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Standardized saving methodologies

Energy, CO_2 savings and costs

Deliverable D2.2 - first PA round

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Abbreviations and acronyms

Acronym	Description
BACS	Building Automation and Control System
BEV	Battery Electric Vehicle
BEV	Battery Electric Vehicle
CHP	Combined Heat and Power
dmnl	dimensionless
EED	Energy Efficiency Directive
EEOS	Energy Efficiency Obligation Scheme
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
ETS	Emission Trading System
EU GPP	European Green Public Procurement
EV	Electric Vehicles
GHG	Greenhouse Gas
ICE	Internal combustion engine
LNG	Liquified natural gas
LPG	Liquified Petroleum Gas
MFH	Multi Family House
MS	Member State
NCV	Net calorific value
PA	Priority Action
PHEV	Plug In Hybrid Electric Vehicle
PV	Present Value
SFH	Single Family House
UNFCCC	United Nations Framework Convention on Climate Change
VAT	Value-added tax
WP	Work Package

Summary

To achieve the reduction targets under the Energy Efficiency Directive (EED), a clear need arose for **simplified, yet accurate, methodologies to calculate energy savings from energy efficiency actions** being implemented by Member States. During streamSAVE's consultation (Autumn 2020) to identify the main challenges that Member States face when implementing Article 3 and Article 7 of the EED, data collection procedures were stressed, as well as the lack of quality data. Moreover, the amendment of the EED 2018/2002 brings additional challenges to Member States, in particular regarding Article 7 and several requirements of its Annex V.

The **Knowledge Facility of streamSAVE** is developing streamlined calculation methodologies for savings actions, the so-called Priority Actions: despite their high potential for energy savings, a lack of experience, practices and data is hindering the adoption of these actions by several Member States. This streamSAVE facility develops **10 Priority Actions over two cycles** of experience sharing and capacity building. Priority Actions under analysis in the first round are:

- Heat recovery (district heating and excess heat from industry);
- Building Automation and Control Systems (BACS);
- Commercial and Industrial refrigeration system (C&I Refrigeration);
- Electric vehicles (private & public EVs);
- Lighting systems and public lighting.

Next to a **general guidance** on **energy savings calculations** for both **Article 3 and 7 EED** and information on how to **assess costs and GHG emissions reduction** related to the Priority Actions, this report provides **8 newly developed bottom-up calculation methodologies** featuring indicative calculation values, data on costs and estimations of GHG emission reduction. The following methodologies have been prepared:

- Heat recovery for on-site use in industry - feedback of excess heat into a process
- Heat recovery for on-site use in industry - use of excess heat for on-site applications
- Heat recovery for feed-in to a district heating grid
- Building Automation and Control Systems in residential and non-residential buildings
- Energy efficient compression refrigeration units
- Fuel Switching to Electric Vehicles
- Energy efficient road lighting systems – engineering approach
- Energy efficient road lighting systems – simplified approach

A clear **guidance is included for each methodology**, so Member States can estimate the monitored and/or ex-ante final and primary energy savings, based on EU-wide averages or can translate these into national specific savings. Next to this guidance, the methodologies can also be consulted via user-friendly excel templates per Priority Action. These templates are integrated on the online Training module of the streamSAVE platform: https://streamsave.flexx.camp/training.

Note: In this intermediate deliverable, the first round of Priority Actions is described. In the second part of the project, the assessment of five new Priority Actions will be included.

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Keywords

Deemed savings; bottom-up calculation methodologies for energy efficiency; energy savings calculations; costs of energy efficiency actions; GHG savings; Article 3 of EED; Article 7 of EED

Introduction

About streamSAVE

Energy efficiency is one of the five key dimensions of the Energy Union, and consequently of the Member States' National Energy and Climate Plans. The Energy Efficiency Directive sets the 2020 and 2030 energy efficiency targets and a series of measures that contributes to their achievement within the Union. The streamSAVE project streamlines energy savings calculations and provides the support needed to increase Member States' chances of successfully and consistently meeting their energy efficiency targets. The streamSAVE project specifically focuses on Article 3 and 7 of the EED which are devoted to energy efficiency targets and national energy savings obligations, respectively.

Given the importance of deemed savings approaches in Member States' EED reporting streamSAVE focuses on streamlining bottom-up calculations methodologies of standardized technical actions. streamSAVE offers these savings methodologies in a transparent and streamlined way, not only to improve the comparability of savings and related costs between Member States (MS), but also between both EED articles. The savings actions are targeted to those measures with high energy saving potential and considered as priority issues by Member States, the so-called *Priority Actions*.

More broadly, the project aims at fostering transnational knowledge and dialogue between public authorities, technology experts, and market actors. The key stakeholders will improve their energy savings calculation skills and ensure thus the sustainability and replicability of the streamSAVE results towards all European Member States.

Standardized savings methodologies for Priority Actions

During October-November 2020, a stakeholder consultation was carried out by the streamSAVE consortium in EU Member States and the UK. The consultation showed that there are savings potentials that might not yet be well covered by existing bottom-up methodologies and that for other methodologies already available, Member States find it difficult to identify the baseline or calculation values for the savings estimation in accordance with the EED framework.

Recognizing the needs Member States have, the **Knowledge Facility of streamSAVE** analysed the existing bottom-up methodologies within Member States (D2.1. Status of energy savings calculations for Priority Actions in European countries). This overview of methodologies supports the development of streamlined methodologies for savings calculations, for which a lack of experience, practices and data is hindering its adoption by several MS, although its high potential for energy savings – *the Priority Actions (PA)*. streamSAVE will target a total of 10 Priority Actions over two cycles of experience sharing and capacity building. The five Priority Actions under analysis in the first round are:

- Heat recovery (district heating and excess heat from industry)
- Building Automation and Control Systems (BACS)
- Commercial and Industrial Refrigeration System
- Electric Vehicles (private & public EVs)
- Public Lighting Systems

This report describes the **standardized calculation methodology for each of these Priority Actions**, supporting the implementation of Article 3 and 7 of the EED. The basic bottom-up approach for calculating energy savings achieved by an action is (1) to take into account all essential influences on the energy consumption of an appliance or system (e.g., performance of a compressor, operating hours) and; (2) compare the baseline situation to the situation after the PA implementation. The savings methodologies are based on literature, statistical data, EED requirements as well as the expertise from streamSAVE's partners. Moreover, the draft methodologies have been discussed during the peer-to-peer dialogue groups (WP3), so the expertise and experiences of key stakeholders, i.e. public authorities & technology group experts, are reflected as well.

This guidance contains the following information for each of the actions:

- Description of the action, including application area or scope of the standardized calculation methodology (e.g. subsector; limits of methodology);
- Calculation formula and parameter definition;
- Indicative values per parameter (e.g. lifetime) based on EU-wide data;
- Reference consumption or baseline and update;
- Correction for behavioural and/or regional effects;
- Costs and benefits, allowing to assess cost effectiveness of the action;
- Calculation formula and related indicative values to estimate CO_2 savings.

At the beginning of this guidance, a general chapter is included on Article 3 and Article 7 requirements and recommendations, in relation to energy savings estimations. Special attention is given to the **definition of baseline, as well as the cumulation of savings** over lifetime according to the Article 7 requirements. Next to savings estimations, the guidance explains how to perform an assessment of the **cost effectiveness and CO_2 reductions** for the implementation of the Priority Actions, so policy makers can analyse efficient ways to fulfil greenhouse gas reduction targets within their country.

The streamlined energy savings methodologies are not only shared by means of this guidance, but by user-friendly excel templates per Priority Action as well, which are **integrated online on the Training module of the streamSAVE platform.** This way, Member States are able to consult and use the streamSAVE output in the way they prefer for their own needs and EED reporting obligations at: https://streamsave.flexx.camp/training.

Chapter 1 Calculation of savings within the EED framework

In December 2018, the European Parliament and the Council of the European Union adopted the amending Energy Efficiency Directive 2018/2002/EU which set the 2030 energy efficiency target to be at least 32.5 % compared with levels projected in the European Commission's 2007 baseline scenario. The 32.5 % energy efficiency target for the EU-27 means that EU-27 energy consumption in 2030 should not exceed 1,128 Mtoe for primary energy and 846 Mtoe for final energy (European Commission, 2018). However, according to the European Commission's 2020 progress report on improving energy efficiency, 12 Member States will (very) unlikely achieve their target for Article 7 of the EED during the obligation period 2014-2020 (European Commission, 2020). Moreover, the national contributions to the 2030 EU target, as reported by Member States in their final National Energy and Climate Plans, stand short of the 32.5% ambition.

The EU Green Deal will incentivise even more efforts on energy efficiency, so the updated 2030 emissions reduction target of net 55% compared to 1990 levels can be reached. Therefore, most Member States need to tackle untapped energy savings potentials. Within the frame of the Task Force on mobilising efforts to achieve the 2020 targets for energy efficiency, Member States pointed out possible reasons to the European Commission, depending on their national context, that explain the difficulty to increase energy savings (European Commission, 2019):

- good economic performance and low oil prices;
- delayed implementation of energy efficiency policies;
- difference in the *estimated energy savings* and the actual energy savings achieved;
- insufficient consideration of the *impact of behavioural aspects* such as the rebound effect;
- lack of funding for energy efficiency policies and restrictions by EU State aid rules.

The Member States clearly raised the difficulty to calculate, and thereby report, the energy savings from measures taken or planned, as it is challenging to estimate savings aligned with actual savings achieved, including behavioural impacts (Labanca & Bertoldi, 2016). A more streamlined approach which covers how Article 3 targets as well as Article 7 savings of energy efficiency measures are to be estimated is very relevant, especially in the context of the 2030 National Energy and Climate Plans (NECPs) under the Governance Regulation 2018/1999.

In this chapter, a general description is included of the Article 3 and Article 7 requirements and recommendations, in relation to energy savings estimations. Special attention is given to the definition of baseline, as well as the cumulation of savings over lifetime (Article 7). Although not explicitly mentioned in the EED, rebound effects are also described, so Member States are able to produce more accurate estimates of the energy savings generated from the Priority Actions. Next to the savings estimations, analysing the cost effectiveness and CO_2 reductions of Priority Actions may introduce policy makers to efficient ways to fulfil greenhouse gas reduction targets. The assessment of costs and estimation of GHG savings are explained in section 1.2 and section 1.3, respectively.

1.1 Estimation of energy savings

Under *Article 3 of the Energy Efficiency Directive*, EU countries set their own national non-binding contributions for energy efficiency for 2030. These targets can be based on primary or final energy consumption, on primary or final energy savings, or on energy intensity. The Energy Efficiency Directive requires, however, that when doing so, Member States also express those targets in terms of absolute levels of primary and final energy consumption. The progress towards targets is monitored by means of Member States' energy balances, more specifically, the Eurostat primary and final energy consumption used for monitoring progress towards 2020 and 2030 targets (Primary/Final energy consumption - Europe 2020-2030; Eurostat code: PEC2020-2030 and FEC2020-2030) (Eurostat, 2021).

To support the achievement of these goals, *Article 7 of the Energy Efficiency Directive* requires Member States to achieve yearly new energy savings through *an energy efficiency obligation scheme* (EEOS) *(Article 7a) or alternative measures (Article 7b)*. The amending Directive includes an extension to the *energy savings obligation* in end use: the EU Member States have to achieve new energy savings of 0.8% of final energy consumption[1] each year for the 2021-2030 period (European Commission, 2018). In order to reach this target, in case of an EEOS, obligated parties have to carry out measures which help final consumers improve their energy efficiency. Member States may also implement alternative policy measures which reduce final energy consumption, for example fiscal measures; financial incentives; regulations or voluntary agreements; energy labelling schemes beyond requirements under EU law; and information measures (Article 2(18) of EED). Article 7a(5) and Article 7b(2) of the EED emphasises the importance of monitoring and verification in ensuring that policy measures achieve their objectives. Member States should demonstrate that energy savings are not double-counted (Article 7(12) of EED), where the impacts of policy measures or individual actions overlap.

Annex V of the EED sets out methodological options for the calculation of these Article 7 energy savings. The Annex identifies four main methodologies to calculate final energy savings (European Commission, 2018):

- "*deemed savings*, by reference to the results of previous independently monitored energy improvements in similar installations.
- *metered savings*, whereby the savings from the installation of a measure, or package of measures, are determined by recording the actual reduction in energy use, taking due account of factors such as additionality, occupancy, production levels and the weather which may affect consumption.
- *scaled savings*, whereby engineering estimates of savings are used. This approach may be used only where establishing robust measured data for a specific installation is difficult or disproportionately expensive, or where those estimates are carried out on the basis of nationally established methodologies and benchmarks by qualified or accredited experts that are independent of the obligated, participating or entrusted parties involved;
- *surveyed savings*, where consumers' response to advice, information campaigns, labelling or certification schemes or smart metering is determined. This approach may be used only for savings resulting from changes in consumer behaviour".

[1] Averaged over the most recent three-year period prior to 1 January 2019, as defined in Article 7(1)b.

Next to the methodological options, Annex V of the EED also describes the principles to apply to the calculation of additionality (to what have occurred anyway) and the materiality of the activities of obligated, participating or entrusted parties; a requirement to ensure that quality standards for energy efficiency measures are introduced and maintained; and a methodology for the notification of energy efficiency measures to the European Commission (European Commission, 2018). The European Commission published the Recommendation (EU) 2019/1658, where more information can be found on the steps Member States need to take when implementing Article 7, and how to comply with these requirements (European Commission, 2019).

A large share of the savings reported under Article 7 come from deemed savings approaches (Labanca & Bertoldi, 2016). As mentioned above, deemed savings are pre-determined, validated estimations of energy savings attributable to an energy efficiency action as opposed to savings determined through measurement activities (metered savings) or project or action specific calculations (scaled savings). Deemed savings can be considered as a good practice to minimize administrative burden, provide quick feedback and give visibility to stakeholders, especially when it comes to efficiency measures with a straightforward impact (Labanca & Bertoldi, 2016). Given the importance of deemed savings approaches in Member States' EED reporting, streamSAVE focuses on streamlining bottom-up calculations methodologies of standardized technical actions, i.e. **deemed savings complemented with scaled savings based on engineering estimates**. The deemed savings in streamSAVE include savings formula or calculation methodologies, next to indicative values which are based on commonly accepted, evidence-based data sources and analytical methods.

1.1.1 Differences in savings calculation for Article 3 & Article 7

The amended EED 2018/2002 stipulates in Article 3(5) that by 2030, the Union's energy consumption shall be no higher than 1,128 Mtoe of primary energy consumption or 846 Mtoe of final energy consumption. Member States shall set indicative targets to reduce their energy consumption, based on either primary or final energy consumption, primary or final energy savings, or energy intensity (European Commission, 2018). The energy consumption of Member States is reported on a yearly basis via energy balances, according to the Regulation (EC) 1099/2008 on energy statistics. In addition to the definition of energy products, it contains details on the balance aggregates (including final energy consumption) to be reported. For each balance aggregate, the main consumption sectors and energy conversion activities are listed. As Article 3 focusses on reducing the total energy consumption according to the energy balances, also primary energy savings are taken into account. Therefore, every effect on energy consumption can be considered a saving for Article 3, regardless of what caused this reduction. In contrast, Article 7 is about considering additional final energy savings at the level of a policy action.

Almost all countries set their 2030 Article 3 contributions to match their "With Additional Measures' (WAM) projections (Economidou, et al., 2020). The savings of these additional measures or actions to reach the target can be counted on top of the baseline or a "with existing measures" (WEM) scenario. The WEM scenario already takes into account existing measures, such as minimum standards for new appliances as well as autonomous evolutions, such as the necessary replacement of outdated appliances, population growth and economic growth. Therefore, only savings from energy efficiency actions exceeding the WEM-scenario are additional and can therefore - at the action or technology level - be considered as savings relevant to estimate the Article 3 target setting. In context of Article 7, Member States should demonstrate that energy savings are not double-counted

(Article 7(12) as well as additional to what have occurred anyway (e.g. existing EU legislation) (Annex V of EED).

As the concept of the WEM-scenario is generally in line with the baseline definition for Article 7 saving calculations, the annual energy saving calculations for Article 3 and Article 7 as suggested in this guidance by streamSAVE are similar for most of the energy saving actions. In the project, it is therefore assumed that savings exceeding the assumptions of the WEM-scenario are in line with the Article 7 target achievement, i.e. being additional and without double counting. However, when implementing the streamSAVE methodologies and related baselines within a MS, it is recommended to take country specificities into account, such as policy developments and current performance of the market or stock. Moreover, it should be noted that while Article 7 only focusses on final energy, for Article 3 both final and primary energy consumption are relevant.

Converting final energy to primary energy savings for Article 3

The following formula can be used as a basis to convert final energy savings into primary energy savings:

$$\boldsymbol{EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec} \cdot f_{PE,ec})}$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
share	Share of final energy carrier in final energy consumption [dmnl]
f_{PE}	Primary energy factor of final energy carrier [dmnl]
ec	Index of energy carrier
Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of an action

To determine the primary energy consumption of the conditions before and after the action, the energy consumption is multiplied with the primary energy factor of the respective energy carrier. In multiple cases, one specific energy carrier is replaced when implementing a single energy saving action. However, there are also energy saving actions in which several energy carriers are replaced at the same time. As soon as several energy carriers are involved, *a weighted primary energy factor* has to be applied. Such a weighted primary energy factor can also be used when creating standardized values or when evaluating several energy saving actions at the same time.

Table 1 provides indicative values of primary energy factors for final energy carriers, corresponding to EU average values. When possible, using primary energy factors defined based on national data is more accurate.

The selection of energy carriers is based on the list of energy carriers in Annex VI of the Greenhouse Gas Directive 2018/2066/EU. Energy carriers not being used as a final energy carrier (e.g. crude oil) are not included for this assessment, as the methodologies prepared for this report focus on both Article 3 and 7 EED. The primary energy factor is determined by comparing the amount of primary energy needed to provide the relevant amount of final energy. The complete EU-27 Energy Balance of the Eurostat database (Eurostat, 2021) was used as data basis for the calculation.

Table 1: Primary energy factors (f_{PE}) per energy carrier

Energy carrier	factor final to primary [-]
Electricity	2.281
District heat	1.663
Natural gas	1.007
Gas/Diesel oil	1.119
Motor gasoline	1.119
Biodiesels	1.001
Biogasoline	1.001
Other liquid biofuels	1.001
Biogas	1.032
Wood/wood waste	1.001
Other primary solid biomass	1.001
Kerosene (other than jet kerosene)	1.119
Liquefied petroleum gases	1.119
Naphtha	1.119
Natural gas liquids	1.119
Petroleum coke	1.119
Refinery gas	1.119
Residual fuel oil	1.119
White spirit and SBP	1.119
Other petroleum products	1.119
Anthracite	1.002
Lignite	1.002
Charcoal	1.001
Coal tar	1.002
Coke oven coke and lignite coke	1.002
Coking coal	1.002
Patent fuel	1.002
Sub-bituminous coal	1.002
Other bituminous coal	1.002
Industrial wastes	1.000
Blast furnace gas	1.102
Coke oven gas	1.102
Oxygen steel furnace gas	1.102
Oil shale and tar sands	1.000
Peat	1.000

The primary energy conversion factor for *energy carriers except electricity and district heat* is calculated using the data available in the complete energy balances per energy carrier group. Those groups are:

- natural gas
- renewables and biofuels
- biogas
- oil and petroleum products
- solid fossil fuels
- manufactured gases
- non-renewable waste
- peat and peat products

Calculation of more disaggregated conversion factors is not possible due to the complete energy balances not depicting the conversion processes at the required level of detail. To determine the conversion factor for final to primary energy consumption for these groups, the following calculation is therefore used:

	Gross inland consumption of [energy carrier]
-	Transformation input of [energy carrier]
+	Transformation output of [energy carrier]
-	Energy sector – energy use of [energy carrier]
-	Final consumption – non-energy use of [energy carrier]
-	Statistical differences of [energy carrier]
=	**primary energy consumption of [energy carrier]**

To determine the primary energy factor, the primary energy consumption has to be divided by the final energy consumption of the relevant energy carrier.

A different methodology has to be used for *electricity and district heat* in comparison to other energy carriers, as these are generated using other energy carriers, including conversion losses. Primary energy consumption for electricity and district heat is therefore determined as follows:

	final energy consumption of electricity/district heat
+	distribution losses of electricity/district heat
+	transformation input of other energy carriers for electricity/district heat generation
-	transformation output of electricity/district heat
+	transformation input of electricity/district heat
=	**primary energy consumption of electricity/district heat**

To determine the primary energy factor, the primary energy consumption has to be divided by the final energy consumption of electricity/district heat.

In the case of combined heat and power plants, transformation input has to be divided between electricity and district heat, as the same fuel is used for the generation of both products. For this analysis, the division is performed using the output share of electricity and district heat as stipulated in the energy balance.

Primary energy savings and Article 7

It should be kept in mind that even though actions implemented in accordance with Article 7 EED can be converted into primary energy savings, some actions affecting primary energy consumption do not have an effect on final energy consumption. Energy input used for the production of electricity and district heat is allocated to the energy transformation sector and therefore cannot be considered for Article 7. This includes renewable electricity production as well as electricity production in co-generation plants.

Concerning heat production by renewables, heat recovery and co-generation, system boundaries and reference heating systems have an influence on whether savings are eligible for Article 7 or not. Contrary to the definitions stipulated by the Energy statistics Regulation 1099/2008, the EED makes an exception for ambient heat. Ambient heat used by heat pumps is not considered as final energy consumption so only the electricity consumption of a heat pump is compared to the final energy consumption of other heating systems.

1.1.2 Definition of a baseline

Annex V (2) (a) of the EED states that Member States need to show that savings reported for the fulfilment of their Article 7 target need to **be additional to actions** which would have been implemented at any event. In Annex V (2) (b) it is further elaborated that savings triggered by mandatory Union law cannot be considered additional. Therefore, the baseline situation for savings reported under Article 7 EED action must be defined in a way that, at least, only savings going beyond the minimum requirements stipulated in Union law are considered. While Annex V (2) (a) only refers to Article 7, this report also looks into the effects on energy consumption relevant for Article 3. As stated in chapter 1.1.1, the approach chosen for assessing the effect on Article 3 energy consumption does already consider existing measures. For the methodologies presented in the report, it is assumed that for specific implemented actions, the baseline for Article 7 equals the baseline for Article 3. This approach is a necessary simplification, as Article 3 takes into account an autonomous trend, but not on the level of individual actions. Figure 1 illustrates what can be considered as savings achieved under Article 7 EED, in the case of an action dealing with a product covered by an EcoDesign regulation (European Commission, 2019):

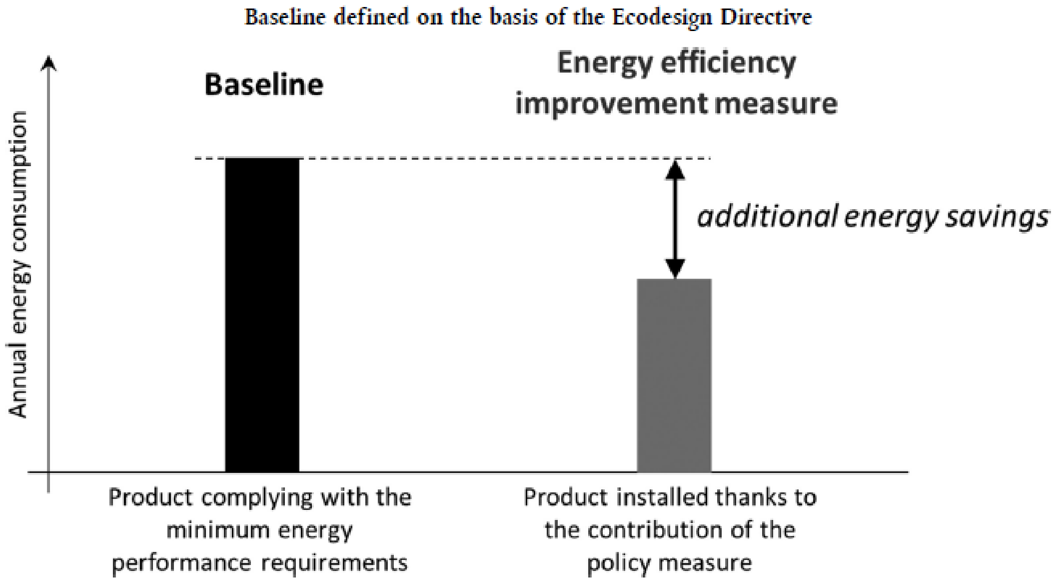

Figure 1: Baseline definition in accordance with Union law

Another factor to consider in defining a correct baseline depends on whether the savings derive from replacing an existing appliance or installing a new one. While the baseline in case of a new installation will always be the minimum requirements as explained in the previous paragraph, another baseline might be defined in case of replacements. However, it has to be noted that only “early replacements”, so replacement of appliances before the average expected end of their lifetime, can be considered here according to Annex V (2) (f) of the EED. Replacements which take place after an appliance has reached the end of its lifetime should be considered as new installations.

