differences in the participating firms' characteristics and their savings concepts, as well as implications for future concept designs. Selected concepts are used for illustration. Impact evaluation presents the most important quantitative results of the programme and presents impact projections up until the year 2020.

After this introduction, the paper follows with a short background and literature overview about waste heat reduction and usage as well as methodological approaches to energy efficiency policy evaluation. It continues with the presentation of the evaluation methodology and finally outlines the evaluation results in the waste heat programme. A conclusion is drawn in the last chapter.

## Background and literature review

According to Germany's environmental protection agency, Umweltbundesamt, (UBA), German industry produces at least 200 terawatt hours (TWh) of waste heat per year. This amount corresponds to the total annual energy consumption of Denmark. Using this waste heat could save between three and six billion Euros in energy costs and between 50 and 60 million tons of $CO_2$ per year (news aktuell GmbH, 2017).

The aim is therefore to reduce waste heat production to an unavoidable level and to use the remaining waste heat wherever possible.

### ENERGY-INTENSIVE INDUSTRIES

Waste heat reduction and utilization is relevant especially for energy-intensive industries such as cement, chemicals, food, glass, non-ferrous metals, paper or steel. In 2014, metal production and processing was the industry with the highest share of total energy consumption at 25 %, followed by the chemical industry with 20 % (FIZ Karlsruhe, 2018).

### POSSIBLE APPLICATIONS FOR INDUSTRIAL WASTE HEAT

As a first step, the possibility of avoiding waste heat should be considered. Simple measures like insulation of pipes and components such as flanges, fittings or valves are suitable measures to avoid waste heat.

When using waste heat, it is important to observe the waste heat cascade, meaning it has to be investigated, which industrial processes are best suited to use the produced waste heat:

1. In-process use: Waste heat is fed back to the process or plant from which it originated. This form of waste heat recovery is also referred to as heat recovery.
2. Internal use of waste heat and – if applicable – generation of electricity (depending on temperature and further use): Waste heat is used for other processes or plants within the same operation.
3. External use: Waste heat is used outside the company at other companies or via a feed-in in district heating networks.
4. Generation of electricity from waste heat using e.g. Organic Rankine Cycle (ORC) systems and grid feed-in.

Often a combination of measures should be implemented together in order to avoid waste heat in the first place and use the remaining waste heat in a reasonable and effective way. These are referred to as systemic measures. A typical systemic measure is control engineering which is not directly linked to waste heat but essential to the system.

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[1] The support programme for cross-cutting technologies has been modified to accept also large companies in 2016. However, maximum investment amounts are mainly interesting for SMEs.

#### INFLUENCING FACTORS ON THE USABILITY OF WASTE HEAT

Effective waste heat utilisation depends on numerous influencing factors such as:

- Waste heat quantity
- Waste heat medium/pollution of the medium
- Temperature level
- Time availability/time requirements (continuous or fluctuating, seasonal, full load hours per year)

#### Technologies for avoiding and using industrial waste heat

Besides thermal insulation in plants for waste heat reduction, the following technologies are appropriate for the use of waste heat in the form of heat, cold or electricity: In order to generate heat from waste heat, heat exchangers, heat pumps and, if necessary, heat storage tanks can be used. Waste heat can be used to produce cold with the help of refrigerators. Waste heat can be used to generate electricity using steam or ORC processes. In addition, the corresponding measures in the periphery such as control systems, pipelines etc. are necessary for both waste heat reduction and waste heat utilisation.

The cooling and heating requirements of a site can be systematically analysed with the help of a pinch analysis. With the help of this method, it can be clarified whether the heat and cold demand can be covered internally by the use of waste heat or whether it has to be supplied externally. It is important to clarify which types of heat exchangers are required to determine the theoretical minimum for heating and cooling. The biggest advantages of such an analysis are energy optimisation and the improvement of knowledge about the entire energy flow.

#### ECONOMIC CHALLENGES

The economic challenges lie, above all, in the willingness to invest, which is subject to business criteria. Especially in plants where waste heat is generated, very short payback periods – often 1 to 2 years – are expected from new investments. According to Grote, Hoffmann & Tänzer (2015) measures for the usage of waste heat often have payback times periods of 5 to 10 years. Support programmes for the promotion of waste heat recovery measures contribute to an increase of the perceived economic efficiency of these measures and thus increase their attractiveness for companies.

