



Extended guidance for standardized savings methodologies & indicative values

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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 (Winter 2024-2025), 5 new Priority actions has been defined. The main challenges that Member States face when implementing Article 4 and Article 8 of the EED were data collection procedures as well as the lack of quality data. Moreover, the amendment of the revised Energy Efficiency Directive (EU/2023/1791) brings additional challenges to Member States, in particular regarding Article 8 and several requirements of its Annex V.

Next to a general guidance on energy savings calculations for both Article 4 and 8 EED and information on how to assess costs and GHG emissions reduction related to the existing Priority Actions (streamSAVE), this report provides 5 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:

- Deep renovations in buildings;
- IT equipment in data centres;
- Cooling in data centres;
- Heat recovery in ventilation; and
- Public traffic management.

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 will be later integrated on the online Platform of the streamSAVE+: <https://streamsaveplus.eu/priority-actions>.

Introduction

About streamSAVE+

With the ambitious recast of the Energy Efficiency Directive (EED - EU/2023/1791), there is increased pressure on the Member States (MSs) to introduce new policy measures or enhance existing policies to increase significantly energy savings. Supporting countries has never been more relevant and important to better design, adopt and report on energy saving measures. Although a lot has been done to streamline the energy savings calculations (cf. H2020 streamSAVE) and to improve measurement and verification procedures (cf. H2020 ENSMOV), many Member States still need to further improve their approaches to successfully meet their EED targets.

The streamSAVE+ project aims to support Member States in their efforts to achieve their energy efficiency goals and provide highly scalable energy savings in accordance with Articles 4, 5, and 8 of the updated Energy Efficiency Directive. The project's main goal is to streamline energy savings calculations. Particularly for actions - the so called Priority Actions - that still offer substantial savings or for which energy savings can be difficult to evaluate. These actions can cover a variety of sectors, such as electrification in transport, deep renovation and integration of RES for heating in buildings, and improvements in industrial technologies such as refrigeration or electric motors.

Four key activities are envisioned within the project:

- (1) Development of a knowledge hub. Given the importance of deemed savings approaches in Member States' EED reporting streamSAVE+ focuses on streamlining bottom-up calculations methodologies of the Priority 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 the EED articles.
- (2) Facilitation of dialogue among MSs to foster knowledge sharing and peer-to-peer cooperation.
- (3) Capacity building. Assistance to participating countries considering their requirements and needs. In-depth support will be given by technology experts, policy experts and country experts.
- (4) Analysing policies and future trends to establish the data framework and preparation of the policy packages of the participating countries.

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 December 2024 – February 2025, a stakeholder consultation was carried out by the streamSAVE+ consortium in EU Member States. 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+ enhances the understanding of existing energy savings calculation methodologies across various Member States (MSs) by providing a consolidated overview of current bottom-up methodologies, categorised by energy consumption sector and end-use, across the EU-27 and the UK. The methodologies related to the 10 Priority Actions identified in the streamSAVE project have been analysed to assess whether updates are required in response to the Energy Efficiency Directive (EED) recast. Additionally, five newly identified Priority Actions (deep renovations in buildings, IT equipment in data centres, cooling in data centres, heat recovery in ventilation, and public traffic management) have been determined through the survey conducted within the streamSAVE+ community.

This report describes the standardized calculation methodology for each of these new Priority Actions, supporting the implementation of Article 4 and 8 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 will be 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 CO₂ savings.

At the beginning of this guidance, a general chapter is included on Article 8 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 8 requirements. Next to savings estimations, the guidance explains how to perform an assessment of the cost effectiveness and CO₂ 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 a 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://streamsaveplus.eu/priority-actions>.

Chapter 1. Calculation of savings within the EED framework

The EU energy efficiency directive (EED) was originally adopted in 2012 to help the EU and its Member States make energy efficiency improvements of at least 20 % by 2020. The EED places an upper limit on total EU energy consumption and includes a series of provisions to help Member States collectively meet this goal. The EED was amended in 2018 to deliver on the EU objective of at least 32.5 % energy efficiency improvements by 2030 compared with levels projected in the European Commission's 2007 baseline scenario (European Commission, 2018). Under Article 3 of the EED, EU countries set their own national non-binding contributions for energy efficiency for 2030. These targets could be based on primary or final energy consumption, on primary or final energy savings, or on energy intensity. The EED required, however, that when doing so, Member States also express those targets in terms of absolute levels of primary and final energy consumption. To support the achievement of these targets, Article 7 of the EED required Member States to achieve cumulative energy savings over 10-year periods. For the period 2021-2030, this target was set as yearly, new energy savings of 0.8 % of Member States' final energy consumption averaged over 2016-2018. Member States can meet their target through an energy efficiency obligation scheme (EEOS) (Article 7a) and/or alternative measures (Article 7b). Under an EEOS, obligated parties must undertake measures to improve energy efficiency for final consumers. Member States may also implement alternative policy measures which reduce final energy consumption, for example fiscal measures; financial incentives; regulations or voluntary agreements; national energy efficiency funds; and information measures.

By the legislative Fit-for-55 Package (July 2021), the EU Green Deal incentivised more efforts on energy efficiency, so the updated 2030 emissions reduction target of net 55 % compared to 1990 levels - previously 40 % - can be reached. In the REPowerEU plan, presented in May 2022, the Commission proposed to raise the ambition further to reduce the EU's reliance on fossil fuel imports from Russia. In July 2023, the EU adopted the **revised Energy Efficiency Directive ((EU)2023/1791)**, which establishes a framework for achieving an 11.7 % reduction in EU energy consumption by 2030, compared to the 2020 reference scenario projections. The Directive introduces a binding final energy consumption target of no more than 763 Mtoe by 2030 and sets an indicative target for primary energy consumption at no more than 992.5 Mtoe (EU, 2023). Member States shall collectively ensure that these EU-wide targets are achieved, by including an updated national contribution in their 2024 updated NECPs, as stipulated in Article 4 (former Article 3) following the calculation principles set in the new Annex I of the EED recast. According to Article 8 (former Article 7), Member States shall achieve increased, new annual energy savings of 1.5 % per year on average until 2030, starting with 1.3 % in 2024-2025 and progressively increasing to 1.9 % from 2028 onwards. These 2030 targets require substantial acceleration in energy efficiency: in 2022, the final and primary energy consumption levels in the EU-27 were 22% above the newly adopted 2030 targets. Indeed, the Commission's assessment of Member States' 2024 updated NECPs indicates that despite progress towards more efficient energy use, a significant gap remains to reaching the EU's 2030 energy efficiency targets. The aggregated contributions result in a projected final energy consumption of 794.1 Mtoe by 2030, which is 31.1 Mtoe above the final energy consumption target of 763 Mtoe, which translates to an EU target of just 8.1 % (EU, 2025).

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 4 targets as well as Article 8 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 4 and Article 8 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 8). 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 CO₂ 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 4 of the Energy Efficiency Directive recast 2023/1791, Member States contribute to the European targets by providing indicative national 2030 contributions for both final and primary energy consumption, accompanied by indicative trajectories for each. When calculating the national contributions for both FEC and PEC, a Member State has full flexibility on how this will be done, while respecting a comprehensive list of factors and national characteristics set out in the EED (Article 4(3)). Importantly, they can use a formula designed to enable Member States to determine their contributions in a fair and feasible way (Annex 1 of the EED recast) (EU, 2023). When establishing their indicative contributions, each Member State must guarantee that the ambition level of their contribution does not surpass the formula-derived value by more than 2.5%. Member States had to submit their indicative national energy efficiency contributions by 30 June of 2023; and to update this, reflecting the stricter European targets for energy efficiency, by 30 June 2024 in their final updated NECPs.

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 energy consumption - Energy Efficiency Directive [code: PEC_EED]; and, Final energy consumption - Energy Efficiency Directive [code: FEC_EED]) (Eurostat, 2025).

To support the achievement of these goals, Article 8 of the Energy Efficiency Directive requires Member States to achieve yearly new energy savings through an energy efficiency obligation scheme (EEOS) (Article 9) or alternative measures (Article 10) or both. The EED recast kept some of the EED provisions unchanged while, at the same time, introducing some new requirements. In particular, it significantly raised the level of ambition from 2024 onwards (Article 8(1)) of new annual energy savings when calculating the amount of cumulative savings set out for 2021-2030. It impacts both the current (2021-2030) and the future obligation periods (2031-2040 and beyond) of the energy savings obligation. The stricter requirements are shown in the table below, starting with 1.3 % in 2024-2025 and progressively increasing to 1.9 % from 2028 onwards (EU, 2024).

Table 1: Minimum rates of new annual energy savings of final energy consumption as required by Article 8(1). (EU, 2024)

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
0,8 %	0,8 %	0,8 %	1,3 %	1,3 %	1,5 %	1,5 %	1,9 %	1,9 %	1,9 %

Notes:

- New rates applicable as from 2024 are in bold.
- Specific rates apply to Cyprus and Malta (see Section 4.1.2).

Article 9 and Article 10 of the EED recast 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 8(14) of EED recast), 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 8 energy savings. The Annex identifies four main methodologies to calculate final energy savings (EU, 2023):

- **“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”.

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 (EU, 2023). 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 the former Article 7, and how to comply with these requirements (European Commission, 2019). Moreover, guidance on the interpretation of those provisions of Directive (EU) 2023/1791 that have been amended in Article 8 in comparison with Directive 2012/27/EU, is given in **Recommendation (EU) 2024/1590** (EU, 2024). The latter recommendations should be read alongside the former Recommendation (EU) 2019/1658.

A large share of the savings reported under Article 8 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 4 & Article 8

The EED Recast stipulates in Article 4(3) that by 2030, the Union's energy consumption shall be no higher than 992.5 Mtoe of primary energy consumption or 763 Mtoe of final energy consumption. Member States contribute to the European targets by providing indicative national 2030 contributions for both final and primary energy consumption, accompanied by indicative trajectories for each. When calculating the national contributions for both FEC and PEC, a Member State has full flexibility on how this will be done, while respecting a comprehensive list of factors and national characteristics set out in the EED (Article 4(3)). Importantly, they can use a formula designed to enable Member States to determine their contributions in a fair and feasible way (Annex 1 of the EED recast). When establishing their indicative contributions, each Member State must guarantee that the ambition level of their contribution does not surpass the formula-derived value by more than 2.5 %. 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 4 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 4, regardless of what caused this reduction. In contrast, Article 8 is about considering additional final energy savings at the level of a policy action.

Almost all countries set their 2030 Article 4 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 4 target setting. In context of Article 8, Member States should demonstrate that energy savings are not double-counted (Article 8(14)) as well as additional to what would 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 8 saving calculations, the annual energy saving calculations for Article 4 and Article 8 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 8 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 8 only focusses on final energy, for Article 4 both final and primary energy consumption are relevant.

Converting final energy to primary energy savings for Article 4

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

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

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]
fPE	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.

Chyba! Nenalezen zdroj odkazů. 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 4 and of the 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 for 2023 (Eurostat, 2025) was used as data basis for the calculation. However, it should be noted that this approach of calculating the final to primary energy conversion factors is considered a rough estimate; whenever possible, national conversion factors should be used instead.

Table 2: Primary energy factors (f_{PE}) per energy carrier

Energy carrier	factor final to primary [-]
Electricity	2.064
District heat	1.592
Natural gas	1.007
Gas/Diesel oil	1.117
Motor gasoline	1.117
Biodiesels	1.002
Biogasoline	1.002
Other liquid biofuels	1.002
Biogas	1.026
Wood/wood waste	1.002
Other primary solid biomass	1.002
Kerosene (other than jet kerosene)	1.117
Liquefied petroleum gases	1.117
Naphtha	1.117

Natural gas liquids	1.117
Petroleum coke	1.117
Refinery gas	1.117
Residual fuel oil	1.117
White spirit and SBP	1.117
Other petroleum products	1.117
Anthracite	1.002
Lignite	1.002
Charcoal	1.002
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	1.089
Coke oven gas	1.089
Oxygen steel furnace gas	1.089
Oil shale and tar sands	1.000
Peat	1.002

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 electricity¹ 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 8

It should be kept in mind that even though actions implemented in accordance with Article 8 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 8. 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 8 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.

In addition, in the EED recast Points (2)(h), (i), (j) and (m) of Annex V introduce restrictions for energy savings related to technologies using direct combustion of fossil fuels to be eligible to energy savings obligation. Recital (65) clarifies that those provisions apply to cases where the uptake of efficient fossil

¹ Article 31 of the EED recast stipulates that Member States shall apply a default coefficient of 1,9 unless they use their discretion to define a different coefficient based upon justified national circumstances.

fuel technologies (like fossil fuel boilers, or vehicles running on gasoline) is supported or the early replacement of such technology by similar products.

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 8 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 8 EED action must be defined in a way that, at least, only savings going beyond the minimum requirements stipulated in Union law are considered². While Annex V(2)(a) only refers to Article 8, this report also looks into the effects on energy consumption relevant for Article 4. As stated in chapter 1.1.1, the approach chosen for assessing the effect on Article 4 energy consumption does already consider existing measures. For the methodologies presented in the report, it is therefore assumed that for one specific action implemented, the baseline for Article 8 equals the baseline for Article 4. This approach is a necessary simplification, as Article 4 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 8 EED, in the case of an action dealing with a product covered by an Ecodesign regulation (European Commission, 2019):

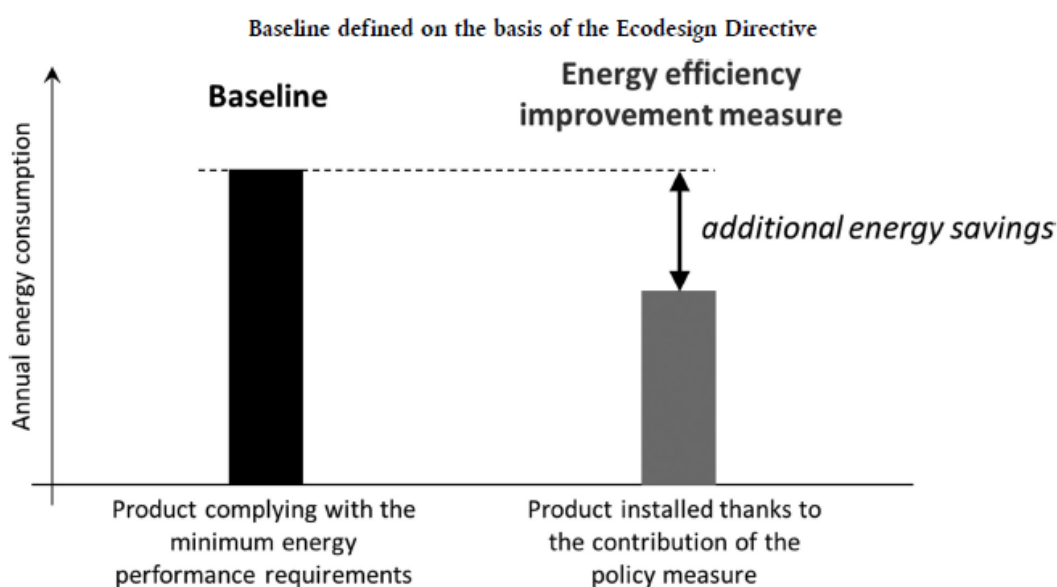


Figure 1: Baseline definition in accordance with Union law

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) (m) 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

² According to Annex V(2)(v), derogations from that requirement are savings related to the renovation of existing buildings, including the savings resulting from the implementation of minimum energy performance standards in buildings in accordance with Directive 2010/31/EU.

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).

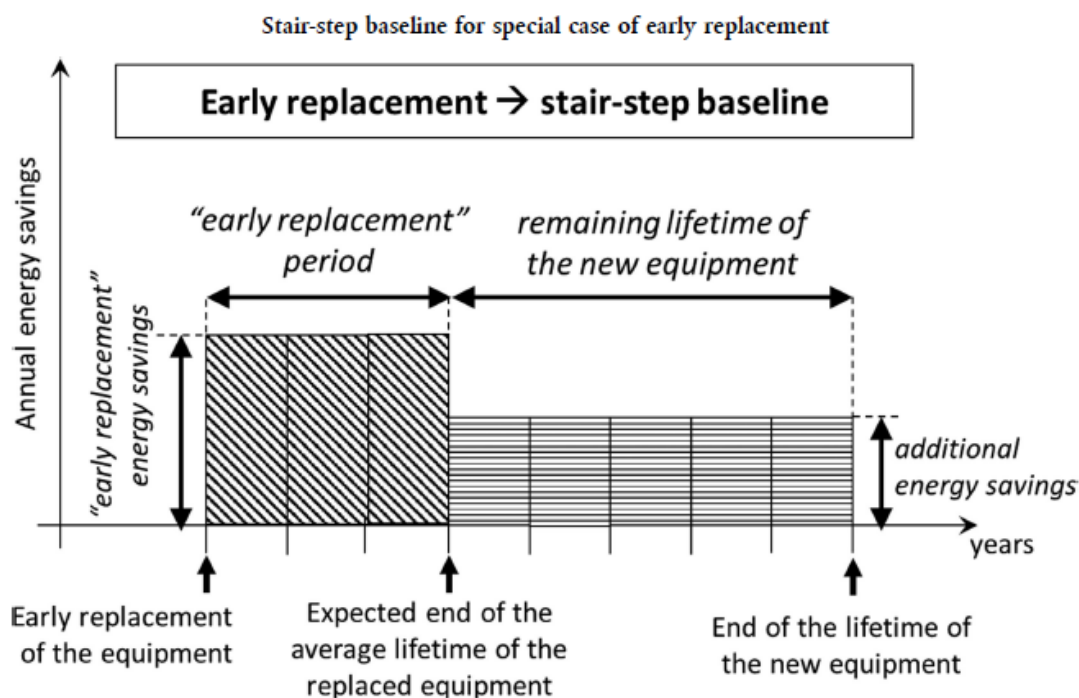


Figure 2: Adjustment of baseline in case of early replacement

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 8 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 8. 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.

1.1.3 Approaches for cumulating energy savings under Article 8

When calculating final energy savings for Article 8, EED Annex V(2)(p) 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 8 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.
- **Discount method:** For the discount method, a discount factor is applied to the savings achieved in the years following the implementation of an action, resulting in decreased annual savings per action over time. 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, cap method or discount rate 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). It is clarified in section 7.1 of the Recommendation³ though that the direct rebound effect (e.g. higher indoor temperature after insulating a building) has to be taken into account.

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). Another example is when fuel poor households improve the efficiency of their homes ending up using more energy than they previously did. This would be reflected by a large rebound, but these households were not adequately meeting their energy needs at first and the action helped alleviate the fuel poverty.

³ Section 7.1 of the Recommendation: « That phenomenon of higher energy service (here comfort) instead of reduction of energy consumption is generally called the direct rebound effect. Both effects (prebound and rebound) should normally be taken into account when calculating energy savings reported to Article 8(1). »

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 considered (also in line with the scope of Article 8 EED).

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 & Griebhammer, 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 Priority Actions (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 of differences between estimated and actual energy savings

Other factors than behavioural effects that can explain the differences observed between estimated and actual energy savings, include, amongst others, performance 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., 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 CO₂ reduced, an indication can be made on the cost effectiveness of the different Priority Actions, i.e. which action fulfils the energy savings or CO₂ reduction targets at the lowest cost? 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 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, such as residual values.

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/database> . These historical prices can be used as starting point to define scenarios of future price developments.
- 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).

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

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.

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

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 CO₂ 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)⁴.

⁴ Avoidance cost in the DEEP EFIG platform is the average cost for each energy saved over the lifetime of the measure (<https://deep.eefig.eu/>).

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 (HICP⁵) (HICP 2015 =100):

$$\text{real price}_n = \text{nominal price}_n \times \frac{\text{HICP}_{\text{base year}}}{\text{HICP}_n}$$

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). As the level of VAT varies across countries, products and types of services, action specific values are preferably used to calculate social costs.
- Social discount rates are used instead of private discount rates. The European Commission recommended in the past 4 % as social discount rate (European Commission, 2017). In a more recent publication of 2021 a rate of 3 % is proposed for EU-funded projects in the period 2021-2027 (European Commission, 2021). This 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 6 %. 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).
- 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

⁵ HICP for energy (Eurostat); HICP 2015 =100: https://ec.europa.eu/eurostat/databrowser/view/teicp250/default/table?lang=en&category=t_prc.t_prc_hicp

the EU Green Deal. 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) (EU, 2018), last amended by Commission Implementing Regulation (EU) 2024/2493, 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:

$$GHG_{SAV} = GHG_{Baseline} - GHG_{Action}$$

GHG _{SAV}	Greenhouse gas savings [t CO ₂ /a]
GHG	Greenhouse gas emissions [t CO ₂ /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 in the baseline situation 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 carriers 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 /a]
FEC	Annual final energy consumption [kWh/a]
share	Share of final energy carrier on final energy consumption [dmnl]
fGHG	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 at their point of use (but may generate emissions for their generation).

The direct emissions factors (in g CO₂ per kWh, CO₂ 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) (EU, 2018), last amended by Commission Implementing Regulation (EU) 2024/2493. In this report, focus is on the calculation of direct emissions, including emissions from electricity and heat.

Table 3: Emission factor by energy carrier – average European values (data from 2023 energy balances used for the calculation of the emission factor of electricity and district heat)

Energy carrier	emission factor [g CO ₂ /kWh]
Electricity	104.39
District heat	194.70
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, 2025) (European Commission, 2018):

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

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

fGHG	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 co-generation plants (combined heat and power)
HP	Index of heat plants
el	Index of electricity

dh	Index of district heat
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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 electricity and district heat. It should be noted that the factors presented depend on the composition of the power plant park and energy carriers used in the conversion in the case of electricity and district heating. As the underlying data used in the calculation was extracted from EUROSTAT during summer 2025, it is advised to use the latest available data for calculations performed at a later stage.

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Chapter 2. Savings calculation for deep renovations of buildings (residential and non-residential)

Deep renovation (also known as **deep energy retrofit**) refers to a comprehensive and substantial upgrading of a building's structure and (or) systems to significantly improve its overall efficiency. This type of renovation goes beyond cosmetic updates or minor improvements; it typically involves a holistic approach resulting in an extensive transformation of the building to significantly enhance its energy efficiency, particularly by lowering primary energy consumption, thereby reducing the environmental impact, and improve the quality of life for its occupants. It focuses on long-term sustainability, achieving substantial reductions in operational energy consumption and operating costs through integrated, whole-building solutions.

Deep renovation often includes **major modifications to the building envelope** (e.g., walls, roof, windows), as well as **updates to mechanical systems** (e.g., space heating, domestic hot water, space cooling, ventilation, and air conditioning), electrical systems (lighting, building automation and control systems), and the integration of renewable energy technologies (e.g., solar panels, heat pumps), such as summarised in the table below.

Table 4: Summary of key aspects of deep renovations

Key aspects of Deep Renovation	Components of Deep Renovation
Extensive Energy Performance Improvements: Deep renovation aims to achieve significant improvement in the building's overall energy performance by improving the building envelope, mechanical and electrical systems, and integrating renewable energy technologies (see right-hand side of table).	Building Envelope: Thermal insulation of walls, roofs, floors, doors and windows and improvement of airtightness to reduce heat loss through the building envelope.
Whole-Building Approach: Unlike shallow renovations, which focus on individual upgrades, deep renovation addresses multiple building components, including both the building's envelope and its technical systems. It is a comprehensive, long-term strategy to improve the building's energy performance.	Mechanical/technical Systems: Upgrading or replacing heating, cooling, ventilation and air-conditioning systems (e.g., replacing old boilers or air conditioning units with high-efficiency alternatives like heat pumps).
Long-Term Impact: Deep renovations typically result in long-term improvements in energy performance, lasting decades. They reduce the need for ongoing maintenance and repairs, lower operational costs, and significantly enhance the building's comfort and durability.	Electrical Systems: Installing energy-efficient lighting, advanced control systems, and smart meters to optimize energy use.
Reduction of Carbon Footprint: A deep renovation aims to not only improve energy performance but also reduce the building's carbon emissions and environmental impact, contributing to broader sustainability goals, such as climate change mitigation.	Renewable Energy Integration: Incorporating renewable energy technologies such as solar photovoltaic (PV) panels, solar thermal systems, or small wind turbines to reduce reliance on non-renewable energy sources.