In case of **early replacement**, it is therefore possible to use the normalized final energy consumption before the action was implemented as a baseline for the savings calculation. This approach is only applicable for the timeframe in which the replaced appliance’s average end of lifetime has not been reached. Afterwards, the same baseline as for new installations has to be considered for the rest of the new appliance’s lifetime of savings (stair-step baseline). Figure 2 illustrates this approach, which is based on (European Commission, 2019).

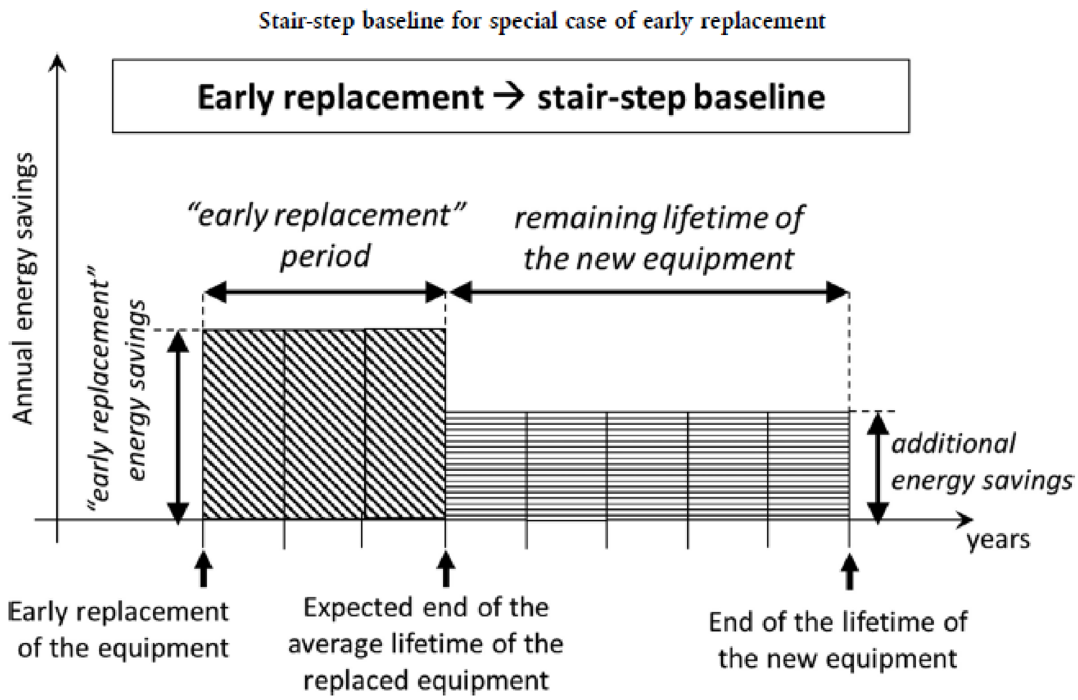

Figure 2: Adjustment of baseline in case of early replacement

If for example a boiler was installed in the year 2010 with an expected average lifetime of 20 years and is replaced by a new, more efficient boiler in the year 2021, the baseline for the savings calculation will be the old boiler's energy consumption for the period 2021 – 2030. In the years 2030 to 2041, the baseline needs to be reduced to the baseline defined for new installations, resulting in lower energy savings for this second period.

In order to be able to calculate the savings generated by early replacement of appliances correctly, additional information on the old appliance needs to be collected (year of installation, type of appliance, normalized energy consumption either by metered data or engineering estimates). Additionally, Member States need to demonstrate that this early replacement was incentivised by their policies set in place. As this data collection increases bureaucratic burden, some Member States opt to use the baseline for new installations in any case, even if results from early replacement calculation would in fact be higher.

When defining the baseline for **newly installed** appliances, different approaches are possible (European Commission, 2019):

- *Market average*: The market average takes into account the normalized energy consumption of all appliances available at the market. As all appliances available should meet at least the legal requirements, the market average will most likely meet those requirements or even result in lower energy consumption to define the baseline situation. Only the purchase of products and appliances which are even more efficient than what is regularly sold on the market can be considered additional. Apart from market research, relevant data might be taken from certification programs for different technologies, like the Eurovent Certification performed for ventilation and cooling equipment and heat pumps.
- *Legal requirements*: As already mentioned above, Annex V of the EED stipulates that savings must be additional to standards defined in Union law. Most relevant for this are the Energy Performance of Buildings Directive (EPBD) (Directive 2010/31/EU), the Ecodesign Directive (Directive 2009/125/EC) and the Union emission performance

standards for new passenger cars & new light commercial vehicles following the implementation of Regulations (EC) No 443/2009 and (EU) No 510/2011. When defining the baseline conditions, Member States should also consider national policies relevant for the Article 7 reporting, especially in order to prevent double counting. If, for example, national building codes define higher standards than stipulated in EPBD (i.e. higher standards than nearly-Zero Energy Buildings), the additional savings can be reported under Article 7. In case an additional subsidy program for higher energy efficiency in buildings is in place, the baseline for this program will be the national building code, in order to prevent double counting of the savings achieved under both policies (subsidy program and building code).

- *Going beyond most economic decision*: This approach for baseline definition should be considered separately for each action reported. In some cases, for example equipment for industrial processes, there might be no homogenous solutions suitable for this purpose and therefore comparison to similar actions is hard to achieve. In the latter case, parties implementing the action have to show that they did not opt for the most cost-efficient option, but also considered energy efficiency in their decision. From a reporting perspective, this can be done either by asking for materiality criterions from obligated parties in an EEOS or, for example, linking the conditions of a subsidy to this criterion (e.g., threshold on payback time).

In order to prove that the savings calculated can be considered additional to what would have been implemented in any case, it is advised to start the baseline definition with the most “strict” criterion, i.e. the market average. In case no data is available, first legal requirements and then going beyond the most economic decision should be considered.

When defining deemed savings methodologies, the baseline needs to be **updated on a regular basis.** Most importantly, future changes in EU legislation and/or national legislation have to be considered and incorporated. In case these changes are already published, this can be done by proposing different baselines depending on the year of implementation of an action. Additionally, the data used for baseline definition, like market averages, should be updated regularly in order to check how the baseline is affected by new appliances entering the market. Another aspect to be checked regularly is market saturation: over time, certain technologies formerly considered as the more efficient option might become the most commonly used technology; in this case, the additionality criterion is no longer viable.

The methodologies prepared within this report in Chapter 2 to Chapter 6 have been prepared until August 2021. Relevant future changes in the regulatory framework already published at this point have been considered in the definition of baseline and indicative calculation values, but further updates will not be provided.

1.1.3 Approaches for cumulating energy savings under Article 7

When calculating final energy savings for Article 7, EED Annex V (2) (i) stipulates that the lifetime of each individual savings actions as well as the rate at which these savings decline over the years have to be taken into account. When an action is implemented, it will – depending on the action itself – continue to deliver savings in the upcoming years. Therefore, in a first step, the lifetime of a savings action has to be determined. The Commission Recommendation (EU) 2019/1658 offers a list of indicative average lifetimes of energy efficiency improvement measures and programmes for bottom-up calculations (European Commission, 2019). Other possible sources for the identification of the lifetime of an action can be the EU standard EN15459-1:2017 (European Standards, 2017), legal depreciation periods or empirical studies (especially for measures fostering behavioural changes). Each implemented action generates yearly savings from its implementation date until the end of its lifetime. However, only savings generated until December 31st, 2030, are accountable for the current Article 7 period (2021-2030). There are three options on how Member States can cumulate savings:

- *Straightforward method:* The straightforward method counts the actual savings per year. These savings in a certain year will consist both of savings by actions implemented in the relevant year (“first year savings”) as well as savings from actions implemented in previous years which still generate savings. In this approach, saving actions with a lifetime exceeding the 2021 – 2030 period which are implemented at the beginning of the period will result in higher cumulative savings than actions implemented at the end of the period.
- *Index value method:* For the index value method, the first year’s savings are multiplied with a factor. With the help of a scale, the actual lifetime of a savings action is converted to this factor. Due to this method, savings actions will always generate the same amount of cumulative savings, regardless of their implementation date.
- *Cap method:* When using the cap method, a maximum lifetime is assigned to all savings actions. The first year’s savings are then multiplied by the maximum lifetime (unless the actual lifetime of the action is shorter) to calculate the cumulated savings. Due to this method, savings actions will always generate the same amount of cumulative savings, regardless of their implementation date.

When choosing one of the alternative approaches (index value method or cap method), Member States have to make sure that cumulative savings reported are not higher than savings calculated using the straightforward approach. It is therefore necessary to predict what energy savings actions will be implemented in terms of their lifetimes and implementation dates in order to correctly adjust the cap or scaling for index values.

Due to the different approaches available, the methodologies prepared for this report only calculate *first year savings*.

1.1.4 Correction for behavioural effects

Energy savings actions can trigger changes in behaviour of final energy consumers, this can lead to both increased and decreased savings. Behavioural effects are hard to evaluate and should be based on empirical data (e.g. survey, studies on how behaviour is affected). Although not explicitly mentioned in the EED, rebound effects should be estimated and taken into account by Member States within their savings methodologies in order to produce sufficiently accurate estimates of the generated energy savings (Labanca & Bertoldi, 2016).

Rebound effect (direct)

What are direct rebound effects? In general, the rebound effect (or take-back effect) can be defined as the reduction in expected gains from an intervention that increases the efficiency of resource use (energy), because of behavioral or other systemic responses. As a result, the theoretical impact an intervention could have is smaller than observed. It occurs when e.g. a decrease in the cost of using a product results in an increased use of the product. Direct rebound effects have been described extensively for the transport sector and for residential heating. For example: More efficient internal combustion engines make it possible to build more economical vehicles. Direct rebound effects occur when the engines become more powerful or when the vehicle is driven more frequently (VITO, Ricardo, Öko Institut, Wageningen University, 2020).

Next to direct rebound effects, also indirect rebound effects (occurring when decreased costs of using a product result in increased use of other products or expenditures) and macro-economic rebound effects (the initial savings from an intervention result in a stimulated demand of the whole economy) exist (VITO, Ricardo, Öko Institut, Wageningen University, 2020). As in streamSAVE we focus on Priority Actions, and not on the system perspective, only direct rebound effects are taken into account.

The rebound effect can have a temporal dimension as well, so a differentiation can be made between short-term and long-term rebound effects. Rebound effects can occur through a variety of mechanisms (Fish & Grießhammer, 2013):

- Income effects: when money is saved through efficiency measures, these savings can lead to increased use of the more efficient goods (direct rebound) or of other goods (indirect rebound);
- Substitution effect: the price of the resource is lower due to the efficiency measure, which leads to the resource being used more intensively and effectively substituting other resources;
- Psychological effects: the efficiency measures produce a “green conscience” and in turn the same or other goods are used more;
- Technological rebound: the price reduction of a resource allows new technologies that require this resource to emerge which were previously not economically viable;
- Consumer accumulation: new, more efficient technologies are used additionally instead of replacing less efficient technologies.

Several studies have quantified the rebound effect. These studies show that the size of the rebound effect is very context dependent, not only with respect to the sector and instrument type, but also to national circumstances (e.g. rebound effects are higher in lower income countries). Direct rebound effects are easier to define and measure, because they are related to the demand for a specific product or service. In contrast, indirect rebound effects are more difficult to determine, because data on all resource demand from an individual or a household needs to be collected.

Rebound effects can be very significant in certain sectors, reducing the total impact of a savings actions. Energy savings calculations that do not include rebound effects thus could overestimate the impact of a Priority Action on energy savings or avoided greenhouse gas emissions. Determining the size of rebound effects is often difficult, but existing studies show that direct rebound effects for energy use in households are (very) significant, i.e. between 10-30 % (VITO, Ricardo, Öko Institut, Wageningen University, 2020).

Sufficiency & spill over effects

Behavioural effects are not, however, necessarily negative. Consumer behaviour can also change in a way that further resource savings are achieved. Such sufficiency (when within the same area) or spill-over (in other areas) effects are the opposite of direct or indirect rebound effects (EE-Rebound project, 2020). For example, if the purchase of a more efficient washing machine leads to an increased awareness of energy-efficient washing and machines are thus loaded better or washed at lower temperatures, this would be an example of sufficiency. Spill-over effects occur, for example, when purchasing a more economic showerhead leads to a better understanding of water efficiency and the purchase of water-saving fittings for the washbasin (VITO, Ricardo, Öko Institut, Wageningen University, 2020).

Within the PA, only effects directly related to the savings action will be discussed: direct rebound effects, and – if available or applicable – sufficiency. Spill-over effects are linked to savings in other areas than the PA, so out of scope of the Priority Action.

Other factors than behavioural effects that can explain the differences observed between estimated and actual energy savings, include, amongst others, peformance gaps. The performance gaps might be related to, for instance, poor installation or maintenance, resulting in lower quality and performance of the implemented action. In the streamSAVE methodologies, sufficient quality requirements are assumed, next to proper Monitoring & Verification schemes to mitigate the risks of performance gaps. For more details about sources of differences between estimated and measured energy savings, see for example (Sipma et al., EPATEE, 2019).

1.2 Estimation of relevant costs connected to energy savings actions

Next to savings estimations, an estimation of costs of the Priority Actions can provide relevant input for policy makers and implementing parties. By comparing the costs of Priority Actions with the effects, kWh of energy saved or ton of CO_2 reduced, on indication can be made on the cost effectiveness of the different Priority Actions, i.e. which action fulfils the energy savings or CO_2 reduction targets at the lowest cost? During stakeholder consultation, a strong need to improve the understanding of cost effectiveness arose as these assessments are typically Member State-specific and dependent on a series of cost parameters. The cost parameters that are important for the assessment of Priority Actions are explained below, as well as in the respective section of the Priority Actions.

Cost estimations are also relevant for policy makers and implementing parties that want to assess and compare Priority Actions based on other financial criteria, such as net present value, (discounted) pay-back time and internal rate of return.

1.2.1 Typology of costs

In the cost calculations, streamSAVE focuses on the costs directly related to the purchase, installation and operationalization of the Priority Action. These direct costs encompass investment costs, variable and fixed operational costs. The implementation of a Priority Action may also generate negative direct costs or revenues, such as additional revenues from the sale of residual products and by-products (National Center for Environmental Economics, Office of Policy, U.S. Environmental Protection Agency , 2014) (Meynaerts, Ochelen, & Vercaemst, 2003).

Investment or capital costs include expenditures on installation or retrofit of structures or equipment. These expenditures are sometimes referred to as “one-time costs” and include expenditures for equipment installation and start-up. Also, the implementation of a Priority Action may result in an existing installation having to be replaced before the end of its economic life. In that case, costs of early replacement have to be taken into account.

The **operational costs** are the recurring expenditures to keep the Priority Action operational. A distinction can be made between variable operational costs (e.g. variable overheads, utilities, energy costs, waste disposal costs) and fixed operational costs (e.g. general overheads, insurance costs, labour costs, periodic fixed maintenance and repairing costs).

- For calculating the costs related to the consumption of electricity and fuels, the same energy unit prices can be used for all Priority Actions. Annual prices for electricity and gas for households and non-households in the EU Member States can be consulted at Eurostat: https://ec.europa.eu/eurostat/web/energy/data/database.

- In 2020, average hourly labour costs were estimated at EUR 28.5 in the European Union. However, this average masks sizeable gaps between EU Member States, with hourly labour costs ranging between EUR 6.5 and EUR 45.8. Hourly labour costs for the different EU Member States and NACE sectors can be consulted at Eurostat as well: https://ec.europa.eu/eurostat/databrowser/view/lc_lci_lev/default/table?lang=en

1.2.2 Discounting of costs and benefits

Discounting allows for comparing the costs and benefits of a Priority Action that occur during the lifetime of the action by expressing their values in present terms (National Center for Environmental Economics, Office of Policy, U.S. Environmental Protection Agency , 2014) (Meynaerts, Ochelen, & Vercaemst, 2003) (European Commission, 2017). There are several methods for discounting future values to the present: the most common are (net) present value (PV) and annualized costs and benefits. Discounting can be done from the perspective of a society as-a-whole (social discounting) or from the perspective of an individual or firm (private discounting). Also, real or nominal benefits, costs, and discount rates can be used (cf. section 1.2.3).

$$\boldsymbol{PV} = \sum_{t=0}^{n} \frac{\boldsymbol{cost\ or\ benefit}}{(\mathbf{1}+\boldsymbol{r})^{t}}$$

PV	Present Value
r	Discount rate
n	(economic) lifetime of the technical action

To have an indication of the profitability of the Priority Actions, the present value of costs and benefits can be estimated separately and then be compared to arrive at **net present value.** An example of the calculation of the (net) present value can be found in (European Commission, 2017). Other financial criteria that can be used to assess the profitability of Priority Actions are, for example, the internal rate of return (IRR) and the (discounted) payback period. The internal rate of return is the discount rate that turns the net present value to zero. The (discounted) pay-back period is the period of time it takes to cover the initial investment cost in year 0 with the (discounted) future cash flows.

When comparing PA with different time horizons, it is recommended to calculate the **annualised costs and benefits** (instead of NPV) and convert the time varying stream of values to a constant stream.

$$\boldsymbol{annualized\ cost\ or\ benefit} = \boldsymbol{PV} \cdot \frac{\boldsymbol{r} \cdot (\mathbf{1}+\boldsymbol{r})^{n}}{(\mathbf{1}+\boldsymbol{r})^{(n+1)} - \mathbf{1}}$$

PV	Present Value
r	Discount rate
n	(economic) lifetime of the technical action

Annualized costs of a Priority Action can also be compared with non-monetized, annual benefits that are constant over the considered time period, such as annual reduction in ton CO_2 emissions or annual reductions in kWh energy consumption. An example of the latter is the "avoidance cost indicator" by the De-risking Energy Efficiency Platform (DEEP)[2] .

1.2.3 Real and nominal values

Investment and (net) operating costs of the Priority Action can be expressed in nominal or real prices. Costs expressed in current prices are called nominal values. Costs expressed in prices of a certain base year, i.e. by taking into account inflation, are called real or constant values. Nominal prices can be converted to real prices of a certain base year by using e.g. the harmonized index of consumer prices (HICP) (https://ec.europa.eu/eurostat/web/hicp/data/database) (HICP 2015 =100):

$$\boldsymbol{real\,price_n} = \boldsymbol{nominal\,price_n} \times \frac{\boldsymbol{HICP_{base\,year}}}{\boldsymbol{HICP_n}}$$

1.2.4 Private and social perspective

The *private cost* is the cost from the point of view of the person who does the investment in the Priority Action. In calculating the private cost, taxes (e.g. VAT), subsidies or other allowances such as increased investment deduction for a company, must be taken into account. The *social cost* is the cost from the point of view of society as a whole. By definition, the social cost is the opportunity cost (or economic cost) to society as a result of implementing the Priority Action (European Commission, 2017) (Meynaerts, Ochelen, & Vercaemst, 2003) (European Commission, 2015). When calculating the social cost, some corrections have to be made, e.g.:

- Taxes and subsidies are not included in calculating social costs as these are transfer payments that do not represent real economic costs or benefits for society. In Ecodesign Impact Accounting, an EU average percentage of the Value Added Tax (VAT) of 20 % is considered (VHK, 2019).
- Social discount rates are used instead of private discount rates. The European Commission recommends 4 % as social discount rate (European Commission, 2017). This 4 % rate is in real terms and is applied to costs and benefits expressed in real or constant prices. When dealing with nominal prices, the social discount rate should be increased with the inflation rate. For example, if inflation amounts to 3 %, then the nominal, social discount rate is 7 %. The private discount rate will generally exceed the social discount rate by an amount that reflects the risk of the investment and the time value of money. A commonly used approach consists of estimating the actual cost of capital. A proxy for this estimation is represented by the real return on government bonds, the long-term real interest rate of commercial loans, or a weighted average of these two rates (Weighted Average Capital Cost – WACC) (European Commission, 2015) (European Commission, 2017).

[2] Avoidance cost in the DEEP EEFIG platform is the average cost for each energy saved over the lifetime of the measure (https://deep.eefig.eu/).

- For calculating social costs, shadow prices are used to reflect the social opportunity cost of goods and services as market prices may be distorted by e.g. taxes, duties, subsidies, rigid exchange rates, rations on production or consumption, regulated tariffs, oligopoly or monopoly price setting and imperfect information. Several approaches exist to calculate shadow prices (e.g. willingness-to-pay). An overview of the different approaches and some practical examples are provided in the Guide to Cost-Benefit Analysis of Investment Projects (European Commission, 2015).

1.3 Estimation of greenhouse gas savings

Although the EED does not directly monitor results in terms of reduction of greenhouse gas emissions, the EED is clearly meant to contribute to the achievement of the EU climate target as put forward by the EU Green Deal Initiative. Next to preparing calculation methodologies for final and primary energy savings and costs of Priority Actions, this report includes guidance on how the greenhouse gas (GHG) emission reduction potential of energy savings actions implemented under the EED can be assessed. The following chapter explains the rationale behind these calculations and offers indicative values for the relevant GHG emission factors.

According to Article 24 of the Greenhouse Gas Directive (2018/2066/EU), operators of installations subject to the emissions trading system (ETS) can determine the GHG emissions generated in installations by a standardized calculation methodology. For the calculation, the activity data (e.g. fuel combusted) has to be multiplied by the GHG emission factor of the respective energy carrier. The emission factor is a conversion factor between energy consumption based on net calorific values of a specific energy carrier and emissions. This means that the effects of energy efficiency measures on the greenhouse gas balance can also be determined using emission factors.

Similar to the determination of energy savings, the difference between the GHG emissions before and after the action’s implementation are used to calculate the emission savings. The calculation formula is as follows:

$$\boldsymbol{GHGSAV = GHG_{Baseline} - GHG_{Action}}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
GHG	Greenhouse gas emissions [t CO_2 p.a.]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action

To determine the greenhouse gas emissions before and after implementation of an action, the energy consumption must be multiplied by the emission factor of the respective energy carrier. Usually, one specific energy carrier is replaced in a single energy saving action. However, there are also energy saving actions in which several energy carries are replaced at the same time. As soon as several energy carriers are involved, a weighted emission factor should be applied. Such a weighted emission factor can also be used when creating standardized values or when evaluating several energy saving actions at the same time. The following formula can be used for evaluations in which either only one or several energy carriers are affected:

$$GHG_{Baseline/Action} = FEC_{Baseline/Action} \cdot \sum_{ec} (share_{ec} \cdot f_{GHG,ec})$$

GHG	Greenhouse gas emissions [t CO_2 p.a.]
FEC	Annual final energy consumption [kWh/a]
share	Share of final energy carrier on final energy consumption [dmnl]
f_{GHG}	Emission factor of final energy carrier [t CO_2 / kWh]
ec	Index of energy carrier
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action

Either direct emissions (from the combustion of an energy carrier) or indirect emissions (taking into account the upstream chains) can be used to determine the emission factors (Sotos, et al., 2015, p. 33). When selecting the GHG emission factors, the national circumstances must be taken into account. When determining the effects of an energy saving action on a country's greenhouse gas balance/inventory, only those upstream chains that are domestically affected by the action can be taken into account in the indirect emission factors. Relevant for most Member States are the indirect emissions from electricity and district heat, as these secondary energy carriers, by definition, do not cause direct emissions.

The direct emissions factors (in g CO_2 per kWh, CO_2 equivalents of other greenhouse gases not included), as well as the indirect emission factors for electricity and district heat, are listed in the table below. Emission factors are taken from Annex VI of the Greenhouse Gas Directive (2018/2066/EU) (European Commission, 2018). In this report, focus is on the calculation of *direct emissions, including emissions from electricity and heat*.