#### TARGET ACHIEVEMENT AND IMPACT EVALUATION

Approaches for impact evaluation can be roughly categorised in two groups: bottom-up methods and top-down methods. The former are calculating savings and the related indicators using micro data on a case-level to determine representative results for the programme as a whole and for projections on the macro policy level. Top-down methods use aggregated data on a higher level, like sector level to deduce results on the project level.

The EMEEES project (Eichhammer et al., 2008) collected evaluation methodologies employed in energy efficiency evaluations. It lists a total of 10 methods including both of the broad categories as well as hybrid methods that feature characteristics of both groups. In bottom-up methods, as used in the waste-heat programme, it distinguishes five non-hybrid methods ranging from the most exact one, the direct measurement of unitary energy savings to further estimated methods like unitary energy savings based on billing analysis. Other methods include estimates based on detailed engineering models and deemed estimates based on unitary energy savings.

The impact evaluation of the waste heat programme mainly employs the latter method. An energy consultant develops an energy concept for the individual company and calculates savings as the difference to a counterfactual value of the currently used technology. Information is based on product sheets by the equipment manufacturer or measured savings from former uses of the technology. Further information on the used information is stated in part 3 of the evaluation form paragraph in the Methodology chapter below. Implications of this methodology have been discussed in Adan & Fuerst (2016).

## Methodology

#### EVALUATION OF WASTE HEAT CONCEPTS IN THE KFW SUBSIDISED CREDIT PROGRAMME

The aim of the monitoring was to be able to derive information on the further design and, if necessary, the need to amend the funding guidelines after the first year of the support program. Core of the funding application is the waste heat concept. Applicants describe and justify their waste heat recovery measures under the technology-open support program using the respective waste heat concept. For this reason, the waste heat concepts of approved funding requests were in the focus of the monitoring. The evaluation included a total of 50 waste heat concepts.

Few formal requirements were laid down for the development of KfW's waste heat concept. In addition, there were a number of guidelines for the application under the support program. The waste heat concepts were examined to determine whether they meet the necessary requirements for receiving subsidies.

On the one hand, the waste heat concepts were examined, checked for relevant data and evaluated. On the other hand, data on electricity and fuel savings for the target achievement and impact evaluation were determined and made available from the waste heat concept.

For this purpose, a uniform evaluation form was developed which should enable a standardised and comprehensible evaluation of the waste heat concepts. Afterwards, the waste heat concepts were checked and evaluated by different editors, using the standardised evaluation form.

The evaluation form was designed based on the guidelines for the KfW programme, which are derived from the fact sheets on the promotional programme and the specifications for waste heat concepts resulting from the sample concept and further questions posed by the Ministry for Economic Affairs and Energy.

#### Evaluation form for testing waste heat concepts

The evaluation sheet was divided into three parts. In the first part general information on the company and its consultants were collected and evaluated . Information and data on the measures were the subject of the second part and evaluation of qualitative criteria subject of the third part. The individual questions and items in the three parts were numbered. In the first part, nine aspects were examined, in the second part 62 aspects and data were examined (where slightly more than half of the questions were used to determine energy consumption by different energy sources), and in the third part, 17 aspects were treated and valued.

*Part 1 – General information*
Part 1 of the evaluation form contains general information on the waste heat concept, the companies and consultants. The name of the company and the loan number were recorded so that the waste heat concept can be clearly identified. The size of the enterprises was determined in order to allow a classification. It was also determined if the waste heat concept was drawn up by an internal or external consultant since companies with a certified EMAS energy management system are allowed to develop the concept internally.

*Part 2 – Data and information from the waste heat concepts*
In Part 2 of the evaluation form, criteria for assessing the following facts were examined:

- Measures/technologies
- Energy consultants
- Repayment subsidy and profitability
- Energy consumption and $CO_2$ savings

The data on energy consumption were collected separately according to the different energy sources so that $CO_2$ reductions for the waste heat measures could be calculated for the target achievement analysis according to the methodology specified by defined emission factors.

Since energy service companies are explicitly named as a target group of the support programme, it was determined whether the measures should be implemented within the scope of an energy savings contracting scheme.

The nature and scope of the measures were analysed. The question was whether these were smaller or larger measures, individual measures or integrated measures. Furthermore, the position in the waste heat cascade was determined in order to analyse which measures were requested for the funding programme.

The investment costs for the efficiency of waste heat recovery measures were listed according to their eligibility and the costs for the waste heat concept. In addition, the economic efficiency criteria (return on investment costs, payback period, internal interest rate, etc.) selected by the companies were examined. In addition, it was also recorded when energy key figures were presented in the waste heat concept.