Deep energy renovation definition

The calculation of energy savings for deep renovations is essentially identical to any calculation for **conventional (shallow) building renovations**, only the larger scale of measures is addressed. However, the issue is the very definition of deep renovation as there was no uniform definition of Deep

Renovation at the EU level until 2024 and the national definition varied from one EU country to another, and not all countries have set such a definition. In some countries, there were also multiple definitions under different energy efficiency support schemes (BPIE, 2021; streamSAVE+, 2025).

Some guidance on deep renovation has been provided by expert studies, such as the **BPIE study** (BPIE, 2021), which analysed the definition and identified deep renovation as a state where baseline energy consumption is reduced by at least 60-75 % or a certain, relatively low level of primary energy consumption is achieved (e.g. 60-80 kWh/(m²*year)). This corresponds to earlier Commission Recommendation 2019/786, which in note 4 mentions renovation depth based on the Building Stock Observatory and primary energy savings as *light (less than 30 %), medium (between 30 % and 60 %); and deep (over 60 %)*, while “NZEB renovations are not defined in terms of a specific primary energy saving threshold, but according to official national NZEB renovation definitions.” (European Commission, 2019).

Nevertheless, only the revised **Energy Performance of Buildings Directive (EPBD IV)** (European Union, 2024) brought a more significant role in the definition of deep renovations. Under Article 2, paragraph (20), the Directive introduced the following **definition of deep renovation**:

“‘deep renovation’ means a renovation which is in line with the ‘energy efficiency first’ principle, which focuses on essential building elements and which transforms a building or building unit:

- *before 1 January 2030, into a nearly zero-energy building;*
- *from 1 January 2030, into a zero-emission building;”*

According to recital 45 of the EPBD IV *“This definition serves the purpose of increasing the energy performance of buildings. A deep renovation for energy performance purposes may also be a prime opportunity to address other aspects such as indoor environmental quality, living conditions of vulnerable households, increasing climate resilience, resilience against disaster risks including seismic resilience, fire safety, the removal of hazardous substances including asbestos, and accessibility for persons with disabilities.”* (European Union, 2024).

An alternative numerical expression to deep renovation is presented under Article 17 on Financial incentives, skills and market barriers, paragraph 16: *“Member States shall incentivise deep renovation and staged deep renovation with higher financial, fiscal, administrative and technical support. Where it is not technically or economically feasible to transform a building into a zero-emission building, a renovation resulting in at least a 60 % reduction of primary energy use shall be considered to be a deep renovation for the purposes of this paragraph.”* (European Union, 2024).

However, the deep renovation definition raises the additional issue as the **definition of a nearly zero-energy building (nZEB) differs between countries** and energy standard of zero-emission building (ZEB) has not yet been set, as transposition of Directive on the energy performance of buildings (European Union, 2024) into national legislation is still ongoing in most EU Member States (it should be done by 29 May 2026 according to Article 35). Although the basic requirements and the calculation scope and methodology for determining the energy performance (Annex I of the EPBD IV) are common, the **nZEB or ZEB standards are set on the basis of a calculation of cost-optimal levels of minimum energy performance requirements** (Article 6 EPBD IV), which **varies between Member States**, taking into account local climatic and national techno-economic conditions and the level of detail of the cost-optimal calculation.

In the case of a nearly zero-energy building (nZEB), according to Article 2, paragraph 3, countries determine its parameters *“in accordance with Annex I, which is no worse than the 2023 cost-optimal level reported by Member States pursuant to Article 6(2) and where the nearly zero or very low amount*

of energy required is covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or energy from renewable sources produced nearby” (European Union, 2024). **Therefore, as described above, the nZEB definition differs in each member state.**

Benefits of deep renovation

The deep renovation offers significant energy efficiency benefits, including up to 60% reductions in primary energy use, lower utility bills, integration of renewable energy, and enhanced energy security. Beyond energy savings, it also improves indoor comfort, health, and property value, supports job creation and the economy, and helps future-proof buildings with modern systems and smart technologies. These renovations contribute to environmental sustainability and better quality of life while aligning with emerging energy and climate standards.

Possible benefits of deep renovations, respectively of increasing energy efficiency are shown on a figure below, which is based on the approach proposed by Odyssee-Mure, which divided benefits into social (blue), environmental (green) and economic (red) areas, and is part of the Commission Recommendation 2021/1749. More details can be found in various studies, e.g. (Reuter et al., 2020).

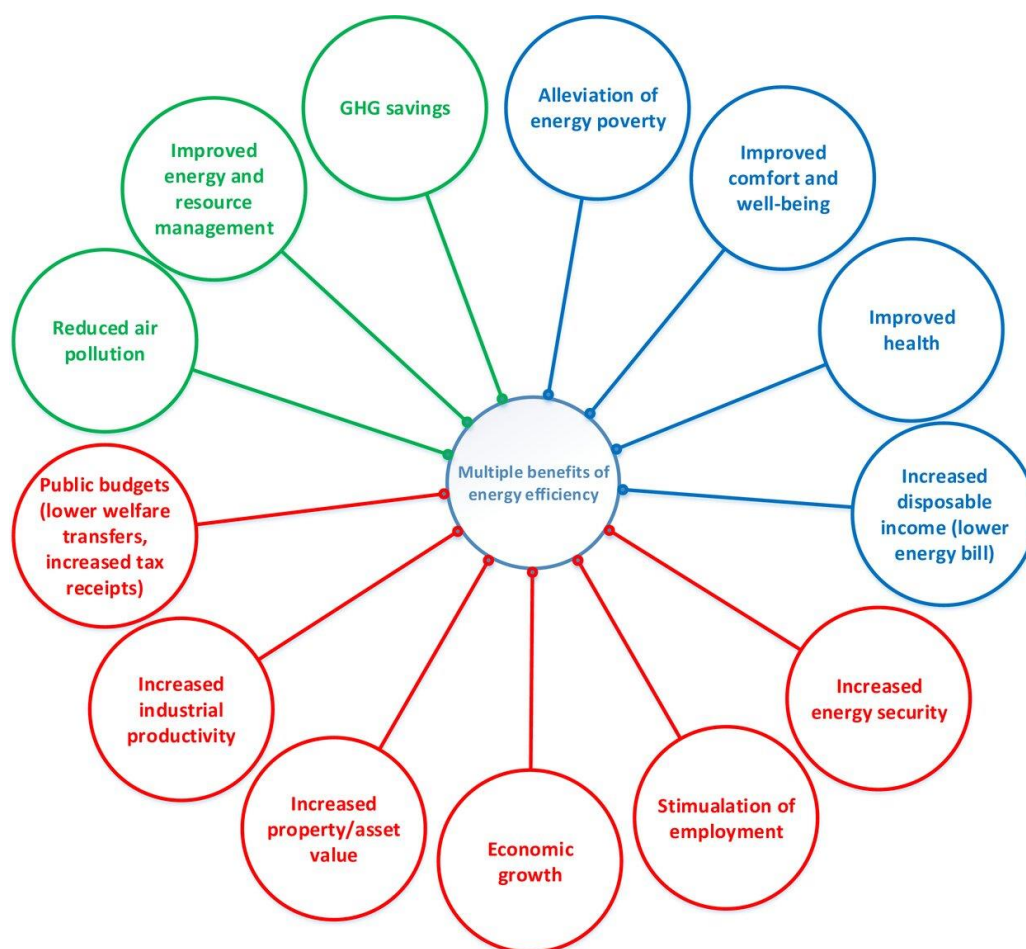


Figure 3: Possible multiple positive benefits of energy efficiency (European Commission, 2021).

Deep renovation brings, to a greater or lesser extent, similar benefits (but not always the same) that are typical of shallow renovations. However, the big advantage is the overall comprehensiveness and holistic approach of deep renovation, which aims to fully exploit the building's potential to reduce its energy consumption and maximise the benefits it brings.

2.1. Deep renovation of buildings (residential and non-residential)

The methodology for calculating energy savings in the context of **deep renovation of buildings**, both residential and non-residential, focuses on estimating the energy consumption reduction potentially achievable through extensive retrofitting and renovation measures. The calculation methodology provides a framework for evaluating the energy performance of a building before and after the renovation.

The total final energy savings are calculated reflecting the effect of a bundle of deep renovation measures and are determined based on the difference in annual energy consumption for heating needs of the building before and after the renovation (space heating and domestic hot water), but with included energy consumption for other building services as well, such as lighting, ventilation and cooling. These systems may have a significant share in overall energy consumption in certain types of non-residential buildings, while in residential buildings they might not exist (e.g. ventilation). The calculation method does not allow to calculate the savings achieved via specific individual measures. (Exceptions; system efficiencies for space heating and domestic hot water and electricity use for ventilation, cooling and lighting via more efficient technologies). To calculate the effect of each specific measure on energy savings, use D2.2 from the previous StreamSave project (streamSAVE, 2022). The calculation method allows to include RES in the calculation - further details are described in the methodology aspects section.

2.1.1 Calculation of final energy savings (Article 8)

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

$$TFES = (FEC_{before,Art8} - FEC_{after,Art8}) * f_{BEH}$$

Whereas:

$$FEC_{before,Art8} = \left(\sum_i^n \frac{SHD_{before} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_i^n \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before} \right) \cdot A \cdot cf_x$$

$$FEC_{after,Art8} = \left(\sum_i^n \frac{SHD_{after} * w_{SHD,i,after}}{\eta_{SHD,i,after}} + \sum_i^n \frac{HWD_{after} * w_{HWD,i,after}}{\eta_{HWD,i,after}} + E_{L,after} + E_{V,after} + E_{C,after} \right) \cdot A \cdot cf_x$$

TFES	Total final energy savings [kWh/year] due to deep renovation of the building
$FEC_{before,Art8}$	Final energy consumption before deep energy renovation [kWh/ year]
$FEC_{after,Art8}$	Final energy consumption after deep energy renovation [kWh/ year]
A	Conditioned floor area of the building [m ²]
cf_x	Climate correction factor [dmnl]
f_{BEH}	Factor to calculate behavioural aspects taking into account rebound effect, spill-over effect and free-rider effect [dmnl]
SHD_{before}	Specific area space heating demand of the building before deep energy renovation [kWh/m ² year]
$w_{SHD,i,before}$	The share of the energy demand for area space heating of the building attributable to the respective energy source before deep energy renovation [dmnl]

	If only one source is used, the common coefficient $w_{SHD,before} = 1$. If a system of multiple energy sources with one average seasonal efficiency for whole system is used, the common coefficient $w_{SHD,before} = 1$. In other cases, the coefficient for each energy source shall be used, where $w_{SHD,i,old} < 1$ and $\sum_i^n w_{SHD,i,old} = 1$.
$\eta_{SHD,i,before}$	Annual operating efficiency of the old (replaced) building heating system by energy carrier before deep energy renovation [dmnl]
HWD_{before}	Domestic hot water demand before deep energy renovation [kWh/m ² year]
$w_{HWD,i,before}$	The share of the energy demand for domestic hot water preparation attributable to the respective energy source before deep energy renovation [dmnl] If only one source is used, the common coefficient $w_{HWD,before} = 1$. If a system of multiple energy sources with one average seasonal efficiency for whole system is used (e.g. heat pump with bivalent energy source), the common coefficient $w_{HWD,before} = 1$. In other cases, the coefficient for each energy source shall be used, where $w_{HWD,i,old} < 1$ and $\sum_i^n w_{HWD,i,old} = 1$.
$\eta_{HWD,i,before}$	Annual operating efficiency of the old (replaced) domestic hot water system by energy carrier before deep energy renovation [dmnl]
$E_{L,before}$	Building energy consumption for lighting before deep energy renovation [kWh/m ² year]
$E_{V,before}$	Building energy consumption for ventilation system before deep energy renovation [kWh/m ² year]
$E_{C,before}$	Building energy consumption for cooling before deep energy renovation [kWh/m ² year]
SHD_{after}	Specific area space heating demand of the building after deep energy renovation [kWh/m ² year]
$w_{SHD,i,after}$	The share of the energy demand for area space heating of the building attributable to the respective energy source after deep energy renovation [dmnl]
$\eta_{SHD,i,after}$	Annual operating efficiency of the new building heating system by energy carrier after deep energy renovation [dmnl]
SPF_{SHD}	Seasonal performance factor of the heat pump for heating [dmnl]
HWD_{after}	Domestic hot water demand after deep energy renovation [kWh/m ² year]
$w_{HWD,i,after}$	The share of the energy demand for domestic hot water preparation attributable to the respective energy source after deep energy renovation [dmnl]
$\eta_{HWD,i,after}$	Annual operating efficiency of the new domestic hot water system by energy carrier after deep energy renovation [dmnl]
SPF_{HWD}	Seasonal performance factor of the heat pump for domestic hot water preparation [dmnl]
$E_{L,after}$	Building energy consumption for lighting after deep energy renovation [kWh/m ² year]
$E_{V,after}$	Building energy consumption for ventilation system after deep energy renovation [kWh/m ² year]
$E_{C,after}$	Building energy consumption for cooling after deep energy renovation [kWh/m ² year]

The cumulative final energy savings can be calculated with the following equation. The formula takes into account the different lifetimes of construction and technological measures. The first step calculates the energy savings from building measures (only thermal renovation of building envelope) that have a longer lifetime, then only the savings from technological measures with a shorter lifetime are calculated (see [Table 13](#) for more details).

Total energy cumulative savings

$$TFES_{cumulative} = TFES_{con} + TFES_{tech}$$

Cumulative energy savings in given year n after deep renovation

$$TFES_{cumulative,n} = \left(\frac{TFES_{con}}{lt_{con}} + \frac{TFES_{tech}}{lt_{tech}} \right) * n$$

1st step – thermal renovation

$$TFES_{con} = (FEC_{before,Art8} - FEC_{after,con,Art8}) * f_{BEH} * lt_{con}$$

Whereas:

$$FEC_{before,Art8} = \left(\sum_i^n \frac{SHD_{before} * w_{SHD,i,before}}{\eta_{SHD,i,before}} \right) \cdot A \cdot cf_x$$

$$FEC_{after,con,Art8} = \left(\sum_i^n \frac{SHD_{after,con} * w_{SHD,i,before}}{\eta_{SHD,i,before}} \right) \cdot A \cdot cf_x$$

2nd step – technology improvements

$$TFES_{tech} = (FEC_{after,con,Art8} - FEC_{after,Art8}) * f_{BEH} * lt_{tech}$$

Whereas:

$$FEC_{after,con,Art8} = \left(\sum_i^n \frac{SHD_{after,con} * w_{SHD,i,before}}{\eta_{SHD,i,before}} + \sum_i^n \frac{HWD_{before} * w_{HWD,i,before}}{\eta_{HWD,i,before}} + E_{L,before} + E_{V,before} + E_{C,before} \right) \cdot A \cdot cf_x$$

$$FEC_{after,Art8} = \left(\sum_i^n \frac{SHD_{after} * w_{SHD,i,after}}{\eta_{SHD,i,after}} + \sum_i^n \frac{HWD_{after} * w_{HWD,i,after}}{\eta_{HWD,i,after}} + E_{L,after} + E_{V,after} + E_{C,after} \right) \cdot A \cdot cf_x$$

TFES _{cumulative}	Total cumulative final energy savings due to deep renovation of the building [kWh]
TFES _{cumulative,n}	Total cumulative final energy savings due to deep renovation of the building after n years [kWh] For n= 1 TFES _{cumulative,n} = TFES
TFES _{con}	Total cumulative final energy savings from construction measures, i.e. after thermal renovation of the building, with existing old heat supply system [kWh]
TFES _{tech}	Total cumulative final energy savings from technology measures, i.e. after thermal renovation of the building, with existing old heat supply system [kWh]
FEC _{after,con,Art8}	Final energy consumption of the thermally renovated building after the technology systems improvements (heating, heat water preparation, cooling, lighting and/or ventilation) [kWh/year]
SHD _{after,con}	Specific area space heating demand of the building after thermal renovation with an existing old heat supply system existing old heat supply system [kWh/m ² year]
Lt _{con}	Lifetime for construction measures [year]
lt _{tech}	Lifetime for technology measures [year]

Other parameters are the same as for the calculation of first-year savings.

Standardized values

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:

Table 5: Indicative values for final energy consumption and specific energy demand per building type

Parametar [kWh/m ² *year]	Residential sector	Non-residential sector
FEC _{before,Art8} per useful area of a building	149.29	159.85
FEC _{after,Art8} per useful area of a building	59.716	63.94
SHD _{before}	88.29	119.87
SHD _{after}	35.32	45.95
HWD _{before}	14.65	25.61
HWD _{after}	5.86	10.24
E _{L, before}	3.40	16.06
E _{L, after}	Depending on type of individual actions	Depending on type of individual actions
E _{V, before}	0 (no ventilation considered) *	4.83
E _{V, after}	Depending on type of individual actions	Depending on type of individual actions
E _{C, before}	2.86 or 0 (if the cooling system is not present)	9.09
E _{C, after}	Depending on type of individual actions	Depending on type of individual actions

Source: (JRC, 2024), except (*) based on (Van Tichelen et al., 2020)

Table 6: Indicative values for efficiency of a reference heating system and new heating system

η _{before} – weighted value	Residential sector	Non-residential sector
Heating - η _{SHD, before}	0.730	0.807
Domestic hot water - η _{HWD, before}	0.723	0.708
η _{after} – weighted value	Residential sector	Non-residential sector
Heating - η _{SHD, after}	0.902	1.015
Domestic hot water - η _{HWD, after}	0.835	0.870

Table 7: Indicative values for efficiency of a reference heating system before and after retrofit per energy carrier

η_{before} – reference heating system per energy carrier	Residential sector		Non-residential sector	
	Heating - $\eta_{\text{SHD,before}}$	Domestic hot water - $\eta_{\text{HWD,before}}$	Heating - $\eta_{\text{SHD,before}}$	Domestic hot water - $\eta_{\text{HWD,before}}$
Solids	0.669	0.685	0.645	0.674
Liquified petroleum gas (LPG)	0.602	0.675	0.651	0.607
Diesel oil	0.573	0.600	0.589	0.578
Natural gas	0.668	0.668	0.681	0.654
Gas heat pumps	-	-	2.266	-
Conventional gas heaters	-	-	0.675	-
Biomass	0.649	0.719	0.549	0.682
Geothermal	0.800	0.838	0.835	-
Distributed heat	0.796	0.838	0.826	0.828
Advanced electric heating	2.669	0.689	2.694	0.704
Conventional electric heating	0.751		0.753	
Electricity in circulation	1.000	-	1.000	-
Solar	-	1.000	-	1.000
η_{after} – reference heating system in 2021	Heating - $\eta_{\text{SHD,after}}$	Domestic hot water - $\eta_{\text{HWD,after}}$	Heating - $\eta_{\text{SHD,after}}$	Domestic hot water - $\eta_{\text{HWD,after}}$
Gas heat pumps	-	-	2.900	-
Biomass	0.774	0.849	0.584	0.818
Geothermal	0.856	0.878	0.872	-
Distributed heat	0.853	0.901	0.885	0.899
Advanced electric heating	3.581	-	3.561	-
Conventional electric heating	0.892	0.770	0.872	0.884
Electricity in circulation	1.000	-	1.000	-
Solar	1.000	1.000	-	1.000

Table 8: Minimum seasonal efficiencies of heating and hot water sources per energy carrier

η_s	Residential sector		Non-residential sector	
	Heating - $\eta_{s,\text{SHD,min}}$	Domestic hot water - $\eta_{s,\text{HWD,min}}$	Heating - $\eta_{s,\text{SHD,min}}$	Domestic hot water - $\eta_{s,\text{HWD,min}}$
Biomass	0.750	0.750	0.770	0.770
Geothermal	0.869	0.890	0.872	0.890

Distributed heat	0.838	0.876	0.885	0.876
Advanced electric heating	3.100	1.100	3.100	1.100
Conventional electric heating	0.360	0.370	0.360	0.370
Electricity in circulation	1.000	1.000	1.000	1.000
Solar	1.000	1.000	1.000	1.000

Table 9: Indicative values for seasonal performance factors of heat pumps

SPF _{SHD}	Value
<i>Electrically driven</i>	
Air sourced heat pump	2.6
Ground-air heat pump	3.2
Ground-water heat pump	3.5
<i>Driven by thermal energy</i>	
Air sourced heat pump	1.2
Ground-air heat pump	1.4
Ground-water heat pump	1.6
SPF _{HWD}	
All types of electrically driven heat pumps	2.4
All types of thermal heat pumps	1.1

Table 10: Indicative values for heating system components' efficiency

Part of heating system	System before	System after
Heating system efficiency – $\eta_{\text{sys,SHD}}$	0.68	0.86
Heat distribution efficiency – $\eta_{\text{dis,SHD}}$	0.93	0.97
Heat emission efficiency – $\eta_{\text{em,SHD}}$	0.78	0.93
Heat control system efficiency – $\eta_{\text{c,SHD}}$	0.94	0.95
Hot water system – $\eta_{\text{sys,HWD}}$	0.3-0.75	0.6-0.75

Note: values to be used in combination of known source efficiency (case 2 in methodology aspects below)

Table 11: Indicative values for climate correction factor

c _{fx} [dmnl]	Residential sector			Non-residential sector		
	North	West	South	North	West	South
Total final energy consumption, consisting of	1.32	1.00	0.82	0.96	1.00	0.79

Space heating	1.35	1.00	0.73	1.00	1.00	0.66
Space cooling	0.82	1.00	2.58	0.85	1.00	1.50
Water heating	0.94	1.00	0.95	0.93	1.00	1.07
Lighting	1.12	1.00	1.03	1.03	1.00	1.05
Venilation	-	-	-	1.08	1.00	1.13
Specific energy demand for						
Space heating	1.42	1.00	0.66	0.97	1.00	0.70
Water heating	0.96	1.00	0.93	0.91	1.00	0.96

Table 12: Indicative values for behavioural impact factor

f_{BEH}	[dmnl]
Residential sector	0.70
Non/residential sector	0.90

Table 13: Lifetime of savings

Lifetime of savings	[a]
Construction	>25
Technology	10
Air to air heat pump	10
Air to water heat pump	15
Geothermal heat pump	25
High-efficiency boilers (< 30 kW)	20
High-efficiency boilers (> 30 kW)	25
Efficient lighting systems	15
Efficient central air-conditioning and chillers	17
Efficient ventilation systems	15

Methodological aspects:

The formula for calculating final energy savings has two parts, both of which can be used standalone, according to available data. The first part is a general calculation based on the difference in total final energy consumption before ($\text{FEC}_{\text{before}}$) and after ($\text{FEC}_{\text{after}}$) the deep renovation, taking into account behavioural aspects (f_{BEH}), where also more general statistical data can be used. The second part is a more detailed calculation of final energy consumption that takes into account individual energy carriers and technical systems. The detailed part of the formula for calculating energy savings in final energy consumption is based on the calculation methodology of Slovenia identified in Deliverable 2.1 ([Translated existing bottom-up methodologies in EU-27, Annex IV](#)) and is complemented by elements based on the calculation methodology of Croatia and Hungary.

The detailed formula is based on the principle of multiplying the final energy consumption by the conditioned (useful) floor area of the building or part thereof (A), possibly adjusted for external conditions by means of the regional or climate factor (cf_x). The final energy consumption (FEC_{before} and FEC_{after}) can be retrieved from the specific area space heat demand (SHD) and domestic hot water demand (HWD) and the efficiency of the system to cover it (η). The methodology allows taking into account the possibility of using more energy sources through share coefficient (w) (for example, heat pumps are often supplemented by a bivalent heat source) and the possibility to calculate consumption of heating and domestic hot water preparation separately (this allows to take into account, for example, the different efficiencies of heat pumps for heating and for hot water preparation). The calculation was extended to include energy consumption for lighting (E_L), ventilation (E_V) and cooling (E_C). Therefore, the methodology considers all significant relevant energy consumption in a building (both residential and non-residential) that may be affected by the implementation of the deep renovation measures.

One of the aspects of deep energy renovation is also to focus on improving the quality of the indoor environment of the building. Therefore, carrying out a deep renovation in certain types of buildings (e.g. residential, educational) may lead to a partial increase in energy consumption of some systems, for example when new ventilation or cooling systems are installed that were not present in the building before the deep renovation. Some countries may also require these systems as part of the building renovation (mainly ventilation system, which on the other hand helps to reduce energy demand for heating). This increase in energy consumption needs to be taken into account (in the formula covered by E_V and E_C).