Table 2: Emission factor by energy carrier

Energy carrier	emission factor [g CO_2/kWh]
Electricity	133.30
District heat	209.90
Natural gas	201.96
Gas/Diesel oil	266.76
Motor gasoline	249.48
Biodiesels	0.00
Biogasoline	0.00
Other liquid biofuels	0.00
Biogas	0.00
Wood/wood waste	0.00
Other primary solid biomass	0.00
Kerosene (other than jet kerosene)	258.84
Liquefied petroleum gases	227.16
Naphtha	263.88

Natural gas liquids	231.12
Petroleum coke	351.00
Refinery gas	207.36
Residual fuel oil	278.64
White spirit and SBP	263.88
Other petroleum products	263.88
Anthracite	353.88
Lignite	363.60
Charcoal	0.00
Coal tar	290.52
Coke oven coke and lignite coke	385.20
Coking coal	340.56
Patent fuel	351.00
Sub-bituminous coal	345.96
Other bituminous coal	340.56
Industrial wastes	514.80
Blast furnace gas	936.00
Coke oven gas	159.84
Oxygen steel furnace gas	655.20
Oil shale and tar sands	385.20
Peat	381.60

To determine emission factors for electricity and district heat as given in the table above, the energy inputs (so input of other energy carriers) for district heat generation and electricity generation are multiplied with the respective emission factors and divided through the total energy input for each energy carrier (Eurostat, 2021) (European Commission, 2018):

$$\boldsymbol{f_{GHG,el}} = \frac{\sum_{ec}\left(\left(\boldsymbol{TI_{PP,ec}} + \boldsymbol{TI_{CHP,ec}} \cdot \frac{\boldsymbol{TO_{CHP,el}}}{\boldsymbol{TO_{CHP,el+dh}}}\right) \cdot \boldsymbol{f_{GHG,ec}}\right)}{\sum_{ec}\left(\boldsymbol{TI_{PP,ec}} + \boldsymbol{TI_{CHP,ec}} \cdot \frac{\boldsymbol{TO_{CHP,el}}}{\boldsymbol{TO_{CHP,el+dh}}}\right)}$$

$$f_{GHG,dh} = \frac{\sum_{ec}\left(TI_{HP,ec} \cdot f_{GHG,ec} + TI_{CHP,ec} \cdot \frac{TO_{CHP,dh}}{TO_{CHP,el+dh}} \cdot f_{GHG,ec}\right)}{\sum_{ec}\left(TI_{HP,ec} + TI_{CHP,ec} \cdot \frac{TO_{CHP,dh}}{TO_{CHP,el+dh}}\right)}$$

f_{GHG}	Emission factor of energy carrier [t CO_2 / kWh]
TI	Transformation input of the electricity or heat generation plant [TJ]
TO	Transformation output of the electricity or heat generation plant [TJ]
ec	Index of energy carrier used for electricity/district heat generation
PP	Index of power plants

CHP	Index of cogeneration plants (combined heat and power)
HP	Index of heat plants
el	Index of electricity
dh	Index of district heat

For combined heat and power plants, the output share of district heat and electricity is taken to determine the relevant input quantity for district heat and electricity production. Renewable plants (e.g. hydro power) as well as nuclear power are assigned an emission factor of zero.

As there can be significant differences among countries, the national circumstances must be taken into account, when selecting GHG emission factors, especially for indirect emissions, such as electriticy and distrit heat.

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Chapter 2 Savings calculation for heat recovery and district heating

Savings calculation methodologies covered by this Priority Action focus on heat recovery from industrial processes, on-site and in district heating grids respectively. There is a wide spectrum of heat consuming applications in industry that are suitable for heat recovery actions. Therefore, it is not feasible to define one representative application.

Hence, methodologies for three groups of use cases are elaborated within this chapter:

- Heat recovery for on-site use in industry - feedback of excess heat into a process
- Heat recovery for on-site use in industry - use of excess heat for on-site applications
- Heat recovery for infeed into a district heating grid

In addition to saving energy, heat recovery systems lead to the reduction of waste heat into the ambient air or into rivers, which puts less strain on nearby ecosystems. The lower fuel input can also reduce air pollutant emissions.

2.1 Heat recovery for on-site use in industry - feedback of excess heat into a process

This methodology refers to the use of excess heat from an industrial process directly on-site. As energy saving action, a heat consuming industrial process (e.g. oven) is retrofitted with a heat recovery system (e.g. economizer). The recovered heat is fed back into the process and therefore causes a reduction of the energy input needed for the process.

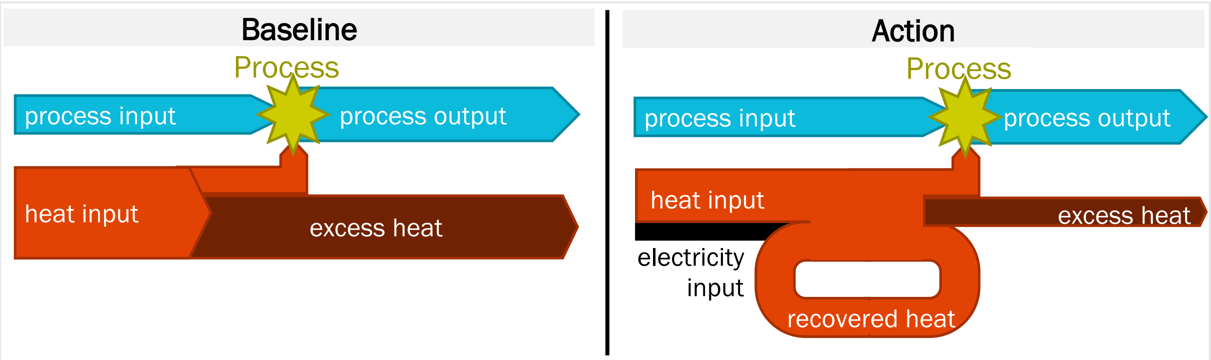

Figure 3: Schematic illustration of feedback of excess heat into the process

The methodology is limited to facilities that **manufacture goods (industry sector)**. Within this sector, it is applicable regardless of the energy carrier and the heat recovery technology. Recovered heat from buildings (heating, ventilation and air conditioning) cannot be evaluated with this methodology. Further excluded from this methodology (for the calculation of Article 7 savings) are facilities that generate electricity and district heating, as their energy input does not count as final energy according to the Regulation (EC) 1099/2008 on energy statistics.

Industrial processes with a potential for excess heat recovery are heterogeneous regarding their functions, dimensions, capacities etc. and are usually custom-made. Hence, it is impracticable to evaluate industrial heat recovery measures with standardised values. Instead of providing indicative calculation values, this methodology focuses therefore on guidelines for the acquisition of appropriate data.

2.1.1 Calculation of final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$TFES = \left(\frac{FEC_{Baseline}}{po_{Baseline}} - \frac{FEC_{Action}}{po_{Action}}\right) \cdot \mathrm{po}_{Action}$$

TFES	Total final energy savings [kWh/a]
FEC	Final energy consumption [kWh/a]
po	Production output [units/a]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action

Indicative calculation values for this methodology are only prepared for the lifetime of savings due to the wide range of industrial applications.

Table 3: Indicative calculation value for feedback of excess heat into a process

Lifetime of savings	[a]
Heat recovery in industry	10

Methodological aspects:

Basically, the calculation formula compares the specific final energy consumptions of the process before and after implementation of the action. The final energy consumption (before/after the action) is related to the production outputs (before/after the action). Thus, the calculation method implicitly normalizes varying production rates.

Presuming that the action would not have been implemented without an incentive, it is obvious that the final energy consumption of the existing process (without heat recovery) equals the baseline for the evaluation of the action.

The implementation of a heat recovery system is sometimes accompanied by **rebound effects.** For instance, a rebound effect occurs when a high energy consumption of the pumping of the heat conducting medium compensates the energy savings from the action. Therefore, this methodology considers all energy carriers consumed in the process (main energy carriers, auxiliary power etc.).

Data sources for indicative calculation values:

Due to the large variety of industrial processes and the wide scope of this methodology, indicative calculation values are considered impracticable. Instead, this methodology provides a guidance for the evaluation of savings based on measured values.

The methodology is intended to be applied by implementing parties themselves. As there are no indicative calculation values for final energy consumption and production outputs, data must be generated individually. Measurements have to be carried out in the same setting before and after the implementation of the action.

The **final energy consumption before/after the implementation of the action** ($FEC_{Baseline}$, FEC_{Action}) includes all energy sources of the relevant process. Consequently, it takes into account all used fuels (e.g. for a furnace) and energy consumption for the technical equipment (e.g. pumps, compressors, control units), respectively. All relevant energy consumption has to be measured over representative periods before and after the action and, if applicable, converted into kWh. Representative periods may vary depending on the production process. If, for example, production fluctuates over the course of a year, at least a full year of measurements should be considered. On the opposite, for processes with steady production rates, shorter periods may be sufficient. Therefore, the measuring periods have to be well-considered.

If more than one production process is fed by the heat consumer, the energy consumption must be allocated proportionally.

If a relevant part of the energy consumption of the process depends on the weather, the weather-related consumption must be normalized. Normalization with heating or cooling degree days is recommended:

$$FEC_{norm} = \mathrm{FEC}_{measured} \cdot \frac{DD_{norm}}{DD_{mp}}$$

FEC_{norm}	Normalized final energy consumption [kWh/a]
$FEC_{measured}$	Measured final energy consumption [kWh]
DD_{norm}	Average annual heating or cooling degree days [Kd/a]
DD_{mp}	Average heating or cooling degree days during the measuring period [Kd]

The average heating or cooling degree days have to be calculated from weather related measurement records. To determine degree days, each recording period (e.g. hours, days) has to be multiplied with the temperature difference between the required process temperature and the average outdoor temperature. To obtain the normalised (DD_{norm}) degree days, it is advisable to average over several years.

The **production output before/after the implementation of the action** ($po_{Baseline}$, po_{Action}) refers to the amount of goods which is produced or manipulated in the relevant process. Semi-finished goods, intermediates or material inputs (e.g. steam) can also be considered as production output in terms of this methodology. The production output before and after implementing the action has to be measured (or documented) using the same unit (volume, tons, pieces, etc.).

Final energy consumption and production output must be measured within the same (representative) period. Measured data has to be extrapolated to a calendar year.

For monitoring reasons, it is suggested to use measuring protocols including the installation layout, measurement setup and period.

The **lifetime of savings** corresponds to the Indicative energy savings lifetimes of waste-heat recovery in industry according to Appendix VIII of the Commission Recommendation (EU) 2019/1658 of 25 September 2019 on transposing the energy savings obligations under the Energy Efficiency Directive (European Commission, 2019).

2.1.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 2.1.1 on calculation of final energy savings (Article 7).

Due to the nature of the methodology presented, it cannot be used for Article 3 ex-ante assessments. In order to prepare estimations on the amount of savings which can be achieved in the area of heat recovery, national waste heat potentials monitored under Article 14 and Annex VIII EED or monitored savings of heat recovery projects from earlier years (e.g. from previous periods of EED reporting or databases of subsidy schemes) could be used.

The effect on primary energy consumption can be calculated with the following equation:

$$EPEC = \left(\frac{FEC_{Baseline}}{po_{Baseline}} \cdot \sum_{ec}(share_{ec,Baseline} \cdot f_{PE,ec}) - \frac{FEC_{Action}}{po_{Action}} \cdot \sum_{ec}(share_{ec,Action} \cdot f_{PE,ec})\right) \cdot po_{Action}$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
po	Production output [units/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the energy carrier used [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of the action
ec	Index of energy carrier

Because the energy consumption of the respective process must be measured anyway, the energy carrier distribution is implicitly determined as well. For this reason, no indicative calculation values for the shares of energy carriers are provided here. Furthermore, the diversity of industrial processes does not allow for a generalized narrowing down to specific energy carriers for the determination of emission factors.

EU27 average values for the conversion factors from final to primary energy for different energy carriers are listed in chapter 1.1.1 of this report.

2.1.3 Overview of costs related to the action

Overview of relevant cost components

Costs associated with the implementation of an industrial waste heat recovery system include investment and operational expenditures.

Investment expenditures cover all costs for materials, components, engineering and installation work. Main components that need to be purchased and installed at least include:

- heat exchanger(s)
- pipelines
- circulating pumps
- measuring and control technology
- insulation

Depending on the type and dimension of the process as well as the heat transfer medium (steam or hot water), the list of components may be extended widely.

Next to direct costs of components and materials, investment costs include labour costs initiated by project design, installation work, commissioning of the facility and training of employees. Costs caused by the interruption of the process (production downtimes) due to heat recovery installation work must also be taken into account. Businesses may combine the retrofitting of the facility with scheduled revisions to limit costs.

Operational expenditures include fixed costs for periodic maintenance and repair to the heat recovery system, in terms of labour and materials. Maintenance costs depend on the installed technology which may result in increased labour and material costs or even occasional downtimes of the facility. Variable operational expenditures – linked to the operating hours - include mostly electricity costs for the circulation of the heat transfer medium (electricity consumed by pumps and control units) and minor utilities. Some systems also need cooling water for the operation of a condenser.

In addition to the reduced fuel costs for the industrial process, excess- or under-consumption of specific energy carriers may influence operating costs. Depending on the energy carrier (e.g. natural gas, electricity), heat recovery can lead to reduced performance peaks and therefore reduce performance related tariff components. On the other hand, the installation of a heat exchanger normally causes an additional pressure loss, which in the end results in increased power consumption.

Table 4: Indicative costs (excl. VAT) for feedback of excess heat into a process

[euro2008-2021]	Investment costs
Total investment costs	0.10 – 0.56 € / kWh recovered heat
Design and Engineering work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in engineering)
Installation work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Training of personnel (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Production downtimes	Not available
[euro2021/a]	Variable operational costs
Costs of reduced fuel input	Energy prices from chapter 1.2.1 (depending on fuel used in the industrial process, before implementation)
Electricity costs	Energy prices from chapter 1.2.1 (electricity for non-household consumers)
Cooling water costs	No data available
[euro2021/a]	Fixed operational costs
Maintenance (labour costs)	2 % of equipment installed costs
Production downtimes	No data available
[euro2021/a]	Revenues
	No revenue
[a]	Lifetime
Lifetime	10

Methodological aspects

Information on costs of heat recovery in industry is scarce, as such applications are highly individual and usually sold as an overall service consisting of technical planning, legal submissions, purchase of equipment and installation and calibration of the heat recovery system. Such service contracts are private law agreements and not publicly available.

The data retrieved for **investment costs** was published by "klimaaktiv", an Austrian benchmarking programme for (inter alia) industry sectors funded by the Austrian Ministry for Climate Action (BMK). The database contains approximately 100 heat recovery projects which were implemented between 2008 and 2021. The lower and upper quantiles of the listed projects were used to calculate the above range and to exclude outliers. Investment costs were examined per sector; however, no significant differences could be identified. As no data on the installed power of the listed heat recovery systems is available, investment costs are related to the quantity of recovered heat.

In order to estimate **labour costs**, chapter 1.2.1 offers data for the EU Member States. No information on the number of working hours was found.

Due to the implementation of heat recovery, **variable operational costs** of the existing application will change as follows:

- Costs of fuel input: Due to the heat recovery feeding back into the same process, the fuel consumption of this process is reduced by the amount of heat recovered. In order to calculate fuel cost savings, fuel prices, for fuels used before implementation, and conversion efficiency of the process have to be considered.
- Electricity costs: Additional heat exchanges in the system cause increased pressure loss in the system. Additional pumping energy is needed to compensate for this.
- Cooling water costs: The amount of cooling water needed is reduced by the implementation of heat recovery. Depending on national legislation regarding the use of surface- or groundwater in Member States, this may also lead to reduced costs.

Fixed operational costs mostly consist of the labour cost needed for maintenance of the application. A study conducted by „Institut für Energie- und Umweltforschung Heidelberg" sets the average maintenance cost at 2% of the investment costs. Additionally, potential production downtimes of the process during maintenance should be considered.

As the heat recovered from a process is fed back into the same process, no **revenue** is generated. However, amortisation of such projects is achieved by reduced fuel consumption (cf. section on variable operational costs).

Data sources for indicative cost values:

The total investment costs are related to the amount of recovered heat quantities and were derived from a publicly available best-case database (BMK, 2021) of the "klimaaktiv" programme of the Austrian Ministry for Climate Action (BMK).

Information on maintenance cost is taken from a study conducted in 2019 by "Institut für Energie- und Umweltforschung Heidelberg" for the German Ministry of Economy and Energy (Blömer et al., 2019).

2.1.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = \left(\frac{FEC_{Baseline}}{po_{Baseline}} \cdot \sum_{ec}(share_{ec,Baseline} \cdot f_{GHG,ec}) - \frac{FEC_{Action}}{po_{Action}} \cdot \sum_{ec}(share_{ec,Action} \cdot f_{GHG,ec})\right) \cdot po_{Action} \cdot 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
FEC	Annual final energy consumption [kWh/a]
po	Production output [units/a]
share	Share of final energy carrier on final energy consumption [dmnl]
f_{GHG}	Emission factor of final energy carrier [g CO_2/kWh]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of the action
ec	Index of energy carrier

The final energy consumption (FEC) as well as the process output (po) of the baseline and the action can be taken from the savings calculation for Article 7.

Because the energy consumption of the respective process must be measured anyway, the energy carrier distribution is implicitly determined as well. For this reason, no indicative calculation values for the shares of energy carriers are provided here. Furthermore, the diversity of industrial processes does not allow for a generalized narrowing down to specific energy carriers for the determination of emission factors. The full table containing all emission factors is available in chapter 1.3.

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2.2 Heat recovery for on-site use in industry - use of excess heat for on-site applications

This methodology refers to the use of excess heat from an industrial process on-site. As energy saving action, a heat consuming industrial process (e.g. oven) is retrofitted with a heat recovery system (e.g. heat exchanger). The recovered heat serves as a heat source for **another** application on the site (e.g. space heating system, preheating another process). Therefore, it causes a reduction of the input of the main energy carrier in the other application.

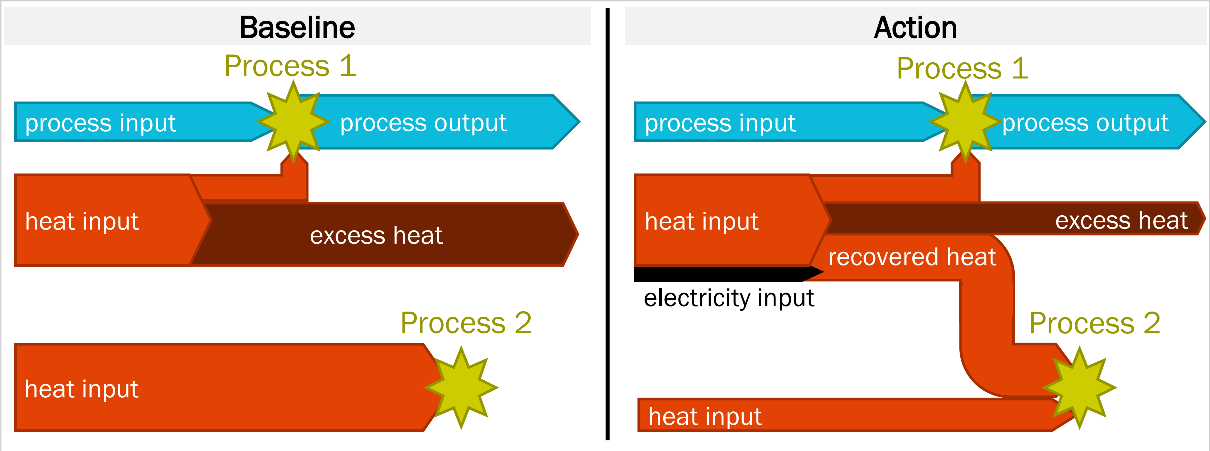

Figure 4: Schematic illustration of on-site use of excess heat for other applications

The methodology is limited to facilities that **manufacture goods (industry sector).** Within this sector, it is applicable regardless of the energy carrier and the heat recovery technology. Recovered heat from buildings (heating, ventilation and air conditioning) cannot be evaluated with this methodology. Further excluded from this methodology (for the calculation of Article 7 savings) are facilities that generate electricity and district heating, as their energy input does not count as final energy according to the Regulation (EC) 1099/2008 on energy statistics.

Industrial processes with a potential for excess heat recovery are heterogeneous regarding their functions, dimensions, capacities etc. and are usually custom-made. Hence, it is impracticable to evaluate industrial heat recovery measures with standardised values. Instead of providing indicative calculation values, this methodology focuses on guidelines for the acquisition of appropriate data.

2.2.1 Calculation of final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$TFES = Q_{rec} \cdot \frac{1}{eff_{mhs}} \cdot f_{BEH}$$

TFES	Total final energy savings [kWh/a]
Q_{rec}	Recovered heat consumption of the application [kWh/a]
eff_{mhs}	Conversion efficiency of the main heating system of the relevant application [dmnl]
f_{BEH}	Factor for correction of behavioural effects [dmnl]

Indicative calculation values for this methodology are only prepared for the lifetime of savings due to the wide range of industrial applications.

Table 5: Indicative calculation value for use of excess heat for on-site applications

Lifetime of savings	[a]
Heat recovery in industry	10

Methodological aspects:

The calculation formula considers the amount of recovered heat which is used in another application and thus (partly) substitutes the energy source for the main heating system of the application. To take heat generation losses into account, the efficiency of the main heating system of the other application is brought into the equation.

Presuming that the action would not have been implemented without an incentive, it is obvious that the energy consumption of the existing application (without use of recovered heat) equals the baseline for the evaluation of the action.

Behavioural, rebound effects may arise because the recovered waste heat is inexpensive compared to any other energy carrier. For example, the use of waste heat for space heating can trigger increased comfort requirements (higher room temperature, increased heated floor area).

Data sources for indicative calculation values:

Due to the large variety of industrial processes and the wide scope of this methodology, indicative calculation values are considered impracticable. Instead, this methodology provides a guidance for the evaluation of savings based on measured values.

The methodology is intended to be applied by implementing parties themselves. As there are no indicative calculation values for the recovered heat from processes and efficiencies of heat consuming applications, data must be generated individually.

The **Recovered heat consumption of the application** (Q_{rec}) should be measured by a heat meter and, if applicable, converted into kWh. For monitoring reasons, it is suggested to use measuring protocols including the installation layout, measurement setup and period.

If the provided application is another production process on the site, the heat consumption of this process probably needs to be normalized. It is recommended to do a normalization based on production output rates:

$$Q_{rec,norm} = Q_{rec,measured} \cdot \frac{po_{lt}}{po_{mp}}$$

$Q_{rec,norm}$	Normalized recovered heat consumption [kWh/a]
$Q_{rec,measured}$	Measured recovered heat consumption [kWh]
po_{lt}	average annual production output over the lifetime of the action [units/a]
po_{mp}	production output during the measuring period [units]

For the **Conversion efficiency of the main heating system of the application** (eff_{mhs}), application-specific information is to be used preferably. In some cases, the conversion efficiency is provided by the manufacturer of the application (e.g. on the eco-label). If specific values are unavailable, average efficiencies (e.g. from National Standards, literature) may be taken into account.

If more than one application is fed by the recovered heat, energy consumption and efficiency must be considered separately for each application.

The **lifetime of savings** corresponds to the Indicative energy savings lifetimes of waste-heat recovery in industry according to Appendix VIII of the Commission Recommendation (EU) 2019/1658 of 25 September 2019 on transposing the energy savings obligations under the Energy Efficiency Directive (European Commission, 2019).

2.2.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 2.2.1 on calculation of final energy savings (Article 7).

Due to the nature of the methodology presented, it cannot be used for Article 3 ex-ante assessments. In order to prepare estimations on the amount of savings which can be achieved in the area of heat recovery, national waste heat potentials monitored under Article 14 and Annex VIII EED or monitored savings of heat recovery projects from earlier years (e.g. from previous periods of EED reporting or databases of subsidy schemes) could be used. In case this database is not available, rough estimations can only be made (high uncertainty).

The effect on primary energy consumption can be calculated with the following equation:

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} \left(share_{ec,Baseline} \cdot f_{PE,ec} \right) - FEC_{Action} \cdot \sum_{ec} \left(share_{ec,Action} \cdot f_{PE,ec} \right)$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the energy carrier used [dmnl]

Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of the action
ec	Index of energy carrier

Because the energy consumption of the respective processes and appliances must be measured anyway, the energy carrier distribution is implicitly determined as well. For this reason, no indicative calculation values for the shares of energy carriers are provided here. Furthermore, the diversity of industrial processes does not allow for a narrowing down to specific energy carriers for the determination of emission factors.

EU27 average values for the conversion factors from final to primary energy for different energy carriers are listed in chapter 1.1.1 of this report.

2.2.3 Overview of costs related to the action

Overview of relevant cost components

Costs associated with the implementation of an industrial waste heat recovery system include investment and operational expenditures.

Investment expenditures cover all costs for materials, components, engineering and installation work. Components that need to be purchased and installed at least include:

- heat exchanger(s)
- pipelines
- circulating pumps
- measuring and control technology

Depending on the type and dimension of the process as well as the heat transfer medium (steam or hot water), the list of components may be extended widely.

Next to costs of components and materials, investment costs include labour costs initiated by project design, installation work, commissioning of the facility and training of employees. Costs caused by the interruption of the process (production downtimes) due to heat recovery installation work must also be taken into account. Businesses may combine the retrofitting of the facility with scheduled revisions to limit costs.

Operational expenditures include fixed costs for periodic maintenance and repair works of the heat recovery system, in terms of labour and materials. Maintenance costs depend on the installed technology which may result in increased labour and material costs or even occasional downtimes of the facility. Variable operational expenditures include mostly electricity costs for the circulation of the heat transfer medium (electricity consumed by pumps and control units) and minor utilities.