*Part 3 – Evaluation of waste heat concepts*
The waste heat concepts were rated according to a multi-criteria evaluation in the third part of the questionnaire based on a set of 12 different criteria.

The overall grade was determined linearly from the individual grades for the 12 criteria. For some of them, the individual grades were determined on a scale of 1 to 4 or 1 to 5, depending on the individual characteristics of the criteria, with 1 being the best rating.

For the evaluation criterion "Determination of energy consumption values", for example, the editor was able to choose between measurements, projections and estimations. If the results of exemplary measurements were used to determine the energy consumption values of measures, then this evaluation criterion was given the grade 1; if projection calculations were carried out to determine the values, the concept was rated with grade 2. Grade 3 was used when energy consumption values in the concept were estimated. If no information was given on this point, the grade 4 was used.

The evaluation criterion "Comprehensibility of the description of the waste heat utilisation measures" was evaluated with grades 1 to 5. The editors were also given the opportunity to make an individual grade if the given grade specifications were not applicable or appropriate for the individual case. Furthermore, in many cases "not applicable" could be selected. In this case the criterion was excluded from the calculation of the overall grade of the waste heat concept.

Part 3 also included facts that could not be easily graded but were necessary for assessing the waste heat concepts. For example, the level of complexity of the waste heat recovery measures were determined. It was also determined whether the calculation of the energy saved and the $CO_2$ emissions saved was carried out according to electricity and fuel savings using a plausible calculation methodology and whether the production quantity was taken into account when calculating energy consumption and energy savings. Furthermore, it was examined whether the energy consultant was listed in the list of energy efficiency experts for the federal government's support programs.

### Assessment of waste heat concepts

The individual evaluation sheets, each with about 90 data entries, were compiled in an evaluation table and prepared for a detailed analyses and evaluation. For the 4,500 (90 × 50 = 4,500) individual criteria and figures, statistical parameters like number, sum, mean value, median as well as the highest and lowest values were calculated. For the other criteria, the number of different selection options was taken – e.g. "yes" or "no" or grades from "very good" to "inadequate" or the indication "not determined". Fields, in which texts have been entered, such as comments, information on the company or consultant, have been taken into account individually.

The evaluations were additionally differentiated according to the four company size classes: small (<50 employees, <€5 M annual revenue), medium (<250 employees, <€50 M annual revenue), medium-sized (<€500 M annual revenue) and large companies (>€500 M annual revenue).

*Survey of KfW employees on the support programme*
Part of the monitoring was also a survey conducted by KfW on problems or obstacles to the submission of applications. For this purpose, a list of questions was deducted from the first results of the evaluation and discussed with KfW's expert staff in telephone interviews.

The general questions on the support programme included the question of rejection of applications and their reasons. In addition, the typical process of an application for the waste heat support programme was reviewed. In this context, it was of interest to learn more about the number of concepts that had to be modified after the first review due to missing information.

The quality of the waste heat concepts was also element of the survey with focus on whether the descriptions of the processes, measures and calculations were sufficient.

### IMPACT EVALUATION AND ECONOMIC ANALYSIS

The waste heat programme is a financial incentive programme funded from public means. The German constitution requires the Federal Court of Auditors to evaluate government spending, hence evaluation of the cost-effectiveness of the programme and implicitly an evaluation of target achievement is mandatory (Art. 114 II 2 GG Federal Republic of Germany). The Federal Court of Auditors frequently directs evaluation to the responsible governmental body who once again directs it to independent external experts in the required field. Common interpretation of subordinal laws states that evaluation should be conducted following a set of predeterminded indicators (Dittrich, 2017, § 7 BHO, p. 10) to guarantee transparency. Hence, evaluation should be "comprehensible, accepted, relevant, representative and, as far as possible, measurable" (Schlomann, et al., 2017). In order to achieve these properties, an evaluation methodology has to be developed fitting to the needs of the policy. The methodological approach for the waste heat programme has been developed for the German Energy Efficiency Fund, a policy scheme by the Federal Ministry of Economic Affairs and Energy consisting of a wide array of measures, one being the waste heat programme. The applied methodology is the subject of the following subchapters.

The methodology was developed based on the eight-step approach presented below and elaborated in Schlomann, et al., 2017.