For the calculation, the determination of the energy demand for heating (SHD) is important. In the context of **deep renovation**, it is necessary to look at the improvement in the energy performance of a building comprehensively and take into account the **energy efficiency first principle**. This involves **first reducing the energy demand for heating through improving the thermal performance of the building envelope or by reducing heat loss through ventilation (through ventilation systems)**, and **then improving the efficiency of the technical systems** (note: Hungary has this approach explicitly expressed in its calculation methodology, although it can be assumed that this is also taken into account in other countries (see [Translated existing bottom-up methodologies in EU-27, Annex IV](#))).

This methodology reflects only effects of a bundle of deep renovation measures, not only specific individual measures, but these can be calculated via D2.2 from the previous StreamSave project (streamSAVE, 2022). This means that in relation to space heating the individual building envelope improvement measures (thermal insulation of envelope components, airtightness), ventilation heat recovery and solar thermal contribution to space heating all are reflected in parameter energy demand for heating SHD_{after} . Similar is the case for the energy demand for hot water preparation HWD_{after} . It has to be noted that these parameters are also calculated for the purpose of energy performance certificates (EPC), hence building specific values before and after renovation could be obtained from EPC. This is particularly important after the renovation – the methodology provided here does not provide indicative values for ‘after’ situation but recommends that the building specific values are calculated.

Renewable energy produced on-site is to be reflected in a distributed manner. The contribution of on-site produced renewable energy (mainly from solar thermal collectors) should be reflected in the SHD and HWD values by subtracting its contribution from these values (it cannot be accounted for in the detailed method in a separate manner starting from the energy yield of the renewable energy system). Exception is the renewable part of a heat pump that is directly reflected in the system performance factor SPF . Similarly for the contribution of on-site produced renewable energy that is exported.

The efficiency of the system (η) represents the efficiency of energy conversion in the heat source and supply for final consumption. For the conversion efficiencies of reference heating systems, the use of seasonal efficiencies is preferable. If these are not available, the efficiencies at nominal load can be used as an approximation. System efficiency can have a very significant impact on the resulting final

energy consumption, therefore we present 3 cases to determine the efficiency of a heating and hot water preparation systems, depending on the level of detail and level of knowledge of the system:

- **Case 1:** If no detailed system information is known, the total system efficiency value derived from the IDEES database can be used ($\eta_{SHD,before}$ and $\eta_{HWD,before}$). A weighted average of efficiencies for the whole residential or service sector may be used, or efficiency by energy carrier if known.

In this case use the weighted average values from Table 6, respectively Table 7.

Case 1 is best to use in combination with the SHD and DHW values determined from the IDEES database (see Table 6). If SHD and DHW are determined from a bottom-up calculation, it is necessary to use Case 2 or 3 for a more accurate result, i.e., to use the efficiency of the energy source multiplied by the rest of the system efficiency (i.e. without energy source, see Table 10) instead of one overall efficiency from Table 6 or split by energy carrier in Table 7.

- **Case 2:** The efficiency of the source for heating ($\eta_{s,SHD}$) or hot water production ($\eta_{s,HWD}$) is known, but the efficiencies about the heating or hot water distribution system are not known. The source efficiency (η_s) is then used and multiplied by the system efficiency values, which can be taken, for example, from national values or energy performance certificates.

In case 2, following formula is used for **heating system**:

$$\eta_{SHD,i} = \eta_{s,SHD,i} \cdot \eta_{sys,SHD,i}$$

Where

- $\eta_{s,SHD,i}$ is the standardized seasonal efficiency of the heat source for heating, which takes into account the actual operating characteristics of the heat source (actual load), is defined as the ratio between the annual energy consumed for heating (Q_{SHD}) and the annual heat output of the heat source (Q_p) under partial load conditions of the heating system.
- $\eta_{sys,SHD,i}$ is efficiency of heating system without efficiency of heat source, which can be calculated from partial efficiencies using following formula:

$$\eta_{sys,SHD,i} = \eta_{dis,SHD,i} \cdot \eta_{em,SHD,i} \cdot \eta_{c,SHD,i}$$

Where

$\eta_{dis,SHD,i}$ is efficiency of the distribution system for heating

$\eta_{em,SHD,i}$ is efficiency of heat emission for heating

$\eta_{c,SHD,i}$ is control system efficiency for heating

In case 2, following formula is used for hot **water preparation system**:

$$\eta_{HWD,i} = \eta_{s,HWD,i} \cdot \eta_{sys,HWD,i}$$

Where

- $\eta_{s,HWD,i}$ is the standardized seasonal efficiency of the heat source for heating, which takes into account the actual operating characteristics of the heat source (actual load), is defined as the ratio between the annual energy consumed for hot water preparation (Q_{HWD}) and the annual heat output of the heat source (Q_s) under partial load conditions of the hot water system.
- $\eta_{sys,HWD,i}$ is efficiency of hot water system without efficiency of heat source and includes distribution efficiency (affected by pipe insulation), losses due to circulation (the circulation regime may vary depending on the size and type of building and its operational profile) and losses in the hot water storage tank (depending on the size of the tank and its insulation properties).

The “i” index is used when multiple sources or separate systems are used.

The formula can be used for both before and after deep renovation measures, only the corresponding values with the ‘before’ or ‘after’ tag are used.

In case 2, energy source efficiencies should preferably be taken according to reality but should not be lower than the values in Table 10, for heat pumps the values in Table 9 can be taken.

For the efficiency of both heating and hot water systems values can be taken, for example, from national values, energy performance certificates, or use indicative values from Table 7 (in case of hot water, for older systems or systems in poor technical condition, lower values are used, i.e. worse system efficiency).

- **Case 3:** The source and system efficiency values are known. These can be taken, for example, from national values, from building energy performance certificates or from the assessment of energy specialist.

In case 3 use the known values, following the formulas already presented in case 2. If the partial values of efficiencies and losses for the hot water system are known, the individual coefficients are multiplied among themselves, as in the case of the heating system. Where appropriate, national formulae and specifics shall be used.

In energy efficiency projects, **the behavioural factor (f_{BEH})** is commonly used to account for occupant-related effects such as rebound, spill-over, and free-riding. In the context of deep renovations, day-to-day energy use habits of occupants play an even more substantial role. While energy savings are typically calculated using standardized assumptions about occupant behaviour, real-life patterns - such as occupancy schedules, appliance and window usage, heating preferences, and residents' understanding and willingness to engage with new technologies - can differ significantly from these models (Mastrorilli et al., 2023). This mismatch often leads to a considerable **energy performance gap**: a situation where the actual energy savings fall short of the calculated savings based on regulatory assumptions (e.g., set heating temperature, heated area, ventilation rates, etc.). Since f_{BEH} can only be accurately determined through empirical studies, a literature review was conducted to identify indicative values of this factor, focusing on both residential and non-residential retrofitted buildings. For residential buildings, studies show that actual savings can range from 20% to 80% of the calculated (expected) savings. The indicative value for f_{BEH} was selected based on the frequency and robustness of findings across the literature, prioritizing studies where occupants pay their own energy bills. This approach excludes results from certain social housing studies, which often report significantly lower realised savings. A similar approach was applied to non-residential buildings, where available literature is scarce and mostly related to office buildings. In these settings, the behavioural factor tends to be higher than in the residential sector. This is attributed to the more restricted occupant control over building systems (e.g., temperature settings, window operation, blinds, lighting modes) in non-residential buildings, leading to more standardized energy use patterns (de Wilde et al., 2025).

Data sources for indicative calculation values:

The value for the total final energy consumption per unit floor area [$\text{kWh/m}^2\text{year}$] before deep renovation (**FEC_{before}**) is based on the Integrated Database of the European Energy System (IDEES) database (JRC, 2024 – residential sector and service sector). In the IDEES, JRC gathers essential statistical information relevant to the energy sector and complements it with processed data that further decomposes energy usage. The full JRC-IDEES output is available to the general public and is revised periodically (Rózsai et al., 2024).

This FEC in the JRC-IDEES 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. Actual JRC-IDEES compiles energy system statistics from 2000 to 2021, for our estimation values, we selected datasets 2010-2021 to reflect the most recent data on the one hand, while also having a long enough average period of values to normalise for yearly changes in energy consumption. The dataset “RES_hh_fecs” and “SER_hh_fecs” are used, while the data are averaged over three climatic zones divided as in (Van Tichelen et al., 2020)

and includes the following countries: North (CZ, DK, EE, FI, LT, LV, PL, SE, SK), South (BG, CY, EL, ES, HR, HU, IT, MT, PT, RO, SI), West (AT, BE, DE, FR, IE, LU, NL).

The value for the total final energy consumption per unit floor area [kWh/m²year] after deep renovation (**FEC_{after}**) is based on the value before deep renovation (**FEC_{before}**) and is calculated as energy reduction of at least 60 % of that value. This is rather an indicative value that has to be adjusted according to national specificities, but this can be complicated because levels of final energy are not well known for nZEB and ZEB (i.e. the energy standards that a deep renovation should achieve). Moreover, according to EPBD IV and Commission Recommendation 2019/786, the reduction should be calculated in primary energy, which is confirmed by the article (Maduta et al., 2024) that quantified the EU member states levels of the nZEB and ZEB standards in the primary energy consumption. However, considering that the primary energy factors are always at least 1 and neglecting the RES effect, the share of primary and final energy reduction can be very similar.

The value for the West region is taken as the default, the other values are obtained by multiplying by the regional climate factor (**cf_x**), which is determined from the JRC-IDEES database, reflecting the average deviation of final energy consumption in all Northern and Southern countries in comparison to the Member States in the West, between 2010-2021.

The values for final energy consumption of ventilation system before deep renovation (**E_{v, before}**) is considered 0 for residential buildings as its share on the total final energy consumption in residential sector has been negligible in the past years (Van Tichelen et al, 2020). Energy consumption of lighting (**E_{L, before}**) is based on the JRC-IDEES database by calculating from Specific electric appliances consumption per household (in kWh) and Households useful surface area (in sqm/household). Energy consumption of space cooling (**E_{C, before}**) is based on the JRC-IDEES database by calculating from values for Number of households with cooling, Final energy consumption for cooling and Households useful surface area. For non-residential buildings data on service sector consumption for ventilation, lighting and space cooling were used.

The useful floor area (**A**) corresponds to the total floor area of Member States' building stocks. The useful floor area is the floor area that is conditioned during the year (heated during most of the winter months, cooled or ventilated). In residential buildings, 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. The same is valid for non-residential buildings, where this significantly varies depending on the type/purpose of a building. It is different from the gross floor area, which includes common areas in multifamily buildings (e.g. corridors), attics, basements or verandas or technical spaces, stairwells and elevator shafts in non-residential buildings (Building Stock Observatory, 2021).

The values for the space heating demand (**SHD_{before}**) as well as the hot water demand (**HWD_{before}**) of residential building before deep renovation per unit floor area [kWh/m²a] are based on the Integrated Database of the European Energy System (IDEES) database (JRC, 2024 – residential sector and service sector). The total heating and hot water demand are based on the statistics Thermal energy service from “RES_hh_tess” dataset for residential sector and “SER_hh_tess” for service sector, which represent the energy demand and corresponds to Final energy consumption multiplied by the System efficiency indicator (both data can be found in the IDEES database). To normalize for yearly (e.g. weather) fluctuations, the indicative values for heating and hot water generation are based on values averaged for the period 2010-2021 for each Member state and divided into three climatic zones climate factor (**cf_x**), as described above.

Energy demand for heating (**SHD_{after}**) and hot water (**HWD_{after}**) after the deep renovation are calculated similarly to the FEC via a 60% reduction from the “before” values. Note that these demand values may not fully capture the potential of Deep renovation, where the principle of trade-off between building systems can be applied to achieve the desired level of energy reduction (for example, by significantly improving lighting). In the case of hot water, it is also likely that such significant reductions will be difficult to achieve. Thus, these values should be taken as indicative, and the target values should rather

be based on national values (e.g. nZEB or ZEB requirements) or energy performance certificates with the aim of achieving an aggregate energy reduction of 60%.

Anyway, the average values of final energy consumption for ventilation ($E_{v,after}$), lighting ($E_{L,after}$) and cooling ($E_{C,after}$) and values for the space heating demand (SHD_{after}) as well as hot water demand (HWD_{after}) for building after deep renovation may be calculated based on national empirical studies, analyses of energy certificates, buildings databases or the national building codes. Moreover, subsidy guidelines can be applied, specifying a certain thermal quality to be reached when applying for subsidies. Also, project-specific values can be used for the savings calculation, if a representative default value is difficult to determine. In this case, calculations for energy performance certificate may be valuable source of information.

Factors (w_{SHD} and w_{HWD}) represents share of the energy demands for area space heating and hot water preparation of the building attributable to the respective energy source. If only one source is used, the common coefficient $w = 1$. If a system of multiple energy sources with one average seasonal efficiency for whole system is used (e.g. heat pump with bivalent energy source), the common coefficient is also $w = 1$. In other cases, the coefficient for each energy source shall be used ($w_i < 1$ and $\sum_i^n w_i = 1$), which can be based e.g. on national empirical studies or analyses of energy certificates.

System efficiency values (η) are determined based on several sources depending on the type of case level of detail and level of knowledge of the system. For the conversion efficiencies of reference heating systems, the use of seasonal efficiencies is preferable. If these are not available, the efficiencies at nominal load can be used as an approximation.

For Case 1 described in the methodology section, the values are given in Table 6 and Table 7. The (seasonal) efficiencies are to be weighted over the energy consumption of the technologies used, before the implementation of the action. A weighted values of efficiencies before deep renovation ($\eta_{SHD,before}$ and $\eta_{HWD,before}$) in are based on an average of heating and hot water system efficiencies (these values already represent weighted averages over energy carriers) from the IDEES database (JRC, 2024) from “RES_hh_eff” and “SER_hh_eff” datasets for each Member state. To normalize for yearly (e.g. weather) fluctuations, the indicative values of energy source efficiency for heating and hot water generation sources are based on values averaged for the period 2010-2021 for each Member state. The values for each energy carrier (reference heating system per energy carrier) are based on the IDEES database (JRC, 2024) on the “RES_hh_eff” and “SER_hh_eff” datasets for each member state are averaged over the years 2010-2021.

The indicative weighted values of efficiencies after deep renovation in Table 6 ($\eta_{SHD,after}$ and $\eta_{HWD,after}$) are calculated in a similar way as values “before” but using “RES_hh_eff_in” and “SER_hh_eff_in” datasets (JRC, 2024) with data for new and renovated buildings. Values for 2021 are used as the most up-to-date values that will be closest to current requirements and trends. Similarly, system efficiencies by energy carrier (again by 2021) were determined.

For Case 2 described in the methodology section, where a more detailed calculation is used to determine the efficiency of the whole heating or hot water system, the values in Table 9 may be used for the efficiency of heat pumps. For the definition of the conversion efficiency of different heat pump technologies, the default values for the **Seasonal Performance Factor (SPF)** of different heat pump technologies per climate regions as stated in Tables 1 and 2 of (European Commission, 2013b, p.6) were used. As climate regions mentioned in this document vary from the climate regions used in this methodology, it was assumed that “Colder climate” equals the north region, “Average climate” the west region and “Warmer climate” the south region. Only values for average climate are presented. The value of seasonal performance factor for water use in case of electrically driven heat pumps is derived from the Techno-economic assumptions of the PRIMES model (E3-Model, 2024) and in case of thermal driven heat pumps from minimal efficiencies according to Ecodesign (European Commission, 2013a).

If the efficiency of the source and, if applicable, the efficiency of the systems is known, a more detailed calculation of the overall system efficiency can be used (the formula is described in the methodological aspect above). The seasonal efficiency of the heat source ($\eta_{s,SHD}$ or $\eta_{s,HWD}$) is used for this calculation and its value should not fall below the values given in Table 8, which represent the minimum required efficiency in accordance with EU legislation (e.g. Ecodesign Regulation – for more information see table below). For “Geothermal energy” and “Distributed heat”, stock averages taken from the latest year of the tables RES_hh_eff and SER_hh_eff of the IDEES database (JRC, 2024). Low seasonal values are given for electric heating and hot water, but electric heaters on the market typically achieve nominal efficiencies of 95 to 99%. The resulting seasonal efficiency thus depends mainly on the extent to which their use along with heating system is optimised and the setting of the heating system. The minimum seasonal space heating energy efficiencies of “Advanced electric heating” (= heat pumps) for heating is taken Appendix X of the Commission Recommendation 2019/1658 (European Commission, 2019) and for hot water preparation according to Ecodesign requirements (European Commission, 2013a). The minimal values for heat pumps can also be taken according to Table 9. Efficiency of the biomass boiler is based on the Ecodesign requirements (European Commission, 2013a), however (European Commission, 2019) states that best technology available on the market has efficiency of 0.920. Indicative efficiencies for other heating and hot water system components are presented in Table 10 and their determination is described further below.

This scope for heat sources and hot water sources and their substitutions is very broad and various. Our focus is aimed only at Ecodesign’s scope of product categories which cover a significant part of the market. The scope, appropriate regulations, and an example of a specific product category are in the following table. Part of this Ecodesign scope of heat generators (capacity up to 70 kW) is subjected to obligatory energy labeling and thus publishing information in the EPREL database (<https://eprel.ec.europa.eu/screen/home>). Out of the scope of this calculation are local space heaters (stoves, fireplaces) and heat generation out of the scope of the table below.

Table 14: Sources for heat source efficiencies

Ecodesign product category	Ecodesign Regulation	Ecodesign Scope	Labeling regulation	Labeling Scope (EPREL)	Specific heat and hot water source category examples
Solid Fuel Boilers	1189/2015	≤ 500 kW	1187/2015	≤ 70 kW (co-generation ≤ 50 kW)	Coal boilers, log wood or wood pellet boilers
Space heaters	813/2013	≤ 400 kW	811/2013	≤ 70 kW (co-generation ≤ 50 kW)	Gas boilers, electric boilers, LPG boilers, heating oil boilers, heat pump space heaters
Water heaters	814/2013	≤ 400 kW	812/2013	≤ 70 kW	Electric water heaters
Air heating products (electricity)	2281/2016	≤ 1 MW	n/a	n/a	Warm air heaters using electricity, air-to-air heat pumps using electricity (except rooftop heat pumps)

The Ecodesign regulations mentioned above set the minimal allowable efficiency of heat generators which could be placed on European market. The Ecodesign and labeling regulations use so called seasonal space heating energy efficiency η_s which is defined as ratio between the space heating demand for a designated heating season, supplied by a heater and the annual energy consumption required to meet this demand, expressed in %. For hot water heaters, water heating energy efficiency η_{wh} is used (ratio between the useful energy provided by a water heater and the energy required for

its generation, expressed in %). Due to overall complexity, only load profile L is considered for water heaters efficiency calculations⁶.

The efficiencies of heating and hot water systems without energy source ($\eta_{\text{sys,SHD}}$ or $\eta_{\text{sys,HWD}}$) can be expressed as overall values or by individual relevant system elements. In the case of a heating system, this assesses the efficiency of distribution ($\eta_{\text{dis,SHD}}$), the efficiency of heat transfer ($\eta_{\text{em,SHD}}$) from the final element to the space and the efficiency of system control ($\eta_{\text{c,SHD}}$) (to avoid, for example, unintentional overheating of the space). The values for the efficiency of the parts of the heating system are taken from Annex IV to D2.1 (streamSAVE+, 2025). Based on an analysis of the values used by each Member State and an expert assessment, values from the Croatian methodology have been used for distribution and heat transfer efficiencies and values from the Slovenian methodology for system control. The overall efficiency ($\eta_{\text{sys,SHD}}$) is determined by multiplying them together in accordance with the formula set out in the methodology section. The indicative values are in Table 10.

In the case of a hot water system ($\eta_{\text{sys,HWD}}$), energy efficiency determines the heat loss in the circulation system (Bocian et al. 2022, Hamburg et al. 2021) as well as in the storage device (Junga et al. 2024). This energy loss usually amounts to at least 25%. The loss in older buildings might be as much as 70%. Many factors influence this deviation, including the water storage's capacity (NPRO), the temperature of the room and the water, the water circulation plan and operation duration (Kitzberger et al. 2019), the pipes' length (Grasmanis et al. 2015), and the insulation of the distribution and storage systems (Rocheron et al. 2012). The correct determination of the loss values for both the heating system and the hot water system is not easy to determine and depends very significantly on the type of system in the building and its set-up. The indicative values in Table 10 are therefore only very indicative and the resulting values should be taken, for example, from the building energy performance certificate, energy audit or national values.

If Building Automation and Control Systems (BACS) are used, the system control values ($\eta_{\text{c,SHD}}$) can be used according to chapter 3 in D2.2 from the previous StreamSave project (streamSAVE, 2022).

The value of the **behavioural factor** (f_{BEH}) is derived from a review of literature focused on the energy performance gap related to occupant behaviour in post-retrofitted buildings. The table below presents the key studies analysed, along with the main findings used to establish indicative values for this factor in both residential and non-residential buildings. In the residential sector there is a substantial body of literature addressing the post-retrofit energy performance gap and the rebound effect. The sources that were strictly related to social housing with occupants at high risk of energy poverty were excluded from the analysis (behavioural factor for energy poverty related measures may be found in streamSAVE, 2022). In contrast, studies on non-residential buildings are much more limited, particularly given the wide variety of building types. Only three relevant non-residential studies were identified in this context. Therefore, the indicative value for this sector is determined, but not recommended to be used due to lack of robust evidence and the variety of non-residential building types/uses.

Table 15: Overview of behavioural influences to energy savings in renovated buildings

Sector	Reference	Country	Sample size / type	Behavioural energy performance gap / Rebound effect
Residential	Khoury et al., 2016	Switzerland	10 buildings (~1,100 flats)	Only 42% of theoretical savings achieved → ~58% gap
	van den Brom et al., 2018	Netherlands	1.4 million dwellings	Energy label A dwellings consume ~20–30% more gas than predicted; Label G dwellings consume ~20–30% less than predicted

⁶ Load profile L is defined in Annex III of 814/2013 regulation (130 liters)

	Hondeborg et al., 2023	Switzerland	400 buildings	10–20% energy savings achieved → ~80–90% gap
	Massié and Belaïd, 2024	17 European Countries	Country-level data	Rebound effect: 18% (short-run), 43% (long-run)
	Zheng et al., 2024	Sweden	44 buildings	Average savings ~30–35% lower than predicted
	Salvia et al., 2020	UK	63 dwellings	Gaps from -50% to +150% vs. predicted energy use after retrofit – on average, +50%
	streamSAVE, 2022	Based on literature review (14 studies)		$f_{BEH} = 0.75$
Non-residential	Grossman et al., 2016	Germany	4 public service buildings	Rebound reduces savings by 5–20%
	Bordass et al., 2007	UK	5 schools	±25% deviation from predicted energy use
	Menezes et al., 2012	UK	63 buildings	~34% average gap 10–80% of gap attributed to user behavior

The **lifetime of savings** depends on the type of measures implemented. In the case of renovations, both construction and technology are often improved. While building measures have a long lifetime, usually around more than 25 years, most technologies average between 10 and 20 years, so the lifetime depends on used technology (e.g. heating source) and construction. Indicative lifetimes in this report in Table 13 (selection for the most relevant for deep renovation of both residential and non-residential buildings) are taken from ANNEX VIII of the Commission Recommendation on transposing the energy savings obligations under the Energy Efficiency Directive (European Commission, 2019b). A formula is also presented within this chapter that takes into account the lifetime savings for construction measures and for technologies.

2.1.2 Calculation of impact on energy consumption (Article 4)

The calculation of primary energy savings is based on the previous formula for calculating savings in final energy consumption (for Article 8) presented in chapter 2.1.1.