In addition to the reduced fuel costs for the industrial process, excess- or under-consumption of specific energy carriers may influence operating costs. Depending on the energy carrier (e.g. natural gas, electricity), heat recovery can lead to reduced performance peaks and therefore reduce performance related tariff components. On the other hand, the installation of a heat exchanger normally causes an additional pressure loss, which in the end results in increased power consumption.

Table 6: Indicative costs (excl. VAT) for use of excess heat for on-site applications

[euro2008-2021]	Investment costs
Total investment costs	0.10 – 0.56 € / kWh recovered heat
Design and Engineering work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in engineering)
Installation work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Training of personnel (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Production downtimes	Not available
[euro2021/a]	Variable operational costs
Costs of reduced fuel input	Energy prices from chapter 1.2.1 (depending on fuel used in the on-site application)
Electricity costs	Energy prices from chapter 1.2.1 (electricity for non-household consumers)
Cooling water costs	No data available
[euro2021/a]	Fixed operational costs
Maintenance (labour costs)	2 % of equipment installed costs
Production downtimes	No data available
[euro2021/a]	Revenues
	No revenue
[a]	Lifetime
Lifetime	10

Methodological aspects

Information on costs of heat recovery in industry is scarce, as such applications are highly individual and usually sold as an overall service consisting of technical planning, legal submissions, purchase of equipment and installation and calibration of the heat recovery system. Such service contracts are private law agreements and not publicly available.

The data retrieved for **investment costs** was published by "klimaaktiv", an Austrian benchmarking programme for (inter alia) industry sectors funded by the Austrian Ministry for Climate Action (BMK). The database contains approximately 100 heat recovery projects which were implemented between 2008 and 2021. The lower and upper quantiles of the listed projects were used to calculate the above range and to exclude outliers. Investment costs were examined per sector; however, no significant differences could be identified. As no data on the installed power of the listed heat recovery systems is available, investment costs are related to the quantity of recovered heat.

In order to estimate **labour costs**, chapter 1.2.1 offers data for the EU Member States. No information on the number of working hours was found.

Due to the implementation of heat recovery, **variable operational costs** of the existing application will change as follows:

- Costs of fuel input: Due to the heat recovery being used in another on-site application, the fuel consumption of this application is reduced by the amount of heat recovered. In order to calculate fuel cost savings, fuel price and conversion efficiency of the application have to be considered.
- Electricity costs: Additional heat exchanges in the system cause increased pressure loss in the system. Additional pumping energy is needed to compensate for this.
- Cooling water costs: The amount of cooling water needed is reduced by the implementation of heat recovery. Depending on national legislation regarding the use of surface- or groundwater in Member States, this may also lead to reduced costs.

Fixed operational costs mostly consist of the labour cost needed for maintenance of the application. A study conducted by „Institut für Energie- und Umweltforschung Heidelberg" sets the average maintenance cost at 2% of the investment costs. Additionally, potential production downtimes of the process during maintenance should be considered.

As the heat recovered from a process is used in another on-site application (and therefore not sold to a third party), no **revenue** is generated. However, amortisation of such projects is achieved by reduced fuel consumption (cf. section on variable operational costs).

Data sources for indicative cost values

The total investment costs are related to the amount of recovered heat quantities and were derived from a publicly available best-case database (BMK, 2021) of the "klimaaktiv" programme of the Austrian Ministry for Climate Action (BMK).

Information on maintenance cost is taken from a study conducted in 2019 by "Institut für Energie- und Umweltforschung Heidelberg" for the German Ministry of Economy and Energy (Blömer et al., 2019).

2.2.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = TFES \cdot \sum_{ec} \left(share_{ec,Baseline} \cdot f_{GHG,ec} \right) \cdot 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
TFES	Total final energy saving [kWh/a]
$share_{ec,Baseline}$	Share of final energy carrier on final energy consumption before the implementation of the action [dmnl]
f_{GHG}	Emission factor of the final energy carrier [g CO_2/kWh]

The total final energy savings (TFES) of the action can be taken from the savings calculation for Article 7.

Because the energy consumption of the respective process must be measured anyway, the energy carrier distribution is implicitly determined as well. For this reason, no indicative calculation values for the shares of energy carriers are provided here. Furthermore, the diversity of industrial processes does not allow for a narrowing down to specific energy carriers for the determination of emission factors. The full table containing all emission factors is available in chapter 1.3.

2.3 Heat recovery for feed-in to a district heating grid

A heat consuming industrial process (e.g. furnace) is retrofitted with a heat recovery system (e.g. heat exchanger). The recovered heat is fed into a district heating network, allowing more additional final customers to be supplied with district heating.

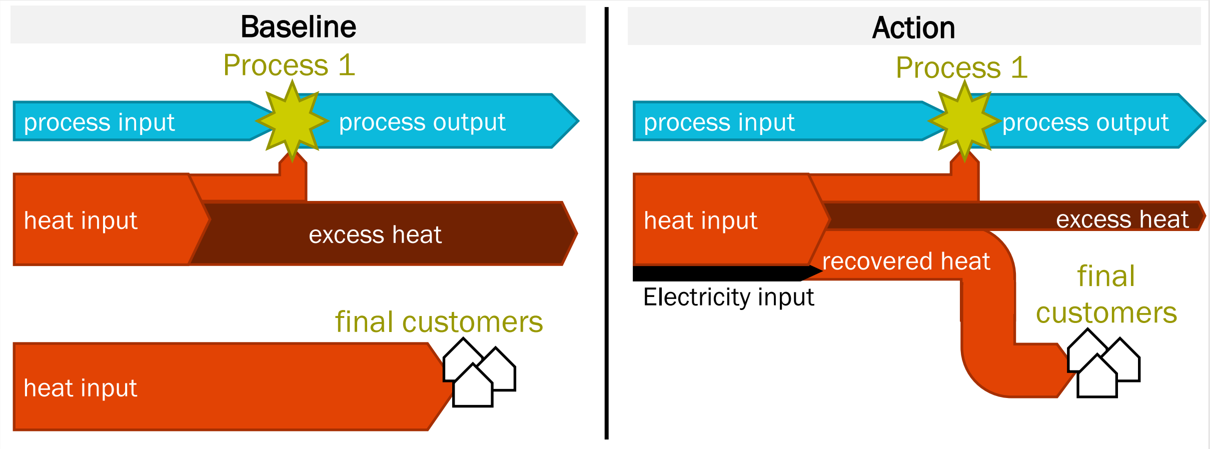

Figure 5: Schematic illustration of feed-in of excess heat to a district heating grid

According to the Energy Statistics Directive (European Commission, 2019), the production of district heat is regarded as part of the energy transformation sector and does not generate any final energy savings. Final energy savings can only be achieved at end-user level in case of lower conversion losses in their specific heating system as a result of switching to district heating. If additional district heating connections are triggered by feeding recovered heat into the district heating network, this can therefore lead to final energy savings.

When assessing additional district heating connections, it should be noted that there is a risk of double counting of energy savings due to several possible incentive providers (district heating network operator, district heating supplier, excess heat supplier, etc.). In order to prevent double counting of energy saving actions between several incentive providers, a legal framework for the allocation or sharing of energy savings is needed.

This evaluation method is limited to **recovered excess heat**. Additional combustion plants producing district heating cannot be assessed with this method.

2.3.1 Calculation of final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$TFES = Q_{EH} \cdot (1 - HL_{DHG}) \cdot \left(\frac{1}{eff_{Baseline}} - \frac{1}{eff_{Action}}\right) \cdot (1 - f_{ei}) \cdot (1 - f_{BEH})$$

TFES	Total final energy savings [kWh/a]
Q_{EH}	Excess heat fed into the district heating grid [kWh/a]
HL_{DHG}	Heat losses in the district heating grid [dmnl]
$eff_{Baseline}$	Conversion efficiency of the reference heating systems [dmnl]

eff_{Action}	Conversion efficiency of the district heat consuming heating systems [dmnl]
f_{ei}	Factor to calculate extrinsic incentives [dmnl]
f_{BEH}	Factor to calculate rebound effects [dmnl]

Indicative calculation values for this methodology have been prepared in the following table. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances.

Table 7: Indicative calculation values for Article 7 of heat recovery for feed-in to a district heating grid

HL_{DHG}	[dmnl]
Heat losses in the district heating grid	0.106
$eff_{Baseline}$	[dmnl]
Efficiency of the reference heating system	0.734
eff_{Action}	[dmnl]
Efficiency of district heating	0.827
f_{ei}	[dmnl]
no other incentive in force	0
Lifetime of savings	[a]
Heat recovery in industry	10
f_{BEH}	[dmnl]
Rebound effects	0.20

Methodological aspects

When evaluating the final energy savings of heat recovery for feed-in to a district heating grid, it is important to note that the final energy savings do not occur directly when the heat is fed into the district heating network, but at the final consumer side (households, services, agriculture and industry) of the district heating network. The formula for evaluating final energy savings consists of three components:

1. The amount of heat that arrives at the final customer side from the recovered and fed-in heat quantity. For this purpose, the losses in the heat distribution network are deducted from the amount of heat fed-in.
2. The actual saving is calculated by the difference of the conversion efficiencies of the district heating connection to the reference heating systems. For example, gas or oil boilers consume more fuel than the heat transfer station to provide the same amount of useful heat (space heating, hot water). However, heat pumps as reference heating systems would have a lower final energy consumption than district heating connections. Depending on the heating system distribution, in terms of technologies and manufacture dates, in the respective district heating supply area, both positive and negative final energy savings can result.

3. The factor of extrinsic incentives is used to subtract those installations that were implemented through other incentives (e.g. district heat pipeline expansion, subsidy programs on district heat connections) or would have been installed in any event.

Data sources for indicative calculation values:

The **excess heat fed into the district heating grid** (Q_{EH}) has to be determined by the implementer of the heat recovery. As energy savings actions are connected to a certain lifetime in which they will deliver savings, this value should reflect an average annual recovered heat quantity to be fed into the district heating grid within the envisaged lifetime of savings.

The **heat losses in the district heating grid** (HL_{DHG}) for the EU27 were derived from the complete energy balances (Eurostat, 2021a). In the energy balances, district heating corresponds to the standard international energy product classification “heat”. To obtain the heat losses, the distribution losses must be divided by the sum of the final energy consumption and the distribution losses. Since the recovered heat quantities are collected precisely, it would also be feasible to collect data on heat losses by the action implementer for the specific heat distribution network.

For the **conversion efficiencies of reference heating systems** ($eff_{Baseline}$), the use of seasonal efficiencies is preferable. If these are not available, the efficiencies at nominal load can be used as an approximation. The (seasonal) efficiencies are to be weighted over the energy consumption of the technologies used, before the implementation of the action, in the district heating supply area. For the EU-wide indicative values, the following procedure was applied:

- The conversion efficiencies of space heating are taken from the latest year of the tables RES_hh_eff and SER_hh_eff of the Integrated Database of the European Energy System of the Joint Research Center (Mantzos, 2018).

Table 8: Ratio of energy service to energy consumption [kWh_{th}/kWh]

Heating system	Residential	Services
Solids	0.519	0.561
Liquified petroleum gas (LPG)	0.672	0.675
Gas/Diesel oil incl. biofuels (GDO)	0.685	0.681
Gas heat pumps		1.100
Gases incl. biogas	0.707	0.773
Biomass and wastes	0.564	0.738
Geothermal energy	0.851	0.825
Derived heat	0.831	0.818
Advanced electric heating	2.392	2.039
Conventional electric heating	0.815	0.785
Electricity in circulation	1.000	1.000

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- The conversion efficiencies per energy carrier were weighted by the final consumption of both sectors which were extracted from the tables RES_hh_fec and SER_hh_fec of the Integrated Database of the European Energy System of the Joint Research Center (Mantzos, 2018).

Table 9: Final energy consumption [ktoe] of the heating systems

Heating system	Residential	Services
Solids	7,411.2	1,024.8
Liquified petroleum gas (LPG)	977.6	163.4
Gas/Diesel oil incl. biofuels (GDO)	24,029.0	12,359.5
Gas heat pumps		266.2
Gases incl. biogas	69,635.1	33,151.7
Biomass and wastes	35,394.6	2,771.8
Geothermal energy	99.9	233.3
Derived heat	17,756.1	7,938.5
Advanced electric heating	2,344.4	3,232.8
Conventional electric heating	8,648.7	8,075.1
Electricity in circulation	2,553.4	728.5

This data is based on EU averages of heating systems installed. As technologies used in space heating in Member States may vary substantially, more precise information on the shares of reference heating systems in the respective district heating supply area should be used preferably.

The **conversion efficiency of district heat consuming heating systems** (eff_{Action}) is based on the technical conversion efficiency for “derived heat” of the tables RES_hh_eff and SER_hh_eff Integrated Database of the European Energy System of the Joint Research Center (Mantzos, 2018).

The **factor to calculate extrinsic incentives** (f_{ei}) can only be determined for a specific action or for a given setting of policy instruments. For example, if a voluntary agreement for industrial companies is combined with a support scheme for district heating grid expansion, then the savings between the two policy instruments could be credited in proportion to their respective contribution.

Additionally, the formula foresees a **factor for rebound effects** (f_{BEH}), as rebound effects occur where increased efficiency of a product or service lowers the cost of consumption and, as a result, more consumption of this product or service occurs (Maxwell et al., 2011). The research on rebound effects for the end-use types heating and cooling in a residential setting suggests a value between 10 and 30% (Sorrell et al., 2009; Maxwell et al., 2011; Buchanan et al., 2014). The indicative value taken up in the table above here, therefore amounts to 20%. It is recommended to use this indicative value in case of savings estimations triggered by additional connections to the district heating grid.

The **lifetime of savings** corresponds to the Indicative energy savings lifetimes of waste-heat recovery of industry according to Appendix VIII of the Commission Recommendation (EU)

2019/1658 of 25 September 2019 on transposing the energy savings obligations under the Energy Efficiency Directive (European Commission, 2019).

2.3.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 2.3.1 on calculation of final energy savings (Article 7).

Due to the nature of the methodology presented, it cannot be used for Article 3 ex-ante assessments. In order to prepare estimations on the amount of savings which can be achieved in the area of heat recovery, national waste heat potentials monitored under Article 14 and Annex VIII EED or monitored savings of heat recovery projects from earlier years (e.g. from previous periods of EED reporting or databases of subsidy schemes) could be used.

The use of district heating generation as the basis for determining final energy savings requires a modified calculation formula for the evaluation of the effect on primary energy consumption compared to chapter 1.1.1:

$$EPEC = Q_{EH} \cdot (1 - HL_{DHG}) \cdot f_{PE}$$

EPEC	Effect on primary energy consumption [kWh/a]
Q_{EH}	Excess heat fed into the district heating grid [kWh/a]
HL_{DHG}	Heat losses in the district heating grid [dmnl]
f_{PE}	Primary energy factor of the reference heating system [dmnl]

Indicative calculation values for this methodology have been prepared in the following table. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 10: Indicative calculation values for Article 3 of heat recovery for feed-in to a district heating grid

f_{PE}	[dmnl]
Primary energy factor of the reference heating system	1.456
HL_{DHG}	[dmnl]
Heat losses in the district heating grid	0.106

Methodological aspects

In order to comply with Article 7, energy saving actions are normally implemented at the end user level and, in addition to final energy savings, also have an impact on primary energy. In the context of this method, the effect on primary energy consumption, namely the reduction of energy input for district heating production, is used as a trigger for final energy savings (installation of additional district heating connections).

Without this energy saving action, the excess heat would be released into the environment. By feeding this excess heat into the grid, the fuel input of the reference heating systems can be compensated. Therefore, when assessing primary energy savings, the amount of heat recovered and fed into the district heating network is multiplied by the primary energy factors of the energy carriers that would have been used for heat production instead of the recovered heat.

Data sources for indicative calculation values

The **primary energy factor of the reference heating system** (f_{PE}) results from the weighted primary energy factors of the energy carriers which would have been used without connecting to the district heating grid.

$$f_{PE} = \sum_{ec} (share_{ec} \cdot f_{PE,ec})$$

f_{PE}	Primary energy factor of the reference heating system [dmnl]
$share_{ec}$	Share of energy carriers of the reference heating system [dmnl]
$f_{PE,ec}$	Primary energy factor of the energy carrier [dmnl]

The **excess heat fed into the district heating grid** (Q_{EH}) has to be determined by the implementer of the heat recovery. As energy savings actions are connected to a certain lifetime in which they will deliver savings, this value should reflect the annual recovered heat quantity to be fed into the district heating grid within the envisaged lifetime of savings.

The **heat losses in the district heating grid** (HL_{DHG}) for the EU27 were derived from the complete energy balances (Eurostat, 2021a). In the energy balances, district heating corresponds to the standard international energy product classification "heat". To obtain the heat losses, the distribution losses must be divided by the sum of the final energy consumption and the distribution losses. Since the recovered heat quantities are collected precisely, it would also be feasible to collect data on heat losses by the action implementer for the specific heat distribution network.

The **primary energy factors of energy carriers** ($f_{PE,ec}$) are determined via the energy carrier-related conversion losses and transport losses with the help of the complete energy balances (Eurostat, 2021a).

$$f_{PE,ec} = \frac{GIC - TI + TO - ES - NEU - SD}{FEC}$$

$f_{PE,ec}$	Primary energy factor of energy carrier [dmnl]
GIC	Gross inland consumption [TJ]
TI	Transformation input – energy use [TJ]
TO	Transformation output – energy use [TJ]
ES	Energy sector – energy use [TJ]
NEU	Final consumption – non-energy use [TJ]
SD	Statistical differences [TJ]
FEC	Final consumption – energy use [TJ]

The **shares of energy carrier of the reference heating system** ($share_{ec}$) for the EU27 were derived from the complete energy balances (Eurostat, 2021a).

Table 11: Primary factors for energy carrier related to the reference heating system

Energy carrier	share [dmnl]	$f_{PE, CE}$ [dmnl]
Anthracite	0.09%	1.002
Other bituminous coal	2.15%	1.002
Lignite	0.19%	1.002
Coke oven coke	0.07%	1.002
Patent fuel	0.03%	1.002
Brown coal briquettes	0.13%	1.002
Peat	0.05%	1.000
Peat products	0.02%	1.000
Natural gas	31.98%	1.007
Liquefied petroleum gases	2.18%	1.119
Motor gasoline	0.18%	1.119
Kerosene-type jet fuel (excluding biofuel portion)	0.18%	1.119
Other kerosene	0.31%	1.119
Gas oil and diesel oil (excluding biofuel portion)	12.08%	1.119
Fuel oil	0.05%	1.119
Petroleum coke	0.01%	1.119
Geothermal	0.15%	1.001
Solar thermal	0.61%	1.001
Ambient heat (heat pumps)	2.90%	1.001
Primary solid biofuels	11.79%	1.001
Charcoal	0.10%	1.001
Blended biogasoline	0.00%	1.001
Pure biodiesels	0.01%	1.001
Blended biodiesels	0.12%	1.001
Other liquid biofuels	0.01%	1.001
Biogases	0.51%	1.032
Industrial waste (non-renewable)	0.04%	1.001
Renewable municipal waste	0.05%	1.000
Non-renewable municipal waste	0.01%	1.000
Electricity	33.99%	2.281
Reference heating system	100.00%	1.456

2.3.3 Overview of costs related to the action

Overview of relevant cost components

Costs for the implementer of the action

Costs associated with the implementation of an industrial waste heat recovery system include investment and operational expenditures.

Investment expenditures cover all costs for materials, components, engineering and installation work. Components that need to be purchased and installed at least include:

- heat exchanger(s)
- pipelines
- circulating pumps
- measuring and control technology

Depending on the type and dimension of the process as well as the heat transfer medium (steam or hot water), the list of components may be extended widely.

Next to costs of components and materials, investment costs include labour costs initiated by project design, installation work, commissioning of the facility and training of employees. Costs caused by the interruption of the process (production downtimes) due to heat recovery installation work must be taken into account. Businesses may combine the retrofitting of the facility with scheduled revisions to limit costs.

Operational expenditures include fixed costs for periodic maintenance and repair works of the heat recovery system, in terms of labour and materials. Maintenance costs depend on the installed technology which may result in increased labour and material costs or even occasional downtimes of the facility. Variable operational expenditures include mostly electricity costs for the circulation of the heat transfer medium (electricity consumed by pumps and control units) and minor utilities.

The installation of a heat exchanger normally causes an additional pressure loss, which in the end results in increased power consumption.

Table 12: Indicative costs (excl. VAT) for feed-in to a district heating grid for the implementing party

[euro2008-2021]	Investment costs
Total investment costs	0.10 – 0.56 € / kWh recovered heat
Design and Engineering work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in engineering)
Installation work (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Training of personnel (labour costs)	Hourly labour costs from chapter 1.2.1 (labour costs in industry)
Production downtimes	Not available
[euro2021/a]	Variable operational costs
Costs of reduced fuel input	No reduction of fuel input
Electricity costs	Energy prices from chapter 1.2.1 (electricity for non-household consumers)
Cooling water costs	No data available
[euro2021/a]	Fixed operational costs

Maintenance (labour costs)	2 % of equipment installed costs
Production downtimes	No data available
[euro2021/a]	Revenues
	No data available
[a]	Lifetime
Lifetime	10

Costs for the final customer

Investment expenditures cover all costs for materials, components, engineering and installation work. Components that need to be purchased and installed at least include:

- heating device (boiler, heat pump, district heating substation)
- connection to grid (gas, district heat)
- fittings and pumping systems
- fuel tank (oil, wood pellets), heat storages (firewood)
- hot water storage
- chimney modernisation
- installation of components
- deep drilling (ground probe heat pump)

Operational expenditures include fixed costs for periodic maintenance of the heating system. Maintenance costs depend on the installed technology which may result in increased labour and material costs. Variable operational expenditures include the fuel costs of the reference heating systems and the district heating tariff.

Table 13: Indicative costs (excl. VAT) for district heat connections and reference heating systems

[euro2020]	Investment costs	
	SFH existing stock	**SFH newly built**
District heat	14,731	14,731
Gas condensing boiler	9,223	8,607
Oil condensing boiler	14,615	12,993
Firewood boiler	15,286	no data
Wood pellet boiler	16,655	15,899
Heat pump - air	15,785	12,372
Heat pump - ground probe	25,426	20,002
[euro2020/a]	Variable operational costs	
Costs of reduced fuel input	Energy prices from chapter 1.2.1 (fuel prices before/after for household consumers)	
[euro2020/a]	Fixed operational costs: Maintenance	

District heat	1.15 %
Gas condensing boiler	1.15 %
Oil condensing boiler	2.12 %
Firewood boiler	2.55 %
Wood pellet boiler	2.62 %
Heat pump - air	2.35 %
Heat pump - ground probe	2.25 %
[euro2021]	Revenues
	No revenues
[a]	Lifetime
Lifetime	10

Methodological aspects

Costs for the implementer of the action

Information on costs of heat recovery in industry is scarce, as such applications are highly individual and usually sold as an overall service consisting of technical planning, legal submissions, purchase of equipment and installation and calibration of the heat recovery system. Such service contracts are private law agreements and not publicly available.

The data retrieved for **investment costs** was published by "klimaaktiv", an Austrian benchmarking programme for (inter alia) industry sectors funded by the Austrian Ministry for Climate Action (BMK). The database contains approximately 100 heat recovery projects which were implemented between 2008 and 2021. The lower and upper quantiles of the listed projects were used to calculate the above range and to exclude outliers. Investment costs were examined per sector; however, no significant differences could be identified. As no data on the installed power of the listed heat recovery systems is available, investment costs are related to the quantity of recovered heat.

In order to estimate **labour costs**, chapter 1.2.1 offers data for the EU Member States. No information on the number of working hours was found.

Due to the implementation of heat recovery, **variable operational costs** of the existing application will change as follows:

- Costs of fuel input: In contrary to the methodologies for on-site use of waste heat recovery, no fuel reduction is triggered by feeding excess heat into a district heating grid.
- Electricity costs: Additional heat exchanges in the system cause increased pressure loss in the system. Additional pumping energy is needed to compensate for this.
- Cooling water costs: The amount cooling water needed is reduced by the implementation of heat recovery. Depending on national legislation regarding the use of surface- or groundwater in Member States, this may also lead to reduced costs.

Fixed operational costs mostly consist of the labour cost needed for maintenance of the application. A study conducted by „Institut für Energie- und Umweltforschung Heidelberg" sets the average maintenance cost at 2% of the investment costs. Additionally, potential production downtimes of the process during maintenance should be considered.

Revenues of recovered heat being fed into a district heating grid result from reimbursement (feed-in tariffs) provided by the district heating grid operator. As these feed-in tariffs are private law agreements, no data on reimbursement costs could be found.

Costs for the final customer

While this methodology is implemented at the premise of industrial enterprises, final energy savings are achieved at the final customer side. Therefore, from a policy perspective, the costs arising at final customer side will also be relevant.