#### Impact evaluation system

In a first step **(1)**, the general characteristics of the policy measure are identified. That includes the available funding, the administrative framework, the funding party, the target group and further demands for the implementation of the policy measure. Secondly **(2)**, Framework conditions are defined including underlying assumptions like energy prices, primary energy factors for different energy sources and greenhouse gas emission factors. In a third step **(3)**, policy targets are reviewed. This step is crucial as it forms the direct basis for the defintion of indicators in step four **(4)**. Target and indicator definitions are described in more detail in the following subchapter. In the next step **(5)**, necessary data for the calculation of indicators is collected. The sixth step **(6)** is the data analysis for gross values. Considerations for accounting methods are detailed in the further course. Net values that give insight into the effectiveness of the measure, which means to what degree the measure is responsible for the goal achievement, are calculated with the help of effect adjustments in step seven **(7)**. A more in-depth view into effect adjustments for free-rider and spill-over effects is given in the end of the methodology chapter. Finally, step eight **(8)** attempts to make future projections based on the calculated data. This can be useful for overarching indicators to which the policy measure's target achievement contributes to. (Schlomann, et al., 2017).

#### Targets and Indicators

As a means to define tailored indicators for the policy measure in question, goals and targets have to be clearly defined in advance. They are often implicitly given by overarching government strategies or, on a lower level, explicitly stated in legal policy guidelines. In the context of the waste heat programme, the German government has established the "Energy Concept" as an overall concept for future energy policy. The concept includes the ambitious goal to reduce primary energy consumption by 20 % until 2020 and 50 % until 2050 compared to 2008 levels. Furthermore, greenhouse gas emissions are to be reduced by 40 % until 2020 and 80 to 95 % until 2050 compared to the Kyoto Protocol base year 1990 (BMWi and BMU, 2010). With the energy concept and reduction goals in mind, the official guideline for the waste heat programme states that its purpose is the reduction of total yearly greenhouse gas emissions by one million tonnes until 2020 (BMWi, 2017). This series of documents serves as the basis for the formulation of clear targets. For the Energy Efficiency Fund, which forms the wider context of the waste heat programme, the targets are defined as follows:

- Contribution to the development of a highly energy-efficient economy
- Contribution to the achievement of climate protection targets
- Exploitation of the existing economic energy saving potentials
- Exploitation of the existing economic electricity saving potentials
- Decreasing the energy costs of all energy consumers (private households, companies, public institutions).

Departing from these defined targets, indicators are formed and grouped into three categories. The first category **(A)** monitors the target achievement. Category **B** investigates the policy effectiveness. In other words, it determines the causality of whether the policy is responsible for the degree of target achievement in category A. For the calculation of these net values, effect adjustments are performed, as stated further below. Finally, Category **C** monitors the economic efficiency of the policy. It relates target achievement and effectiveness to the overall costs of the programme. Table 1 relates the defined targets to the chosen indicators.

#### Savings accounting

An important methodological consideration for data analysis **(step 6 of the impact evaluation system)** in the evaluation of target achievement is the type of savings accounting. Since a universal standard on energy savings accounting does not exist, evaluation should transparently state the applied accounting method. Results for different methods can differ by a high order of magnitude as well as have differing implications for the interpretation of results. While stating the method is of very high importance, each accounting method has its justification. The evaluation of the waste heat programme states gross savings values in four different calculations.

The starting point are the first-year savings $S$ from measures implemented in year i that are realised in year $t$ ($S_{i,t}$). They are expressed as savings per year.

On this basis, values from other periods can be aggregated: cumulated annual savings, periodically cumulated savings, or lifetime savings.

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

| Policy Target | Indicator |
|---|---|
| **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 $MWh_{primary}$) |
| Reduction of energy costs | Achieved energy cost saving (EUR) |
| **Effectiveness** | |
| Net values for quantitative indicators after adjustment for effects (free-rider, spill-over) | |
| **Economic Efficiency** | |
| Funding efficiency (view: funding body) | GHG – funding efficiency (t $CO_2$-eq./EUR of funding]<br>Energy-funding efficiency ($MWh_{final}$/EUR of funding] |

In cumulated annual savings, the savings stemming from newly realised projects in that year are added to the savings encountered in the same year that stem from realised projects in earlier years whose lifetime has not yet ended. The cumulated annual savings ($Ct$) are stated as savings per year. *Equation 1* shows the calculation.

The periodically cumulated savings ($P_t$) are stated in total savings, not savings per year. They represent savings realised until the end of the year of evaluation. *Equation 2* shows the calculation.

Finally, lifetime savings are the total savings that will be realised until the end of the measures' lifetimes from measures that have been implemented until the end of the year of evaluation. The Calculation is shown in *Equation 3*.