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

Standardized values

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

*Table 16: Indicative values for the share of energy carriers for heating and domestic hot water preparation for **residential** buildings*

Share _{ec} – Baseline	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
Solids	4.63	2.21	4.28
Liquefied petroleum gases	1.50	4.20	1.88
Gas/Diesel oil	13.42	10.23	12.96
Natural gas	38.88	37.71	38.71
Wood/wood waste	23.16	8.15	21.00
Geothermal energy	0.02	0.02	0.02
District heat	11.15	7.30	10.60
Electricity	7.23	24.08	9.65
Solar	0.00	6.09	0.88
Share _{ec} – Action	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
For heat pump			
Electricity	100.00	100.00	100.00
For biomass boiler			
Wood/wood waste	100.00	100.00	100.00
For district heating			
District heat	100.00	100.00	100.00

*Table 17: Indicative values for the share of energy carriers for heating and domestic hot water preparation for **non-residential** buildings*

Share _{ec} – Baseline	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
Solids	1.50	0.33	1.30
Liquified petroleum gas (LPG)	0.33	2.33	0.67
Diesel oil	17.17	15.40	16.87
Natural gas	43.05	30.86	41.01
Biomass	4.55	0.59	3.88

Distributed heat	0.43	9.33	12.39
Geothermal	13.01	0.00	0.36
Electricity	19.96	39.08	23.18
Solar	0.00	2.07	0.35
Share_{ec} – Action	Heating [%]	Domestic hot water [%]	Heating and DHW [%]
For heat pump			
Electricity	100.00	100.00	100.00
For biomass boiler			
Wood/wood waste	100.00	100.00	100.00
For district heating			
District heat	100.00	100.00	100.00

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

Methodological aspects:

The calculation methodology of primary energy savings along with sources used is described in detail in chapter 1.1.1 of this report and is based on a standard multiplication of final energy consumption by primary energy factors. The final energy shall be taken from the calculation in chapter 2.1.1, whereby $FEC_{Baseline} = FEC_{before, Art8}$ and $FEC_{Action} = FEC_{after, Art8}$.

Indicative calculation values for the shares of energy carriers in space heating, domestic hot water preparation and combined systems (weighted average of EU total) of the reference (baseline) building systems ($share_{ec, Baseline}$) are based on the IDEES database (Rozsai et al., 2024) and have been prepared in Table 16 and Table 17. Next to that, also the shares ($share_{ec, Action}$) for heat pumps, biomass boilers and heat exchange stations are provided. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances. The share coefficients (w) from chapter 2.1.1 can also be used to determine these values.

In the case of heat pumps, it is considered that the bivalent source is an electric boiler, which is the most common variant on the market. However, in case the bivalent source is based on another energy carrier (most often a natural gas boiler, exceptionally a biomass boiler), the shares need to be adjusted. It can be considered that the bivalent source covers about 10 to 15 % for heating, 10 to 25 % for hot water or 10 to 20 % for the combined system.

Data sources for indicative calculation values:

The conversion factors from final to primary energy ($f_{PE, ec}$) are described in chapter 1.1.1.

The shares of energy carriers are calculated on the basis of the IDEES database, dataset “RES_hh_fec” for final energy consumption. Average values of residential sector for 2010-2021 for EU27 are used to reflect the most recent data on the one hand, while also having a long enough average period of values to normalise for yearly changes in energy consumption. For combined system shares are calculated as the share of sum of final energy consumption for heating and hot water preparation and the total energy consumption.

2.1.3 Overview of costs related to the action

Overview of relevant cost components

In this section, the typical costs falling under the deep renovation are described. Deep renovation often includes major modifications to the building envelope (e.g., walls, roof, windows), as well as updates to mechanical systems (HVAC – systems for heating, cooling and ventilation; hot water heating), electrical systems (lighting), and the integration of renewable energy technologies (e.g., solar panels and heat pumps). Deep renovation costs are therefore the costs related to those components that are implemented in specific deep renovation project.

These main cost categories are investment costs or capital expenditure (CAPEX) and operational costs/expenditures (OPEX). CAPEX in deep renovation refers to the total initial investment required to improve energy performance level of the building to the required level. These costs can vary widely depending on the building type, depth of intervention, and national context. CAPEX includes several major cost categories. A significant portion – often between 30% and 50% – is associated with construction works and labour. This includes preparatory tasks such as demolition, as well as the installation of thermal insulation on walls, roofs, and floors, the replacement of windows and doors, and other structural or façade works. Labour intensity and hourly wages play a crucial role in determining total costs, hence variations between EU Member states are expected. Another large component of CAPEX is the cost of equipment and materials, which usually accounts for 40% to 60% of total investment. These materials and systems include insulation products (such as mineral wool, EPS or cellulose), high-performance glazing, heating and cooling systems (including heat pumps, condensing boilers, and mechanical ventilation with heat recovery), lighting upgrades, RES systems and building automation systems. Equipment costs vary by technology and performance level. In addition to physical upgrades, CAPEX includes design and engineering services, typically accounting for 5% to 15% of the total cost. These services cover architectural and engineering design, energy audits, building performance simulations, compliance with regulations, and commissioning of systems. Project management and ancillary costs also contribute to the overall CAPEX. These may include site supervision, insurance, health and safety compliance, and costs related to temporary relocation or reorganisation of building occupants. A contingency margin – often between 5% and 10% - is usually added to cover unforeseen costs during the renovation process.

OPEX refers to the ongoing costs associated with operating and maintaining a building after deep renovation. These costs are typically divided into fixed and variable components, both of which are influenced by the scale and nature of the renovation measures implemented. Fixed OPEX includes costs that do not change significantly with building usage, such as regular maintenance, inspections, service contracts for HVAC systems, insurance, and administrative overhead. After a deep renovation, fixed operational costs may increase slightly compared to the pre-renovation state. This is due to the introduction of more advanced and complex technologies - such as heat pumps, ventilation with heat recovery, or building automation systems - which often require specialised servicing, monitoring, and sometimes user training. However, these systems are typically more reliable and can be maintained on scheduled cycles, which allows for better cost predictability and performance assurance over time. Variable OPEX is closely tied to energy consumption and usage patterns. Deep renovation aims primarily to reduce these variable costs by significantly lowering the building's energy demand. In many cases, the reduction in variable operating costs outweighs any marginal increase in fixed costs, resulting in a net decrease in total OPEX.

Beyond CAPEX and OPEX, deep renovation involves several other important lifecycle costs. Replacement costs arise as technical systems like heat pumps, ventilation units, or controls typically require renewal every 10–25 years, unlike envelope elements which last 30–50 years. Disposal costs include the removal and safe handling of outdated materials, especially HVAC components, which may contain hazardous substances. Additional upgrade costs may be triggered by structural, fire safety, or accessibility requirements tied to renovation works. Lastly, while systems depreciate over time, deep

renovation can enhance a building's residual value, improving long-term asset performance and regulatory compliance.

The tables below present indicative EU-wide values for the key cost components (building envelope and technology measures), based on publicly available data. Values are expressed in euro2024 (excluding VAT) and shall be refined using national data to reflect differences in labour and equipment pricing. Specific costs, i.e. costs per m² of building envelope element or costs per kW of technical equipment are given. It has to be emphasised that these data are to be used only for information purposes, while for detailed costs estimations country specific data have to be used, as they significantly depend on the market conditions. This is especially the case for labour intensive action, like building envelope insulation. OPEX is provided as a percentage of CAPEX for annual maintenance only.

Table 18: CAPEX and OPEX estimation for deep renovation components

Deep renovation component	CAPEX excluding VAT [euro2024/kW]	OPEX excluding VAT [% of investment costs]
Complex insulation (average for combination of windows and walls/roofs/basement)	180 – 383 [euro2024/m ²]	/
Biomass boiler	150 – 472	2.0 – 4.0
Heat pump (air – water)	631 – 902	1.5 – 4.0
Heat pump (water – water)	834 – 1,191	
Heat pump (ground – water)	1,364 – 1,949	
Heat pump (gas)	1,352	
Electric resistance heating	69	0.5
District heating	84 - 105	0.5 – 1.5
Air conditioning (ventilation and cooling system)	158 - 665	2.0 – 4.0
Photovoltaic system	1,500 - 2,500	0.5 – 1.5
Solar thermal system (including water tank storage)	1,438	1.0 – 2.
Lighting (non-residential)	10	0.5 – 1.0

Table 19: CAPEX estimation for deep renovation

Sector	CAPEX excluding VAT [euro2024/m ²]
Residential	440 - 578
Non-residential	512 – 660

Methodological aspects

The investment costs of deep renovation technologies were estimated using data from the EU Reference Scenario 2020, developed by the European Commission with the PRIMES energy system

model (European Commission, 2021). The Reference Scenario provides baseline projections for energy system evolution and includes detailed techno-economic parameters across sectors. The original cost data reflects conditions as of 2020–2021, with "current" (column „Current“ in datasheet „Domestic“ in Excel file „REF2020_Technology Assumptions_Energy“) purchasing cost values representing baseline estimates for each technology (e.g., heating, cooling, and building envelope components). To update these cost values to reflect 2024 price levels, a standard inflation adjustment was applied using cumulative changes in the Harmonised Index of Consumer Prices (HICP) for the Euro area. HICP is the official inflation metric used across EU Member States, maintained by Eurostat. Between 2021 and 2024, cumulative inflation in the euro area is estimated at approximately **15%**, based on annual HICP rates of 2.9% (2021), 9.2% (2022), 6.4% (2023), and 2.6% (2024). This yields a compounded price index increase of approximately 1.15 $[(1.029 \times 1.092 \times 1.064 \times 1.026) \approx 1.15]$, which has been applied uniformly to the original cost values. The resulting euro2024 cost estimates are expressed per kilowatt for technologies and represent updated approximations of investment requirements under current economic conditions. This inflation adjustment methodology is consistent with approaches used in energy system modelling, cost–benefit analyses, and technology impact assessments. While the method assumes linear price scaling and does not account for technology-specific market dynamics or supply chain disruptions, it provides a transparent and replicable basis for converting nominal 2021 prices into present-day terms. The cost estimations are cross-checked with data used for cost-benefit analyses within Comprehensive assessments on efficient heating and cooling, under the article 25 of Energy Efficiency Directive in Croatia (EIHP, 2024). OPEX is expressed as percentage of CAPEX and represent annual maintenance costs. Data provided are engineering estimates, usually used in cost-benefit analyses (EIHP, 2024) and are also confirmed by the data from (JRC, 2017). For overall costs of deep renovation for both residential and non-residential there are no structured data available, that could provide a single number that would be relevant EU-wide. Hence, the estimation has been made based on available data from national sources, particularly from Croatian building renovation programmes (MPGI, 2025 & MPGI, 2025a). In these programmes and related public calls for grants, the maximal investment costs of deep energy renovation are prescribed based on the market research and expressed in euro per gross floor area of a building. In addition to these costs (equipment and works), costs of project preparation (activities prior to renovation, approximately 7% of equipment and works costs) and project management costs (during renovation, set to maximal level of 3% of equipment and works costs) are also specified in these programmes. It has to be emphasised that costs for residential sector are related to multi-apartment buildings. For family houses, these costs are lower but could not be determined due to lack of relevant data sources.

Data sources for indicative calculation values

Data from the EU Reference Scenario 2020, developed by the European Commission with the PRIMES energy system model (European Commission, 2021) were used as a starting point to obtain EU-wide data on investment costs per deep renovation component. Eurostat was a source of data for HICP, which was used to correct PRIMES prices to the euro2024 level. Publicly available data from national sources, especially from Croatian building renovation programmes that promote deep renovation of residential and non-residential (public) buildings were used to determine overall costs of deep renovation.

2.1.4 Calculation of CO₂ savings

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

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

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 [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

Standardized values

Indicative calculation values for the shares of energy carriers in space heating, domestic hot water preparation and combined systems are described in chapter 2.1.2 of this report.

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

Methodological aspects:

The calculation methodology of CO₂ savings along with sources used is described in detail in chapter 1.3 of this report and is based on a standard multiplication of final energy consumption by emission factors. The final energy shall be taken from the calculation in chapter 2.1.1, whereby $FEC_{\text{Baseline}} = FEC_{\text{before,Art8}}$ and $FEC_{\text{Action}} = FEC_{\text{after,Art8}}$.

Data sources for indicative calculation values

The **shares of energy carriers per end-use type and sector** are based on the IDEES database, dataset “RES_hh_fec” for final energy consumption. Average values of residential sector for 2010-2021 for EU27 are used. Details are described in chapter 2.1.2.

The **emission factor(s)** for energy carriers (f_{GHG}) are taken from Annex VI of the Regulation on the monitoring and reporting of greenhouse gas emissions (2018/2066/EU), see chapter 1.3. **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 IT equipment and systems in data centres

A data centre is defined as a structure or group of structures used to house, connect, and operate computer systems and associated equipment for data storage, processing, and/or distribution, along with related activities (European Commission, 2022). These may include multiple buildings or designated spaces whose boundaries can be clearly defined to encompass both the ICT equipment and the supporting infrastructure for power distribution, environmental control, resilience, and security. The computer room space specifically refers to the area hosting the core IT functions: data processing, storage, and telecommunications (European Commission, 2023c).

Functioning as the physical backbone of today's digital economy, data centres support a vast range of services such as cloud computing, artificial intelligence, financial transactions, and telecommunications. They are among the most energy-intensive types of facilities, consuming substantial and continuous amounts of electricity to operate servers, storage, and networking equipment, as well as to maintain optimal environmental conditions. This energy demand is fuelled by the exponential growth of digital services, including the expansion of IoT, AI workloads, and streaming platforms.

Globally, data centres account for approximately 1.4 % of total electricity consumption, according to estimates by the Joint Research Centre (Booth, John et al., 2024). While overall energy use has remained relatively stable in recent years (due to notable improvements in energy efficiency), this trend may not continue as computing workloads intensify, particularly with the deployment of high-performance systems and generative AI applications. As a result, energy consumption in the sector is projected to rise unless further measures are adopted.

Recognising this growing impact, data centres are a central focus of EU energy and climate policy. Measures such as the EU Code of Conduct for Data Centre Energy Efficiency (Booth, John et al., 2024), the Energy Efficiency Directive (European Commission, 2023a), and the EU Taxonomy Climate Delegated Act (European Commission, 2024b) aim to improve the sector's energy performance and mitigate its environmental footprint.

Given that IT equipment accounts for over 60 % of a data centre's total energy use under a typical PUE (Power Usage Effectiveness) of 1.6 (ICIS, 2025), enhancing its efficiency presents one of the most immediate and impactful opportunities to reduce overall energy consumption and environmental impact. This methodology offers a structured framework for assessing energy savings specifically attributable to IT-related efficiency measures. It enables data centre operators to quantify performance improvements, make informed investment decisions, and align operational strategies with broader sustainability goals.

3.1. IT Efficiency Improvements in Data Centres

The objective of this methodology is to evaluate energy savings that result from improvements in the efficiency of information technology (IT) equipment within data centres. By focusing on IT-specific measures such as server consolidation, virtualisation, workload optimisation, and hardware upgrades, the methodology provides a structured approach to quantify energy impacts, identify priority areas for action, and support strategic investment decisions. The methodology is aligned with the EU policy frameworks, including the EU Code of Conduct for Data Centre Energy Efficiency, the Energy Efficiency Directive, and the EU Taxonomy Climate Delegated Act.

Data centres are complex technical environments that integrate multiple subsystems to ensure high availability, fault tolerance, and operational performance. These include ICT equipment, cooling systems, power infrastructure, monitoring and control systems, and the physical building envelope.

While all components contribute to energy consumption, this **methodology focuses exclusively on ICT systems**, which are typically the largest and most direct energy consumers within the data centre.

ICT equipment is broadly grouped into three principal categories:

- Servers, which are responsible for executing applications, processing user requests, and managing virtualised workloads.
- Storage devices, including hard disk drives (HDDs), solid-state drives (SSDs), and storage arrays, used for data retention, backup, and retrieval.
- Network equipment, such as switches, routers, and firewalls, which manage data communication within and beyond the data centre.

Improving the energy efficiency of these ICT systems offers significant opportunities for reducing electricity use and environmental impact. The following measures are recommended, grouped by equipment category.

Server optimisation offers the most immediate and impactful opportunities. Key measures include (Booth, John et al., 2024; Uptime Institute, 2024; U.S. Environmental Protection Agency, 2016; VMware, 2022):

- Server virtualisation and workload consolidation, which increase system utilisation and reduce the number of active machines.
- Decommissioning obsolete or underutilised servers, which can immediately lower energy use and free up space.
- Deployment of energy-efficient server hardware, featuring improved power supplies, thermal design, and CPU power management.
- Dynamic workload scheduling, which allows systems to be powered down during off-peak hours without service disruption.
- Activation of power-saving modes, such as dynamic voltage and frequency scaling (DVFS), CPU throttling, and sleep states.
- Use of lightweight virtualisation platforms, such as containers (e.g., Docker, Kubernetes), which reduce resource overhead.
- Monitoring and analytics tools, which enable energy-aware management through rack-level or server-level data.

Storage systems also present notable energy-saving potential through (JRC, 2020; SNIA, 2022):

- Data deduplication, compression, and lifecycle optimisation, which reduce storage load and unnecessary data replication.
- Storage tiering, which shifts rarely accessed data to low-energy devices such as cold storage or archival drives.
- Energy-aware storage systems, which support features like automatic spin-down of idle drives.
- Hardware modernisation, replacing older HDDs with SSDs or hybrid systems for better performance-per-watt.

Though typically consuming less energy, **network infrastructure** can still be optimised through (Green Grid, 2021; ITU, 2020):

- Efficient network design and topology simplification, reducing redundant paths and unused devices.
- Use of energy-efficient Ethernet standards, such as IEEE 802.3az, which scale power use with data throughput.
- Port and link management, including disabling inactive ports and adjusting link speeds during low traffic.
- Network energy monitoring, which supports strategic upgrades and operational fine-tuning.

3.1.1 Calculation of final energy savings (Article 8)

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

$$TFES = \frac{EC_{before}}{PUE} * ICT_{load} * ES_m$$

$TFES$	Total final energy savings [kWh/a]
EC_{before}	Energy consumption before the implementation of the action [kWh/a]
PUE	Power Usage Effectiveness [dimensionless]
ICT_{load}	Proportion of ICT energy consumption attributed to each load component [%]
ES_m	Energy savings by type of efficiency measure [%]

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:

Table 20: Energy consumption before the implementation of the action for different categories of data centres (EC_{before})

Category	IT Power	[MWh/a]
Very Small	100–500 kW	650 – 4,000
Small	500–1,000 kW	3,250 – 8,000
Medium	1–2 MW	6,500 – 17,000
Large	2–10 MW	14,000 – 85,000
Very Large	>10 MW	>85,000

Table 21: Power Usage Effectiveness for different categories of data centres (PUE)

Category	IT Power	PUE
Very Small	100–500 kW	1.5 – 1.8
Small	500–1,000 kW	1.4 – 1.7
Medium	1–2 MW	1.3 – 1.6
Large	2–10 MW	1.3 – 1.5
Very Large	>10 MW	1.1 – 1.4

Table 22: Proportion of ICT energy consumption attributed to each load component (ICT_{load})

Load	%
Servers	60 – 70%
Storage Devices	10 – 15%
Networking	10 – 15%

Other ICT Loads	5 – 10%
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Table 23: Energy savings by type of efficiency measure (ES_m) and lifetime of savings for servers' loads

Load	%	Lifetime (years)
Server virtualisation and consolidation	20 – 40%	6
Decommissioning obsolete servers	5 – 15%	3
Deployment of energy-efficient server hardware	10 – 25%	5
Intelligent workload scheduling	10 – 30%	4
Activation of power management features	5 – 20%	4
Efficient virtualisation/container platforms	10 – 20%	5
Monitoring and analytics for server energy use	0 – 5%	2

Table 24: Energy savings by type of efficiency measure (ES_m) and lifetime of savings for storage loads

Load	%	LifetimeYears
Data management optimisation	5 – 15%	4
Storage tiering and energy-aware systems	10 – 20%	5
Modernisation of storage hardware	10 – 20%	5

Table 25: Energy savings by type of efficiency measure (ES_m) and lifetime of savings for network loads

Load	%	LifetimeYears
Efficient network design and topology optimisation	5 – 15%	4
Energy-efficient network equipment	5 – 15%	5
Intelligent port and link management	5 – 10%	4
Monitoring network device consumption	0 – 5%	2

Methodological aspects:

This methodology evaluates energy savings in data centres by comparing final energy consumption before and after the implementation of specific efficiency measures, with the aim of quantifying reductions attributable to ICT-related interventions.

The approach relies on the calculation of final energy savings using the following conceptual elements:

- Baseline energy consumption is established based on the energy demand of the data centre prior to the implementation of any measure. This is typically expressed in kilowatt-hours per year (kWh/year) and varies according to the installed IT power and the size category of the data centre.
- The classification of data centre size used in this methodology is aligned with the categories defined in Commission Delegated Regulation (EU) 2024/1364 (European Commission, 2024a), which establishes the first phase of a common Union rating scheme for data centres. This

alignment ensures consistency with EU-wide monitoring and reporting requirements and enables benchmarking across different facility types.

- The metric Power Usage Effectiveness (PUE) is used to account for the proportion of total facility energy that is consumed by IT equipment. This indicator, which is dimensionless, provides a standard method for evaluating how efficiently energy is delivered to computing loads within the data centre. The determination of PUE should follow the methodology established in ISO/IEC 30134-2:2016 (ISO/IEC, 2016), which standardises the calculation and reporting of this key performance indicator.
- The methodology considers the energy consumption distribution across the main ICT components. These include servers, storage devices and network equipment. Each component is associated with a specific share of the overall ICT energy consumption.
- An energy savings effect (ES_m) is applied according to the efficiency measure implemented. The values of ES_m are based on benchmarks published at the EU level and may be adapted to reflect national conditions or to an individual data centre level. Each measure is also associated with a typical expected lifetime, expressed in years, which supports lifecycle and cost-benefit analyses.

Final energy savings are estimated by applying the percentage savings of each measure to the energy share of the corresponding ICT component. The calculation assumes that the measure would not have been implemented without support, and therefore the energy consumption prior to the action is considered the valid baseline.

When multiple efficiency measures are applied to the same ICT component (e.g. servers), the total percentage energy savings for that component should be calculated by multiplying the individual savings effects sequentially, rather than summing them. For example, if two independent measures reduce the server load by 15 % and 10 % respectively, the combined effect is calculated as:

Combined savings = $1 - (1 - 0.15) \times (1 - 0.10) = 0.235$ or 23.5%

When different efficiency measures are applied to more than one ICT component, the final energy savings for each load type should be calculated separately using this approach, and the total savings are then obtained by summing the savings across all ICT components.

To ensure comparability and reliability, the methodology incorporates normalisation factors that account for differences in data centre size, usage patterns and operating conditions. These include indicative values for:

- Total ICT energy consumption by data centre category;
- Typical PUE values by facility type;
- ICT load distribution among servers, storage and networking equipment;
- Typical savings for each efficiency measure;
- Expected lifetime of measures implemented.

By addressing each ICT component separately and linking it to specific efficiency actions, this methodology provides a practical and structured approach for evaluating energy performance improvements in data centres, fully aligned with the European regulatory framework.

Data sources for indicative calculation values:

Due to the diversity in data centre designs, operating models, and technological configurations, this methodology **does not rely on rigid indicative values**. Instead, it is based on the use of sectoral benchmarks and empirically validated parameters drawn from recent EU and international sources. The methodology assumes that implementers will assess energy savings using measured or calculated values, supported by a set of typical ranges and assumptions derived from recognised references.

Key inputs such as IT energy consumption, Power Usage Effectiveness (PUE), and ICT load distribution are drawn from (Booth, John et al., 2024; European Commission, 2024a; International Energy Agency, 2023; United States Department of Energy, 2024; Uptime Institute, 2024).

These sources provide the basis for typical operating parameters, including:

- Operating hours (typically 8,000–8,760 hours/year);
- Estimated energy use per data centre size category;
- PUE ranges aligned with current best practices;
- Proportional ICT energy use by load type (servers, storage, networking).

Energy savings associated with specific ICT efficiency measures and expected lifetime are based on literature and technical guidance, including (ASHRAE, 2021; CEN-CENELEC, 2022, 2023; Cisco, 2020; Green Grid, 2020, 2021; IDC, 2020, 2021; Intel, 2020; ISO, 2017; ISO/IEC, 2022, 2022, 2023; ITU, 2020; JRC, 2020; SNIA, 2022).

Although this methodology includes recommended value ranges to support calculation, actual savings must be determined based on measured or documented data before and after the implementation of the action. Data should be collected over a representative period, reflecting steady or typical ICT operations.

