Technical assistance services to assess the energy savings potentials at national and European level

Summary of EU results

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Table of Contents

1 Executive Summary

This report presents the assessment results of the technical and economic final energy saving potential within EU27, covering energy intensive industries, commercial, residential and road transport sector, hereafter referred to as the 'assessment'. The results were based on a bottom-up modelling approach quantified based on the remaining uptake of Energy Saving Opportunities (ESOs) within the respective 4 sectors. ESOs are organised into 'Programmes', which consist of multiple relevant ESOs (as which could be applied to a similar sub-sector, energy end-use and type of fuel. The resulting technical and economic energy saving potential are quantified with reference to the application of these relevant aggregated ESOs under the Programme.

Table 1 summarises the EU27 technical and economical final energy saving potential between 2020 and 2030 (in ktoe and %) with reference to the projected Business-as-Usual (BAU) final energy consumption, derived from Eurostat and EU Reference Scenario 2016 projections.

Table 1. Summary of EU27 technical and economic saving potential by 2030

Sector	BAU projected consumption by 2030	Technical saving potential by 2030		Economic saving potential by 2030	
	[ktoe]	[ktoe]	[%]	[ktoe]	[%]
Residential	236,129	77,113	32.7%	36,673	15.5%
Commercial	127,502	29,956	23.5%	20,375	16.0%
Industry	275,038	66,994	24.4%	64,716	23.5%
Road Transport	248,537	26,086	10.5%	16,107	6.5%
Total	**887,206**	**200,149**	**22.6%**	**137,871**	**15.5%**

Programmes which are deemed to be cost-effective are categorised as economic saving potential. Economic saving potential accounts for Programmes with a Cost of Conserved Energy[1] which is lower than the energy tariff cost within the sector (i.e. the cost to conserve per unit of energy is lower than the per unit cost of the respective energy type within the sector). As expected, the resulting economic saving potential for the residential, commercial and road transport sector is lower in comparison with the technical potential. As most ESOs within the energy intensive sector have a very long lifespan, the Cost of Conserved Energy of energy saving Programmes is thus significantly lower. Correspondingly, many of the energy intensive sector Programmes are deemed to be cost-effective, resulting a much higher portion of technical savings being deemed as economical potential savings.

The following list presents our recommendation on the highest energy saving potential across the 4 sectors in EU27:

[1] Cost of Conserved Energy accounts for each Programme's lifecycle benefits and costs across the period of assessment (i.e. 2020 – 2050). It measures the cost to conserve 1ktoe of final energy over the entire period of assessment.

Residential sector

ESOs related to space heating accounts for the largest energy saving potential at 52%. This is closely followed by approximately 42% of the energy saving for the residential sector could potentially be attributed to improvement of household energy related appliances/equipment/fixtures, these include wastewater heat recovery system, low-flow shower heads, thermal curtains, solar heating system, improved hot water system insulation, higher efficiency heating appliances. Subsequently, around 28% of the sector energy saving potential could potentially be attributed to building structural improvement, most likely realised through 'deep renovation'. These ESOs include stringent housing standards or building codes, improved wall/basement insulation, draft proofing and higher efficiency glazing. Although there is significant potential which could be realised from behavioural measures, this assessment has taken a much more conservative approach when accounting for its potential energy savings (i.e.<5%).

Commercial sector

The energy saving potential for the commercial sector is attributed by a diverse set of ESOs. Over 21% of the energy saving potential could potentially be attributed to ESOs related to improved lighting system, these include higher efficiency lighting/fixtures (across all lighting categories) and better lighting controls. ESOs relevant to Heating, Ventilation and Air Conditioning (HVAC) could potentially attribute to over 19% energy saving potential, these ESOs include higher efficiency heat pumps, energy recovery from ventilation system, higher efficiency boilers, economisers for heating equipment and destratification fans. Approximately 14% of the energy savings could potentially be attributed to structural improvement on buildings, these include more stringent building standards/codes, higher performance glazing and building insulation. ESOs related to water heating could potentially accounts for around 14% of energy saving potential, these include higher efficiency faucet aerators, improved insulation of water piping, improved hot water circulation pump controls, low-flow shower heads and solar water preheating. Around 9% could potentially be attributed to better building control systems, including building recommissioning, advanced building control system, adaptive thermostats and improved computer managed equipment.