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

*Equation 1. Cumulated annual savings (t=0 is the year of analysis).*

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

*Equation 2. Periodically cumulated savings as a sum of cumulated annual savings ($C_t$).*

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

*Equation 3. Lifetime savings.*

| | |
|---|---|
| t=0 | Current evaluation year (end of the year) |
| N | Calculation period (e.g. 2012 to 2014 → N=3) |
| T | Lifetime of the measure |
| i | Full number |
| j | Full number |
| $S_{i,t}$ | First year savings in year *t* from measures from year *i*. |
| $C_t$ | Cumulated annual saving |
| $P_t$ | Periodically cumulated savings |
| $L_t$ | Lifetime savings |

### Effect adjustment

Finally, the methodology of the energy efficiency fund evaluation includes the adjustment of savings for a series of effects. Net savings resulting from the adjustments give information about the causality of savings. They exclude savings that would have also happened, had the policy not existed. In the case of the waste heat programme, adjustments for two effects are performed. The free-rider effect negatively affects the savings values and the spill-over effect which positively affects the savings values. The free-rider effect describes how much of the total effect stems from those who would have implemented the measure also without the incentive policy. The values are subtracted from the gross results. According to Olsthoorn et al. (2018) and (Violette & Rathbun, 2014), free-rider effects can be ordered in three categories. Strong free-riders, weak free-riders and deferred free-riders. Strong free-riders were already planning to invest in a measure and decided to benefit from the financial incentive additionally. Weak free-riders were not originally planning a measure but started to do so upon receiving information about a fitting technology package for their needs and on top of that decide to benefit from the financial incentive. Hence, they would not have needed the financial incentive but rather only the information for a positive investment decision. Deferred free-riders would have invested in the measure without the incentive scheme at a later time, hence for the anticipated time, savings accrue to the policy. Deferred free-riders can be both strong and weak themselves.

The spill-over effect on the other hand describes how many additional savings have been generated inside and outside the participating company due to the existence of the policy without counting the direct savings resulting from it. Spill-over effects can be caused by the word of mouth and generation of general knowledge about investment opportunities. The values for the spill-over effect are added to the gross effect.

In the evaluation of the waste-heat programme, both effects are quantified based on survey results. Free-rider effects are on a general level determined by the question "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". Answer 1 means no free-rider effect. Answer 2 means 100 % free-rider effect. Answers 3 to 5 were looked at in combination with another question. The main motivation for the usage of the incentive scheme was asked.

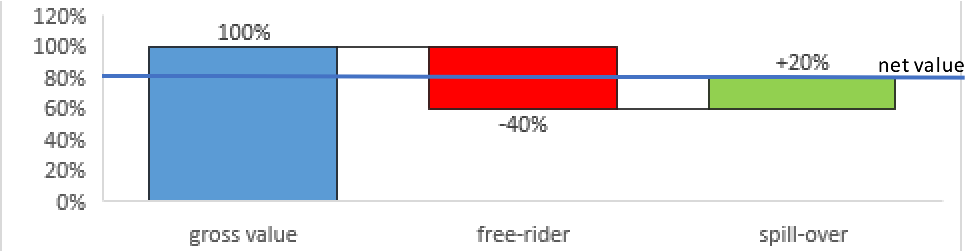

*Figure 1. Net savings value calculation.*

For those who checked answer 4 or 5 in the first question and indicated that the public financial incentive was the main motivation, the assumption is made that they are free-riders only to a low degree, because they are more sensitive to payout variations. 25 % free-rider effect is assumed. Otherwise 50 % is assumed. Respondents of 3 and 5 are deferred free-riders. Hence, the free-rider effect is only counted from the time onwards, that the measure would otherwise have been implemented. Because no reliable results can be expected from explicitly asking in the survey about how much later, the measure would have been implemented, an assumption has to be made about the amount of anticipation due to the incentive programme. The assumption is made that this timeframe is relative to the lifetime of the measure. Hence, larger measures with a longer lifetime are planned a longer time in advance. Wilson and Eilertsen (2010) conducted a survey and found that capital budget planning cycles on average are between three and five years. The entire time for implementation of the waste heat measures takes an average of 1.5 years. Subtracting these from the budget cycle results in an advance planning period of 1.5 to 3.5 years. As a social desirability bias is very probable for responding that the energy efficiency measure was planned for a later time, this value is rounded up to between two and four years. Lifetimes of waste heat projects range between 10 and 20 years. Hence advance planning periods of two years per 10-year lifetime are assumed.