To strengthen the accuracy and contextual relevance of these inputs, the methodology is designed to evolve in parallel with regulatory developments and improved data availability. Under the revised Energy Efficiency Directive (Directive (EU) 2023/1791), all data centres with an installed IT power of 500 kW or more are required to report annually on their energy performance, beginning in 2024 (European Commission, 2023c). This reporting includes metrics such as total and IT-specific energy consumption, Power Usage Effectiveness (PUE), cooling efficiency, renewable energy share, and waste heat reuse. The data must be submitted either through national platforms or to the central EU database, allowing for structured benchmarking and facilitating policy monitoring at both Member State and Union levels.

In future iterations, the dataset collected under this reporting obligation should serve as the foundation for refining the typical values used in the present methodology. It will also enable the development of nationally specific benchmarks (or at an individual data centre level) and support more accurate, country-level energy savings assessments. This alignment ensures that the methodology remains up to date, evidence-based, and responsive to the evolving performance landscape of data centre infrastructures across Europe.

3.1.2 Calculation of impact on energy consumption (Article 4)

The calculation of final energy savings for Article 4 can be taken from the previous calculation of final energy savings (Article 8).

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.

3.1.3 Overview of costs related to the action

Overview of relevant cost components

This section provides an overview of the most relevant cost components associated with the implementation of ICT energy efficiency measures in data centres. These indicative values support Member States in calculating cost-effectiveness ratios (e.g., total annual cost per unit of energy saved).

The focus is on direct costs, namely on costs directly related to the purchase, installation, configuration, and operation of IT hardware and software components linked to the energy savings action. The following cost components are included:

- Investment costs - upfront capital expenditure for new energy-efficient ICT equipment, such as servers, storage arrays, and network devices, including hardware procurement and associated setup;
- Fixed operational costs - recurring costs required to maintain and support the equipment (e.g., maintenance contracts, software licensing);
- Variable operational costs - costs that depend on system usage, including electricity consumption, firmware updates, and service-level adjustments.

If applicable, costs associated with the baseline situation (e.g., operating costs of legacy systems or old server infrastructure) should also be included to capture net impacts.

Other direct cost components may include:

- Information and audit costs (e.g., measurement tools, metering systems);
- Administrative and implementation costs;
- Training costs for technical staff on virtualisation, energy monitoring platforms, or workload optimisation tools.

In some cases, cost savings or revenue gains may arise from implementing ICT efficiency measures. For instance, server consolidation and virtualisation can reduce floor space, cooling demand, and maintenance expenses, leading to cost reductions beyond the IT domain.

The table below presents indicative EU-wide values for the key cost components, based on publicly available data and industry sources. Values are expressed in euro2025 (excluding VAT) and may be refined using national data to reflect differences in labour, equipment pricing, or electricity costs.

Table 26: Indicative values for cost components of IT equipment and systems in data centres (excl. taxes or fiscal incentives)

Category	Investment Cost (€/kW ICT capacity)	Fixed OPEX (€/kW/year)
Servers	2,000 – 3,500	100 – 250
Storage Devices	1,500 – 2,500	80 – 200
Network Equipment	1,200 – 2,000	60 – 150

Note: Ranges reflect variability in equipment class (basic vs enterprise-grade), implementation scope (retrofit vs new deployment), and project scale.

Methodological aspects

The selection of cost components reflects the specific nature of ICT upgrades in data centres, focusing on interventions that directly impact energy use. The categorisation by component (servers, storage,

networking) is aligned with the energy savings methodology and allows for consistent assessment across different facility types and project scopes.

Investment costs are defined per unit of ICT capacity (€/kW), allowing for scaling across data centre sizes. Operational costs distinguish between fixed support activities and variable energy-driven usage.

For national adaptation, Member States may adjust cost inputs based on:

- Market prices for IT hardware and services;
- National electricity tariffs;
- Labour costs for installation and configuration;
- Public incentives or support mechanisms for digital energy efficiency.

Where available, cost trends (e.g., decreasing price per performance for servers or SSDs) can also be used to forecast evolving cost-effectiveness over time.

Data sources for indicative cost values:

The indicative cost values presented in this methodology are based on a combination of technical literature, market data, and project experience. Key references include:

- Manufacturer and vendor catalogues for ICT hardware (e.g., Dell, HP, Cisco) and energy monitoring systems;
- Industry reports, including (Intel, 2020; SNIA, 2022; Uptime Institute, 2024);
- European Commission reports, including (European Commission, 2023b), and EU-funded project outputs, notably those focused on data centre optimisation and digital energy services (GreenDataNet, 2020).

Where relevant, cost data may also be refined using insights from implementation experiences reported under the Energy Efficiency Directive (European Commission, 2023a), particularly concerning the monitoring and reporting of large data centres.

3.1.4 Calculation of CO₂ 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 e p.a.]
FEC	Annual final energy consumption [kWh/a]
$f_{GHG,electricity}$	Emission factor for electricity [g CO ₂ /kWh]

The final energy consumption (FEC) of the baseline and the action can be taken from the savings calculation for Article 8 in section 3.1.1 of this report.

Values for the emission factors for electricity are 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 the national level according to the “Complete energy balances” of the [EUROSTAT database](#).

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Chapter 4. Savings calculation for cooling of data centres

The scope of this Priority Action (PA) includes all retrofit, upgrade, or modernization interventions aimed at enhancing the performance, efficiency, and sustainability of data centre cooling systems, provided that they do not alter the IT processing load. These interventions span both technological and operational improvements to the cooling infrastructure that supports continuous IT operation.

Such measures may include the replacement of outdated Computer Room Air Conditioning/Handling (CRAC/CRAH) units with more energy-efficient models; the adoption of advanced liquid-based cooling strategies such as direct-to-chip or immersion cooling for high-density workloads; the implementation of free cooling systems utilizing ambient air or water to reduce mechanical cooling demands; and the deployment of airflow optimization strategies, including cold/hot aisle containment, raised floor reconfiguration, or intelligent ventilation control. Additionally, integration with smart control systems, automation platforms, or energy management systems that enhance load-matching and reduce idle energy use is also encompassed within the scope.

The core methodology proposed uses changes in the Power Usage Effectiveness (PUE) metric to quantify energy savings by assessing improvements in the efficiency of facility infrastructure that supports IT operation, primarily cooling systems. PUE captures the ratio between the total facility energy consumption and the energy used by IT equipment, making it a comprehensive and practical indicator of overall infrastructure performance.

By monitoring reductions in PUE following the implementation of energy efficiency measures, such as the replacement of cooling systems, optimization of airflow, or the adoption of liquid cooling, this approach enables a direct estimation of avoided energy consumption attributable to the cooling systems in data centres. It offers a transparent, scalable, and repeatable framework for energy savings estimation that is particularly valuable in scenarios where sub-metering data is incomplete, inconsistent, or unavailable.

Moreover, the methodology allows for normalization based on IT load profiles, making it adaptable to diverse data centre configurations. This facilitates consistent reporting and enables meaningful comparison and aggregation of results at regional or national levels. As such, it offers a technically robust yet flexible approach that can support compliance with regulatory frameworks—such as the EU Energy Efficiency Directive and contribute to the development of corporate energy performance strategies.

4.1. Cooling Efficiency Improvements in Data Centres

This methodology offers a structured and transparent approach to estimating energy savings from improvements in data centre cooling efficiency. It is based on Power Usage Effectiveness (PUE), an internationally recognized metric that expresses the ratio of a data centre's total energy consumption to the energy used by its IT equipment. PUE serves as a reliable proxy for evaluating the performance of support systems like cooling, power distribution, and lighting.

The core idea is to compare PUE values before and after implementing efficiency measures—such as replacing outdated equipment (e.g., legacy CRAC units), optimizing airflow, or adopting advanced technologies (e.g., free or liquid cooling). A lower PUE indicates reduced non-IT energy overhead.

This PUE-based approach is robust, auditable, and repeatable, making it particularly useful where sub-metering is limited. It supports energy audits, regulatory compliance (e.g., Article 8 of the Energy Efficiency Directive), and corporate sustainability reporting by providing a practical, high-level method for assessing infrastructure efficiency relative to IT load.

Application Area: This methodology applies specifically to data centre cooling systems, targeting the energy consumption of infrastructure that maintains optimal thermal conditions for IT hardware. It is particularly relevant for retrofit projects, where outdated or inefficient cooling technologies are replaced or upgraded to reduce energy use, and for modernization efforts involving more advanced or intelligent cooling systems.

The approach is designed to assess energy savings from measures that do not alter the IT workload, ensuring a consistent IT load throughout the evaluation. Applicable interventions include replacing conventional CRAC or CRAH units with more efficient models, implementing chilled water systems or air-side economizers, and adopting liquid cooling solutions such as direct-to-chip or immersion cooling.

The methodology is suitable across a wide range of data centre types—including enterprise-owned facilities, hyperscale cloud platforms, co-location providers, and decentralized edge centres. Regardless of business model, IT architecture, or facility scale, it accommodates diverse configurations, from legacy infrastructures to modern modular setups, offering broad applicability and flexibility in system design and cooling technology.

Eligible actions include a range of technologies and strategies aimed at reducing cooling-related energy use within data centres. The following technologies have been considered, taking into account the best practice guidelines reported in (Acton et al., 2024) and (Acton et al., 2023):

- **Replacement of conventional CRAC (Computer Room Air Conditioning) and CRAH (Computer Room Air Handling) units** involves substituting legacy equipment with newer, more efficient models that feature improved airflow design, variable speed fans, and integrated control systems. Such upgrades reduce both energy use and operational noise.
- **A transition from air-based to chilled water** systems enables more efficient heat transfer and supports centralized cooling. Chilled water systems often operate with higher coefficients of performance and allow for the use of variable flow designs.
- Air-side and water-side economizers known as **free cooling** reduce mechanical cooling demand by using outdoor air or ambient water when conditions allow. This technology is particularly effective in temperate climates and can significantly cut energy use during cooler seasons.
- **Direct-to-chip liquid cooling** targets high-density compute environments by applying liquid coolant directly to the hottest components, such as CPUs and GPUs. This technique enables much higher thermal transfer efficiency and supports greater IT load consolidation.
- **Immersion cooling**, where entire server boards are submerged in thermally conductive but electrically insulating liquid, allows for compact system design, near-silent operation, and exceptional thermal efficiency. Immersion systems also facilitate waste heat recovery.

The methodology supports **both legacy infrastructure and modern modular systems**, and is agnostic to server types or IT workloads. Its flexibility allows it to accommodate variable cooling system configurations, levels of metering, and operational control sophistication.

Boundary Conditions: This methodology is suitable for implementation across all EU Member States and in all European climate regions, provided that appropriate normalization for IT load fluctuations is applied. It is particularly intended for use in existing data centres that are undertaking measures to improve cooling efficiency—whether through retrofit of legacy systems, operational optimization, or technology upgrades.

The methodology is not suited for newly constructed data centres unless a pre-commissioning PUE baseline has been clearly defined and can be validated. The method requires access to reliable estimates or measurements of annual IT energy consumption (in kWh), as well as baseline and post-intervention PUE values that can be derived from either direct metering or aggregated facility-level energy data.

It has been designed with regulatory alignment in mind, specifically for compatibility with Article 8 of the Energy Efficiency Directive (2023/1791), and it complements the methodological frameworks

promoted in the streamSAVE+ initiative and the EU Code of Conduct for Data Centres. While particularly useful in situations where sub-metering infrastructure for cooling systems is limited, the methodology supports a harmonized approach for energy auditors and national authorities seeking to validate energy efficiency claims in the data centre sector.

Significant changes in IT usage or major infrastructure expansion that impacts baseline comparability may require additional adjustments or complementary methodologies to ensure the accuracy and reliability of savings estimates.

PUE was introduced in 2007 by The Green Grid, a consortium dedicated to advancing energy efficiency in data centres. Since its inception, PUE has been globally adopted and widely reported with its methodology standardized under ISO/IEC 30134-2:2016 and EN 50600-4-2:2016 (Sunbird DCIM, 2024). PUE is a well-established industry metric that quantifies the proportion of total energy used by a data centre that is consumed by its core IT equipment, as opposed to non-IT systems such as cooling, lighting, and power distribution (Sunbird DCIM, 2024).

By comparing **PUE values before and after** the implementation of efficiency measures, this approach enables a straightforward estimation of the reduction in non-IT energy consumption, particularly cooling energy which typically constitutes the largest share of overhead in a data centre.

This methodology is especially suitable for retrofit or optimization scenarios where:

- The IT load remains relatively stable;
- Metering of cooling-specific energy use is limited or unavailable;
- Aggregate energy and PUE values are available from monitoring systems or audits.

Using this approach, energy savings can be calculated without the need for detailed sub-metering of each cooling component, thereby providing a **cost-effective and scalable solution** for audits in line with **Article 8 of the Energy Efficiency Directive (Directive (EU) 2023/1791)**.

Power Usage Effectiveness (PUE) is defined as:

$$PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}$$

where,

- **Total Facility Energy** includes all electricity consumed by the data centre, including IT equipment, cooling systems, power distribution, lighting, and other auxiliary systems.
- **IT Equipment Energy** refers solely to the energy used by computing infrastructure (servers, storage, networking).

The ideal PUE value is 1.0, which would indicate that all consumed energy is used by IT equipment and none is lost to overhead. In practice, lower PUE values indicate more efficient data centres.

4.1.1 Calculation of final energy savings (Article 8)

$$TFES = EC_{Before} * S_{Cooling} * (PUE_{before} - PUE_{after})$$

TFES	Total final energy savings [kWh/a]
EC_{Before}	Annual energy consumption of ICT equipment (servers, storage, networking) [kWh/year]

$S_{Cooling}$	Estimated or measured share of cooling within the non-ICT loads (cooling, UPS, lighting)
PUE_{before}	Power Usage Effectiveness before implementation of the action [without unit]
PUE_{after}	Power Usage Effectiveness after implementation of the action [without unit]

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 27: Reference values for Power Usage Effectiveness for different cooling technologies of data centres (PUE)

Technology	Baseline PUE	Improved PUE	Lifetime [years]
Upgrade CRAC/CRAH units to variable-speed systems	> 1.8	1.5 – 1.6	15
Transition to chilled water system with air-side economizers	> 1.6	1.3 – 1.5	15
Implement free cooling (air-side, water-side, TES etc.)	1.6 – 1.8	1.2 – 1.4	15
Deploy liquid cooling (direct-to-chip or immersion)	1.6 – 1.8	1.02 – 1.1	15
Optimize two-phase/passive cooling (e.g., thermosiphon loops)	1.5 – 1.7	1.1 – 1.3	15
Integrate thermal energy storage (TES) for peak shaving and free cooling	1.6 – 1.8	1.2 – 1.4	15

For better orientation on the PUE ranges for the baseline considering also the size of data centre, the tables below can be used. Categories and indicative values are aligned with the categories presented in Chapter 3.

Table 28: Annual energy consumption in data center before the implementation of the action for different categories of data centres (EC_{before})

Category	IT Power	[MWh/a]
Very Small	100–500 kW	650 – 4,000
Small	500–1,000 kW	3,250 – 8,000
Medium	1–2 MW	6,500 – 17,000
Large	2–10 MW	14,000 – 85,000
Very Large	>10 MW	>85,000

Table 29: Power Usage Effectiveness for different categories of data centres (PUE)

Category	IT Power	PUE
Very Small	100–500 kW	1.5 – 1.8
Small	500–1,000 kW	1.4 – 1.7
Medium	1–2 MW	1.3 – 1.6
Large	2–10 MW	1.3 – 1.5
Very Large	>10 MW	1.1 – 1.4

Table 30: Energy consumption of non-ICT loads (cooling, UPS, lighting) by Data Center Category before the implementation of the action for different categories of data centres (EC_{before})

Category	IT Power	[MWh/a]
Very Small	100–500 kW	360 – 2,700
Small	500–1,000 kW	1,900 – 5,700
Medium	1–2 MW	4,000 – 13,000
Large	2–10 MW	9,300 – 65,000
Very Large	>10 MW	>65,000

Table 31: Estimated energy consumption for cooling by Data Center Category before the implementation of the action for different categories of data centres (EC_{before})

Category	IT Power	[MWh/a]
Very Small	100–500 kW	293 – 2,000
Small	500–1,000 kW	1,300 – 3,600
Medium	1–2 MW	2,275 – 6,800
Large	2–10 MW	4,200 – 29,750
Very Large	>10 MW	>21,250 – > 25,500

Table 32: Estimated share of cooling $S_{cooling}$ in non ICT load for different categories of data centres

Category	IT Power	$S_{cooling}$ [%]
Very Small	100–500 kW	80% – 75%
Small	500–1,000 kW	70% – 65%
Medium	1–2 MW	55% – 50%
Large	2–10 MW	44% – 48%
Very Large	>10 MW	32% – 40%

Methodological aspects:

This methodology evaluates energy savings in cooling of data centres by comparing final energy consumption before and after the implementation of specific type of cooling technology.

The approach relies on the calculation of final energy savings using the following conceptual elements:

- Baseline energy consumption is established based on the energy demand of the data centre prior to the implementation of any measure. This is typically expressed in kilowatt-hours per year (kWh/year) and varies according to the installed IT power and the size category of the data centre.
- The classification of data centre size used in this methodology is aligned with the categories defined in Commission Delegated Regulation (EU) 2024/1364 (European Commission, 2024a), which establishes the first phase of a common Union rating scheme for data centres. This alignment ensures consistency with EU-wide monitoring and reporting requirements and enables benchmarking across different facility types.
- The metric Power Usage Effectiveness (PUE) is used to account for the proportion of total facility energy that is consumed by IT equipment. This indicator, which is dimensionless, provides a standard method for evaluating how efficiently energy is delivered to computing loads within the data centre. The most efficient data centre would have PUE = 1.
- The methodology considers the energy consumption of cooling in data centres to be between 40% and can reach up to 50% in annual energy consumption of data centre as reported in (Zhang et al., 2022) and (Zhang et al., 2022). Taking this into account the annual energy consumption attributed to cooling for the different categories of data centres has been calculated along with the corresponding shares.
- An improved PUE is expected in accordance with improved cooling technology implementation.
- Each measure is also associated with a expected lifetime, expressed in years, which supports lifecycle and cost-benefit analyses. The lifetime value is in line with the APPENDIX VIII: LIFETIME OF MEASURES AND RATE AT WHICH SAVINGS DECLINE OVER TIME of the (European Commission, 2019) proposal for various cooling technologies in services sector.

Final energy savings are estimated by applying the percentage of annual energy consumption of data centre related to cooling (measured or estimated) and calculating the difference of PUE for the reference and improved technology. The calculation assumes that the measure would not have been implemented without support, and therefore the energy consumption prior to the action is considered the valid baseline.

To ensure comparability and reliability, the methodology incorporates normalisation factors that account for differences in data centre size, usage patterns and operating conditions. These include indicative values for:

- Total ICT energy consumption by data centre category;
- Typical PUE values by facility type;
- Typical PUE values for different cooling technologies of data centres (PUE);
- Total non ICT energy consumption by data centre category;
- Total energy consumption for cooling by data centre category;
- Share of energy consumption for cooling in non ICT energy consumption by data centre category;
- Expected lifetime of measures implemented.

This methodology provides a practical and structured approach for evaluating energy performance improvements in cooling of the data centres, fully aligned with the European regulatory framework.

Data sources for indicative calculation values:

Due to the diversity in data centre designs, operating models, and technological configurations, this methodology **does not rely on rigid indicative values**. Instead, it is based on the use of sectoral benchmarks and empirically validated parameters drawn from recent EU and international sources. The methodology assumes that implementers will assess energy savings using measured or calculated values, supported by a set of typical ranges and assumptions derived from recognised references.

The **baseline PUE values** (PUE_{before}) and **improved PUE values** (PUE_{after}) are based on the latest research literature considering the peculiarities of different cooling technologies, namely:

- Upgrade CRAC/CRAH units to variable-speed systems: (Acton et al., 2024), (Acton et al., 2023) and (F. Zhou et al., 2024), (Alkrush et al., 2024);
- Transition to chilled water system with air-side economizers: (F. Zhou et al., 2024), (Sunbird DCIM, 2024), (Alkrush et al., 2024);
- Implement free cooling (air-side, water-side, TES etc.): (Zhang et al., 2022), (Mi et al., 2023), (F. Zhou et al., 2024), (Alkrush et al., 2024);
- Deploy liquid cooling (direct-to-chip or immersion): (Haghshenas et al., 2022), (Kong et al., 2024), (F. Zhou et al., 2024), (Alkrush et al., 2024);
- Optimize two-phase/passive cooling (e.g., thermosiphon loops): (Y. Zhou et al., 2025), (Jing et al., 2024), (Kong et al., 2024);
- Integrate thermal energy storage (TES) for peak shaving and free cooling: (Zhang et al., 2022), (Mi et al., 2023);
- Reference PUE values may be adapted to reflect the operating conditions of peculiar data centre.

The methodology considers the **share of cooling in annual non ICT energy consumption of data centres** ($S_{cooling}$) to be between 32% and can reach up to 80%. The shares have been calculated taking into account the shares of cooling in total annual consumption of data centres as reported in (Zhang et al., 2022), (Jing et al., 2024) and (Li et al., 2024).

Although this methodology includes recommended value ranges to support calculation, actual savings must be determined based on measured or documented data before and after the implementation of the action. Data should be collected over a representative period, reflecting steady or typical ICT operations.

4.1.2 Calculation of impact on energy consumption (Article 4)

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
EPEC	Effect on primary energy consumption [kWh/a]

Data sources for indicative calculation values:

Indicative calculation values for estimating the effect on primary energy consumption are prepared in **Chyba! Nenalezen zdroj odkazů.** Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances.

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.

4.1.3 Overview of costs related to the action

Overview of relevant cost components

The cost of cooling technologies plays a pivotal role in the design and long-term operation of data centers, especially as facilities move toward higher rack densities and energy efficiency. While air-cooled systems have historically dominated, chassis-based immersive liquid cooling is increasingly emerging as a technically and economically viable alternative.

In a representative case study (Bunger et al., 2019) of a 2 MW data center operating at 10 kW per rack, it was found that the total capital expenditure (CapEx) per watt is nearly equivalent between traditional air cooling and immersive liquid cooling. Specifically:

- Air-cooled system: €6.46/W
- Liquid-cooled system (10 kW/rack): €6.42/W

Despite the premium associated with immersion technology (e.g., sealed chassis, dielectric fluid, and micro-pumps), substantial savings are achieved by eliminating conventional mechanical cooling components like chillers and CRAHs (Computer Room Air Handlers). Additional reductions come from smaller UPS and switchgear requirements, and savings in physical infrastructure such as space and containment.

As the data center increases in power density, the cost advantage of liquid cooling becomes more significant. At 20 kW/rack, the CapEx per watt for liquid cooling drops to €5.83, and at 40 kW/rack, it falls further to €5.54, representing up to 14 % CapEx savings relative to the air-cooled baseline. This shift is largely due to fewer racks being required for the same computing power, leading to reduced spending on racks, containment, floor space, and associated infrastructure.

Table below summarizes the estimated capital expenditure per watt for different data center cooling configurations at various rack densities. The figures include all major cost categories relevant to the deployment of cooling infrastructure, such as mechanical and electrical systems, equipment premiums or savings, and infrastructure-related modifications. The comparison highlights how cost components shift between air-cooled (baseline) and liquid-cooled architectures and demonstrates how increasing rack density with liquid cooling contributes to improved cost efficiency. The values are expressed in euros per watt (€/W) and reflect normalized cost assumptions based on a 2 MW data center scenario.