Industrial sector

Over 70% of energy saving potential for the industrial sector could be attributed to improvements in process heating, of which around 33% related to improvement of process heating control system. These ESOs include flue gas monitoring system, advanced control system for process heating, boiler load management, waste heat recovery, premium efficiency burners, combustion air preheating, improvement of heating system insulation, combustion optimization and improved preventive maintenance. Over 15% of the energy saving potential could be attributed to improvement of motor systems, these include application of premium efficiency motors, demand-controlled ventilation, optimisation of ventilation system, control system optimization and premium efficiency speed drives.

Road Transport sector

Over 66% of energy saving potential for the road transport sector are attributed to improvement of vehicle efficiency for passenger transport subsector. The same ESOs could potentially reduce the energy demand for heavy goods vehicles by around 20% and light duty vehicles by around 10%. Theses potential energy savings are quantified with reference to an average energy efficiency rating for all the respective category of road transport vehicles with reference to the EU Reference Scenario 2016.

2 Introduction

ICF supported the Commission to analyse and quantitatively assess in depth the remaining energy saving potential, and energy saving options, across the residential, commercial, industrial and road transport sector. The assessment was carried across all 27 EU Member States (plus UK) by applying ICF's Energy Saving Opportunity Assessment Tool at Member State level, a bottom up modelling assessment of energy saving potential across the sectors mentioned. The base year applied for this assessment is with reference to 2018. However, the period of assessment is from 2020 – 2050 for ease of reference and comparison with Member State National Energy and Climate Plans (NECPs). As such, base year of this assessment has been adjusted from 2018 to 2020, and the results presented in this assessment accounts only for energy savings from 2020 onwards.

For this assessment, all energy saving measures are referred to as Energy Saving Opportunities (ESOs). ESOs are grouped into Programmes, which is setup to group up similar ESOs which can be applied to the same subsector, fuel type and end-use category. The Programme energy savings are categorised into technical and economic saving potential.

Technical saving potential. The technical energy saving potential is the level of energy savings that could be achieved if the baseline technology of an energy using equipment, products or processes within the respective sectors were replaced with higher technical efficiency ESOs or additional energy saving measures, by implementing the suite of ESOs within the respective Programme at a pre-defined uptake rate. The technical saving potential for these individual ESOs applied are then aggregated to a Programme and presented on a Programme level to support policy makers in scoping out the relevant areas for energy saving potential.

Economic saving potential. The economic saving potential quantifies the level of energy savings that could be achieved by implementing only cost-effective Programmes. Each Programme will be tested for cost-effectiveness using a Cost of Conserved Energy (CCE) methodology. CCE represents the lifetime cost of providing an energy service using an efficient technology measure that otherwise would be provided by an inefficient baseline technology. It is the equivalent cost incurred to save 1 kWh of energy (specific to a technology and usage pattern) over the assessment period (2020 – 2050). The lower the CCE, the more economically attractive the Programme is. If CCE is less than the applicable fuel (e.g., electricity, gas, coal, etc) tariff for the given Programme, then it is deemed to be cost-effective

The report also identifies how best to address this energy saving potential, in consideration of the EU energy and climate policy targets for 2030, with elements up to 2040 and 2050.

The content of this report is structured as follows:

- Section 2 presents the objective and scope of the assessment.
- Section 3 presents the overall assessment methodology.
- Section 4 presents the summary results for EU27.

A separate 'Member State *Annex Report'* presents the energy saving profile for the 27 Member States (plus UK). Each Annex is structured as follows:

- Section 1 presents the sector technical and economic saving potential metrics.
- Section 2 presents the top Programmes with highest likelihood of success and ESOs with technical saving potential.
- Section 3 presents the technical recommendation for improving MS energy saving potential.