Cost data was retrieved from an annual study comparing costs of heating systems ("Heizkostenvergleich") conducted by the Austrian Energy Agency (AEA, 2020). Results of the study are published only as a full cost analysis, however, Austrian Energy Agency provided more detailed data as input for this streamSAVE report. Most recent data from the year 2020 was used for the values featured in Table 13.

Investment costs are only available for single family houses (SFH). Expenses for components included are mentioned above. Values for the existing building stock are averages for non-retrofitted and retrofitted buildings.

Fixed operational costs consist of the labour and equipment cost needed for maintenance of the heating system. "Heizkostenvergleich" offers information on maintenance costs for each component of the heating system. The values presented in Table 13 are weighted averages based on the investment costs.

The **variable operational costs** are determined by the fuel price. EU values for fuel prices are provided in chapter 1.2.1. However, it should be kept in mind that the rationale behind this methodology is a decreased price of district heating due to recovered heat being fed into the grid. Therefore, this information can be used to determine the necessary district heating tariff reduction in order to be more cost effective than the reference heating system.

Data sources for indicative cost values

Costs for the implementer of the action

The total investment costs are related to the amount of recovered heat quantities and were derived from a publicly available best-case database (BMK, 2021) of the "klimaaktiv" programme of the Austrian Ministry for Climate Action (BMK).

Information on maintenance cost is taken from a study conducted in 2019 by "Institut für Energie- und Umweltforschung Heidelberg" for the German Ministry of Economy and Energy (Blömer et al., 2019).

Costs for the final customer

All information was retrieved from a study comparing costs of heating systems ("Heizkostenvergleich") conducted by the Austrian Energy Agency (AEA, 2020).

2.3.4 Calculation of greenhouse gas savings

The use of district heating generation as the data basis for determining final energy savings requires a modified calculation formula for the evaluation of GHG-savings compared to chapter 1.3:

$$GHGSAV = Q_{EH} \cdot (1 - HL_{DHG}) \cdot f_{GHG} \cdot 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
Q_{EH}	Excess heat fed into the district heating grid [kWh/a]
HL_{DHG}	Heat losses in the district heating grid [dmnl]
f_{GHG}	Emission factor of the reference heating system [g CO_2/kWh]

The excess heat fed into the district heating grid can be taken from the savings calculation for Article 7.

Indicative calculation values for the estimation of greenhouse gas savings have been prepared in the following table. Please keep in mind that this value is based on EU-wide data and will need to be adjusted to national circumstances:

Table 14: Indicative calculation values for the GHG savings of district heating

F_{GHG}	[g CO_2/kWh]
Emission factor of the reference heating system	158.6

Methodological aspects

This method evaluates the changes to CO_2 emissions in district heating by feeding in recovered waste heat as opposed to the mix of energy carriers used in district heating in case the action would not have been implemented. It is therefore assumed that conventional heating systems would be used or continue to be operated without the feed-in of waste heat. For CO_2 emissions, a weighted average is therefore calculated for the energy carriers used by final customers:

$$f_{GHG} = \sum_{ec} (share_{ec,Baseline} * f_{GHG,ec})$$

f_{GHG}	Emission factor of the reference heating system [g CO_2/kWh]
$share_{ec,Baseline}$	Share of final energy carrier on final energy consumption before the implementation of the action [dmnl]
$f_{GHG,ec}$	Emission factor of the final energy carrier [g CO_2/kWh]

Data sources for indicative calculation values

The **excess heat fed into the district heating grid** (Q_{EH}) has to be determined by the implementer of the heat recovery. As energy savings actions are connected to a certain lifetime in which they will deliver savings, this value should reflect the annual recovered heat quantity to be fed into the district heating grid within the envisaged lifetime of savings.

The **heat losses in the district heating grid** (HL_{DHG}) for the EU27 is similar to those of the calculation of final energy savings and were derived from the complete energy balances (Eurostat, 2021). In the energy balances, district heating corresponds to the standard international energy product classification "heat". To obtain the heat losses, the distribution losses must be divided by the sum of the final energy consumption and the distribution losses. Since the recovered heat quantities are collected precisely, it would also be feasible to collect data on heat losses by the action implementer for the specific heat distribution network

The **shares of final energy carriers** ($share_{ec,Baseline}$) for the EU27 were derived from the complete energy balances (Eurostat, 2021a).

The **emission factors of final energy carriers** (f_{GHG}) are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (European Commission, 2018).

The **emission factors of the reference heating system** ($f_{ec,Baseline}$) result from the weighted emission factors of the energy carriers:

Table 15: Emission factors for energy carriers related to the reference heating system

Energy carrier	share [dmnl]	$f_{GHG, ec}$ [g CO_2/kWh]
Anthracite	0.09%	353.9
Other bituminous coal	2.15%	340.6
Lignite	0.19%	363.6
Coke oven coke	0.07%	385.2
Patent fuel	0.03%	351.0
Brown coal briquettes	0.13%	385.2
Peat	0.05%	381.6
Peat products	0.02%	381.6
Liquefied petroleum gases	31.98%	202.0
Motor gasoline	2.18%	227.2
Kerosene-type jet fuel (excluding biofuel portion)	0.18%	249.5
Other kerosene	0.18%	258.8
Gas oil and diesel oil (excluding biofuel portion)	0.31%	258.8
Fuel oil	12.08%	266.8
Petroleum coke	0.05%	278.6
Geothermal	0.01%	351.0
Solar thermal	0.15%	-
Ambient heat (heat pumps)	0.61%	-
Primary solid biofuels	2.90%	-
Charcoal	11.79%	-
Blended biogasoline	0.10%	-
Pure biodiesels	0.00%	-
Blended biodiesels	0.01%	-
Other liquid biofuels	0.12%	-
Biogases	0.01%	-
Industrial waste (non-renewable)	0.51%	-
Renewable municipal waste	0.01%	514.8
Non-renewable municipal waste	0.04%	-
Electricity	0.03%	514.8
Reference heating system	100.00%	158,6

National values for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF). The shares of energy carriers can be adapted to national level according to the "Complete energy balances" of the EUROSTAT database.

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Chapter 3 Savings calculation for building automation and control systems

BACS or Building Automation and Control Systems comprise all products, software and engineering services for automatic controls (including interlocks), monitoring, optimization for operation, human intervention and management to achieve energy-efficient, economical and safe operation of building services. The use of the word 'control' does not imply that the system/device is restricted to control functions. Processing of data and information is possible (CEN, 2017). A survey conducted among streamSAVE stakeholders during autumn 2020 indicated a high priority towards BACS, implying the need exists to estimate energy savings for heating, cooling, domestic hot water, ventilation and lighting across residential and non-residential sectors. However, as BACS covers a wide range of product types, mapping the BACS already installed in the building stock will be rather challenging. In addition, it is not easy to evaluate the energy consumption of buildings in terms of energy consumption per end-use type. In order to correctly estimate the energy savings, consistent and reliable data must be obtained and baselines must be clearly defined.

Methods to assess the impact of BACS on the energy performance of buildings, have been developed in EN 15232 (CEN, 2017). Additionally, the standard defines 4 BAC energy efficiency classes, ranging from A, the most performant, to D, the least energy efficient. A brief insight into the specifications of each of these categories, is provided by Siemens (2018) and presented in Figure 6.

Class	Energy efficiency
A	Corresponds to high energy performance BACS and TBM • Networked room automation with automatic demand control • Scheduled maintenance • Energy monitoring • Sustainable energy optimization
B	Corresponds to advanced BACS and some specific TBM functions • Networked room automation without automatic demand control • Energy monitoring
C	Corresponds to standard BACS • Networked building automation of primary plants • No electronic room automation, thermostatic valves for radiators • No energy monitoring
D	Corresponds to non-energy efficient BACS. Buildings with such systems shall be retrofitted. New buildings shall not be equipped with such systems • Without networked building automation functions • No electronic room automation • No energy monitoring

Note: TBM = Technical Building Management

Figure 6: BAC Energy Efficiency Classes

Additionally, EN 15232 assigns all processing functions to one of these classes for both residential and non-residential buildings. Figure 7 shows an example for automatic heating control, more specifically, the function emission control of thermal energy. Several processing functions are listed, such as 'no automatic control', or 'individual room control with communication' and subsequently assigned to a class for both residential and non-residential buildings.

			Definition of classes							
			Residential				Non residential			
			D	C	B	A	D	C	B	A
AUTOMATIC CONTROL										
1	**HEATING CONTROL**									
1.1	Emission control									
		The control function is applied to the heat emitter (radiators, underfloor heating, fan-coil unit, indoor unit) at room level; for type 1 one function can control several rooms								
	0	No automatic control								
	1	Central automatic control								
	2	Individual room control								
	3	Individual room control with communication				a				a
	4	Individual room control with communication and occupancy detection (not applied to slow reacting heating emission systems, e.g. floor heating)								
	a	In case of slow reacting heat (and cool) emission systems, e.g. floor heating, wall heating, etc. functions 1.1.3 (and 3.1.3) are allocated to BAC class A.								

Figure 7: Example of requirements of the processing function 'emission control of thermal energy' in different BAC energy classes

streamSAVE has developed a methodology to calculate the effect on final energy consumption of buildings, that occurs from installing or upgrading BACS. However, in addition to energy savings and the related carbon savings, the use of BACS also generates benefits beyond energy efficiency. Examples are maintenance and fault prediction, increased comfort, convenience and wellbeing and health, as well as information provision to occupants of the buildings (Verbeke et al., 2020).

3.1 Building Automation and Control Systems in residential and non-residential buildings

The methodology described herein can be used for calculating the impact of installing or upgrading BACS on the energy demand of a building. Determining the impact of an upgrade is possible by using the energy efficiency classes from EN 15232, where 4 classes are defined, ranging from the least efficient (D) to the most efficient (A).

Further, EN 15232 defines over 40 BAC functions that have an impact on the energy performance of buildings, covering different sources of heating and cooling, and different types of ventilation and air conditioning systems. Calculating the impact of BACS on the energy demand can either be done in a detailed way, i.e. per BAC function, or by making use of the more generalized BAC factor. The calculation methodology described below, is based on the BAC factor method and can be used for calculating savings in residential and non-residential buildings, for five types of end-use (heating, cooling, domestic hot water, ventilation and lighting) and for the three European climate regions.

3.1.1 Calculation of final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$\boldsymbol{TFES_x} = (\boldsymbol{FEC_{before,x}} - \boldsymbol{FEC_{after,x}}) \cdot f_{BEH} \cdot cf_x$$

$$FEC_{before,x} = FEC_{floor,before,x} \cdot A$$

$$FEC_{after,x} = \frac{BAC_{after,x}}{BAC_{before,x}} \cdot FEC_{floor,before,x} \cdot A$$

$TFES_x$	Total final energy savings for end-use type x [kWh/a]
$FEC_{before,x}$	Final energy consumption for end-use x, before implementation of the action [kWh/a]
$FEC_{after,x}$	Final energy consumption for end-use x after implementation of the action [kWh/a]
f_{BEH}	Factor to calculate a rebound effect [dmnl]
cf_x	Regional or climate factor for end-use type x [dmnl]
$FEC_{floor,before,x}$	Specific final energy consumption for end-use type x, *before* implementation of the action, per unit floor area [kWh/m²/a]
A	Total floor area of building [m²]
$BAC_{after,x}$	BAC energy efficiency factor *after* BACS upgrade for end-use type x [%], based on EN15232
$BAC_{before,x}$	BAC energy efficiency factor *before* BACS upgrade for end-use type x [%], based on EN15232

Indicative calculation values for this methodology have been prepared in the following tables. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances. Concerning the average BAC factor (before upgrade), the Ecodesign study (Van Tichelen et al., 2020) presents indicative values for the distribution of BAC factors in the base year per end use, per climate region for the EU. The average factors per end use and building type in the different climate regions are taken over below. Next to the average baseline for the BAC factors, the reference or baseline consumption before upgrade (FEC_{before}) needs to be established as well. Making use of the IDEES database (JRC, 2018), indicative values at EU-level have been developed for the average FEC of the building stock, per end-use and building types and for the three European climate regions.

Table 16: Estimated average stock of BAC factors for 2020 by end-use and building type, for each climate region – $BAC_{before,x}$

North Region	SFH	MFH	Offices	Wholesale/ Retail	Education	Hospitals/ Healthcare	Hotels	Restaurants	Other
Space heating	1.010	1.004	1.195	1.139	1.128	1.000	1.000	1.000	1.109
Hot water	1.109	1.109	1.019	1.092	1.030	0.992	0.992	0.992	1.030
Cooling	1.173	1.163	1.082	1.003	0.805	0.617	0.617	0.617	1.200
Ventilation	1.091	1.084	1.138	1.071	0.966	1.000	1.000	1.000	1.154
Lighting	1.079	1.079	0.989	0.991	0.991	1.000	1.000	1.000	1.000
Space heating pumps	1.008	1.006	1.121	1.103	1.072	1.038	1.038	1.038	1.073
Hot water pumps	1.109	1.109	1.018	1.092	1.029	0.991	0.991	0.991	1.029

West Region	SFH	MFH	Offices	Wholesale/ Retail	Education	Hospitals/ Healthcare	Hotels	Restaurants	Other
Space heating	0.991	0.985	1.189	1.125	1.128	0.978	0.978	0.978	1.109
Hot water	1.109	1.109	1.019	1.092	1.030	0.992	0.992	0.992	1.030
Cooling	1.173	1.163	1.082	1.003	0.805	0.617	0.617	0.617	1.200
Ventilation	1.082	1.074	1.135	1.064	0.966	0.978	0.978	0.978	1.154
Lighting	1.079	1.079	0.989	0.991	0.991	1.000	1.000	1.000	1.000
Space heating pumps	0.999	0.997	1.118	1.097	1.072	1.030	1.030	1.030	1.073
Hot water pumps	1.109	1.109	1.018	1.092	1.029	0.991	0.991	0.991	1.029

South Region	SFH	MFH	Offices	Wholesale/ Retail	Education	Hospitals/ Healthcare	Hotels	Restaurants	Other
Space heating	1.028	1.022	1.341	1.139	1.128	1.063	1.063	1.063	1.109
Hot water	1.109	1.109	1.036	1.092	1.030	1.019	1.019	1.019	1.030
Cooling	1.173	1.163	1.205	1.003	0.816	0.656	0.656	0.656	1.200
Ventilation	1.101	1.092	1.273	1.071	0.972	1.063	1.063	1.063	1.154
Lighting	1.079	1.079	0.989	0.991	0.991	1.000	1.000	1.000	1.000
Space heating pumps	1.016	1.014	1.182	1.103	1.072	1.067	1.067	1.067	1.073
Hot water pumps	1.109	1.109	1.035	1.092	1.029	1.018	1.018	1.018	1.029

Note: European (climate) regions: North (Czech Republic, Denmark, Estonia, Finland, Latvia, Lithuania, Poland, Slovakia, Sweden), West (Austria, Belgium, France, Germany, Ireland, Luxemburg, Netherlands) and South (Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Romania, Slovenia, Spain).

Abbreviations: SFH: Single Family House, MFH: Multi Family House

Table 17: Other indicative values for final energy consumption of baseline, European climate region, lifetime and behavioural effects of BACS

$FEC_{before,x}$		[kWh/m² useful floor area /a]		
Residential	Space heating	131.9		
	Space cooling	6.2		
	Water heating	27.5		
	Lighting	3.1		
	Ventilation	Minor, about 0.5% of total FEC (*)		
Non-Residential (services)	Space heating	130.2		
	Space cooling	15.1		
	Water heating	22.1		
	Lighting	20.3		
	Ventilation	15.7		
cf_x		North	West	South
Residential	Space heating	1.21	1	0.71
	Space cooling	0.64	1	1.95
	Water heating	1.19	1	0.97
	Lighting	0.95	1	0.92
	Ventilation			
Non-Residential (services)	Space heating	1.19	1	0.65
	Space cooling	0.74	1	1.45
	Water heating	0.96	1	0.98
	Lighting	1.05	1	1.08
	Ventilation	1.10	1	1.18
Lifetime of savings		[a]		
Lifetime of savings*		15		
f_{BEH}		%		
Residential	Space heating & cooling	80		

Note: European (climate) regions: North (Czech Republic, Denmark, Estonia, Finland, Latvia, Lithuania, Poland, Slovakia, Sweden), West (Austria, Belgium, France, Germany, Ireland, Luxemburg, Netherlands) and South (Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Romania, Slovenia, Spain).

Source: (JRC, 2018), except (*) based on (Van Tichelen et al., 2020)

Methodological aspects

The methodology is based on the BAC factor method as stipulated in EN15232, allowing to estimate the consumption at national/regional level, without the need to collect the details for each BAC function at the building level. Hence, it can be applied to calculate savings on the national/regional scale; however, if details on the BAC factors and final energy consumption per end-use type are available at the building level, the methodology can also be applied for a specific building.

The savings formula takes into account the difference between the final energy consumption before and after the upgrade in BACS class. The formula also foresees the possibility to use factors to calculate rebound effects and to reflect the climate region.

The **final energy consumption before** $FEC_{before,x}$ is calculated by multiplying the final energy consumption for the considered end-use, before implementation of the action, per unit floor area, with the total floor area of buildings. Several data sources exist to calculate $FEC_{before,x}$. It is either possible to work on the basis of building specific FEC per end use, based on the Energy Performance Certificate (EPC) score. This would be the case where detailed information per building is available. In case such information is not available for the individual building(s), it is also possible to work on the basis of regional or national averages. In that case, data from EPC scores per climate region can be used to calculate the average energy consumption of the building stock per end use and building type. However, the applicability of EPC's to estimate the baseline of a building is dependent on their quality to reflect actual energy consumption. Multiple sources indicate that EPCs tend to overestimate energy consumption of a building, as the first objective of EPCs is energy labelling (Amirkhani et al., 2021). Instead of EPC, information from the national or regional energy statistics per end use and building type can be used to calculate the average energy consumption of the building stock. The indicative values developed for FEC_{before} in Table 17, follow the latter method and are based on the IDEES database (JRC, 2018), which draws from the Eurostat data, Odyssee database, Building Stock Observatory and many other sources as explained below. The indicative values for the baseline consumption can be adjusted for external conditions by means of a **regional or climate factor** cf_x , and reflects the average difference of final energy consumption of Northern and Southern countries in comparison to Member States in the West.

The **final energy consumption after the BACS improvement** $FEC_{after,x}$ is calculated by multiplying the specific energy demand for a type of-end use in the 'old' efficiency class ($FEC_{floor,before}$) by the total floor area A and the ratio of the new BAC factor to the old BAC factor. As the BAC factors are reported in the EN 15232 for each BACS class, it is only necessary to know the specific final energy consumption for the type of end-use before the improvement in BAC efficiency class and the total floor area of the building. This formula can be used for each end-use, as BACS factors are available for heating, cooling, domestic hot water, ventilation and lighting or on the more general level of thermal and electrical energy.

Additionally, the formula foresees a **factor for rebound effects** f_{BEH}, as rebound effects occur where increased efficiency of a product or service lowers the cost of consumption and, as a result, more consumption of this product or service occurs (Maxwell et al., 2011). The research on rebound effects for the end-use types heating and cooling in a residential setting suggests a value between 10 and 30% (Sorrell et al., 2009; Maxwell et al., 2011; Buchanan et al., 2014). The indicative value taken up in the table above here, therefore amounts to 80%, reflecting a rebound effect or decreased impact on energy savings of 20%. It is recommended to use this indicative value in case of savings estimations for the upgrade of BACS of the end-uses heating and cooling in residential buildings.

With respect to the baseline, it will be necessary to map the **distribution of BACS classes in the building stock** $BAC_{before,x}$. The Ecodesign preparatory study (Van Tichelen et al., 2020) has developed indicative values on the EU-level, which have been taken up in Table 16. An important side note in this respect consists of the expected impact from the recast energy performance in buildings directive (EPBD) on the baseline of BACS. New provisions in Articles 14 and 15 lay out mandatory requirements for the installation and retrofit of BACS in non-residential buildings (existing and new) with effective rated output of over 290 kW. By 2025 these buildings must have BACS installed, which comply with the requirements. As a first order estimate, the BACS capabilities of Art. 14 and 15 could correspond to class B as defined in EN 15232, which has possible ramifications for the baseline as it would imply that only savings that exceed those requirements, could be counted in frame of Article 7 of the EED. Of course, this is also dependent on the national context.

Data sources for indicative calculation values

BAC factors per BACS class are stipulated in the Siemens study of EN 15232 (Siemens, 2018). BAC factors, which are the result of reference calculations on the level of building types, exist on an aggregated level of end-use (thermal energy or electrical energy) and on a more detailed level of end-use, for heating, cooling, domestic hot water, ventilation and lighting. They are provided for both residential building types, consisting of Single Family Homes (SFH), Multi Family Homes (MFH), and non-residential building types, comprising offices, wholesale and retail, education, hospitals and healthcare, hotels, restaurants and other. The BAC factors for aggregated and detailed types of end-use are included in section 3.3. The following assumptions were made:

- For end-use type **cooling**, detailed BAC factors ($f_{BAC,C}$) are only provided for the non-residential building types. However, for the end-use type heating, detailed BAC factors ($f_{BAC,H}$) for the residential sector have been defined. Hence the excel calculation tool uses the detailed values for cooling for non-residential building types, and the detailed factors for heating ($f_{BAC,H}$) for the residential sector. Additionally, no values have been provided for the building types “education buildings” and “hospitals” in the non-residential sector. For education buildings, the factors for cooling from the building type “lecture hall” have been used ($f_{BAC,C}$); for the hospitals, the BAC factors for aggregated thermal energy in hospitals have been used ($f_{BAC,th}$).
- For end-use type **lighting**, detailed BAC factors are only provided for the non-residential building types. Hence the excel calculation tool uses the detailed values for lighting for non-residential building types, and the aggregated factors for electricity ($f_{BAC,el}$) for the residential sector.
- For end-use type **ventilation**, detailed BAC factors are provided for the non-residential building types (under ‘auxiliary energy’). Hence the excel calculation tool uses the detailed values for auxiliary for non-residential building types, and the aggregated factors for electricity ($f_{BAC,el}$) for the residential sector.
- In EN 15232, BAC factors are provided for the building type “lecture halls”; however, as the Ecodesign study (Van Tichelen et al., 2020) - where the indicative values for $BAC_{before,x}$ were taken from - does not have this category, the values for lecture halls have not been included in the excel calculation tool.

The estimated, average stock $BAC_{before,x}$ of BAC factors for 2020 by end-use and building type, for each climate region have been developed by the Ecodesign preparatory study (Van Tichelen et al., 2020).

The $FEC_{before,x}$ of the final energy consumption for end-use, before implementation of the action, per unit floor area [kWh/m²/a] is based on the IDEES database (JRC, 2018). In the Integrated Database of the European Energy Sector, JRC brings together all statistical information related to the energy sector, and complements this with processed data that further decomposes energy consumption. The complete output of JRC-IDEES is accessible to the general public and is revised periodically (Mantzos et al., 2017).

- The **total Final Energy Consumption** corresponds to the Eurostat energy balances for 2000-2015 of each Member State. This FEC is divided into end-use consumption based on several studies and databases, such as: survey on Energy Consumption in Households, EU Building Observatory, BPIE, TABULA, ENTRANZE, EPISCOPE on buildings characteristics, preparatory studies of the eco-design for energy using products, ODYSSEE-MURE database, JRC studies and reports.

- The **useful floor area** corresponds to the total floor area of Member States' building stocks. The useful floor area is the floor area that is heated during most of the winter months. Rooms that are unoccupied and/or unheated during the heating season, unheated garages or other unheated areas in the basement and/or the attic are not considered. It is different from the gross floor area which includes common areas in multifamily buildings (e.g. corridors), attics, basements or verandas (Building Stock Observatory, 2021). For cooling, only the buildings having space cooling are considered, and not the total building stock, as – on average – 10% of the EU-27 residential stock is cooled and 40% of the EU-27 non-residential stock (JRC, 2018). Same applies to ventilation in the non-residential sector.
- To normalize for **yearly (e.g. weather) fluctuations**, the indicative values for heating, cooling, hot water and ventilation are based on values averaged for the period 2005-2015. The values for lighting are averaged for a smaller period 2010-2015, given the strong efficiency improvements for lighting during the previous decade.

  The indicative values can be **adjusted for external conditions** by means of the regional or climate factor. The three regions in EU-27, as also used in (Van Tichelen et al., 2020), comprise the following countries: North (Czech Republic, Denmark, Estonia, Finland, Latvia, Lithuania, Poland, Slovakia, Sweden), West (Austria, Belgium, France, Germany, Ireland, Luxemburg, Netherlands) and South (Bulgaria, Croatia, Cyprus, Greece, Hungary, Italy, Malta, Portugal, Romania, Slovenia, Spain). The climate factor cf_x is determined from the JRC-IDEES database, reflecting the average deviation of final energy consumption $FEC_{before,x}$ in all Northern and Southern countries in comparison to the Member States in the West, between 2005-2015 (heating, cooling, water, ventilation) or 2010-2015 (lighting).