Table 33: Indicative values for cost components of cooling efficiency improvements in data centres (excl. taxes or fiscal incentives)

Cost Component	Air-Cooled (10 kW/rack) baseline	Liquid-Cooled (10 kW/rack)	Liquid-Cooled (20 kW/rack)	Liquid-Cooled (40 kW/rack)
Chiller/CRAH	€0.00	–€0.84	–€0.84	–€0.84
Liquid cooling technology	€0.00	€0.71	€0.65	€0.63

Dry coolers & CRACs	€0.00	€0.29	€0.29	€0.29
Piping and pump modifications	€0.00	€0.03	–€0.03	–€0.04
UPS & switchgear reduction	€0.00	–€0.13	–€0.13	–€0.13
Space, rack, and containment savings	€0.00	–€0.09	–€0.58	–€0.83
Total CapEx per Watt [euro2024/a]	€6.46	€6.42	€5.83	€5.54

Methodological aspects

Capital Expenditure (CapEx) represents all the upfront costs required to deploy the cooling infrastructure in a data center. This encompasses a broad range of cost elements, beginning with the **cooling equipment** itself—such as chillers and computer room air handlers (CRAHs) in air-cooled systems, or dry coolers and chassis-immersive components like micro pumps, dielectric fluid, sealed chassis, heat exchangers, and dripless connectors in liquid-cooled systems. In addition, **mechanical and electrical systems** are included, covering components such as piping, valves, uninterruptible power supply (UPS) systems, switchgear, and electrical cabling. CapEx also accounts for **construction and installation costs**, including raised flooring, aisle containment structures, HVAC plumbing, and any structural modifications needed to support the cooling solution. Lastly, it includes **design and project management expenses**, which cover engineering services, installation labor, commissioning, and overall project supervision.

Data sources for indicative cost values:

The indicative cost values presented in this methodology are based on a case study (Bunger et al., 2019) published by Schneider Electric.

Where relevant, cost data may also be refined using insights from implementation experiences reported under the Energy Efficiency Directive (when available), particularly concerning the monitoring and reporting of large data centres.

4.1.4 Calculation of CO₂ 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 _{2e} p.a.]
FEC	Annual final energy consumption [kWh/a]
f _{GHG,electricity}	Emission factor for electricity [g CO ₂ /kWh]

The final energy consumption (FEC) of the baseline and the action can be taken from the savings calculation for Article 8 in section 4.1.1.

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 factor(s)** for Energy carrier(s) x, y, z ($f_{\text{GHG},\text{ec}}$) 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). 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 5. Savings calculation for heat recovery in ventilation systems

The scope of this priority action is to estimate the annual energy and emission savings that can be achieved with the installation of heat recovery in ventilation units in buildings. A heat recovery system is a part of a bidirectional ventilation unit equipped with a heat exchanger designed to transfer the heat contained in the (contaminated) exhaust air to the (fresh) supply air (EC, 2014). Via the use of a heat recovery system, part of the energy incorporated in the exhaust air is recovered and used to reduce the energy demand required for heating the supply air.

The total final energy savings reflect the impact of the heat recovery on the final energy use for space heating. The Priority Action comprises heat recovery systems for **ventilation units in residential as well as non-residential buildings**. The scope of technologies comprised in this priority action follows the demarcation of the technologies included in the **Directive on the Ecodesign requirements (EU) 1253/2014 (EC, 2014)**. In it the following technologies are excluded from the scope;

- Ventilation units without a heat recovery system.
- Ventilation units that are exclusively specified for operating in specific conditions, such as a potentially explosive atmosphere, for emergency use for short periods of time, in toxic, highly corrosive or flammable environments or environments with abrasive substances, extreme operating temperatures etc.
- Ventilation units that are classified as range hoods.
- Ventilation units that include a heat exchanger and a heat pump for heat recovery or allowing heat transfer or extraction being additional to that of the heat recovery system, except heat transfer for frost protection or defrosting.

The methodology makes distinction between residential and non-residential buildings and between run-around heat recovery systems and other heat recovery systems in ventilation units, as defined in Regulation (EU) 1253/2014 (EC, 2014). A run-around heat recovery system is defined as a heat recovery system where the heat recovery device on the exhaust side and the device supplying the recovered heat to the air stream on the supply side of a ventilated space are connected through a heat transfer system where the two sides of the heat recovery system can be freely positioned in different parts of a building.

In Europe, improving the energy efficiency of buildings' ventilation, heating, cooling and energy production systems are becoming increasingly important in achieving the goal of reducing the emissions of greenhouse gases and becoming more self-sufficient. That is why the adoption of new technologies or methodologies, such as the implementation of heat recovery in ventilation units, which improve energy efficiency in buildings, is very important.

5.1. Heat recovery in ventilation units

The methodology described herein can be used for calculating the impact of installing or upgrading heat recovery in ventilation units on the energy demand of a building.

Installing heat recovery technology in ventilation units consists of the replacement at end-of-life or at a prior occasion of one or more existing less energy efficient ventilation units by one or more new energy-efficient ventilation units with heat recovery technology. It can also consist of the adaptation of existing ventilation units to include heat recovery technology. In that case it must be foreseen in the design of the existing ventilation unit to enable inclusion of the respective heat recovery technology and it should be possible to adapt or replace other components for instance fans and controls to optimally fit the new configuration. It can also consist of the introduction of one or more new energy-efficient ventilation units with heat recovery technology for instance in situations where there is no ventilation system or in situations where the existing ventilation system is a natural ventilation system.

The methodology can be applied in relation to – a reduction of – the space heating final energy consumption. Indicative values are prepared for the residential and non-residential buildings. The method can be applied to retrofitted as well as non-retrofitted buildings. To account for different climate conditions, the geographical area of Europe in which the action is implemented needs to be considered. For this, different average outside temperatures during the heating season are applied for three geographical areas.

The definition of ventilation units follows the definition in the European Ecodesign Directive EU 1253/2014 (EC, 2014) and the same scope applies.

5.1.1 Calculation of final energy savings (Article 8)

$$TFES_{HR} = (FEC_{before} - FEC_{after}) * f_{BEH}$$

$$FEC_{Before} = (1 - \eta_{HR,before}) * A * h * ACH * \rho_{air} * c_{p,air} * \Delta T * t_{SH} / \eta_{SH}$$

$$FEC_{After} = \frac{1 - \eta_{HR,after}}{1 - \eta_{HR,before}} * FEC_{Before}$$

TFES _{HR}	Total final energy savings due to heat recovery implementation in ventilation [kWh/a]
FEC _{Before}	Annual final energy consumption before the implemented action [kWh/a]
FEC _{After}	Annual final energy consumption after the implemented action [kWh/a]
$\eta_{HR,after}$	Thermal efficiency of the implemented heat recovery system [dmls]
$\eta_{HR,before}$	Thermal efficiency of the heat recovery system before the implemented action [dmls]
A	Useful floor area of the zone serviced by the ventilation system [m ²]
h	Average height of the zone serviced by the ventilation system [m]
ACH	Hourly air change rate [m ³ /(h.m ³)]
ρ_{air}	Density of air [kg/m ³]
$c_{p,air}$	Specific heat at constant pressure of air [kWh/(kg.K)]
ΔT	Average temperature difference between indoor and outdoor environment during the heating season [°C]
t_{SH}	Length of the heating season [h]
η_{SH}	Thermal efficiency of the space heating system [dmls]
f_{BEH}	Factor to calculate behavioural 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 will need to be adjusted to national circumstances.

Table 34: Indicative values for the calculation of the total final energy savings from heat recovery in ventilation units.

$\eta_{HR,after}$	[dmls]
Run-around heat recovery system	0.68
All other types of heat recovery system	0.73
$\eta_{HR,before}$	[dmls]
Building stock average efficiency of heat recovery – Residential	0.044
Building stock average efficiency of heat recovery – Non-residential	0.381
A	[m ²]
Residential	95.079
Non-residential	900.0
h	[m]
Residential	2.9
Non-residential	4.0
ACH	[m ³ /h/m ³]
Residential	0.30
Non-residential	0.39
ρ_{air}	[kg/m ³]
Density of air	1.293
$c_{p,air}$	[kWh/(kg.K)]
Specific heat of air	0.000279
ΔT	[°C]
Cold climate (North)	14.5
Average climate (West)	9.5
Warm climate (South)	5
t_{SH}	[h]
Cold climate (North)	6,552
Average climate (West)	5,112
Warm climate (South)	4,392
η_{SH}	[dmls]
Residential	0.75
Non-residential	0.75
f_{BEH}	[dmls]
Residential	0.80

Non-residential	Not available
Lifetime of savings	[a]
Lifetime of savings of heat recovery in ventilation unit	15

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).

Methodological aspects:

The methodology for calculating total final energy savings from the implementation of heat recovery in ventilation units is based on an analysis of several existing methodologies to determine the energy performance or energy savings from heat recovery in ventilation units (EC, 2014) (Jamek A. et al., 2016) (Laverge J. et al., 2012) and methodologies already in use to determine the total final energy savings from heat recovery in ventilation in countries Czech Republic, France, Hungary, Latvia, Lithuania, Luxemburg and Slovenia as summarised in streamSAVE+ deliverable D2.1.

It is important that the heat recovery system in the ventilation unit is properly designed, installed, commissioned and maintained. Only actions that are properly designed, executed and frequently maintained according to good practice of conduct are considered and therefore aspects such as mechanical ventilation system imbalance, component air leakage, fouling and other suboptimal performance characteristics are not taken into account in the methodology. Only efficiency in relation to the heat recovery system is taken into account. This means that no correction is done to take into account for instance the thermal heat gain from fan motors, additional fan energy use due to increased pressure drop of the heat recovery system, additional defrosting energy (in cold periods in average and cold climate), efficiency gains due to smart controls, improved energy performance of fans, motors and controls or improved air tightness of the ventilation unit or the building envelope.

Data sources for indicative calculation values:

The **thermal efficiency of the implemented heat recovery system** ($\eta_{HR,after}$) [dmls] is the thermal efficiency of the heat recovery system of the ventilation system of the action. The efficiency of the heat recovery unit in the ventilation unit is to be determined according to Commission Regulation (EU) No 1253/2014 (EC, 2014). The value is depending on the type of heat recovery system and the value for the specific heat recovery system can be retrieved from product information, such as the Ecodesign/Ecolabeling information. In case no such specific information is available, for instance in case of large scale calculation such as building stock level calculation, indicative values of 0.73 for all heat recovery systems except run-around heat recovery systems and 0.68 for run-around heat recovery systems can be used. The indicative values of the 0.73 for all heat recovery systems except run-around heat recovery systems and 0,68 for run-around heat recovery systems; correspond with the minimum requirements starting from 1/1/2018 for non-residential ventilation units of Ecodesign requirements EU 1253/2014 and implemented for residential and non-residential buildings in the bottom-up calculation methodology already available within Hungary⁷ for the replacement of a heat recovery unit integrated into a ventilation system.

The **thermal efficiency of the heat recovery system before the implemented action** ($\eta_{HR,before}$) [dmls] is the thermal efficiency of the heat recovery system of the reference ventilation system. It is taken equal to the building stock level average value of the thermal efficiency of heat recovery. Indicative values for EU average thermal efficiency of heat recovery ($\eta_{HR,before}$) equal to 0.044 for residential buildings can be taken and for non-residential buildings equal to 0.381. These indicative values are

⁷ These values are mentioned as standardized calculation values for residential buildings (family houses, condominiums), hotels, educational buildings, healthcare buildings, office buildings and industrial buildings (in the method for calculation of total final annual energy savings for replacement after the end of lifetime of old equipment as indicative values for the reference baseline).

derived from the data used in the Ecodesign Impact Accounting analysis prognosis of the business-as-usual scenario for 2025; linear interpolation of data of 2020 and 2030 (Van Holsteijn R. et al., 2020b) separately for residential and for non-residential buildings. In the weighting according to the air flow rates per type of ventilation system, the values have been recalculated so that the air flow rates do not include infiltration. This is done because the heat recovery does not have an effect on the infiltration part of the total air flow rate. The indicative values for the building stock level averages represent building stock average values including all buildings (i.e., those with natural ventilation or no ventilation and mechanical ventilation with and without heat recovery system).

Indicative values for the **useful floor area of the zone serviced by the ventilation system (A)** [m²] representative for the building stock can be taken equal to the EU27 average useful surface area per building type (residential or non-residential) adopted from the JRC-IDEES library (Roszai M. et al., 2024); 95.079m² for residential buildings and 900.0m² for non-residential buildings. Note that the average surface area of the non-residential building is the surface area of a representative building cell in the services sector. The value is assumed to be identical across all member states. It is derived from available information on surface area and the number of enterprises and aligned to the EU Building Stock Observatory, as explained in the documentation of the JRC-IDEES database (Roszai M. et al., 2024). These indicative values should be used with caution, given the uncertainty on the data. Therefore, national specific data are preferred, if available. In case of calculations on the level of individual ventilation units or buildings, only the floor area for which the action (implementation of HR in VU) is undertaken is to be included.

For the **average height of the zone serviced by the ventilation system (h)** [m], project specific values or stock values are to be taken. Indicative values for EU-27 average height of the zone serviced by the ventilation system for residential buildings can be taken equal to 2.9m and for non-residential buildings can be taken equal to 4.0m. These values are derived from the Ecodesign Impact Accounting (Wierda L., Zanuttini A., 2024), namely the building stock characteristics for the residential and the tertiary sector: the ratio of the building volume to the building surface area; respectively 62 billion m³ / 21.2 billion m² and 32 billion m³ / 8.1 billion m². These indicative values should be used with caution, given the uncertainty on the data of the volume and surface area. Therefore, national specific data are preferred, if available. Only the average height of zones of the building for which the action (implementation of heat recovery in ventilation units) is undertaken is to be included. It is the average storey height of the building zones for which the useful floor area A is inserted (see above).

The product of the useful floor area A and the height h may also be substituted by the building volume [m³]. As it is used to determine the ventilation air volume flow rate, it should be based on internal dimensions. It comprises the air volume within building and room boundaries, without the volume of the construction elements.

Specific values for the **hourly air change rate (ACH)** [m³/h/m³] can be derived from national building regulations or building codes. The values should not include infiltration. This means that the rates of mechanical ventilation are used, also in case of natural ventilation. Residual infiltration (in case of mechanical ventilation) is not considered as it is not subject to heat recovery. Indicative values for EU-27 average ACH – excl. infiltration and heat recovery - are derived from EU-27 average data of air flow rates per heated floor area for residential and for non-residential buildings used in the Ecodesign Impact Accounting analysis (Van Holsteijn R. et al., 2020b). The EU-27 average air flow rate for residential buildings is 0.88m³/h/m² and for non-residential buildings 1.55m³/h/m². These values can be translated to ACH via division by the average height of the zone serviced by the ventilation system “h” (see above). This results in indicative values for ACH of 0.30 for residential buildings and of 0.39 for non-residential buildings.

For the **density of air (ρ_{air})** [kg/m³], a value equal to 1.293 kg/m³ (Jamek A. et al.; 2016) is used.

For the **specific heat of air (c_{p,air})** [kWh/(kg.K)], a value equal to 0.000279 kWh/(kg.K) (or 1.006 kJ/(kg.K)) is used, representative for air at 10°C and atmospheric pressure.

The following input parameters are climate dependent;

- The **average temperature difference between indoor and outdoor environment during the heating season (ΔT)** [°C] depends on the local climate. Indicative values for ΔT of 14.5°C in cold climate zone, 9.5 in average climate zone and 5°C in warm climate zone are used. These indicative values are adopted from Table 1 (in it referred to as ΔT_h) from the Ecodesign Directive (EU)1253/2014 (EC, 2014) applicable to residential buildings for three distinct geographical regions in Europe. These are based on the following assumptions. The average indoor temperature is assumed equal to 19°C to which a correction for internal and solar heat gains ΔT_{gains} of -3°C is applied (provided as a pre-heating of the building). The average outdoor temperature during the heating season is equal to 1.5°C in cold climate zone, 6.5°C in average climate zone and 11°C in warm climate zone rendering values of ΔT of 14.5°C in cold climate zone, 9.5 in average climate zone and 5°C in warm climate zone as adopted from the Ecodesign Directive (EU) 1253/2014 (EC, 2014).
- The **length of the heating season (t_{SH})** expressed in hours [h] depends on the local climate. For cold climate t_{SH} is 6,552 hours; for average climate t_{SH} is 5,112 hours and for warm climate t_{SH} is 4,392hours. Values are adopted from table 1⁸ of (EU)1253/2014 (EC, 2014).

The values for ΔT and t_{SH} from table 1 of (EU) 1253/2014 (EC, 2014) relate to the method for residential ventilation units, but are applied here for both residential and non-residential buildings. The values are considered applicable for non-residential buildings as well⁹.

As climate regions mentioned in the Ecodesign regulation (EU) 1253/2014 (EC, 2014) vary from the climate regions used in this methodology, it was assumed that “Cold climate” equals the north region, “Average climate” the west region and “Warm climate” the south region.

The **thermal efficiency of the space heating system (η_{SH})** [dmls] is the efficiency of the entire space heating system between the final and the net energy level. 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. For both residential and non-residential buildings an indicative value of 0.75 can be used. These values have been adopted from the Ecodesign requirements for residential ventilation units (EU 1253/2014 (EC, 2014) but the value is considered applicable for residential and for non-residential buildings separately (as is done in the Ecodesign Impact Accounting (Van Holsteijn R. et al., 2020b).

The **factor for correction of behavioural effects (f_{BEH})** [dmnl] is taken equal to 0.80 for residential buildings. For non-residential the factor for correction of behavioural effects f_{BEH} is not available. 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 literature on rebound effects does not treat heat recovery in ventilation units as such but focuses on the end-use types. Literature 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 implementation of heat recovery in ventilation units of the end-use heating in residential buildings.

For the **lifetime of savings** [years] a period of 15 years is taken. The lifetime expectancy of heat recovery systems is estimated to be 15 years (Van Holsteijn R. et al., 2020a).

⁸ Table 1 of (EU)1253/2014 is for use in relation to residential ventilation units, but the values of t_{SH} (t_h in the table) are also valid for non-residential ventilation units.

⁹ The outdoor climate is the same for residential and non-residential buildings. It is reasonable to assume similar on average boundary conditions for indoor temperature for non-residential buildings as those used for residential buildings (see for instance the climate bin method of EN 14825: 2022 - which is applicable to both residential and non-residential buildings).

5.1.2 Calculation of impact on energy consumption (Article 4)

The calculation of final energy savings for Article 4 can be taken from the previous calculation of final energy savings (Article 8).

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

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

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 for space heating [dmnl]
f _{PE, ec}	Final to primary energy conversion factor of the used energy carrier for space heating [dmnl]
Before	Index for the baseline situation of the action
After	Index for the situation after the implementation of the action
ec	Index of energy carrier
Other inputs	See 5.1.1

Indicative calculation values for estimating the effect on primary energy consumption are prepared in Table 2. Please keep in mind that these values are based on EU-wide data and will need to be adjusted to national circumstances:

Table 35: Indicative values for the share of energy carriers in final energy (in end-use space heating) for heat recovery in ventilation

Share _{ec} – space heating		[%]
Residential	Solids	3.52
	LPG	1.48
	Gas/Diesel oil incl. biofuels (GDO)	9.91
	Natural gas, incl. biogas	41.30
	Biomass and wastes	24.49
	Geothermal energy	0.03
	District heat	11.39
	Electricity	7.88
Non-residential (services)	Solids	1.24
	LPG	0.36
	Gas/Diesel oil incl. biofuels (GDO)	14.50
	Gases incl. biogas	43.93
	Biomass and wastes	5.70

	Geothermal energy	0.40
	District heat	14.30
	Electricity	19.58

EU27 average values for the conversion factors from final to primary energy $f_{PE,ec}$ of the above-mentioned energy carriers are listed in chapter 1.1.1 of this report.

Methodological aspects:

Indicative calculation values of the **share of final energy carrier on final energy consumption for space heating ($share_{ec}$)** are specified separately for residential buildings and non-residential buildings. The shares of energy carriers before and after the implementation of the heat recovery in ventilation units is assumed to be the same.

Data sources for indicative calculation values:

Indicative calculation values of the **share of final energy carrier on final energy consumption for space heating ($share_{ec}$)** are based on the JRC-IDEES database (Rozsai M. et al., 2024), data of year 2021 (the most recent year available in the dataset) of thermal uses; final energy consumption per energy carrier for end-use space heating.

5.1.3 Overview of costs related to the action

Overview of relevant cost components

This chapter provides an overview of the costs of installing heat recovery in ventilation in buildings as compared to other ventilation technologies.

Investment expenditures include the purchase, delivery and installation of the products. The purchase cost is based on the street price, meaning that the values include margins for wholesale and retail on top of the manufacturer selling price.

Components that need to be purchased, delivered and installed at least include (per ventilation unit and according to the Ecodesign Directive (EU) 1253/2014 (EC, 2014):

- A bidirectional ventilation unit comprising at least two fans (exhaust and supply, each consisting of an impeller and electrical motor), two filters and a casing. This may be a central bidirectional ventilation unit or a local bidirectional ventilation unit.
- a heat recovery system consisting of
 - In case of recuperative heat exchanger: plate or tubular heat exchanger;
 - In case of regenerative heat exchanger: rotating wheel, including material allowing latent heat transfer, a drive mechanism, a casing or frame and seals to reduce bypassing and leakage of air;
 - In case of run-around heat recovery systems: a heat transfer system (connecting the heat recovery device on the exhaust side and the device supplying the recovered heat to the air stream on the supply side of a ventilated space);
 - In case of a thermal bypass facility: additional solutions to circumvent the heat exchanger or control the heat recovery performance (for example: summer box, rotor speed control, control of air flow).

Installation costs include installation materials and labour costs.

Operational expenditures include fixed costs and variable expenditures. Fixed operational expenditures are related to the maintenance of the ventilation system with heat recovery. Maintenance expenditures include costs for e.g. filter replacement, cleaning of fans, ducts, valves and grills, and small repairs. Variable operational expenditures consist of energy costs of the space heating system.

Distinction is made between residential and non-residential buildings and between central bidirectional ventilation units (CBVU), local bidirectional ventilation units (LBVU) - all with heat recovery - and central heat recovery ventilation (CHRV).

Table 36: Indicative values for cost components of heat recovery in ventilation units (excl. taxes or fiscal incentives)

Investment cost		[Euro2024/unit]
Residential	CBVU New built	4,915
	CBVU Renovation	6,350
	CBVU Replacement	n.a.
	LBVU New built	1,415
	LBVU Renovation	1,415
	LBVU Replacement	n.a.
Non-residential	CBVU/CHRV New built	30,063
	CBVU/CHRV Renovation	33,045
	CBVU/CHRV Replacement	8,408
Variable operational costs		[Euro2024/year]
Costs of reduced fuel input		Energy prices from chapter 1.2.1 (fuel prices before/after)
Fixed operational costs		[Euro2024/unit/year]
Residential	CBVU	67
	LBVU	29
Non-residential	CBVU/CHRV	175
[a]	Lifetime	
Technical lifetime	15	

Methodological aspects

Indicative values of costs are derived from the Ecodesign Impact Accounting market analysis (Van Holsteijn R. et al., 2020c), tables 29, 30, 31, 33 and 34, all expressed per ventilation unit.

Investment costs include the purchase, delivery and installation of the products. The purchase cost is based on the street price, meaning that the values include margins for wholesale and retail on top of the manufacturer selling price. A comparison of different sources is included in the final report, showing a downward purchase price trend over the years. For the current guidance, data of the latest year are retained, which are based on the collection of online (internet) price data.

Installation costs include installation materials and labour costs. Installation costs typically are higher for renovation compared to new-built due to higher complexity. Installation costs in case of replacement are lower because no installation materials are counted (in contrast to new-built or renovation). For residential buildings no indication of replacement cost is available. As absolute values for installation costs are substantially lower compared to those for non-residential buildings, the differences between replacement and renovation or new built in the case of residential buildings will be substantially smaller and neglected here.

Operational fixed costs are costs in relation to the maintenance of the ventilation system with heat recovery. The costs for maintenance include costs for e.g. filter replacement, cleaning of fans, ducts, valves and grills, and small repairs. These are expressed as an annual cost per unit.

Operational variable costs are costs per energy carrier for energy delivered to the space heating system of the building zones serviced by the ventilation system with heat recovery. The variable operational costs are determined by the fuel price. EU values for fuel prices are provided in chapter 1.2.1.

For residential buildings, a distinction is made between central and local bidirectional ventilation units with heat recovery. Costs (expressed per ventilation unit) for LBU¹⁰ with heat recovery are substantially lower than those for CBVU¹¹ with heat recovery. The costs are to be brought in relation to the useful floor area the ventilation unit provides the ventilation service to. There may be more than one or a combination of different types of bidirectional ventilation units in one building. LBUs are not considered for non-residential buildings. The markets report (Van Holsteijn R. et al., 2020c) mentions that the reason for the studies (2012 Lot 6 preparatory study and the Ecodesign Impact Accounting study) not considering small local ventilation units for non-residential buildings is because probably these are considered to be 'residential' by the existing regulations.