For the determination of weak free-riders, an additional question is asked. “Was it difficult in the internal decision-making process to request the incentive scheme?” Those who answer “no, not difficult” are taken as weak free-riders because barriers for investment are low. Their free-rider effect is multiplied with a factor that corresponds to the information part of the overall programme expenditure. Since the information part accounts for only a small fraction of the total cost, but a separation of information and financial incentive is not possible in practice, weak free-riders are multiplied by 50 %.

Spill-over effects are very difficult to quantify. A series of five questions[2] dealing with how the programme has influenced the prioritisation of energy efficiency in the company has been asked on a five-point Likert scale from four to zero (“totally agree” to “do not agree at all”). A higher priority internally increases the probability that positive feedback about the programme is being communicated in the firm’s business environment and that the same firm invests in further energy efficiency measures. Each number on the Likert scale is then scaled by a multiplier according to the importance of the question. The maximum achievable effect is based on an empirical study by Rosenberg, Vine and Pettit (2011) in which they found spill-over effects between 23 % and 30 % in the household lighting incentive programme in California using the different methods. However, spill-over effects are more pronounced in households than in companies, therefore the maximum achievable value in this programme has been set at 26 % in the lower field of the calculated real value of california households. The results are finally added up over all five questions and an average is taken to account for a less-than-complete returrate of surveys.

Values for both effects are then added and subtracted from the gross savings value to determine the net savings value. Figure 1 illustrates the calculation of the net savings value. The percentages are a fictional example for illustration purposes.

## Results

The results section covers insights from both the in-depth analysis of waste heat concepts delivered to KfW by the individual companies or their respective energy consultants, as well as results from the current state of impact evaluation that is due to be continued in the forthcoming years.

### EVALUATION OF WASTE HEAT CONCEPTS IN THE KFW SUBSIDISED CREDIT PROGRAMME

#### Applicants

The individual analysis of concepts has been performed for the 50 companies that submitted a waste heat concept between the programme start in May 2016 until February 2017. Of these 50 companies 21 are small enterprises (more than 40 %). This is by far the largest group of applicants. The waste heat concepts of the medium, medium-sized and large companies represent around 20 % for each group. It can be assumed that larger companies are less interested in subsidy programmes because they generally regard them as time-consuming and costly. The creation of a waste heat concept involves personnel costs. Even if this is carried out by external energy consultants, in-house experts must be involved. 60 % of the companies belong to energy-intensive industries. The waste heat concepts in almost 80 % of the applications were made by external energy consultants. The energy consultants who developed the waste heat concept must be listed in the list of energy efficiency experts (EEE-list) for federal subsidy programmes, managed by dena

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[2] E.g. “The incentive scheme has contributed that we are targeting investments in energy efficiency more targeted now.“ (multiplier 1.5).”How probable is it, that you will recommend investments in energy efficiency in your professional environment? (multiplier 1.5).

and activated for the category "Energy Consulting for SMEs" (BAFA). According to the EEE-list, 403 experts were approved in January 2018 recognising waste heat utilisation as an area of competence according to their own statements. In total, more than 3,400 energy consultants for companies and municipalities can be found on the EEE-list.

### Measures for the use of waste heat

Around 30 % of the companies plan to retrofit their plants, another 30 % plan to modernise the production process or plant technology in the context of waste heat utilisation, and almost 40 % plan to build new plants. Measures are usually planned for internal waste heat usage with external usage being the least sought after measure.

Waste heat in the process or process changes and insulation measures are among the second most common measures. In the group of small companies, around 90 % of applicants plan to use the waste heat for heating purposes. External use or power generation from waste heat is rarely planned. External use requires arrangements with other companies, which is why this group of measures is very complex and therefore rarely represented. The use of waste heat through electricity generation is cost-intensive and only economically viable if a larger amount of waste heat is generated at a high temperature level (ORC: 70–450 °C, steam generation: 250–540 °C). An important reason for the planned construction of new plants may be that waste heat recovery systems are not easily integrated, but require extensive system measures. In the case of older production plants, it may therefore be advisable to replace them completely by new plants that allow better integration of waste heat recovery. The replacement of old plants with new ones not only improves or enables the use of waste heat, but also increases the energy efficiency of the entire production plant. New buildings generally use new, energy-efficient components that also reduce electricity consumption. More than 60 % of the planned measures from the waste heat concepts are integrated systemic measures, i.e. measures involving several subsystems.