- **Rebound effects** happen where increased efficiency of a product or service lowers the cost of consumption and, as a result, more consumption of this product or service will occur (Maxwell et al., 2011). The literature on rebound effects does not treat BACS as such but focuses on the end-use types. Space heating seems to be the most researched end-use type, and Sorrell et al. (2009) in their review found that the savings from energy efficiency measures in heating may actually be lower than what engineering models predict. This can partly be explained by the so-called temperature take-back, or the change in mean internal temperatures following the energy efficiency improvement, in which both the physical characteristics of the house and behavioural changes play a role. For example, for space heating a range between 10% and 30% (Maxwell et al., 2011; Buchanan et al., 2014) is put forward, while another review mentions a mean value of 20% (Sorrell et al., 2009) (direct rebound effect) for space heating and a range of 1-26% for household cooling. On the contrary, not many sources dealt with behavioural effects on the end-use type lighting, which is why we recommend using the suggested factor only for the end-use types heating and cooling.

3.1.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from 3.1.1 on calculation of final energy savings (Article 7).

The effect on primary energy consumption can be calculated with the following equation:

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec,Baseline} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec,Action} \cdot f_{PE,ec})$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the used energy carrier [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action
ec	Index of energy carrier

Indicative calculation values for the shares of energy carriers for different end-use types have been prepared in the following table. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 18: Shares of energy carriers per end-use type in BACS

$Share_{ec}$ space heating		[dmnl]
Residential	Solids	5%
	LPG	1%
	Gas/Diesel oil incl. biofuels (GDO)	17%
	Natural gas, incl. biogas	37%
	Biomass and wastes	21%
	Geothermal energy	0%
	District heat	12%
	Electricity	7%
Non-Residential (services)	Solids	2%
	LPG	0%
	Gas/Diesel oil incl. biofuels (GDO)	21%
	Gases incl. biogas	46%
	Biomass and wastes	2%
	Geothermal energy	0%
	District heat	13%
	Electricity	15%

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Share$_{ec}$ space cooling		[dmnl]
	Gas heat pumps	0,9%
	Electric space cooling	99,1%
Share$_{ec}$ hot water		**[dmnl]**
Residential	Solids	4%
	Liquified petroleum gas (LPG)	6%
	Gas/Diesel oil incl. biofuels (GDO)	13%
	Gases incl. biogas	36%
	Biomass and wastes	13%
	Geothermal energy	0%
	District heat	9%
	Electricity	17%
	Solar	3%
Non-Residential (services)	Solids	0%
	Liquified petroleum gas (LPG)	3%
	Gas/Diesel oil incl. Biofuels (GDO)	18%
	Gases incl. Biogas	34%
	Biomass and wastes	1%
	District heat	9%
	Electricity	34%
	Solar	1%
Share$_{ec}$ ventilation		**[dmnl]**
Residential	Electricity	100%
Non-residential	Electricity	100%
Share$_{ec}$ lighting		**[dmnl]**
Residential	Electricity	100%
Non-residential	Electricity	100%

EU27 average values for the conversion factors from final to primary energy of the above-mentioned energy carriers are listed in chapter 1.1.1 of this report.

3.1.3 Overview of costs related to the action

Overview of relevant cost components

Main components of a BACS system consist of sensors, controllers, output devices, the communication protocol and the dashboard for data reporting and interaction with the BACS system. Nevertheless, it is crucial to distinguish the role of the hardware and the software within the boundaries of the BACS system. Obviously, the number of BACS functions defines the actual investment cost for the installation of the BACS systems, as different equipment has to be installed. Typical costs components associated with the installation of BACS products are (Van Tichelen et al., 2020):

- Components and hardware costs
- Software costs
- Design costs
- Engineering, installation and commissioning costs
- Service and repair costs
- End of life costs.

The investment cost for the installation of the BACS systems is considered as the most significant category of cost. The investment cost includes both the purchase of the main components of the BACS system (product related costs) and the labour cost, which is required for the installation of the equipment and the training of the personnel.

Similar to the proposed method for the calculation of the delivered energy savings, the costs are determined per unit floor area basis so it becomes possible to scale these up for the proportion of the building (stock) which is addressed by installed BACS products. Indicative values are presented in the following table, both for the investment and the maintenance & repair costs. These indicative values for the EU level (€2020, excl. VAT) cover class C and class A BACS for the building types (single family home, multi-family home, retail outlet or office) and are differentiated for an existing building or a new building (Van Tichelen et al., 2020). Hardwired solutions were generally assumed for installations in new buildings and wireless solutions for retrofitting to existing buildings (Van Tichelen et al., 2020).

Table 19: Indicative costs (excl. VAT) of BACS as function of the building type and BACS class A and C. The lower bound represents renovation of existing buildings; upper bound of new buildings

Upgrade to BACS class C	SFH	MFH	Offices	Wholesale/ Retail	Other non-residential
Product cost [€2020/m² floor area]	1.5-3.0	1.5-3.0	9.0	7.0	NA
Investment costs, incl. installation [€2020/m²]	2.8-5.6	2.8-5.6	21.2	16.5	NA
Maintenance & repair [% per year]	3%	3%	3%	3%	3%
Upgrade to BACS class A					
Product cost [€2020/m² floor area]	4.7-7.1	4.3-7.0	13.3-14.7	12.0-13.2	NA
Investment costs, incl. installation [€2020/m²]	11.1-16.8	10.1-16.5	31.2-34.6	28.2-31.1	30 (6-60)
Maintenance & repair [% per year]	3%	3%	3%	3%	3%

Methodological aspects

Considering the investment costs for BACS upgrades, significant variations are found depending upon the building type and climate zone (Verbeke et al., 2020), which is reflected in the above Table 19. It can also be noticed that the costs of installation are on average a factor of 1.4 higher than the BACS product costs. The labour or installation costs are reflected in the difference between the investment costs and product costs. It should be noted that the labour cost can be adjusted for each country separately by taking into account the deviation of the mean labour expenditures from EU averages. The products costs are assumed to be constant across the EU. Another cost component of the BACS system is the variable maintenance and repair costs. The maintenance costs are expressed as a yearly percentage in relation to the required investment costs. Estimating these types of costs of BACS is very challenging due to their extremely diverse nature (Van Tichelen et al., 2020).

Except for other non-residential buildings, all indicative values for costs are based on the recent Ecodesign preparatory study (Van Tichelen et al., 2020). For the buildings in other non-residential sectors, a limited number of cost information could be collected, and therefore a range of 6 € per m^2 floor area to 60 €/m^2 is assumed, where the lower end of these cost ranges is broadly in alignment with the costs for upgrading an existing BACS to a Class C BACS. The upper end reflects the inclusion of other non-EN15232 functionalities in the project cost, such as plant controls, meters, digital services, etc. (Van Tichelen et al., 2020). Based on (Waide, 2013) a rough estimate of 30€/m^2 on average is assumed for an upgrade to class A of this building type.

The above costs may overestimate the true costs associated with a significant increase in BACS deployment because they assume no economies of scale whereas in reality, a significant proportion of BACS costs are related to labour including marketing and sales support, both of which may well scale down on a per unit deployment basis if BACS deployment is significantly accelerated (Waide, 2019).

Data sources for indicative cost values

An extensive bibliographical review was conducted in order to identify unitary estimates both for the investment and the variable maintenance cost of the BACS systems, such as (Waide, 2013; Waide, 2019; Verbeke et al., 2020). A high variation of unitary costs could be identified for the investment costs, which can be explained by different parameters such as the climate regions, the functionality levels, the energy performance classes, the differences in baseline, etc. Nevertheless, the analysis of the collected data confirmed that the unitary cost estimates for the case of the non-residential buildings are considerably higher than the respective estimates for buildings in the residential sector.

It was decided to base the above, indicative values for investments and maintenance costs on the Ecodesign preparatory study of BACS (Van Tichelen et al., 2020), as this recent study took previous assessments, such as (Waide, 2013; Verbeke et al., 2020) into account next to survey results. As said, for the buildings in other non-residential sectors, a limited number of cost information could be collected, and therefore a broader range was assumed based on (Waide, 2013) and (Van Tichelen et al., 2020).

3.1.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = \left[FEC_{Baseline} \cdot \sum_{ec} \left(share_{ec,Baseline} \cdot f_{GHG,ec}\right) - FEC_{Action} \cdot \sum_{ec} \left(share_{ec,Action} \cdot f_{GHG,ec}\right)\right] * 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2e p.a.]
FEC	Annual final energy consumption [kWh/a]
share	Share of final energy carrier on final energy consumption [dmnl]
f_{GHG}	Emission factor of final energy carrier [t CO_2/kWh]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after implementation of the action
ec	Index of energy carrier

The final energy consumption (FEC) of the baseline and the action can be taken from the savings calculation for Article 7 in chapter 3.1.1.

Indicative calculation values for the estimation of greenhouse gas savings have been prepared in the following table. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 20: Shares of energy carriers per end-use type in BACS

$Share_{ec}$ space heating		[dmnl]
Residential	Solids	5%
	LPG	1%
	Gas/Diesel oil incl. biofuels (GDO)	17%
	Natural gas, incl. biogas	37%
	Biomass and wastes	21%
	Geothermal energy	0%
	District heat	12%
	Electricity	7%
Non-Residential (services)	Solids	2%
	LPG	0%
	Gas/Diesel oil incl. biofuels (GDO)	21%
	Gases incl. biogas	46%
	Biomass and wastes	2%
	Geothermal energy	0%
	District heat	13%
	Electricity	15%

Share$_{ec}$ space cooling		[dmnl]
	Gas heat pumps	0,9%
	Electric space cooling	99,1%
Share$_{ec}$ hot water		**[dmnl]**
Residential	Solids	4%
	Liquified petroleum gas (LPG)	6%
	Gas/Diesel oil incl. biofuels (GDO)	13%
	Gases incl. biogas	36%
	Biomass and wastes	13%
	Geothermal energy	0%
	District heat	9%
	Electricity	17%
	Solar	3%
Non-Residential (services)	Solids	0%
	Liquified petroleum gas (LPG)	3%
	Gas/Diesel oil incl. Biofuels (GDO)	18%
	Gases incl. Biogas	34%
	Biomass and wastes	1%
	District heat	9%
	Electricity	34%
	Solar	1%
Share$_{ec}$ ventilation		**[dmnl]**
Residential	Electricity	100%
Non-residential	Electricity	100%
Share$_{ec}$ lighting		**[dmnl]**
Residential	Electricity	100%
Non-residential	Electricity	100%

Values for the emission factors of the above-mentioned energy carriers are listed in chapter 1.3 of this report.

Data sources for indicative calculation values

The **shares of energy carriers per end-use type and sector** are based on the IDEES database (JRC, 2018). In the Integrated Database of the European Energy Sector, JRC brings together all statistical information related to the energy sector and complements this with processed data that further decomposes energy consumption.

- The total Final Energy Consumption per energy carrier corresponds to the Eurostat energy balances for 2000-2015 of each Member State. This FEC is divided into end-use consumption based on several studies and databases, such as: EU Building Observatory, BPIE, TABULA, ENTRANZE, EPISCOPE on buildings characteristics, ODYSSEE-MURE database, JRC studies and reports.
- To normalize for yearly fluctuations, the indicative shares per energy carrier for heating, cooling and hot water are based on values averaged for the period 2005-2015.

- The shares of energy carriers before and after the implementation of the BACS upgrade are assumed to be the same.

The shares of energy carriers per end-use type and sector can be adapted to national level based on the IDEES results for a specific Member State (JRC, 2018).

The **emission factors for energy carriers** are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU). **National values** for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF).

3.2 Bibliography for building automation and control systems

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3.3 BAC Efficiency Factors

In this section, you can find the BAC efficiency factors, taken from Siemens, 2018 as indicated in the standard EN 15232.

3.3.1 Aggregated level

Factors for thermal energy ($f_{BAC,th}$) – Non-residential

Non-residential building types	**BACS efficiency factors thermal $f_{BAC,th}$**			
	D	**C**	**B**	**A**
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
Offices	1.51	1	0.80	0.70
Lecture halls	1.24	1	0.75	0.5 [a]
Educational buildings (schools)	1.20	1	0.88	0.80
Hospitals	1.31	1	0.91	0.86
Hotels	1.31	1	0.85	0.68
Restaurants	1.23	1	0.77	0.68
Wholesale and retail buildings	1.56	1	0.73	0.6 [a]
Other types: • Sport facilities • Storage • Industrial facilities • etc.		1		
[a] The values are highly dependent on heating/cooling demand for ventilation				

Source: Siemens, 2018

Factors for thermal energy ($f_{BAC,th}$) – Residential

Residential building types	**BACS efficiency factors thermal $f_{BAC,th}$**			
	D	**C**	**B**	**A**
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.10	1	0.88	0.81

Source: Siemens, 2018

Factors for electrical energy ($f_{BAC,el}$) – Non-residential

Non-residential building types	BACS efficiency factors electrical $f_{BAC,el}$			
	D	C	B	A
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
Offices	1.10	1	0.93	0.87
Lecture halls	1.06	1	0.94	0.89
Educational buildings (schools)	1.07	1	0.93	0.86
Hospitals	1.05	1	0.98	0.96
Hotels	1.07	1	0.95	0.90
Restaurants	1.04	1	0.96	0.92
Wholesale and retail buildings	1.08	1	0.95	0.91
Other types: • Sport facilities • Storage • Industrial facilities • etc.		1		

Source: Siemens, 2018

Factors for electrical energy ($f_{BAC,el}$) – Residential

Residential building types	BACS efficiency factors electrical $f_{BAC,el}$			
	D	C	B	A
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.08	1	0.93	0.92

Source: Siemens, 2018

3.3.2 Detailed level

Factors for heating ($f_{BAC,H}$) – Non-residential

Non-residential building types	Detailed BACS efficiency factors $f_{BAC,H}$ and $f_{BAC,C}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$
Offices	1.44	1.57	1	1	0.79	0.80	0.70	0.57
Lecture halls	1.22	1.32	1	1	0.73	0.94	0.3 [a]	0.64
Educational buildings (schools)	1.20	–	1	1	0.88	–	0.80	–
Hospitals	1.31	–	1	1	0.91	–	0.86	–
Hotels	1.17	1.76	1	1	0.85	0.79	0.61	0.76
Restaurants	1.21	1.39	1	1	0.76	0.94	0.69	0.6
Wholesale and retail buildings	1.56	1.59	1	1	0.71	0.85	0.46[a]	0.55
Other types: • Sport facilities • Storage • Industrial facilities • etc.	–	–	1	1	–	–	–	–
[a] The values are highly dependent on heating/cooling demand for ventilation								

Source: Siemens, 2018

Factors for heating ($f_{BAC,H}$) – Residential

Residential building types	Detailed BACS efficiency factors $f_{BAC,H}$ and $f_{BAC,C}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.09	–	1	–	0.88	–	0.81	–

Source: Siemens, 2018

Factors for cooling ($f_{BAC,C}$) – Non-residential

Non-residential building types	Detailed BACS efficiency factors $f_{BAC,H}$ and $f_{BAC,C}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$
Offices	1.44	1.57	1	1	0.79	0.80	0.70	0.57
Lecture halls	1.22	1.32	1	1	0.73	0.94	0.3 [a]	0.64
Educational buildings (schools)	1.20	–	1	1	0.88	–	0.80	–
Hospitals	1.31	–	1	1	0.91	–	0.86	–
Hotels	1.17	1.76	1	1	0.85	0.79	0.61	0.76
Restaurants	1.21	1.39	1	1	0.76	0.94	0.69	0.6
Wholesale and retail buildings	1.56	1.59	1	1	0.71	0.85	0.46[a]	0.55
Other types: • Sport facilities • Storage • Industrial facilities • etc.	–	–	1	1	–	–	–	–
[a] The values are highly dependent on heating/cooling demand for ventilation								

Note: No values have been provided for the building types "educational buildings" and "hospitals" in the non-residential sector. For education buildings, the factors for cooling from the building type "lecture hall" have been used ($f_{BAC,C}$); for the hospitals, the BAC factors for aggregated thermal energy in hospitals have been used ($f_{BAC,th}$).

Source: Siemens, 2018

Factors for cooling ($f_{BAC,C}$) – Residential

Residential building types	Detailed BACS efficiency factors $f_{BAC,H}$ and $f_{BAC,C}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$	$f_{BAC,H}$	$f_{BAC,C}$
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.09	–	1	–	0.88	–	0.81	–

Note: No detailed BAC factors have been provided for the residential building types. However, they are defined for the end-use type heating ($f_{BAC,H}$). Hence the excel calculation tool uses the detailed factors for heating ($f_{BAC,H}$) for cooling in the residential sector.

Source: Siemens, 2018

Factors for Domestic Hot Water ($f_{BAC,DHW}$) – Non-residential

Non-residential building types	**Detailed BACS efficiency factors $f_{BAC,DHW}$**			
	D	**C**	**B**	**A**
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
Offices Lecture halls Educational buildings (schools) Hospitals Hotels Restaurants Wholesale and retail buildings Other types: • Sport facilities • Storage • Industrial facilities • etc.	1.11	1.00	0.90	0.80

Source: Siemens, 2018

Factors for Domestic Hot Water ($f_{BAC,DHW}$) – Residential

Residential building types	**Detailed BACS efficiency factors $f_{BAC,DHW}$**			
	D	**C**	**B**	**A**
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.11	1.00	0.90	0.80

Source: Siemens, 2018

Factors for ventilation ($f_{BAC,el,aux}$) – Non-residential

For non-residential ventilation, the detailed values for auxiliary energy $f_{BAC,el,aux}$ can be used.

Non-residential building types	Detailed BACS efficiency factors $f_{BAC,el,L}$ and $f_{BAC,el,aux}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$
Offices	1.1	1.15	1	1	0.85	0.86	0.72	0.72
Lecture halls	1.1	1.11	1	1	0.88	0.88	0.76	0.78
Educational buildings (schools)	1.1	1.12	1	1	0.88	0.87	0.76	0.74
Hospitals	1.2	1.1	1	1	1	0.98	1	0.96
Hotels	1.1	1.12	1	1	0.88	0.89	0.76	0.78
Restaurants	1.1	1.09	1	1	1	0.96	1	0.92
Wholesale and retail buildings	1.1	1.13	1	1	1	0.95	1	0.91
Other types: • Sport facilities • Storage • Industrial facilities • etc.	–	–	1	1	–	–	–	–

Source: Siemens, 2018

Factors for ventilation ($f_{BAC,el}$) – Residential

Not available separately for ventilation residential, but aggregated electric residential can be used as alternative.

Residential building types	**BACS efficiency factors electrical $f_{BAC,el}$**			
	D	**C**	**B**	**A**
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.08	1	0.93	0.92

Source: Siemens, 2018

Factors for lighting ($f_{BAC,el,L}$) – Non-residential

Non-residential building types	Detailed BACS efficiency factors $f_{BAC,el,L}$ and $f_{BAC,el,aux}$							
	D		C		B		A	
	Non energy efficient		**Standard (reference)**		Advanced energy efficiency		High energy performance	
	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$	$f_{BAC,el,L}$	$f_{BAC,el,aux}$
Offices	1.1	1.15	1	1	0.85	0.86	0.72	0.72
Lecture halls	1.1	1.11	1	1	0.88	0.88	0.76	0.78
Educational buildings (schools)	1.1	1.12	1	1	0.88	0.87	0.76	0.74
Hospitals	1.2	1.1	1	1	1	0.98	1	0.96
Hotels	1.1	1.12	1	1	0.88	0.89	0.76	0.78
Restaurants	1.1	1.09	1	1	1	0.96	1	0.92
Wholesale and retail buildings	1.1	1.13	1	1	1	0.95	1	0.91
Other types: • Sport facilities • Storage • Industrial facilities • etc.	–	–	1	1	–	–	–	–

Source: Siemens, 2018

Factors for lighting ($f_{BAC,el}$) – Residential

Not available separately for lighting residential, but aggregated electric residential can be used as alternative.

Residential building types	BACS efficiency factors electrical $f_{BAC,el}$			
	D	C	B	A
	Non energy efficient	**Standard (reference)**	Advanced energy efficiency	High energy performance
• Single family dwellings • Multi family houses • Apartment houses • Other residential or residential-like buildings	1.08	1	0.93	0.92

Source: Siemens, 2018

Chapter 4 Savings calculation for industrial and commercial refrigeration

Commercial and industrial refrigeration systems involve process cooling, performed by a chiller, in which the temperature of a space, a product or a process is mechanically cooled or reduced.

Process chillers within a refrigeration process or appliance are primarily intended to cool down and continuously maintain the temperature of a liquid using a vapour compression cycle, rejecting the heat into the air or ambient water.

- Air–chiller: the unit extracts the heat from the indoor water-based system and transfers it to the outside air.
- Water- chiller: the unit extracts the heat from the indoor water-based system and transfers it to the outdoor water, which might be sent to a water loop system or a ground loop.

The minimum equipment requirements are a compressor provided with an electric motor and an evaporator. Industrial and commercial process cooling chillers are so-called high temperature chillers that can deliver water temperatures of between 2°C and 12°C and have a cooling power of up to 2000 kW (European Commission, 2009).

Comfort cooling is not covered in this document since it is used for air conditioning applications to ensure comfortable temperatures in residential and non-residential buildings.

From a life cycle analysis perspective, the significant environmental impacts of high-temperature process chillers are related to their primary energy consumption during the use phase via greenhouse gas emissions (European Commission, 2018). Therefore, savings calculation methodologies covered in this Priority Action focus on calculating energy, cost, and emission savings from efficiency improvements in commercial and industrial refrigeration systems by implementing more efficient products.

The methodology streamSAVE presents in this document is valid for **new installations of air- or water chilled compression refrigeration units with compressors powered by electrical energy.** However**,** the methodology is limited to compression refrigeration only; cooling systems using free cooling or heat recovery are not covered.

This methodology has been developed in compliance with the Ecodesign Directive (European Commission, 2009). This regulation also sets minimum efficiency levels. It is based on the Seasonal Energy Performance Ratio (SEPR) of high-temperature process chillers at the rated refrigeration capacity of the unit. This seasonal performance metric measures the seasonal energy efficiency of process chillers by calculating the ratio between annual cooling demand and annual energy input. This metric offers the possibility to compare the efficiency of refrigeration units at different operation points regardless of their implementation area, both from a technical and a climatic point of view, giving a realistic indication of the cooling system's real energy efficiency and environmental impact.

The methodology is applicable for water-chilled units with an installed cooling power of up to 1500 kW and air-chilled systems of up to 600 kW. Users must provide the number and power of cooling systems installed at a specific cooling capacity and the full-load hours. The developed methodology also addresses the following challenges:

- **Data collection:**

  It is suggested that Member States develop and maintain a database with national values for the emissions factor [gCO_2/kWh] of each energy carrier. However, indicative EU-wide values are provided with specific data for the primary energy carriers.

- **Definition of baseline:**

  The methodology suggests indicative values to streamline baseline calculations among all MS.

- **Approach to additionality:**

  The requirements of the EU regulations are introduced into the specific final energy consumption of the reference high temperature process chillers to fulfil the criterion of additionality. Therefore, the indicative values are in line with the latest Ecodesign Directive.

- **Assessment of behavioural aspects:**

  Product design influences consumer behaviour, which subsequently influences the impact on climate and the energy efficiency of the product. The methodology does not evaluate behavioural aspects since no empirical data was available on the magnitude of these effects. However, the formula includes the option to consider behavioural aspects and the main potential effects are described.

4.1 Energy efficient compression refrigeration units

This methodology is valid for new installations and the replacement of air- or water-chilled compression refrigeration units. Two different formulas for the calculation of energy savings of the implemented measures are presented

The methodology can be applied in all Member States for a specific project, following the provided indicative values.

4.1.1 Calculation of total final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$TFES = n \cdot Pc \cdot h_{FL} \cdot \left(\frac{1}{\text{SEPR}_{Ref}} - \frac{1}{\text{SEPR}_{Eff}} \right) \cdot f_{BEH}$$

TFES	Total final energy savings [kWh/a]
n	Number of cooling systems installed at a specific cooling power [dmnl]
P_c	Installed cooling power of the cooling system [kW]
h_{FL}	Full-load hours related to the maximum installed cooling power [h]
$SEPR_{Ref}$	Seasonal Energy Performance Ratio of the reference compression refrigeration system [dmnl]
$SEPR_{Eff}$	Seasonal Energy Performance Ratio of the more efficient compression refrigeration system [dmnl]
f_{BEH}	Factor to calculate behavioral aspects [dmnl]

Indicative calculation values for this methodology have been prepared in the following table. Please keep in mind that these values are based on EU-wide data and can be adjusted to national circumstances, in case more specific data is available:

Table 21: Indicative values for final energy savings calculation of refrigeration

	[dmnl]
$SEPR_{Ref}$	5.62
$SEPR_{Eff}$	6
For water-chilled coolers	[dmnl]
$SEPR_{Ref}$	8.76
$SEPR_{Eff}$	11.41
Lifetime of savings	[a]
Lifetime of savings	8

Users should provide the number and power of cooling systems installed at a specific cooling capacity and the full-load hours for **each specific project**. However, some references are given in the following table based on the Eurovent power range of certified units

(Eurovent, 2021). Reference values for full-load hours are not provided since the climate conditions in the European Union highly vary through regions (European Commission, 2009).