For non-residential buildings, the central systems are denominated central bidirectional ventilation units / central heat recovery ventilation (CBVU/CHRV). This is done for consistency with the source information and for the fact that the central systems in non-residential buildings on average are larger systems (with higher nominal flow rates; on average approximately 2,250 m³/h) and with potentially more complex technologies compared to central systems (CBVU) for residential buildings (with average nominal flow rates of approximately 250 m³/h).

All cost indications are excluding VAT and translated to 2024 euros via Eurostat data for Harmonised Index of Consumer Prices (HICP).

Due to the fact that the proposed indicative values are derived from a study published in 2020 with data for Europe and the observed trend of downward purchase prices at that time it is crucial to apply adjustments of these values when applying the cost data to the applicable country and time. Hereto, country specific costs, such as labour costs and fuel costs, should be taken into account. Suggestions for Member States' specific labour costs (per NACE sector) and energy prices (electricity and gas) are given in Chapter 1.2.1.

Data sources for indicative cost values:

All cost information was retrieved from the Ventilation Units Ecodesign and Energy Labelling Preparatory Review Study reporting on Markets (Van Holsteijn R. et al., 2020c).

Indicative values for the **investment costs for CBVU of residential buildings** are calculated as the sum of purchase costs and installation costs. The purchase cost is adopted from table 29 (value corresponding with 'internet for 250 m³/h', which is an estimate from a linear trend in the dataset). Installation cost values are derived from table 33; total installation costs being the sum of the installation materials cost and the installation labour costs for new-built and for renovation separately.

Indicative values for the **investment costs for LBU of residential buildings** are calculated as the sum of purchase costs and installation costs. The purchase cost is adopted from table 31 (value corresponding with 'internet for 113 m³/h', which is an estimate from a linear trend in the dataset). Installation cost values are derived from table 33; total installation costs being the sum of the installation materials cost and the installation labour costs for new-built and for renovation separately.

¹⁰ Local bidirectional ventilation units are balanced ventilation systems mainly for local use, i.e. ventilating a single room or a part of a building.

¹¹ Central bidirectional ventilation units are balanced ventilation systems mainly for central use, i.e. ventilating an entire building.

Indicative values for the **investment costs for CBVU/CHRV of non-residential buildings** are calculated as the sum of purchase costs and installation costs. The purchase cost is adopted from table 30 (value corresponding with 'internet for 2,250 m³/h', which is an extrapolation from a linear trend in the dataset). Installation cost values are derived from table 34; total installation costs being the sum of the installation materials cost and the installation labour costs for new built, for renovation and for replacement separately. In case of replacement, no installation materials are counted.

The indicative value for the operational fixed costs for residential CBVU is derived from the annual maintenance and repair costs for residential CBVUs of table 35.

The indicative value for the operational fixed costs for residential LBVU is derived from the annual maintenance and repair costs for residential LBVUs of table 35.

The indicative value for the operational fixed costs for non-residential CBVU/CHRV is derived from the annual maintenance and repair costs for non-residential CBVU/CHRV of table 35.

Cost parameters from the original source publication are expressed in 2015 euros or 2019 euros and are translated to 2024 euros using the HICP (by multiplication with factors 1.297 and 1.234 respectively).

In chapter 1.2 of this report, useful data sources on fuel prices in Europe can be consulted.

For the lifetime expectancy a value of 15 years is taken. This corresponds with an estimate for the lifetime expectancy of heat recovery systems and of ventilation systems with heat recovery (Van Holsteijn R. et al., 2020a). The estimate is valid for both residential and non-residential buildings.

5.1.4 Calculation of CO₂ savings

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

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

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]
Before	Index for the baseline situation of the action
After	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 8 in 5.1.1.

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 37: Indicative values for the share of energy carriers (for space heating) in heat recovery in ventilation

Share _{ec} – space heating		[%]
Residential	Solids	3.52
	LPG	1.48
	Gas/Diesel oil incl. biofuels (GDO)	9.91
	Natural gas, incl. biogas	41.30
	Biomass and wastes	24.49
	Geothermal energy	0.03
	District heat	11.39
	Electricity	7.88
Non-residential (services)	Solids	1.24
	LPG	0.36
	Gas/Diesel oil incl. biofuels (GDO)	14.50
	Gases incl. biogas	43.93
	Biomass and wastes	5.70
	Geothermal energy	0.40
	District heat	14.30
	Electricity	19.58

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 JRC-IDEES database (Rozsai M. et al., 2024), data of year 2021 (the most recent year available in the dataset) of thermal uses; final energy consumption per energy carrier for end-use space heating. This is done separately for residential buildings (residential sector) and non-residential buildings (services sector). The shares of energy carriers before and after the implementation of the heat recovery in ventilation units is assumed to be the same.

The **emission factor(s)** for Energy carrier(s) ($f_{GHG,ec}$) 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). The shares of energy carriers can be adapted to national level according to the “Complete energy balances” of the [EUROSTAT database](#).

5.2. Bibliography for heat recovery in ventilation systems

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Chapter 6. Savings calculation for public traffic management

Traffic management is the organisation, arrangement, guidance and control of both stationary and moving traffic including all the types of users (such as pedestrians, cyclists and all types of vehicles).

The main objective is the provision of safe, orderly and efficient movement of persons and goods and the protection of the quality of the local environment on and adjacent to roads.

The traffic management can be achieved through the application of targeted traffic control measures, within a defined policy framework, over a length of road or an area, in order to attain specified objectives. The main characteristic of the traffic management is the fact that it is typified by its application over a specific area or length of the route. Therefore, the application of a traffic management measure is unique creating difficulties during the development of a standardised bottom-up equation so as to calculate the triggered impacts.

The conduction of active transportation and demand management measures is considered as a fundamental pillar of the traffic management measures aiming at the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow of transportation facilities. Active management of transportation and demand can include multiple approaches such as spanning demand management, traffic management, parking management and efficient utilization of other transportation modes and assets.

The implementation of traffic management measures can alleviate congestion and promote smoother traffic flow. The reduction of the stop-and-go driving and the minimization of the idling time as outcome of the traffic management measures can lead to considerably lower fuel consumption for the affected vehicles. Moreover, the traffic management measures can also reduce the travel distance and time (reduction in total vehicle-distance traveled) leading to improved energy efficiency (reduction of per-km energy consumption).

Finally, traffic management measures can encourage people to use public transport for a share of their journey leading to additional energy savings due to the fact that the users switch to a less energy-intensive transportation mode.

The developed methodology also addresses the following challenges:

- **Data collection:**
The methodology provides useful insights for the specific energy consumption of the different categories of vehicles, the average yearly distance travelled of reference vehicles and the expected energy savings delivered by the traffic management measures.
- **Definition of baseline:**
The methodology suggests indicative values to streamline baseline calculations for the different Member States, based on the actual energy consumption data, which are available.
- **Lack of standardized calculation methodologies:**
The methodology allows the calculation of the delivered energy savings through a simplified approach based on the actual energy consumption data for each Member State separately.

6.1. Public traffic management

Different categories of traffic management policies, practices and techniques can be initiated to fulfil particular objectives within the framework of the traffic management measures. The primary focus is given on the three following categories of traffic management measures:

I. Active Traffic Management



The category of active traffic management includes measures to dynamically manage recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions.

II. Active Demand Management

The category of active demand management foresees measures to reduce or redistribute travel demand to alternative modes or routes through the provisions of rewards to drivers for travelling during off-peak hours with less traffic congestion.

III. Active Parking Management

The category of active parking management includes measures to affect the demand on parking capacity.

IV. Traffic calming measures

The implementation of traffic calming measures aims at the reduction of the vehicle speeds and traffic.

An indicative list of potential traffic management measures for the above-mentioned categories is presented in Annex I.

6.1.1 Calculation of final energy savings (Article 8)

The application of the traffic management measures can affect all the various types of vehicles in the transport sector. The actual determination of the affected types of vehicles can be performed based on the design of the implemented traffic management policies (e.g. specific area or length of the targeted route and the utilization of specific categories of vehicles).

The boundary conditions are defined by the application of each traffic management measure separately according to the design aspect. The boundary conditions are unique as they can be differentiated based on the design of the implemented traffic management measures (e.g. specific area or length of the targeted route).

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

$TFES = \sum_i (n_i \cdot DT_i / 100 \cdot sFEC_{ref,i}) \cdot S$	
TFES	Total final energy savings [kWh/a]
$sFEC_{ref,i}$	Specific final energy consumption of each type of affected vehicle [kWh/100 km]
n_i	Number of affected vehicles [number]
DT_i	Average yearly distance travelled of affected vehicles [km/a]
S	Energy saving factor [%]
i	Index of the different types of affected vehicles

Indicative calculation values for the specific final energy consumption of each type of affected vehicles are presented in Table 38. The indicative values have been presented both at EU level. The indicative values can be utilised for the baseline situation as they represent the actual usage of the affected vehicles.

Indicative values for the energy saving factors (S) are presented analytically in table in Annex II for different types of traffic management measures. The collected energy saving factors are characterised by a significant fluctuation ranging from 2 % to 70 %. The analysis of the collected data led to the conclusion that the median value equals to 17 % taking into account the quantified impacts of the identified traffic management measures (Table 39).

Table 38: Indicative values for the specific final energy consumption of each type of affected vehicles (kWh/100 km) (Source: Rózsai et al, 2024).

Categories of vehicles	EU27
Total vehicles	98.4
Passenger transport	79.5
Powered two-wheelers	41.1
Passenger cars	75.1
Gasoline engine	76.4
Diesel oil engine	74.3
LPG engine	79.9
Natural gas engine	80.5
Plug-in hybrid electric	41.3
Battery electric vehicles	16.8
Motor coaches, buses and trolley buses	637.2
Gasoline engine	204.3
Diesel oil engine	641.6
LPG engine	519.8
Natural gas engine	638.6
Battery electric vehicles	355.1
Freight transport	197.7
Light commercial vehicles	104.2
Gasoline engine	99.8
Diesel oil engine	104.5
LPG engine	115.8
Natural gas engine	103.8
Battery electric vehicles	21.8
Heavy goods vehicles	424.1
Domestic	391.5
International	503.6

Table 39: Indicative values for the energy saving factor.

Indicative values of savings	[%]
Traffic management measures	Range from 2% to 70% depending on the design of the measure (Table in Annex II) 17% of energy savings as median value

Table 40: Indicative values for the lifetime of the traffic management measures.

Lifetime of savings	[years]
Traffic management measures	10 years or the actual duration of the measures (Source: Green ICT ecosystem, 2025)

Methodological aspects

The methodology is based on the reduction of the specific final energy consumption (or primary energy consumption in the case of Article 4) for the affected vehicle distance-travelled as resulted by the application of the traffic management measure. The specific energy consumption (expressed in kWh/100 km) is multiplied by the affected vehicle distance-travelled (expressed in km) and with the energy saving factor (expressed in %). The estimation of the affected vehicle distance-travelled and the number of the affected vehicles are considered as the most difficult elements of the bottom-up methodology, as they depend on the design aspects of the applied traffic management measure (e.g. specific area or length of the targeted route).

The affected vehicle distance-travelled and the number of the affected vehicles can be assessed through the conduction of a detailed study of the targeted route in the base year before the implementation of the traffic management measure.

The study should include the following steps:

- Document the study area including layout and design features;
- Detail the traffic and parking conditions;
- Assess the total travel characteristics of the study area (all modes);
- Determine the distribution of this traffic (directions of approach and departure) and the utilized routes;
- Identify paths and routes used by non-car traffic (deliveries, pedestrians, cyclists, buses etc.);
- Assess effects on traffic operation and circulation, including intersections;
- Assess traffic operations within the study area;
- Determine the level of traffic generation using specific KPIs (e.g. number of affected vehicles, composition of vehicles, average vehicle distance-travelled, energy consumption etc.).

Data sources for indicative calculation values:

The **specific final energy consumption of each type of affected vehicle ($sFEC_{ref}$)** was derived from the JRC-IDEES database (Rózsai et al., 2024) taking into consideration the available data in the period 2010-2021 at EU level.

Indicative energy saving factors (S) of the different traffic management measures were collected from different studies, reports, papers and plans after the conduction of a bibliographical review.

6.1.2 Calculation of impact on energy consumption (Article 4)

The calculation of final energy savings for Article 4 is based on the calculation of final energy savings (Article 8), which was presented in the previous chapter.

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

$$EPEC = \sum_i^n (n_i \cdot DT_i / 100 \cdot sFEC_{ref,i} \cdot f_{PE,i}) \cdot S$$

EPEC	Effect on primary energy consumption [kWh/a]
sFEC_{ref,i}	Specific final energy consumption of each type of affected vehicle [kWh/100 km]
n_i	Number of affected vehicles [number]
DT_i	Average yearly distance travelled of affected vehicles [km/a]
S	Energy saving factor [%]
i	Index of the different types of affected vehicles
f_{PE,i}	Final to primary energy conversion factor based on the affected vehicles

The selection of the conversion factors from the final to primary energy consumption should be performed based on the type of affected vehicles and the respective utilised fuel.

The calculated conversion factors from final to primary energy ($f_{PE,i}$) are listed in Table 41 based on the consumed fuel for each category of vehicles separately in the period 2010-2021 according to the available data by JRC-IDEES database (Rózsai et al, 2024) and the respective conversion factors for each energy carrier as presented in Chapter 1.

Table 41: Conversion factors from final to primary energy for each category of vehicles at EU level.

Categories of vehicles	EU27
Total vehicles	1.113
Passenger transport	1.114
Powered two-wheelers	1.116
Passenger cars	1.114
Gasoline engine	1.115
Diesel oil engine	1.112
LPG engine	1.119
Natural gas engine	1.008
Plug-in hybrid electric	1.599
Battery electric vehicles	2.281
Motor coaches, buses and trolley buses	1.113
Gasoline engine	1.115
Diesel oil engine	1.112
LPG engine	1.119
Natural gas engine	1.010
Battery electric vehicles	2.281
Freight transport	1.112
Light commercial vehicles	1.112
Gasoline engine	1.115
Diesel oil engine	1.112
LPG engine	1.119
Natural gas engine	1.008
Battery electric vehicles	2.281
Heavy goods vehicles	1.112
Domestic	1.112

International	1.112
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6.1.3 Overview of costs related to the action

Overview of relevant cost components

The costs associated with the traffic management measures can be classified into the three following categories:

Investment costs: The upfront costs are triggered by the procurement and installation of the required equipment within the context of the selected traffic management measure. The investment costs constitute one-time expenditure and include the capital equipment costs and other soft costs linked with the design and installation of the selected equipment. The investment cost can include both the basic "backbone" infrastructure equipment and the installation of additional roadside elements.

Operating and maintenance costs: The operating and maintenance costs are required on annual basis in order to run and maintain the traffic management measures. The operating costs includes the required staffing for the continuous operation of the selected traffic management measures. The maintenance costs can include the costs for additional maintenance staff, ongoing training, upkeeping and replacing minor system components.

Replacement costs: The replacement costs include the periodic costs of replacing and/or redeploying system equipment in the case that their technical lifetime will end to ensure the continuation of the applied traffic management measures.

Indicative investment costs within the context of the active management measures can include the following one:

- Activities associated with the systems engineering process;
- DMS and supporting sign supports and gantries;
- Any widening and shoulder reconstruction;
- Ramp terminal treatments;
- Traffic signal controllers;
- Detection and surveillance;
- Communications and power;
- Software;
- Central hardware and TMC enhancements;
- Training;
- Public outreach and communications campaigns;
- Mobilization and contingency costs.

Methodological aspects

The estimation of the costs related to the traffic management measures is not easy and standardized, as it depends on the actual characteristics of the applied traffic management measure (e.g. specific area or length of the targeted route).

According to available unitary estimates, which were collected within the framework of the conducted bibliographical review, the costs per directional distance vary widely.

Indicative values for the implementation cost are presented in Table 41, which can lead to a median value equal to 1.8 million \$ per directional mile (US Department of Transportation – Federal Highway Administration, 2022).

Table 42: Implementation costs of indicative traffic management measures (Source: US Department of Transportation – Federal Highway Administration, 2022).

Location (Year)	Measure	Cost
United Kingdom M42 (2008)	Dynamic Speed Limit, Dynamic Lane Assignment and Dynamic Shoulder Lane with shoulder treatments	15 million \$ per route mile - equates to 7.5 million \$ per directional mile
Washington State I-5 (2010)	Dynamic Speed Limit, Dynamic Lane Assignment and Queue Warning	23 million \$ for 7-mile northbound segment - equates to 3.2 million \$ per directional mile for three-lane section and 4 million \$ per directional mile for five-lane section
Washington State I-90 and SR 520 (2010-2012)	Dynamic Speed Limit, Dynamic Lane Assignment and Queue Warning	38.4 million \$ for 17-mile segment (both directions) - equates to 1.1 million \$ per direction mile
Minnesota I- 35W (2010)	Dynamic Speed Limit, Dynamic Lane Assignment and Dynamic Shoulder Lane	21.5 million \$ for 10-mile stretch - equates to 1.1 million \$ per direction mile
Minnesota I-94 (2010)	Dynamic Speed Limit, Dynamic Lane Assignment and Queue Warning	15 million \$ for 4-mile stretch - equates to 3.75 million \$ per route mile or 1.9 million \$ per direction mile
Philadelphia I-95 (2014)	Dynamic Speed Limit and Dynamic Lane Assignment	950 thousand \$ per directional mile
New Jersey (2015)	Dynamic Speed Limit, Dynamic Lane Assignment and Queue Warning	1.8 million \$ per directional mile

It should be noted that the future evolution of such costs should also be taken into account since a potential reduction of the investment costs is expected.

6.1.4 Calculation of CO₂ savings

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

$$GHGSAV = \sum_i (n_i \cdot DT_i / 100 \cdot sFEC_{ref,i} \cdot f_{GHG,i}) \cdot S$$

GHGSAV	Greenhouse gas savings [t CO ₂ p.a.]
sFEC_{ref,i}	Specific final energy consumption of each type of affected vehicle [kWh/100 km]
n_i	Number of affected vehicles [number]
DT_i	Average yearly distance travelled of affected vehicles [km/a]
S	Energy saving factor [%]
i	Index of the different types of affected vehicles
f_{GHG,i}	Emission factors of affected vehicles [t CO ₂ /kWh]

The selection of the emission factors for the estimation of greenhouse gas savings should be performed based on the type of affected vehicles and the respective utilised fuel.

The emission factors for the estimation of greenhouse gas savings ($f_{\text{GHG},i}$) are presented in Table 43 based on the consumed fuel for each category of vehicles separately in the period 2010-2021 according to the available data by JRC-IDEES database (Rózsai et al, 2024) and the respective emission factors for each energy carrier as presented in Chapter 1.

Table 43: Emission factors for the estimation of greenhouse gas savings (g CO₂/kWh).

Categories of vehicles	EU27
Total vehicles	246.6
Passenger transport	245.1
Powered two-wheelers	242.2
Passenger cars	245.0
Gasoline engine	240.2
Diesel oil engine	250.2
LPG engine	227.2
Natural gas engine	191.7
Plug-in hybrid electric	238.4
Battery electric vehicles	133.3
Motor coaches, buses and trolley buses	246.8
Gasoline engine	241.0
Diesel oil engine	250.4
LPG engine	227.2
Natural gas engine	178.9
Battery electric vehicles	133.3
Freight transport	250.0
Light commercial vehicles	249.3
Gasoline engine	241.0
Diesel oil engine	250.3
LPG engine	227.2
Natural gas engine	193.2
Battery electric vehicles	133.3
Heavy goods vehicles	250.4
Domestic	250.3
International	250.5

In the case that a different composition of affected types of vehicles is decided, weighted values of the emission factors can be estimated based on the share of the utilised fuels.

6.2. Bibliography for public traffic management

Rózsai, M., Jaxa-Rozen, M., Salvucci, R., Sikora, P., Tattini, J. and Neuwahl, F. (2024). JRC-IDEES-2021: the Integrated Database of the European Energy System – Data update and technical documentation, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/614599, JRC137809.

Green ICT ecosystem, (2025). The Carbon Footprint of the ICT Sector, available at: https://greenict.fi/en/greenict_producerguide/greenict_carbonfootprint/

US Department of Transportation – Federal Highway Administration, (2022). Active Transportation and Demand Management, available at: <https://ops.fhwa.dot.gov/atdm/about/index.htm>.

Annex I

Active Traffic Management (Source: US Department of Transportation – Federal Highway Administration, 2022)

Indicative measures

- **Adaptive Ramp Metering:** Deploying traffic signal(s) on ramps to dynamically control the rate vehicles enter a freeway facility.
- **Adaptive Traffic Signal Control:** Monitoring continuously arterial traffic conditions and the queuing at intersections and adjusting dynamically the signal timing to optimize one or more operational objectives.
- **Dynamic Junction Control:** Allocating dynamically allocating lane access on mainline and ramp lanes in interchange areas where high traffic volumes are present and the relative demand on the mainline and ramps change throughout the day.
- **Dynamic Lane Reversal or Contraflow Lane Reversal:** Reversing the lanes in order to dynamically allocate the capacity of congested roads, thereby allowing capacity to better match traffic demand throughout the day.
- **Dynamic Lane Use Control:** Closing or opening the individual traffic lanes dynamically as warranted and providing advance warning of the closure(s) (through the use of Lane-Use Control Signals), in order to safely merge traffic into adjoining lanes.
- **Dynamic Merge Control:** Managing dynamically the entry of vehicles into merge areas with a series of advisory messages (e.g., displayed on a dynamic message sign or lane control sign) approaching the merge point that prepare motorists for an upcoming merge and encouraging or directing a consistent merging behavior.
- **Dynamic Speed Limits:** Adjusting speed limits based on real-time traffic, roadway, and/or weather conditions.
- **Part-Time Shoulder Use:** Enabling the use of the shoulder as a travel lane(s), known as Hard Shoulder Running (HSR) or temporary shoulder use, based on congestion levels during peak periods and in response to incidents or other conditions as warranted during non-peak periods.
- **Queue Warning:** Displaying real-time warning messages (typically on dynamic message signs and possibly coupled with flashing lights) along a roadway to alert motorists that queues or significant slowdowns are ahead.
- **Transit Signal Priority:** Managing traffic signals by using sensors or probe vehicle technology to detect when a bus nears a signal-controlled intersection, turning the traffic signals to green sooner or extending the green phase, thereby allowing the bus to pass through more quickly.

Active Demand Management (Source: US Department of Transportation – Federal Highway Administration, 2022)

Indicative measures

- **Dynamic Fare Reduction:** Reducing the fare for use of the transit system in a particular corridor as congestion or delay on that corridor increases.
- **Dynamic High-Occupancy Vehicle (HOV) / Managed Lanes:** Changing dynamically the qualifications for driving in a high-occupancy vehicle lane(s).
- **Dynamic Pricing:** Utilizing tolls that dynamically change in response to changing congestion levels, as opposed to variable pricing that follows a fixed schedule.
- **Dynamic Ridesharing:** Facilitating the use of advanced technologies from the travelers, such as smart phones and social networks, to arrange a short-notice, one-time, shared ride through car-sharing and car-pooling schemes.
- **Dynamic Routing:** Using variable destination messaging to disseminate information to make better use of roadway capacity by directing motorists to less congested facilities.
- **Dynamic Transit Capacity Assignment:** Re-organizing schedules and adjusting assignments of assets (e.g., buses) based on real-time demand and patterns, to cover the most overcrowded sections of network.
- **On-Demand Transit:** Facilitating the conduction of real-time trip requests for services with flexible routes and schedules.
- **Predictive Traveler Information:** Using a combination of real-time and historical transportation data to predict upcoming travel conditions and convey that information to travelers pre-trip and en-route in an effort to influence travel behavior.
- **Transfer Connection Protection:** Improving the reliability of transfers from a high-frequency transit service (e.g., a train) to a low-frequency transit service (e.g., a bus).