### Economic parameters in the waste heat concepts

The economic investment parameters used by the majority of companies (40) is the payback period. The payback periods under consideration of subsidies are between 2 and more than 30 years in individual cases. On average, the investment pays off if the subsidies are taken into account in 10 years' time. The payback period for the waste heat recovery measures applied for in this funding programme is very high. On the one hand, it can be assumed that these measures are relatively expensive and on the other hand, companies apply especially for these measures. Without subsidies, the payback period of the measures reaches approximately 16 years. The requirement towards the payback period depends primarily on whether it is a matter of retrofitting, modernization or new construction of a plant. The respective value can therefore only be assessed in connection with concrete measures. High payback periods were determined, for example, in connection with completely new plants.

## IMPACT EVALUATION AND ECONOMIC ANALYSIS

In this part, the results of the target achievement, impact evaluation and economic analysis detailed in the respective methodology chapter are presented on the example of selected indicators. Current data have been analysed for all companies who have been admitted to the programme by KfW from the start in May 2016 to December 2017.

KfW granted credit subsidies in the total amount of 56 million Euros. Total investments in waste heat energy efficiency of roughly 215 million Euros have been triggered by the programme. These values are granted values that are verified by proof of implementation in the end of the process. However, a physical ex-post verification of savings does not occur. The most accurate data hence stem from energy consultants' calculations and granted financial means. After adjustment for free-rider effects and spill-over effects, that will be discussed below, the net investment value amounts to about 181 million Euros. That means that the programme is causal for investments of that amount. These investments lead to a considerable reduction in energy consumption and greenhouse-gas emissions. As the programme has started in the middle of year 2016, annual data are not comparable and are hence not stated in this paper. Table 2 sums up the results in cumulated annual savings. presents results in lifetime savings. Lifetimes have been assumed from an average value in the waste heat concepts. This is reasonable for aggregate measures of target achievement and the value of 15 years' lifetime is used. In addition, savings are assumed to stay constant over the years until the end of the lifetime.

A crucial factor for the policy maker is the causality of savings, hence the net values adjusted by free-rider and spill-over effects. According to survey results, several companies stated that they would have also implemented the measure on the same scale if they had not received the financial incentive. A larger portion stated, they would have done so at a lower scale. Hence, the free-rider effect turned out in the upper middle-field of comparable programmes at 50 %. However, upon more thorough analysis and distinguishing weak and strong free-rider effects, it turned out that more than half of the participants are only weak free riders, which considerably decreases the effect. A total free-rider effect of 32 % was calculated taking it into the low middle-field of comparable programmes. Due to the fact that many energy efficiency measures are of high complexity, investments are made when a technical upgrade has been planned anyways. Hence, companies may research for support schemes after making an investment decision and are therefore counted as free-riders. The fact though, that most of those can be grouped as weak free-riders shows, that the goal of promoting energy efficiency investment and awareness for it has been achieved by the programme. The information aspect of the programme has been highly effective.

Furthermore, results for spill-over effects were very positive. While the methodology permits a maximum of 26 % spill-over effects, the results point to an effect of 16 %. A majority of companies stated that the programme had led to a stronger awareness and prioritisation for energy efficiency and the intent to consider further investments in the future.

In a last step, the results are then used to perform a projection to the target year of 2020. The policy aims at reaching a yearly greenhouse-gas reduction of 1 million tonnes of $CO_2$-equivalent. Between 2016 and 2017, participation has increased considerably. Under the assumption that participation remains constant from 2017 onwards, yearly GHG emissions savings of 937 thousand tonnes of $CO_2$-equivalent can be expected, a

Table 2. First-year savings (yearly values).

| Cumulated annual savings (yearly) | gross | free-rider effect | spill-over effect | net |
|---|---|---|---|---|
| **Indicator Class A** | | -32 % | +16 % | -16 % |
| GHG emissions reduction (t $CO_2$-eq.) | 273,400 | -86,600 | 43,000 | 229,800 |
| Final Energy savings (MWh) | 931,600 | -295,000 | 146,400 | 783,000 |
| Primary Energy savings (MWh) | 1,246,200 | -394,600 | 195,900 | 1,047,500 |
| **Indicator Class C** | | | | |
| GHG funding efficiency (t $CO_2$-eq./1,000 EUR spent) | 4.85 | -1.54 | 0.76 | 4.08 |
| Final Energy funding efficiency (MWh/1,000 EUR spent) | 16.54 | -5.24 | 2.60 | 13.90 |
| Primary Energy funding efficiency (MWh/1,000 EUR spent) | 22.13 | -7.01 | 3.48 | 18.60 |

Table 3. Lifetime savings (total values); Lifetime: 15 years.