Table 22: Reference values for cooling power in refrigeration

For air-chilled coolers	[Pc]
Cooling power	≤ 600 kW
For water-chilled coolers	**[P_c]**
Cooling power	≤ 1,500 kW

Methodological aspects

The presented methodology allows calculating energy savings resulting from replacing conventional process chillers with more efficient ones and for newly installed compression cooling systems. The methodology can be used for industrial and commercial facilities, where the cooling demand of the industrial or commercial refrigeration system remains constant.

The baseline of the methodology is the difference between the annual energy consumption of the reference refrigeration unit versus the more efficient refrigeration system. The parameters used are the SEPR values of the products, which is the ratio between annual cooling demand and annual energy input. For calculating final energy savings of new installations and replacement of units before the end of their lifetime, the $SEPR_{Eff}$ value of the efficient compression cooling system is compared to the $SEPR_{Ref}$ value of an average compression cooling system available on the market.

The formula also foresees the possibility to use factors to account for behavioural effects. However, no specific user behaviour change has been observed in commercial and industrial applications (Moons, 2014).

This type of methodology has been applied already in the Austrian catalogue on bottom-up calculation methodologies (RIS, 2016) and in the multEE project (multEE, 2016), but limited to comfort chillers. The methodology described herein draws on those sources, but adapting the calculations to industrial commercial facilities.

Data sources for indicative calculation values:

To identify the indicative values for the **European Seasonal Efficiency Ratio before** ($SEPR_{Ref}$) **and after** ($SEPR_{Eff}$) **the implementation** of the action, the database of Eurovent certified air-chiller and water-chiller refrigeration units is used. More specifically, the values are based on averages of units available on the market in 2021 and certified according to the LCP-HP (Liquid Chilling Packages and Heat Pumps) Programme (Eurovent, 2021). Values for $SEPR_{Ref}$ have been obtained as an average of all units with a Eurovent certification. For the more efficient installation, $SEPR_{Eff}$, all certified units with a SEPR exceeding the reference value have been averaged.

The **lifetime of the measure** (a) is taken from the Commission Recommendation about transposing the energy savings obligations (European Commission, 2009).

Reference values for the cooling power capacity (P_c) are based on the range of certified units covered by the LCP-HP Programme of Eurovent (Eurovent, 2021) which includes air-chilled units of up to 600 kW and water-chilled units of up to 1,500 kW.

4.1.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 4.1.1 on calculation of final energy savings (Article 7).

The effect on primary energy consumption can be calculated with the following equation:

$$EPEC = FEC_{Baseline} \cdot f_{PE,electricity} - FEC_{Action} \cdot f_{PE,electricity}$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$f_{PE,electricity}$	Factor to convert final to primary energy savings for electricity [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action

The EU 27 average factor of electricity to convert from final to primary energy savings is listed in chapter 1.1.1 of this report.

4.1.3 Overview of costs related to the action

Overview of relevant cost components

The costs associated with the transition to a more efficient refrigeration process include following cost components:

- Investment costs: The investment considers the purchase cost of the equipment, accounting for process chiller, equipment transport to the site, construction, assembly, equipment rental, as well as labour and contractor fees.
- Variable operating costs: The operating costs of hot temperature process chillers are due to their electricity consumption. Annual prices of electricity can be consulted in section 1.2.1.
- Repair and maintenance costs.

Table 23 presents indicative values for these cost components, excluding taxes. The operating costs can be evaluated considering the fuel prices per energy carrier as presented in section 1.2 and the fuel consumption or savings calculated with the formulas presented in the above methodology.

Table 23: Indicative values for cost components of refrigeration

Investment costs	[euro2010]
Air-Cooled	[2,354 – 2,999]
Water-Cooled	[1,610 – 3,689]
Operating costs	**[euro/a]**
Electricity	Electricity consumption according to above methodology; Prices for electricity are included in section 1.2.1.
Maintenance costs	**[euro2010/a]**
Air-Cooled	[1,007 – 3,107]
Water-Cooled	[840 – 7,340]
Lifetime	**[a]**
	8 years

Methodological aspects

The cost data should be taken as indications and in no case as an estimated value for design, since these figures may vary greatly depending on the capacity of the process chiller, the region, and the year of implementation, among other factors. The investment price is strongly dependent on the selected capacity of the process chiller. The price range provided for hot temperature process chillers corresponds to air-chilled coolers with a capacity lower than 400 and for water chillers coolers between 400 and 1000 kW.

The total costs are also determined by the additional costs of maintenance & repair. The above values have been annualized, taking into account the lifetime of the equipment (8 years, considering 4,380 load hours per year). In this way, even though costly maintenance is not expected in the first years, the user can estimate the costs considering the estimated years of life.

Data sources for indicative cost values

The indicative cost values are based on the preparatory studies in frame of the Ecodesign Directive (Bio Intelligence Services S.A.S, 2011). It should be remarked that the presented prices depend primarily on external elements (market prices of equipment, labour costs, hours of use, equipment power, etc.), so they should be considered as an indication. Moreover, the costs can also further develop due to technical developments.

4.1.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = TFES \cdot f_{GHG,electricity} \cdot 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
TFES	Total final energy savings [kWh/a]
$f_{GHG,electricity}$	Emission factor for electricity [g CO_2/kWh]

The total final energy savings (TFES) can be taken from the savings calculation for Article 7 in chapter 4.1.1.

The emission factor for electricity is listed in chapter 1.3 of this report.

Data sources for indicative calculation values:

The **emission factor for electricity (**$f_{GHG,electricity}$**)** is taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU).

National values for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF). The shares of energy carriers can be adapted to national level according to the "Complete energy balances" of the EUROSTAT database.

4.2 Bibliography for commercial and industrial refrigeration systems

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Chapter 5 Savings calculation for electric vehicles

Electric vehicles (EVs) are means of transportation (including two-wheel vehicles, cars, trucks, buses, trains, or ships) in which electric motors provide, partially or totally, the mechanical power required to produce motion. The electric vehicle infrastructure consists of public and private charging stations to recharge electric vehicles.

In comparison with other technologies, electric motor drives have much better efficiency, very low maintenance requirements, low noise levels and no local emissions (ensuring higher air quality). Depending on the primary energy used, the generation of electricity may produce emissions, but there is a strong ongoing trend towards the decarbonisation of the electricity supply, therefore electric vehicles ensure a reduction in primary energy consumption and GHG emissions. Regarding efficiency improvements, electric motors have higher tank-to-wheel efficiency (73–90%) than internal combustion engines (16 – 37%). Additionally, EVs recuperate kinetic energy through regenerative braking and the consumption of electric motors is mainly dependent on their instantaneous power output rather than their maximum power (Weiss, 2020).

The methodology presented in this document targets the **fuel switching between conventional and electric vehicles.** Therefore, the savings are not only ensured with higher conversion efficiency but also with fuel switching from the use of fossil fuels to electricity, which is increasingly generated based on renewable resources.

streamSAVE performed a stakeholder consultation (October-November 2020) revealing that many stakeholders find gaps in the availability and reliability of historic data to calculate baselines and ex-post evaluations and there is also the need for methodologies to evaluate the savings when there is fuel switching. Therefore, the objective was to develop a uniform methodology to calculate the savings from electric vehicles (fuel switching), considering different types of vehicles (cars, vans, buses, trucks) and different fuel options (including hybrid options).

The developed methodology also addresses the following challenges:

- **Data collection:**

  It is suggested that Member States use their national values from the monitoring of CO_2 emissions of vehicles. However, indicative EU-wide values are provided with typical data for the main types of vehicles.

- **Definition of baseline:**

  The methodology suggests indicative values to streamline baseline calculations among all Member States, based on the EU standards and monitored data for CO_2 emissions.

- **Approach to additionality:**

  The requirements of the EU regulations will be introduced into the specific final energy consumption of the reference vehicles to fulfil the criterion of additionality.

- **Prevention of double-counting of savings:**

  The methodology is specific for electric vehicles, and there is the risk of double-counting of savings. Such risk would be associated with savings from charging infrastructure, but the savings are always ensured by the electric vehicles and not directly by the infrastructure. Additionally, future targets for the charging infrastructure can limit the inclusion of these savings in Article 7. Therefore, the charging infrastructure is not evaluated in this methodology.

- **Assessment of behavioural aspects:**

  The methodology allows to include behavioural effects. In this section we explain possible values for rebound effects when shifting towards EVs.

5.1 Fuel Switching to Electric Vehicles

The methodology is applied to fuel switching between conventional and electric vehicles. The conventional options include vehicles using diesel, petrol and LNG, as well as hybrid options. The more efficient options include electric vehicles.

This methodology can be used both for **newly purchased vehicles as well as the replacement of another, "conventional" vehicle.** Even though the purchase of a new vehicle leads to increased energy consumption, it is assumed that otherwise, a "conventional" vehicle with even higher energy consumption would have been purchased.

5.1.1 Calculation of final energy savings (Article 7)

The final energy savings can be calculated with the following equation:

$$TFES = \left(sFEC_{ref} - sFEC_{eff}\right) \cdot \frac{DT}{100} \cdot n \cdot f_{BEH}$$

TFES	Total final energy savings [kWh/a]
$sFEC_{ref}$	Specific final energy consumption of the reference vehicle [kWh/100 km]
$sFEC_{ref}$	Specific final energy consumption of the efficient vehicle [kWh/100 km]
DT	Average yearly distance travelled with the vehicle [km/a]
n	Number of efficient vehicles purchased [dmnl]
f_{BEH}	Factor for correction of behavioural effects [dmnl]

The specific energy consumption considering different options of fuels can be calculated using the following equation.

$$sFEC = sFC \cdot NCV \cdot \left(1 - Share_{DT,E}\right) + sEC \cdot Share_{DT,E}$$

sFEC	Specific final energy consumption of the vehicle [kWh/100 km]
sFC	Specific fuel consumption of the vehicle [l/100 km]
sEC	Specific electricity consumption of the vehicle [kWh/100 km]
NCV	Net Calorific Value for the fuel used in the vehicle [kWh/l]
$Share_{DT,E}$	Share of the distance travelled using electricity in the vehicle [%]

Indicative calculation values for this methodology have been prepared in Table 24 to Table 29. Please keep in mind that these values are based on EU-wide data and need to be adjusted to national circumstances: To be in line with EU regulations, the values depend on the year of implementation of the measure. For the baseline situation, the methodology offers both values that depend on the fuel used as well as on aggregated average values (EU average) considering the shares per type of car sold, therefore also allowing the evaluation of savings without detailed knowledge of the vehicles replaced.

Table 24: Indicative values for the specific energy consumption of the reference vehicle

$sFEC_{ref}$	[kWh/100 km]
Car – Petrol (2020)	38.08
Car – Diesel (2020)	35.61
Car – LPG (2020)	41.82
Car – LNG (2020)	41.10
Car – PHEV (2020)	24.80
Car – EU average (2020)	36.82
Car – Petrol (2025)	32.39
Car – Diesel (2025)	30.29
Car – LPG (2025)	35.57
Car – LNG (2025)	34.96
Car – PHEV (2025)	15.15
Car – EU average (2025)	31.26
Car – Petrol (2030)	23.81
Car – Diesel (2030)	22.27
Car – LPG (2030)	26.15
Car – LNG (2030)	25.70
Car – PHEV (2030)	13.92
Car – EU average (2030)	23.01
Van – Diesel (2020)	55.11
Van – Diesel (2025)	46.86
Van – Diesel (2030)	38.61
Truck or Bus – Diesel	312.53

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Table 25: Indicative values for the specific energy consumption of the efficient vehicle

$sFEC_{eff}$	[kWh/100 km]
Car BEV	12.4
Van BEV	24.6
Truck and Bus BEV	130.2

Table 26: Share of the distance travelled using electricity for PHEVs

$Share_{DT,E}$	[%]
PHEV 2020	46.6
PHEV 2025+	84.6

Table 27: Indicative values for the distance travelled

DT	[km/a]
Car	13,740
Van	17,480
Bus	55,570
Truck	77,800

Table 28: Indicative values for the Net Calorific Value of the used fuel

NCV	[kWh/l]
Petrol	9.23
Diesel	10.27
Liquefied petroleum gases	7.23
Natural gas liquids	6.25
Biofuels	7.5

Table 29: Indicative values for the emission factors of conventional and electric vehicles

$f_{GHG,ec}$	[g CO_2/kWh]
Petrol	249.48
Diesel	266.76
Liquefied petroleum gases	227.16
Natural gas liquids	231.12
Electricity	133.3

Table 30: Indicative values for the lifetime of savings of electric vehicles

Lifetime of savings	[years]
	10 years

Methodological aspects:

The methodology is based on the difference between the specific final energy consumption (or primary energy consumption in the case of Article 3) of the reference versus the more efficient vehicle. The specific energy consumption is given in kWh/100 km, being, therefore, the consumption multiplied by the average distance travelled with the vehicle. The methodology also has the option to include the impact of behavioural factors, such as the rebound and spill-over effects.

The main formula was based on the formula developed by the multEE project (multEE, 2017) and used in the Austrian catalogue (Anlage 1 BGB1. II, Nr. 172, 2016). In addition, the evaluation of the specific energy consumption was added, to allow for the estimation of savings for hybrid options and different types of vehicles. Therefore, the second formula describes the specific energy consumption based on the consumption of fuel and electricity, the energy density of the used fuel as well as the share of the distance travelled using electricity or fuel. When evaluating non-hybrid options, the formula is simplified, using only the term associated with the fuel or electricity and without the need for including data about the share of distance travelled per mode.

Data sources for indicative calculation values:

- The **specific energy consumption of the reference vehicles** ($sFEC_{Ref}$) was calculated based on the CO_2 emission performance standards for cars and vans (EC, 2021), being considered 95 gCO_2/km (2020), 80.8 gCO_2/km (2025), 95 gCO_2/km (2030) for cars and 147 gCO_2/km (2020), 125 gCO_2/km (2025), 103 gCO_2/km (2030) for vans. Therefore, the indicative values present an update of the reference values within the timeframe 2020-2030. Additionally, the values can be updated every year using the average carbon dioxide emissions from new cars (EEA, 2021a) and vans (EEA, 2021b), considering the most recent data. The EU average values for each year were assessed considering the percentage of vehicles in use per fuel type, presented in (ACEA, 2021). For Plug-in Hybrid Electric Vehicle (PHEV) the share of energy consumption between fuel and electricity presented in Table 26 was used. For buses and trucks, the preliminary CO_2 baseline for heavy-duty vehicles was used (ACEA, 2020)[3]. All data can be adjusted to national circumstances by using data for the sold vehicles in each country. The energy and fuel consumptions were then calculated considering the indicative values for the Net Calorific Value (Table 28) and the indicative values for the emission factors (Table 29). Such values can be adjusted to national circumstances using the average emissions in each country.
- The values for **specific energy consumption of the efficient vehicles** ($sFEC_{Eff}$) were based on the typical electricity consumption of battery electric vehicles (BEV) from the following sources for cars (JEC, 2020a), vans (EV-database, 2021), trucks and busses (JEC, 2020b).

[3] Determination of CO_2 emissions using the VECTO tool, according to Regulation (EU) 2017/ 2400, using CO_2 data as determined by VECTO from manufacturers, and subsequently aggregated and anonymized at fleet level for the European market.

- The values for the **share of the distance travelled using electricity for PHEVs** ($Share_{DT,E}$) were based on (JEC, 2020a).
- The **distance travelled** (DT) was assessed considering the road traffic statistics averaged for EU-27 by type of vehicles (in million vehicle-kilometres) (Eurostat, 2021a) and the number of vehicles by type (ACEA, 2021). Such values can also be adjusted to national circumstances using national statistics.
- The **Net Calorific Values** (NCV) of the used fuels are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU).
- The **emission factors** ($f_{GHG,ec}$) for energy carriers are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU). National values for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF) (UNFCCC, 2021).

The formula includes the option to take into account **behavioural aspects**, despite not presenting an indicative value, since behavioural aspects are highly dependent on the specific technology, users, prices, etc, and are preferably based on empirical data (e.g. surveys). However, the main effects and typical numbers to the savings impact are presented hereafter:

Direct rebound effects occur when a decrease in the cost of using a product results in increased use of the product. More efficient engines make it possible to build more economical vehicles. Therefore, direct rebound effects occur when the engines become more powerful or when the vehicle is driven more frequently or at a higher speed (Ricardo Energy & Environment, 2020). For instance, the speed and acceleration in EVs can lead to a change in driver behaviour with a potential speed rebound of 20% (Galvin, 2016).

Since fuel-efficient vehicles make the travel cheaper, consumers may choose to drive further and/or more often, thereby offsetting some of the energy savings achieved (Sorrel, 2007). Sorrel (2007) estimates the long-run direct rebound effect for personal automotive transport between 10-30%, reflecting the elasticity of vehicle travel with respect to fuel prices (transportation elasticities). According to the Victoria Transport Institute, a 10% increase in fuel efficiency could actually provide a 7-8% net reduction in fuel consumption and a 1-3% increase in vehicle mileage (Victoria Transport Institute, 2010). However, recent studies show a significant reduction in annual mileage associated with the transition to EVs, with social norms for environmentally conscious consumption having a higher impact than a rebound effect (Seebauer, 2017), (Huwe, 2020).

There are also impacts on the road freight transport sector, since environmental policy and technology improvements in vehicle engines and fuels have improved fuel efficiency per vehicle. Through lower fuel use per tonne-kilometre driven, the costs for transport of goods per unit has decreased and longer distances plus more frequent journeys have become cost-efficient. Despite the drop in specific fuel consumption of trucks, energy consumption in freight transport has increased significantly (Maxwell, 2011).

5.1.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 5.1.1 on calculation of final energy savings (Article 7).

The effect on primary energy consumption can be calculated with the following equation.

$$EPEC = FEC_{Baseline} \cdot \sum_{ec} (share_{ec,Baseline} \cdot f_{PE,ec}) - FEC_{Action} \cdot \sum_{ec} (share_{ec,Action} \cdot f_{PE,ec})$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$Share_{ec}$	Share of final energy carrier on final energy consumption [dmnl]
$f_{PE,ec}$	Final to primary energy conversion factor of the used energy carrier [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action
ec	Index of energy carrier

Indicative calculation values for estimating the effect on primary energy consumption are prepared in Table 31. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 31: Indicative values for the share of energy carriers in conventional and electric vehicles

$share_{ec}$ – Baseline	[%]
Petrol	24.5 %
Diesel	66.7 %
Liquefied petroleum gases	2.2 %
Natural gas liquids	0.7 %
Biofuels	5.8 %
Electricity	0.1 %
$share_{ec}$ – Action	**[%]**
Electricity	100 %

EU-27 average values for the conversion factors from final to primary energy of the above-mentioned energy carriers are listed in chapter 1.1.1 of this report.

5.1.3 Overview of costs related to the action

Overview of relevant cost components

The costs associated with the transition to EVs are not only associated with the initial investment cost of the vehicle, but also with other cost components, such as:

- Investment: Depreciation and interest associated with the initial cost of the vehicle, as explained in section 1.2.2 on discounting.
- Operating costs: Operating costs of the vehicle due to the fuel and energy consumption, which is strongly impacted by the behaviour of the driver.
- Maintenance costs: Repair, maintenance and tires of the vehicle.

EVs are often perceived as an expensive option due to the high battery costs which drive up the purchase price, but other cost components, such as operating and maintenance costs are usually lower in comparison to ICE (internal combustion engine) vehicles (Leaseplan, 2020). Therefore, EVs can be a less expensive option over their lifetime. Table 32 presents indicative values for the several cost components, excluding taxes. The operating costs can be evaluated considering the fuel prices per energy carrier presented in section 1.2 and the fuel consumption or savings calculated with the formulas presented in the above methodology.

Table 32: Indicative values for cost components of electric vehicles (excl. taxes or fiscal incentives)

[euro2021]	Investment costs
Small Car – ICE	16,855
Small Car – BEV	25,510
Mid-Size – ICE	22,690
Mid-Size – BEV	30,690
Large Car – ICE	50,840
Large Car – BEV	81,610
Van – BEV	53,660
Bus – BEV	235,200
[euro2021/a]	Maintenance costs
Car – ICE	794
Car – BEV	397
[a]	Lifetime
	10 years

Note: BEV: Battery electric vehicle; ICE: Internal combustion engine

Methodological aspects:

The future evolution of such costs should also be taken into account since a strong evolution of the investment costs is expected. Despite already presenting a lower cost in some cases during its lifetime, EVs have a higher initial investment cost, but due to the falling battery costs, new vehicle architectures, and dedicated production lines, EVs are expected to have lower initial costs, on average, even before subsidies: electric cars and vans will become cheaper to produce than fossil-fuelled vehicles for every light vehicle segment across Europe from 2027 at the latest. Electric sedans (C and D segments) and sport utility vehicles will be as cheap to produce as petrol vehicles from 2026, while small cars (B segment) will follow in 2027. This is illustrated in the figure below, based on (BloombergNEF, 2021).

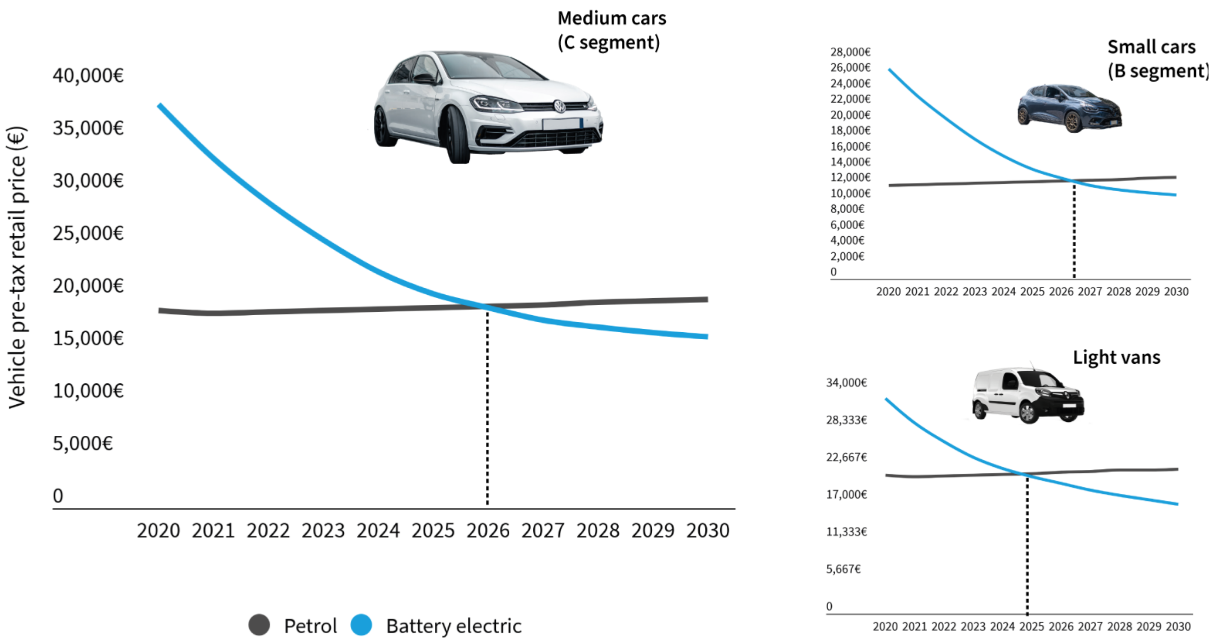

Figure 8: Evolution of costs for different segments of petrol and electric vehicles in Europe

Data sources for indicative cost values:

The investment costs include only the pre-tax retail prices, therefore excluding taxes (VAT and other vehicle taxes) and other administrative and registration costs. Based on AVICENNE ENERGY (2021), different similar options of ICE and EV were compared for the investment costs: using for the small car a Peugeot 208 and a Peugeot e208, for the mid-size car a VW New Golf and a VW eID3, and for the large car a BMW 5 Series and a Tesla Model S. The costs were obtained from the average on the Portuguese market (VolanteSIC, 2021). For vans, the data result from the average of costs collected from vehicles available in online databases, such as (EV-database, 2021). For buses, the value is the average of the values presented in (Transport & Environment, 2018) and (JRC, 2020).