Active Parking Management (Source: US Department of Transportation – Federal Highway Administration, 2022)

Indicative measures

- **Dynamic Overflow Transit Parking:** Utilizing overflow parking facilities in the vicinity of transit stations and/or park-and-ride facilities when the existing parking facilities are at or near capacity.
- **Dynamic Parking Reservation:** Providing the ability to utilize technology to reserve a parking space at a destination facility on demand to ensure availability.
- **Dynamic Wayfinding:** Providing real-time parking-related information to travelers associated with space availability and location so as to optimize the use of parking facilities and minimize the time spent searching for available parking.
- **Dynamically Priced Parking:** Providing parking fees that are dynamically varied based on demand and availability to influence trip timing choice and parking facility or location choice.

Traffic calming measures

Indicative measures

- **New infrastructure development:** Constructing new infrastructure (such as new roads, bypass or ring roads, grade-separators, pedestrian and cyclist infrastructure etc.) and modify existing

ones (such as intersection modification, widening footways, construction of new lanes for public transportation vehicles etc.).

- **Technical measures:** Constructing additional infrastructure, such as speed humps/tables, chicanes, raised crosswalks/intersections, narrowed roads, curb extensions, mini roundabouts etc.
- **Reduction of speed limits:** Reducing the current speed limits within a specific area accompanied by enforcement measures to ensure compliance with the imposed limits.
- **Establishment of traffic restricted zones:** Limiting or controlling the access of vehicles within a specific area to reduce congestion, establishing new pedestrian and cyclist priority areas with the utilization of modal filters.
- **Autonomous vehicles:** Autonomous vehicles are increasingly recognized for their potential to enhance urban traffic systems, particularly in traffic management and sustainability as they are capable of maintaining shorter time headways, enabling them to follow each other more closely and safely, therefore increasing road capacity.
- **Behavioural measures:** Teleworking and employer programs for trip reduction have being promoted as a way to reduce daily travel and address congestion problems, especially during rush-hours.

Annex II

Table: Studies with estimates for the energy saving factors (S) of public traffic management measures.

Parameters	Measures	Country	Impact estimates	References
Traffic incident management	Traffic signal operations	EU	Fuel savings of around 10% to 20% for eco-driving and approximately 10% savings for traffic signal operations	Barth, M., Guoyuan, W., & Knok, B. (2015). Intelligent Transportation Systems for Improving Traffic Energy Efficiency and Reducing GHG Emissions from Roadways. A White Paper from the National Center for Sustainable Transportation, https://rosap.ntl.bts.gov/view/dot/31150
		EU	CO ₂ emission reductions were shown on the order of 5% to 15%	
	Smart Traffic Lights at Intersections	Portugal	CO ₂ emission reductions were shown on the order of 29% to 41%	Santos, O., Ribeiro, F., Metrôlho, J., & Dionísio, R. (2023). Using Smart Traffic Lights to Reduce CO ₂ Emissions and Improve Traffic Flow at Intersections: Simulation of an Intersection in a Small Portuguese City. Applied System Innovation. https://doi.org/10.3390/asi7010003
	Traffic Signal Coordination	-	CO ₂ emission reductions were shown on the order of 9% to 14%	Mascia, M., Hu, S., Han, K., North, R., Van Poppel, M., Theunis, J., Beckx, C., & Litzenberger, M. (2017). Impact of Traffic Management on Black Carbon Emissions: a Microsimulation Study. Netw Spat Econ (2017) 17:269–291. DOI 10.1007/s11067-016-9326-x

	Congestion Charging Scheme	UK	CO ₂ emission reduction stands at 19.5%, while a 15% reduction in vehicle-kilometers was recorded	Beevers, S.D., Carlin Carslaw, D., Dajnak, D., B Stewart, G., Lloyd Williams, M., C Fussell, J., & James Kelly, F. (2016). Traffic management strategies for emissions reduction: recent experience in London, Energy and Emission Control Technologies, 27-39, DOI: 10.2147/EECT.S69858
Traveler information services	Advanced Traveller Information Systems (ATIS) during incidents	Portugal	CO ₂ emission reduction up to 2%	Fontes, T., Lemos, A., Fernandes P., Pereira, S.R., Bandeira, J.M., & Coelho, M.C. (2014). Transportation Research Procedia 3, 41-50. https://doi.org/10.1016/j.trpro.2014.10.089
	Real-time transit information systems	UK	13% reduction for buses; 6% increase for other traffic; net 3% increase overall	National Academies of Sciences, Engineering, and Medicine. (2010). Current Practices in Greenhouse Gas Emissions Savings from Transit. The National Academies Press. https://doi.org/10.17226/14385 .
Traffic signal and urban arterial management	Smart Traffic Lights at Intersections	Portugal	CO ₂ emission reduction stands at 32%-40% on average, while a 53%-95% reduction in waiting time was recorded	Santos, O., Ribeiro, F., Metrôlho, J., & Dionísio, R. (2023). Using Smart Traffic Lights to Reduce CO ₂ Emissions and Improve Traffic Flow at Intersections: Simulation of an Intersection in a Small Portuguese City. Applied System Innovation. https://doi.org/10.3390/asi7010003
Ramp metering	Coordinated Ramp Metering (CORDIN)	France	Travel time reduced between 9.8% and 12%	Cohen, S., Gil, D., Christoforou, Z., & Seidowsky, R. (2017). Evaluating the combined effect of ramp metering and variable speed limits on the French A25 motorway. Transportation Research Procedia, 27, 156–163. https://doi.org/10.1016/j.trpro.2017.12.014
	Ramp Metering with Fuel Reduction Objective	Netherlands	CO ₂ emission reduction stands at 15%-29.6% on average	Vreeswijk, J. D., Woldeab, Z., de Koning, A., & Bie, J. (2011). Ramp metering with an objective to reduce fuel consumption. In 8th European Congress and Exhibition on Intelligent Transport Systems and Services, Lyon, 6–9 June, 2011 (On CD-ROM) (pp. 1–10). ITS. https://research.utwente.nl/en/publications/ramp-metering-with-an-objective-to-reduce-fuel-consumption
Part-time measures – for example seasonally-related ‘Park & Ride’	Tram priority-based traffic control algorithms	Poland	Energy savings of about 10%-19% on average, while a 14%-19% increase in tram speeds was recorded	Górka, A., Czerepicki, A., Krukowicz, T. (2024). The Impact of Priority in Coordinated Traffic Lights on Tram Energy Consumption. Energies. 17, 520. https://doi.org/10.3390/en17020520
	Green Light Optimal	Europe	Energy savings of about 13% on average, while a	Seredynski, M. (2022). Pathways to reducing the negative impact of urban transport on climate

	Speed Advisory (GLOSA)		6.4% increase in average speeds was recorded	change. IET Smart Cities. 5:41–48. doi: 10.1049/smc2.12043
Route guidance	Eco-routing based on fuel-efficient paths	Sweden	Energy savings of about 4% on average	Elbery, A., & Rakha, H. (2019). City-Wide Eco-Routing Navigation Considering Vehicular Communication Impacts, Sensors, 19, 290; doi:10.3390/s19020290
	Emission and energy optimized traffic assignments	-	Energy savings of about 17%-25% on average, while a 14%-18% decrease in CO ₂ emission was recorded	
Speed control	Variable Speed Limits (VSL)	Germany	Energy savings of about 5%-10% on average, a 9% decrease in CO ₂ emission is recorded, while a travel time reduction of 3%-5% was recorded	Weigl, S., Bogenberger, K., & Bertini, R. (2012). Empirical Assessment of Traffic Management Effects of a Variable Speed Limit System on a German Autobahn: Before and After, Conference: 92nd Annual Meeting of the Transportation Research Board. doi: 10.13140/2.1.3485.9206
	Dynamic Speed Management	Netherlands	CO ₂ emission reduction of 6%-15% on average, while a 8%-25% travel time reduction was recorded	Geilenkirchen, G., Bolech, B., Hulskotte, J., Dellaert, S., Ligterink, N., van Eijk, E., Geertjes, K., Kosterman, M., & 't Hoen, M. (2024). Methods for calculating the emissions of transport in the Netherlands. doi: 10.21945/RIVM-2024-0023
	Speed Limit Enforcement (Cameras)	UK	Energy savings of about 5% on average, while a 5%-10% decrease in CO ₂ emission was recorded	UKERC (2006). Quick hits - limiting speed. https://data.ukedc.rl.ac.uk/cgi-bin/data_browser/browse/edc/publications/working_paper/Quick_Hit_-_Limiting_speed.pdf
	Eco-Speed Control for Freight	EU	Energy savings of about 8%-15% on average, while a 10%-20% decrease in CO ₂ emission was recorded	Bogner, T., & Jellinek, R. (2021). Eco-driving initiatives – the key for sustainable and energy-efficient use of motorized vehicles. https://www.odysseumure.eu/publications/policy-brief/eco-driving-fuel-reduction.pdf
	Adaptive Cruise Control (with Speed)	Sweden	Energy savings of about 5%-10% on average, a 5%-8% decrease in CO ₂ emission is recorded, while a 10% travel time	Chen, H., Rakha, H., Jaihani, M., & Ahangari, S. (2020). Developing and Testing an ECO-Cooperative Adaptive Cruise Control System for Buses. Prepared for the Urban Mobility & Equity Center, Morgan State University. https://rosap.nhtl.bts.gov/view/dot/55546

			reduction was referred	
	Eco-driving strategies at signalized intersections	-	Energy savings of up to 18% on average, an up to 25% decrease in CO ₂ emission is recorded, while an up to 20% improvement on travel time was achieved	Jayawardan, V., & Wu, C. (2022). Learning Eco-Driving Strategies at Signalized Intersections, 2022 European Control Conference (ECC), doi: 10.23919/ECC55457.2022.9838000
Passenger transport and car sharing	Car-sharing with hybrid vehicles	Portugal	Energy savings of about 35% on average, while 35% decrease in CO ₂ emission was recorded	Baptista, P., Melo, S., & Rolim, C. (2014). Energy, environmental and mobility impacts of car-sharing systems. Empirical results from Lisbon, Portugal, Procedia - Social and Behavioral Sciences 111, 28-37, doi: 10.1016/j.sbspro.2014.01.035
	Car-sharing with electric vehicles	Portugal	Energy savings of about 47% on average, while 65% decrease in CO ₂ emission was recorded	
	Car-sharing impact on car ownership	Scotland	A 34%-47% decrease in ownership was recorded	Cao, X., Zhou, H., Li, H., & Kong, X. (2023). Analysis of the Contribution of China's Car-Sharing Service to Carbon Emission Reduction. Energies, 16, 5518. https://doi.org/10.3390/en16145518
	Car-sharing impact on car ownership	France	A 23% decrease in ownership was recorded	
	Car-sharing impact on car ownership	Germany	A 7%-15% decrease in ownership was recorded	
Freight management	Pooling supply chains	Sweden	A 6% decrease in CO ₂ emission was recorded	Pan, S., Ballot, E., & Fontane, F. (2013). The reduction of greenhouse gas emissions from freight transport by pooling supply chains. International Journal of Production Economics. 143(1), pp. 86-94. https://doi.org/10.1016/j.ijpe.2010.10.023
Pollution minimization	Route optimization in school	Slovenia	A 25.08% decrease in CO ₂ emission was recorded	Dragan, D., Kramberger, T., & Prah, K. (2014). The reduction of CO ₂ emissions: Transport optimization approach to decrease the Vehicle Miles Travelled. https://doi.org/10.4018/978-1-5225-0001-8.CH019

	transportation			
	Fuel tax increases and carbon taxes	-	A 10%-30% decrease in automotive trips was recorded	Victoria Transport Policy Institute. (2021). Energy Conservation and Emission Reduction Strategies. https://www.vtpi.org/tdm/tdm59.htm
Work zone management border control for both passengers and cargo	Longer freight trains	Norway	Energy savings of 2.6% on average, while a 3.6% decrease in CO ₂ emission was recorded	Pinchasik, D. R., Hovi, I. B., Mjøsund, C. S., Grønland, S. E., Fridell, E., & Jerksjö, M. (2020). Crossing Borders and Expanding Modal Shift Measures: E cts on Mode Choice and Emissions from Freight Transport in the Nordics. Sustainability, 12, 894. doi:10.3390/su12030894
	Combined longer trains and rail ecobonus	Norway	Energy savings of 3.1% on average, while a 3.6% decrease in CO ₂ emission was recorded	
	Road-rail intermodal freight transport	Europe	Energy savings of 43% on average, while a 77% decrease in CO ₂ emission was recorded	https://trimis.ec.europa.eu/documents/using-road-rail-intermodal-freight-transport-reduce-ghg-emissions
Adaptive Ramp Metering	Ramp Metering with Fuel Consumption Objective	Netherlands	Energy savings of 15%-29.6% on average	Vreeswijk, J. D., Woldeab, Z., de Koning, A., & Bie, J. (2011). Ramp metering with an objective to reduce fuel consumption. In 8th European Congress and Exhibition on Intelligent Transport Systems and Services, Lyon, 6–9 June, 2011 (On CD-ROM) (pp. 1–10). ITS. https://research.utwente.nl/en/publications/ramp-metering-with-an-objective-to-reduce-fuel-consumption
Adaptive Traffic Signal Control	Adaptive Traffic Signal Control (SCATS)	-	Energy savings of 2% on average	Stevanovic, A., Stevanovic, J., & Kergaye, C. (2012). Environmental Benefits of Adaptive Traffic Control System: Assessment of Fuel Consumption and Vehicular Emissions. Transportation Research Board 91st Annual Meeting. https://trid.trb.org/view/1128863
	Smart traffic lights at a single intersection	-	A 32%-40% decrease in CO ₂ emission was recorded	Santos, O., Ribeiro, F., Metrôlho, J., & Dionísio, R. (2023). Using Smart Traffic Lights to Reduce CO ₂ Emissions and Improve Traffic Flow at Intersections: Simulation of an Intersection in a Small Portuguese City. Applied System Innovation. https://doi.org/10.3390/asi7010003
Dynamic Junction Control	Smart Traffic Lights with CO ₂ Optimization	Portugal	A 32%-40% decrease in CO ₂ emission was recorded	Santos, O., Ribeiro, F., Metrôlho, J., & Dionísio, R. (2023). Using Smart Traffic Lights to Reduce CO ₂ Emissions and Improve Traffic Flow at Intersections: Simulation of an Intersection in a Small Portuguese City. Applied System Innovation. https://doi.org/10.3390/asi7010003

	Adaptive Traffic Light Control System (ATLCS)	UK	17% overall travel time reduction	R. Aleko, D., & Djahel, S. (2020). An Efficient Adaptive Traffic Light Control System for Urban Road Traffic Congestion Reduction in Smart Cities. Information. 11, 119. doi:10.3390/info11020119
Dynamic Speed Limit	Variable Speed Limit Control (VSL)	Croatia	Energy savings of 10%-31% on average	Vrbanic, F., Miletic, M., Tišljarić, L., & Ivanjko, E. (2022). Influence of Variable Speed Limit Control on Fuel and Electric Energy Consumption, and Exhaust Gas Emissions in Mixed Traffic Flows. Sustainability, 14, 932. https://doi.org/10.3390/su14020932
	80 km/h Speed Limit Implementation	Netherlands	Up to 30% decrease in CO ₂ emission was recorded	European Federation for Transport and Environment. (2010). 30% CO ₂ reduction through 80 km/h speed limit. https://www.transportenvironment.org/articles/30-co2-reduction-through-80-kmh-speed-limit
	Variable Speed Limits during Heavy Traffic	UK	About 2%-8% decrease in CO ₂ emission was recorded	Texas A&M Transportation Institute. (2012). Variable Speed Limits. https://policy.tti.tamu.edu/strategy/variable-speed-limits/
Dynamic Merge Control (DMC)	Traffic Performance Analysis of Dynamic Merge Control Using Microsimulation	-	Reduced delay by more than 90%, increase speed by more than 80%, and increase throughput by more than 10%. Average delay per vehicle was reduced by 46 up to 540 seconds (around 98%).	Jiang, X., Bared, J., Maness, M., & Hale, D. (2015). Traffic Performance Analysis of Dynamic Merge Control Using Microsimulation. Transportation Research Record Journal of the Transportation Research Board. 2484. pp. 23-30. doi:10.3141/2484-03.
Transit Signal Priority	TSP in Leeds, England	UK	Approximately 10% reduction in bus travel time; no change in car travel times	Chada, S., & Newland, R. (2002). Effectiveness of Bus Signal Priority. https://rosap.ntl.bts.gov/view/dot/34510
Dynamic Fare Reduction	9-Euro Monthly Public Transport Ticket (2022)	Germany	5% reduction in car travel distance; 7% increase in public transport trip frequency	Loder, A., Cantner, F., Adenaw, L., Nachtigall, N., Ziegler, D., Waldner, F., Siewert, M., Wurster, S., Goerg, S., Lienkamp, M., & Bogenberger, K. (2023). Germany's nationwide travel experiment in 2022: public transport for 9 Euro per month - First findings of an empirical study. doi:10.48550/arXiv.2306.08297.
	HOV/Eco-Lanes with Increased	Portugal	Up to 37% decrease in CO ₂ emission and an occupancy rate	International Transport Forum / OECD. (2025). Access regulations: High occupancy vehicle/Low-emission lanes. https://itf-oecd.org/node/26630

	AOV (1.5 to 1.7)		increase of 13.3% were recorded	
Dynamic routing	Dynamic Routing in Public Transport	Denmark	Reduced trip times by at least 23% compared to static routing	Peled, I., Lee, K., Jiang, Y., Dauwels, J., & C. Pereira, F. (2021). On the quality requirements of demand prediction for dynamic public transport. arXiv:2008.13443v5
	Eco-Routing Impact on Fuel Consumption and Emissions	Sweden	8.2% fuel savings and a 7.6% reduction in CO ₂ emissions when travelers chose fuel-efficient paths over the shortest travel time paths	Ahn, K., & Rakha, H. (2008). The effects of route choice decisions on vehicle energy consumption and emissions. Transportation Research Part D 13, pp. 151–167. doi:10.1016/j.trd.2008.01.005
	Multi-Depot Vehicle Routing Problem	-	Utilizing multiple depots in vehicle routing problems can reduce carbon emissions by up to 37.6%, depending on factors like customer distribution and vehicle speed.	Wang, S., Han, C., Yu, Y., Huang, M., Sun, W., & Kaku, I. (2022). Reducing Carbon Emissions for the Vehicle Routing Problem by Utilizing Multiple Depots. Sustainability, 14, 1264. https://doi.org/10.3390/su14031264
Dynamic Transit Capacity Assignment	Dynamic Routing in Public Transport	Denmark	Reduction of trip times by at least 23% compared to static routing	Peled, I., Lee, K., Jiang, Y., Dauwels, J., & C. Pereira, F. (2021). On the quality requirements of demand prediction for dynamic public transport. arXiv:2008.13443v5
On-demand transit	On-Demand Bus Services	-	Reduced average passenger trip time by 30%, increased vehicle occupancy rates from 8% to over 50%, and reduced emissions per passenger by over 70% on an average weekday	Liyanage, S., Dia, H., Duncan, G., & Abduljabbar, R. (2024). Evaluation of the Impacts of On-Demand Bus Services Using Traffic Simulation. Sustainability, 16, 8477. https://doi.org/10.3390/su16198477
	On-demand transit with bi-modal systems	-	20% reduction of energy consumption	Sharma, P., M. Heidemann, K., Heuer, H., Mühle, S., & Herminghaus, S. (2022). Sustainable and convenient: bi-modal public transit systems outperforming the private car. arXiv:2211.10221v2
Predictive Traveler Information	Proactive Eco-Routing Strategies for	-	18% reduction in GHG emissions, a 17% reduction in travel distance, and a 21%	Alfaseeh, L., & Farroq, B. (2020). Deep Learning Based Anticipatory Multi-Objective Eco-Routing Strategies For Connected & Automated Vehicles. arXiv:2006.16472v2

	Connecte d Vehicles		reduction in fuel consumption	
	Eco- Driving Strategies at Signalized Intersecti ons	-	Fuel consumption could be reduced by 18%, CO ₂ emissions by 25%, and travel speed could improve by 20%	Jayawardan, V., & Wu, C. (2022). Learning Eco- Driving Strategies at Signalized Intersections, 2022 European Control Conference (ECC), doi: 10.23919/ECC55457.2022.9838000
	Predictive traffic informati on using AI	Germany	8%-12% delay reduction, a 10%- 18% travel time reduction and a 12%-17% congestion reduction	Fraunhofer. (2023). Institute Report 2023.
Transfer Connection Protection	Bundling Transport Deliveries Using SUMO	Austria	34% reduction in CO ₂ emissions	Validi, A., Polasek, N., Alabi, L., Leitner, M., & Olaverri-Monreal, C. (2020). Environmental Impact of Bundling Transport Deliveries Using SUMO, 15th Iberian Conference on Information Systems and Technologies (CISTI). doi: 10.23919/CISTI49556.2020.9141129.
	Cyber- physical Control of Road Freight Transport	Sweden	Achieved fuel savings of over 5%	Besselink, B., Turri, V., van de Hoef, S.H., Liang, K.-Y., Alam, A., Martensson, J., & Johansson, K.H. (2015). Cyber-physical Control of Road Freight Transport. arXiv:1507.03466v1
Dynamic Wayfinding	Dynamic Wayfindin g (smart navigation in urban areas)	UK	Energy savings of 12%-20% on average, a 10%- 18% decrease in CO ₂ emission was recorded, while a 6%-15% travel distance reduction was achieved	Transport for London. (2015). Leveraging Our Data for Maximum Impact. https://content.tfl.gov.uk/sasp-20151015-part-1- item12-leveraging-our-data-for-maximum- impact.pdf
	GPS- Based Dynamic Routing and Wayfindin g	Netherlan ds	Energy savings of 8%-18% on average, a 6%- 14% decrease in CO ₂ emission was recorded, while a 4%-12% travel distance reduction was achieved	Ministry of Infrastructure and the Environment in cooperation with Connekt/ITS Netherlands. (2015). ITS in the Netherlands Progress Report 2010-2014. https://transport.ec.europa.eu/system/files/2016 -09/2014_nl_its_report_2014_en.pdf
Dynamically Priced Parking	Dynamic Parking Pricing	Spain	3.77% reduction in CO ₂ emissions due to decreased vehicle traffic	González-Aliste, P., Derpich, I., & López, M. (2023). Reducing Urban Traffic Congestion via Charging Price. Sustainability, 15, 2086. https://doi.org/10.3390/su15032086

	(Madrid Central)			
	Dynamic Parking Pricing (SER System)	Spain	12% reduction in traffic flow in central areas	Monzón, A., López-Lambas, M., & Suárez, E. (2008). Impact assessment of a new parking pricing scheme in Madrid city centre.
Technical measures	Electronic Toll Collection Systems (ETCS)	-	Improvement of fuel efficiency and emission reduction by 20% to 25%	Nasir, M.K., Md Noor, R., Kalam, M.A., & Masum, B.M. (2014). Reduction of Fuel Consumption and Exhaust Pollutant Using Intelligent Transport Systems. The Scientific World Journal, http://dx.doi.org/10.1155/2014/836375
	Intelligent Transport Systems (ITS)	Europe	5%-15% reduction in CO ₂ emissions	Tran, M., & Brand, C. (2021). Smart urban mobility for mitigating carbon emissions, reducing health impacts and avoiding environmental damage costs. Environmental Research Letters 16. https://doi.org/10.1088/1748-9326/ac302e
	Smart Traffic Lights	Portugal	29%-41% reduction in CO ₂ emissions	Santos, O., Ribeiro, F., Metrôlho, J., & Dionísio, R. (2023). Using Smart Traffic Lights to Reduce CO ₂ Emissions and Improve Traffic Flow at Intersections: Simulation of an Intersection in a Small Portuguese City. Applied System Innovation. https://doi.org/10.3390/asi7010003
	Vehicle Platooning	Sweden	Energy savings of 10% on average	Besselink, B., Turri, V., van de Hoef, S.H., Liang, K.-Y., Alam, A., Martensson, J., & Johansson, K.H. (2015). Cyber-physical Control of Road Freight Transport. arXiv:1507.03466v1
Traffic restricted zones	Madrid Central (Low Emission Zone)	Spain	3.8% reduction in traffic intensity	Moral-Carcedo, J. (2024). Dissuasive effect of low emission zones on traffic: the case of Madrid Central. Transportation, 51: pp. 25–49. https://doi.org/10.1007/s11116-022-10318-4

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