| Lifetime savings (total), Lifetime: 15 | gross | free-rider effect | spill-over effect | net |
|---|---|---|---|---|
| **Indicator Class A** | | -32 % | +16 % | -16 % |
| GHG emissions reduction (t $CO_2$-eq.) | 4,100,700 | -1,298,500 | 644,600 | 3,446,800 |
| Final Energy savings (MWh) | 13,973,900 | -4,424,800 | 2,196,700 | 11,745,800 |
| Primary Energy savings (MWh) | 18,692,900 | -5,919,100 | 2,938,500 | 15,712,300 |
| **Indicator Class C** | | | | |
| GHG funding efficiency (t $CO_2$-eq/1,000 EUR spent) | 72.81 | -23.05 | 11.45 | 61.20 |
| Final Energy funding efficiency (MWh/1,000 EUR spent) | 248.11 | -78.56 | 39.00 | 208.55 |
| Primary Energy funding efficiency (MWh/1,000 EUR spent) | 331.90 | -105.10 | 52.17 | 278.98 |

target achievement of about 94 % in gross values. In net values, this number drops to 787 thousand tonnes or a target achievement of about 79 %. Figure 2 shows the projection.

## Conclusion

This paper presented the methodology behind the evaluation system of the German KfW waste heat reduction and utilisation programme in commercial enterprises. It gives insights into the evaluation practice both on the micro level in the analysis and grading of individual waste heat concepts as well as on the policy-wide macro level upon evaluating the impacts. It showed how both levels are intertwined and how the successful establishment or alteration of a policy requires insights into all aspects.

Results from the evaluation have shown that any new policy has its flaws in the beginning, which can be solved in the future if they are identified in time. The main flaw of the waste-heat programme which has been identified is the large amount of administrative work. On a higher level, it may deter potential participants from applying because of the fear of losing the incurred costs. Waste heat concepts by the individual companies varied largely in quality, which calls for a higher level of standardisation and stricter requirements.

However, overall target achievement is very satisfactory, a growth in the number of was observed between 2016 and 2017 and if numbers remain constant from 2017 onwards, the target will be almost fully achieved by 2020 in gross terms. And the adjustment for effects also draws a positive picture. Free-rider effects remain well within its boundaries at 32 %. Knowing that complex measures often go hand in hand with other larger restructuring processes in companies, it is only logical that those who have such processes planned will want to benefit from the financial incentives. On the flipside, surveys have produced evidence, that awareness for energy efficiency has considerably risen in participating companies and spill-over effects to other companies or to future projects in the same companies are very likely and could be quantified at positive 16 %, setting the overall effect at a low negative 16 %.

It will be interesting to follow up on subsequent evaluations of this and similar programmes to get a better understanding

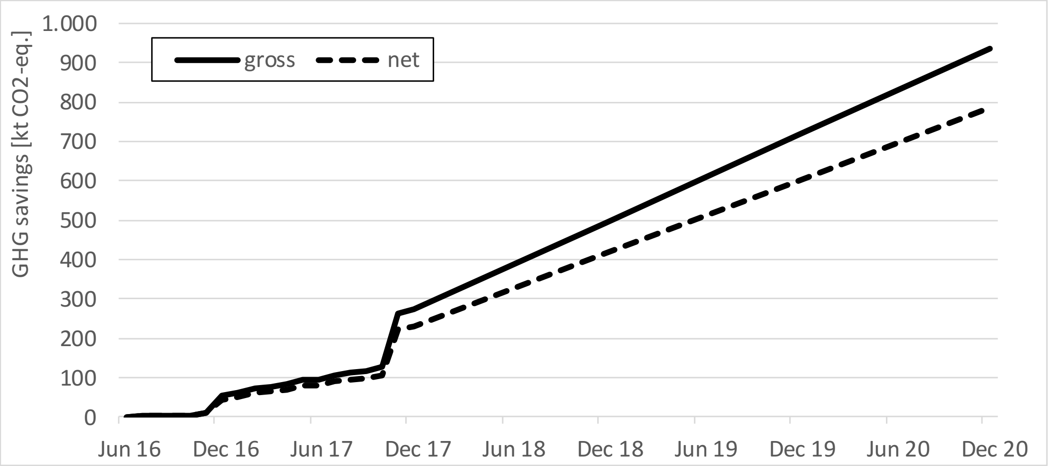

*Figure 2. Projections for target achievement 2020 in two scenarios.*

of the bigger picture. The bigger picture of how much waste heat reduction and usage can contribute to mitigate climate change.

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