The maintenance costs were recalculated considering the data presented in AVICENNE ENERGY (2021) excluding taxes and considering the same distance travelled, as presented in Table 27 (13,740 km/year) for the savings estimations.

5.1.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = \left[FEC_{ref} \cdot \sum_{ec}\left(share_{ec,ref} \cdot f_{GHG,ec}\right) - FEC_{eff} \cdot \sum_{ec}\left(share_{ec,eff} \cdot f_{GHG,ec}\right)\right] \cdot 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
FEC	Annual final energy consumption [kWh/a]
$share_{ec}$	Share of final energy carrier on final energy consumption [%]
$f_{GHG,ec}$	Emission factors of final energy carrier [t CO_2/kWh]
ref	Index for the baseline situation of the action
eff	Index for the situation after the implementation of the action
ec	Index of energy carrier

The final energy consumption (FEC) of the baseline and the action can be taken from the savings calculation for Article 7 in chapter 5.1.1.

Indicative calculation values for the estimation of greenhouse gas savings are prepared in Table 33. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 33: Indicative values for the share of energy carriers in conventional and electric vehicles

$share_{ec}$ - Baseline	[%]
Petrol	24.5 %
Diesel	66.7 %
Liquefied petroleum gases	2.2 %
Natural gas liquids	0.7 %
Biofuels	5.8 %
Electricity	0.1 %
$share_{ec}$ - Action	**[%]**
Electricity	100 %

Values for the emission factors of the above-mentioned energy carriers are listed in chapter 1.3 of this report.

Data sources for indicative calculation values:

- The **emission factors** ($f_{GHG,ec}$) for energy carriers are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU). National values for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF) (UNFCCC, 2021).
- The **share of the respective energy carrier** on the final energy consumption was determined using the EU27 (2019) Eurostat data for the final consumption in the road transport sector (Eurostat, 2021b). The shares of energy carriers can be adapted to the national level according to the “Complete energy balances” of the EUROSTAT database (Eurostat, 2021b).

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Chapter 6 Savings calculation for lighting systems including public lighting

Lighting is the deliberate use of light to achieve practical or aesthetic effects. Lighting includes the use of both artificial light sources like lamps and luminaires/light fixtures, as well as natural illumination by capturing daylight (using windows, skylights, or light shelves). Proper lighting can enhance task performance, improve the appearance of an area, increase security, or have positive psychological effects on occupants. Lighting systems can be found in everyday life, indoor and outdoor, during day and night, for instance in buildings, households, monuments, gardens, pavements and roads.

There are many different terms to refer to lighting systems that light up outdoor environments. The most common terms are "public lighting", "outdoor lighting", "street lighting" and "road lighting". The methodology developed by streamSAVE follows the most recent EU GPP – European Green Public Procurement Criteria for Road Lighting and traffic signals recommendations (European Commission. Joint Research Centre & VITO, 2019a), comments received from different streamSAVE stakeholders and uses the term "road lighting" that is also better aligned with EN 13201 (CEN, 2014) and CIE 115 (Commission Internationale de L'Eclairage, 2010).

The methodology presented in this document targets the **replacement of existing road lighting systems** for more energy efficient technologies. It includes the replacement of old light sources by new, more efficient LED light sources and lighting control technologies.

From a life cycle analysis perspective, the main environmental impacts of road lighting systems are related to their energy consumption during the use phase (European Commission. Joint Research Centre & VITO, 2019a). This impact can be reduced in several ways, by using luminaires and light sources combinations with a higher efficiency, by implementing light control systems to, for instance, dim during periods of low road use and by adequately developing the lighting project to prevent unnecessary over-lighting. The energy savings provided by the implemented measures will contribute to the reduction of electricity consumption and CO_2 emissions. The replacement of the old light source technologies by LED light sources also provides a longer lifetime for savings and a significant reduction of maintenance costs, decreasing the system's life cycle cost.

streamSAVE performed a stakeholders consultation revealing that many stakeholders find it easy to calculate savings, but there are some gaps in the methodologies being used by Member States that offer several challenges. Thus, the developed methodology addresses the following collected challenges:

- **Data collection:**

  It is advised that MS develop and maintain a database with the installed technology characteristics and the replacements performed, for future track record and improved assessment of savings and emission reductions.

- **Definition of baseline:**

  The developed methodology suggests two different formulas with indicative values that will offer the possibility to streamline the baseline calculations among MS.

- **Approach to additionality and consideration of Ecodesign standards:**

  The requirements of the EU regulations are introduced into the specific final energy consumption of the reference lighting technologies to comply with the criterion of additionality. Also, the indicative values follow the requirements of the latest Ecodesign standards.

- **Prevention of double counting of savings:**

  The formulas can calculate the savings provided by two different saving measurements at the same time: replacement of light sources and implementation of lighting control systems.

- **Assessment of behavioural aspects:**

  In road lighting systems, behavioural aspects are not as relevant as for other lighting systems. The methodology does not directly evaluate behavioural aspects, but the formula includes the option to consider rebound effects.

- **Calculation of energy savings through lighting controls:**

  The two formulas prepared for the methodology offer the possibility to calculate the energy savings provided by the implementation of lighting control systems.

During streamSAVE's stakeholder consultation, it was mentioned that besides the efficiency of light sources and systems, other criteria such as lighting levels and quality of service should be considered. The presented methodology addresses the challenges strictly related to the calculation of energy and GHG savings as well as cost effectiveness. To guarantee that all requirements are fulfilled, it is therefore recommended to follow the relevant European and national standards and procedures, namely the performance requirements on EN 13201-2 (CEN, 2016), when implementing the measures and developing projects for new road lighting systems.

6.1 Energy efficient road lighting systems

This methodology deals with the replacement of existing road lighting systems to more energy efficient technologies. It provides two different formulas for the calculation of energy savings that account not only for the replacement of existing light points, but also for the installation of lighting control technologies.

The methodology can be applied in all Member States, following the provided indicative values and indications.

6.1.1 Calculation of final energy savings (Article 7)

In the methodology developed, two different formulas can be used, depending on the availability of data. The **first formula** follows a ***"project-based approach"*** and the **second formula** a more ***"simplified approach"***.

Project-based approach (first formula):

The following formula can be used when the power of the existing and of the new light points are known, extended by the possibility to include savings provided by lighting control technologies, if their dimming levels operation is known.

$$TFES = \left[\left(N_{ref} \cdot \sum_{i=0}^{n} \frac{(P_{ref} \cdot t_{ref\,i} \cdot D_{ref\,i})}{1000}\right) - \left(N_{eff} \times \sum_{i=0}^{n} \frac{(P_{eff} \cdot t_{eff\,i} \cdot D_{eff\,i})}{1000}\right)\right] \cdot f_{BEH}$$

TFES	Total final energy savings [kWh/a]
N_{ref}	Number of light points in the old/inefficient system [dmnl]
N_{eff}	Number of light points in the new/efficient system [dmnl]
P_{ref}	Power of each light point of the old/inefficient system, including lamp and other components on the luminaire (e.g. control gear and communication/control units) [W]
P_{eff}	Power of each light point of the new/efficient system, including lamp and other components on the luminaire (e.g. control gear and communication/control units) [W]
$t_{ref\ i}$	Annual operating time [h/a] of light points in the old/inefficient system in dimming level "i" ($D_{ref\ i}$)
$D_{ref\ i}$	Percentage of working light points power [%], in the old/inefficient system, during the dimming level "i"
$t_{eff\ i}$	Annual operating time [h/a] of light points in the new/efficient system in dimming level "i" ($D_{ref\ i}$)
$D_{eff\ i}$	Percentage of working light points power [%], in the new/efficient system, during the dimming level "i"
f_{BEH}	Factor for correction of behavioural effects [dmnl]
i	Dimming levels "i", being "0" the lighting full power mode
n	Total number of dimming levels

Indicative calculation values for this formula have been prepared in the following table.

Table 34: Indicative values for the final energy savings of road lighting, first formula

Total annual operating time	[h/a]
Total annual operating hours of lighting system (sum of time with and without dimming, that must be equal to $\sum_{i=0}^{n} t_{ref\ i}$ and $\sum_{i=0}^{n} t_{eff\ i}$)	4,015
Factor for correction of behavioural effects	**[dmnl]**
Factor for correction of behavioural effects (f_{BEH})	1
Lifetime of savings	**[a]**
Lifetime of savings	13 years

For the calculation of the **power of each light point of the old/inefficient system (P_{ref})**, as well as for the high intensity discharge (HID) lamps, the following formula should be used to include the energy losses of the control gear:

$$P_{ref} = \left(\frac{P_{ls}}{\eta_{control\ gear}}\right)$$

P_{ref}	Power of each light point of the old/inefficient system, including lamp and other components on the luminaire (e.g. control gear and communication/control units) [W]
P_{ls}	Power of the light source [W]
$\eta_{control\ gear}$	Efficiency of the control gear at full load [%]

The next table presents the indicative values for the control gear efficiency of high intensity discharge (HID) lamps, needed for the calculation of the baseline situation.

Table 35: Indicative values for control gear efficiency of HID lamps

Power of the light source (P_{ls}) [W]	Minimum control gear efficiency ($\eta_{control\ gear}$) [%]
$P_{ls} \leq 30$	78
$30 < P_{ls} \leq 75$	85
$75 < P_{ls} \leq 105$	87
$105 < P_{ls} \leq 405$	90
$P_{ls} > 405$	92

Simplified approach (second formula):

A more simplified approach is presented in the next formula. It can be used in the case of lower data availability and when an equivalence between the power of the existing and the new light points needs to be assumed. The formula also offers the possibility to include savings provided by lighting control technologies, using predefined dimming strategies.

$$TFES = \left[\sum_{j=1}^{n} (N_j \cdot ES_j \cdot LC_j)\right] \cdot f_{BEH}$$

TFES	Total final energy savings [kWh/a]
N_j	Number of light points in the lighting system "j" [dmnl]
ES_j	Indicative value for the Energy Savings of each light point in the lighting system "j", according to the table below [kWh/a]
LC_j	Factor to account for the savings according to the lighting control strategy used in the lighting system "j", according to the table below [dmnl] In the absence of light control technologies, this factor is "1".
F_{BEH}	Factor for correction of behavioural effects [dmnl]
j	Lighting system "j"
n	Total number of lighting systems

Indicative calculation values for this formula have been prepared in the next table, using a total operating time of 4,015 hours per year. The **Energy Savings** (ES_j) per light point are presented according to a conversion table between the old and new technology.

Table 36: Indicative values for the final energy savings of road lighting, second formula

Old/inefficient light point		New/efficient light point		Energy savings (ES_j) [kWh/a]	Value for the ratio (LC_j)	
Technology	Lamp power (W)	Technology	Light point power (W)		Dimming to 50% for 7 h/day	Dimming to 50% for 5 h/day
High-Pressure Sodium (HPS)	400	Light Emitting Diode (LED) with at least 120lm/W	250	777.76	1.41	1.29
	250		160	471.12	1.43	1.31
	200		125	388.88	1.41	1.29
	150		95	286.68	1.42	1.30
	100		60	219.76	1.35	1.25
	70		40	169.40	1.3	1.22
	50		30	115.28	1.33	1.24
Metal-Halide (MH)	400	Light Emitting Diode (LED) with at least 120lm/W	300	577.76	1.66	1.47
	250		180	391.12	1.59	1.42
	175		125	277.76	1.57	1.41
	150		110	226.68	1.62	1.44
	70		50	129.40	1.49	1.35
Factor for correction of behavioural effects				[dmnl]		
Factor for correction of behavioural effects (f_{BEH})				1		
Lifetime of savings				[a]		
Lifetime of savings				13 years		

Methodological aspects:

The first formula presented on this methodology is based on a *"project approach"* to calculate energy consumption of lighting systems, based on simple active power multiplied by the number of operating hours. The baseline is defined using the actual power of the light points of the old/inefficient lighting system. It is recommended that Member States, if not yet available, develop and maintain a database with the characteristics of the installed road lighting technologies and the replacements performed, to allow for an accurate baseline calculation and monitoring.

The formula also offers the possibility to account for savings by using light dimming control technologies. If a light dimming control technology was installed on the old/inefficient system, it can also be accounted for in the baseline. If not, the equation term $\sum_{i=0}^{n}[P_{ref} \times t_{ref\,i} \times D_{ref\,i}]$ will be equal to $P_{ref} \times 4015\,h/a$. The same applies for the new and more efficient lighting system: if no control is used to perform the light dimming, then the term $\sum_{i=0}^{n}[P_{eff} \times t_{eff\,i} \times D_{eff\,i}]$ will be equal to $P_{eff} \times 4015\,h/a$.

The dimming levels are defined using the "percentage of working light points power" (D_i) and the "annual operating time" (t_i), that can be calculated based on the "average daily operating time" (h_i), multiplied by 365 days. For better understanding, the next figure shows how the dimming levels should be defined.

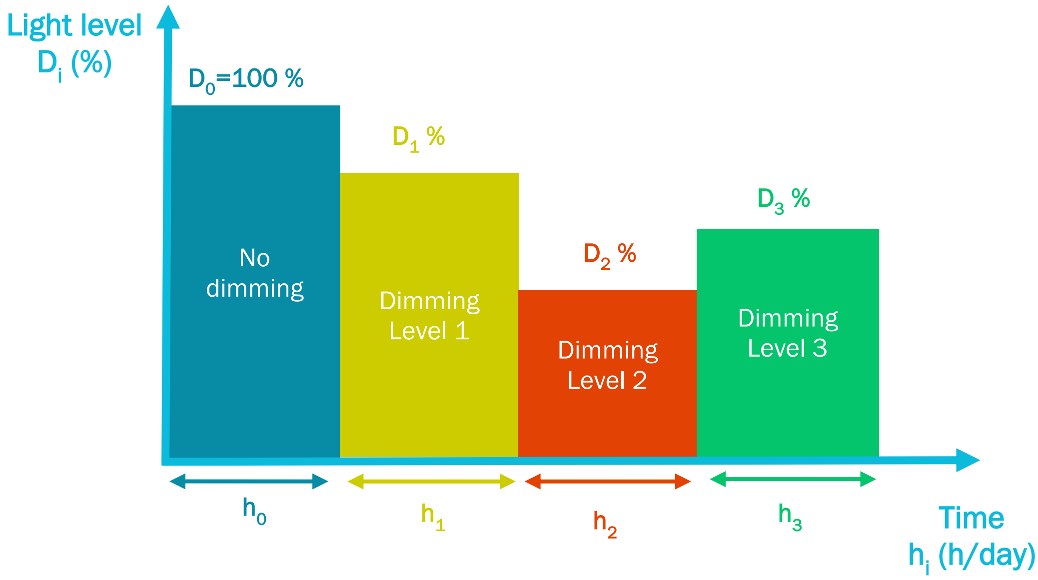

Figure 9: Definition of dimming levels

The different number of light points for the old/inefficient system and for the new/efficient systems is used to account for possible changes in lighting projects. Sometimes, to fulfil the requirements of a new lighting project, there can be the need to increase or decrease the number of lighting points of the system.

This way, the project-based approach can be optimally adapted to each national framework since it accounts for the use of different lighting control technologies (with different dimming strategies) and changes that may occur in newly implemented lighting projects.

The second formula presented is based on a more *"simplified approach"* that is already followed by some countries (e.g. France and Slovenia) when calculating savings provided by more energy efficient lighting systems. The indicative values were obtained considering the below mentioned assumptions and supporting publications.

The methodology does not directly evaluate behavioural aspects, but the formulas include the option to consider behavioural aspects.

Data sources for indicative calculation values:

The **total annual operating hours**, which is equal to the sum of the terms in the formula $\sum_{i=0}^{n}[t_{ref\ i}]$ and $\sum_{i=0}^{n}[t_{eff\ i}]$, is based on the globally accepted value of 11 hours per day (4,015 hours per year). This is the value suggested by the most recent EU GPP (European Commission. Joint Research Centre & VITO, 2019a) and an analogous value (4,000 hours per year) has been used in all the European reference documents regarding road lighting systems, from the EuP Lot 9 (Van Tichelen et al., 2007), to the EuP Lot 37 (Van Tichelen et al., 2016) and the most recent EU GPP Criteria for Road Lighting and traffic signals (European Commission. Joint Research Centre & VITO, 2019b). As referred in EuP Lot 37

(Van Tichelen et al., 2016): *"Seasonal changes between winter and summer increase with distance from the equator. Nordic countries have daylight during almost the whole day in summer and are dark (almost) all day in winter. At equinox (21 March and 21 September), day and night periods are equal everywhere over the globe. As a consequence, 4,000 operating hours per year is the universal default value for Street Lighting."*

For calculation simplification reasons, due to the dimming levels definition (hours per day and consequently the total annual hours), and also following the most recent EU GPP, it was decided to use the 11 hours per day or 4,015 hours per year.

The indicative values for the **efficiency of the high intensity discharge (HID) lamps** are based on the requirements of Commission Regulation (EC) No 245/2009 (European Commission, 2009), which are also included in the new requirements of the Commission Regulation (EC) No 2019/2020 (European Commission, 2019a).

In the first formula, no indicative values (Table 34) are suggested for the **dimming levels** and individual annual operating time, so that specific control technology and project values can be used. Road lighting requirements are traditionally dominated by road traffic safety concerns and the perceived security feeling, especially in densely populated areas. Switching off completely the road lighting systems is rarely applied (Van Tichelen et al., 2016) and there are several arguments, although disputable, for not implementing this action (e.g. road security, criminality levels). When using lighting control technologies to perform dimming of the lighting systems, the light levels must comply with EN 13201 or similar national guidelines.

The second formula uses indicative values (Table 36) for **Energy Savings (ES_j)** per light point according to the old/inefficient technology type and lamp power and an equivalent LED lamp power. The power conversion factor between technologies was obtained by taking into account the indicative rated lamp efficacy of the old/inefficient technology, based on the Commission Regulation (EC) No 245/2009 (European Commission, 2009), and the threshold efficacy for LED light sources based on the new requirements of the Commission Regulation (EC) No 2019/2020 (European Commission, 2019a) (i.e. 120.0 lm/W). The lamp power of the old/inefficient technologies are based on market manufacturers research. Since those manufacturers present a wide variety of different values for the LED lamp power, the equivalent power was calculated based on a simple conversion of the required LED lumen output to be equal or surpass the output provided by the old/inefficient technology, rounded to an integer value within 5W intervals. To simplify, it was assumed that within this calculated power, the efficiency for the control gear for LED light sources is included.

For the energy consumption of the old/inefficient technologies, the calculations take into account the minimum efficiency requirements for control gear for HID lamps, based on the Commission Regulation (EC) No 245/2009, which are included in the new requirements of the Commission Regulation (EC) No 2019/2020, and can be seen in the table for indicative values of the first formula (Table 35).

For the second formula, it is suggested to use indicative values for **the factor to account for the savings according to the lighting control strategy (LCj)** presented in Table 36. These values are based on calculations using the savings achieved by installing lighting control technologies on the new/efficient lighting systems, matching the referred control strategy (i.e. dimming percentage and hours per day), according to each proposed technology retrofit.

It is difficult to define indicative values for the dimming level strategies. These are usually defined at national or local level. The suggestions in the above table with the indicative values for the second formula are derived from streamSAVE's analysis of the MS bottom-up methodologies collection across Europe (i.e. Austria, see D2.1); and from the indication on the EU GPP (European Commission, 2018) technical specification core criteria TS3 for minimum dimming performance. The latter suggests that light sources and luminaires shall be installed with fully functional dimming controls that are programmable to set *at least one pre-set level of dimming* down to at least 50 % of maximum light output.

The project **factors for correction of behavioural effects** are suggested to be included in the formula, since these values can be available for each specific project. No indicative values can be provided EU-wide, due to limitations in supporting publications and studies. More information regarding behavioural effects can be found in section 1.1.4.

The indicative value for the **lifetime of savings** is based on the EU Recommendation 2019/1658 that suggests the use of 13 years for road lighting systems (European Commission, 2019b, p. 68).

6.1.2 Calculation of impact on energy consumption (Article 3)

The calculation of final energy savings for Article 3 can be taken from chapter 6.1.1 on calculation of final energy savings (Article 7).

The effect on primary energy consumption can be calculated with the following equation:

$$EPEC = FEC_{Baseline} \cdot f_{PE,electricity} - FEC_{Action} \cdot f_{PE,electircity}$$

EPEC	Effect on primary energy consumption [kWh/a]
FEC	Annual final energy consumption [kWh/a]
$f_{PE,electricity}$	Factor to convert final to primary energy savings for electricity [dmnl]
Baseline	Index for the baseline situation of the action
Action	Index for the situation after the implementation of the action

The EU27 average factor of electricity to convert from final to primary energy savings is listed in chapter 1.1.1 of this report.

6.1.3 Overview of costs related to the action

Overview of relevant cost components:

The cost categories associated with road lighting systems include installation, maintenance, operating (energy), demolition, recycling and final disposal costs (Commission Internationale de L'Eclairage, 2010). Some of these costs are difficult to evaluate, but at least some of the following cost categories should be obtained for a convenient road lighting cost assessment:

- Investment or product & installation costs:
    - product costs of new light sources, control systems and other ancillaries;
    - product costs for poles, foundations and new connections;
    - installation costs, e.g. labour costs, lifting equipment, etc. Average labour wages throughout Europe are included in section 1.2;
- Energy costs (operating costs): operating costs of the lighting system due to electricity consumption. Annual prices of electricity can be consulted in section 1.2.1.
- Maintenance costs: cleaning of the luminaires, light sources and other components replacement during the defined timeframe and other related system maintenance costs.

Table 37 presents indicative values for the different cost categories in a form of an average range per light point.

Table 37: Indicative values for different cost categories of road lighting (excl. VAT)

Cost category	Range of the costs per light point (EURO2016)
Investment costs	[235 to 745] €/ light point
Operating costs (electricity)	Electricity consumption according to above methodologies; Annual prices for electricity are included in section 1.2.1. On average, [6 to 50] €/ light point/year
Maintenance costs	[12 to 31] €/ light point/year
[a]	Lifetime
	13 years

Methodological aspects:

The European project Streetlight-EPC (OÖ Energiesparverband, 2017), that ended in March 2017, collected and published data from about 49 implementation projects of indoor to outdoor lighting systems in 9 European regions. The projects include the replacement of old inefficient technologies for more efficient light sources based on LED technology, using the Energy Performance Contracting (EPC) model approach.

From the published information (StreetLight-EPC, 2017), the projects related to road lighting systems were selected and then further filtered and screened so that they could be used to determine indicative cost values. The filtering included, among others, the year of implementation, the number of light points before and after, the replaced technologies and the data availability of the different cost categories. Based on the selected project list, a range (minimum and maximum) of the different cost categories per light point was calculated, as presented in Table 37. The final selected projects are mainly from the years 2015, 2016 and 2017, and performed the replacement of high-pressure mercury, high-pressure sodium, and metal halide light sources for LED technologies. Besides energy efficiency improvements of the light source, several projects included improvements to parts of the road lighting infrastructure (new poles, foundations, power connections, ancillaries and control systems).

A typical EPC project is delivered by an energy service company (ESCO) and the contract is accompanied with a guarantee for energy savings. A common principle regarding the economics of an EPC project is that the investments in the energy efficiency measure are to be covered by the expected savings on energy costs for the total duration of the contract. It is worth mentioning that the use of the EPC to finance the implementation of an energy efficient measure can introduce other costs inherent to the model itself (transaction costs), possibly increasing the total investment costs. Thus, the presented values can be slightly higher than the market values, due to the use of the EPC model to finance the selected projects.

Many different factors impact the product costs of new light sources, like for instance the light source power, design, quality aspects and level of added features (intelligence, communications, constant light output, etc). This diversity as well as the possible need to acquire new poles and power connections are among the reasons why the range of investment costs can fluctuate so much.

Data sources for indicative cost values:

The source for the indicative cost values was the Streetlight-EPC (OÖ Energiesparverband, 2017) European project, published report (StreetLight-EPC, 2017) using the above-mentioned methodology.

6.1.4 Calculation of greenhouse gas savings

The greenhouse gas savings can be calculated with the following equation:

$$GHGSAV = TFES \cdot f_{GHG,electricity} * 10^{-6}$$

GHGSAV	Greenhouse gas savings [t CO_2 p.a.]
TFES	Total final energy savings [kWh/a]
$f_{GHG,electricity}$	Emission factor for electricity [g CO_2/kWh]

The total final energy savings (TFES) can be taken from the savings calculation for Article 7 in chapter 6.1.1.

The emission factor for electricity is listed in chapter 1.3 of this report.

Data sources for indicative calculation values:

The **emission factor for electricity** ($f_{GHG,electricity}$) is taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU).

National values for the emission factors are reported on a yearly basis to the UNFCCC and are available in Table 1.A(a) of the Common Reporting Formats (CRF). The shares of energy carriers can be adapted to national level according to the "Complete energy balances" of the EUROSTAT database.

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