Annex 1 presents a separate assessment report for EU data centres summarising the sector's energy profile, energy saving potential, barriers to energy saving potential and future energy trends.

In the earlier version of this modelling assessment, energy savings through the application of heat pumps for residential sector was omitted. Annex 2 was developed as an addendum to the Member State Annex Report, specifically to quantify the energy saving potential through application of heat pumps in residential.

2.1 Objectives of this assessment

The objective of this assessment is to analyse and quantitatively assess the energy saving potential, projected from 2020 to 2030 with a perspective to 2050, considering both technical and cost-effective Energy Saving Opportunities (ESOs). The output of this assessment provides technical information to EU and national policy makers on additional potential measures which could support further implementation of energy saving potential at EU and national level.

In this regard, the ICF Energy Saving Opportunity Assessment Tool contains the following parameters developed to support Member State ongoing refinements and updates to national policy and measures:

- **ESO market uptake rates**. This parameter defines the existing market penetration rate of a given ESO and its projected uptake by 2030 and 2050, which is highly sensitive to policy drivers. The uptake trend from 2020 – 2030 can be altered to adjust the ESO state-of-play at each Member State (see section 3.2.4).
- **ESO cost reduction over time**. The cost of ESOs takes maturity of technologies into account. Technology costs may reduce over time due to multiple factors; including national energy policy implementation, improved economics of scale, improved learning as manufacturers gain design and production experience, and maturity of supply chain. This effect is modelled using a High, Medium, Low or Constant definition to adjust for incremental cost reductions over time (see section 3.2.1, page 11)
- **Subsector end-use profile**. Member State subsector profiles are defined in the tool as per the categories presented in Table 2, which can be refined on an ongoing basis depending on subsector performance (see section 3.3).
- **Member state BAU projection**. This projection defines the business-as-usual (BAU) final energy demand baseline for each sector in each Member State from 2020 - 2050. It provides the overall reference point for the projected technical and economic saving potential in this assessment through to 2050. This will change in time to come and could be updated based on the latest state-of-play in each Member State (see section 3.7).
- **Member State fuel tariff**. For each Programme setup, an economic test for cost-effectiveness using a Cost of Conserved Energy (CCE)[2] methodology, as abovementioned. Ongoing fuel tariff increase, or decrease may shift the cost-effectiveness of an energy saving Programme (see section 3.6).
- **Member State discount rates**. Discount rates are applied to assess the incremental cost of ESOs through to 2050 and performing the cost-

[2] CCE represents the lifetime cost of providing an energy service using an efficient technology measure that otherwise would be provided by an inefficient baseline technology. It is the cost incurred to save 1 kWh of energy (specific to a technology and usage pattern). The lower the CCE, the more economical the Programme becomes.

effectiveness test of energy saving Programmes. Discount rates were primarily sourced from Member State 2018 cost optimal reports and could be refined with ongoing Member State PAMs development (see section 3.3, page 17).

2.2 Scope of assessment

This assessment covers the EU final energy consumption of the following 4 sectors: residential, commercial, industrial and transport. The assessment breaks down the energy saving potential across 3 further sub-levels:

Level 1 defines the subsector / subset of each sector. For each subsector / subset, the typology of the building or industrial plant is defined. For the transport sector, it defines the categories of inland transportation modes. The typology will be expanded across each subsector and subset to capture the national sector landscape.

Level 2 defines the energy end-use categories for each of the typology established in Level 1. This level provides a high-level understanding of how energy is being used for each of the subsector / subset typology.

Level 3 defines the baseline technology of the end-use category for each subsector typology. This level provides a breakdown of the baseline technology type currently for each end-use category.

A summary of the abovementioned level 1 and 2 of assessment presented in Table 2. The baseline technology categories are presented in Table 5 in section 3.3.

Table 2. Level of assessment within each Member State

Sector	Subsector	End-use categories
Residential	• Single family • Multi-family	• Space heating • Hot water heating • Lighting • Appliances • Cooking • Cooling • Ventilation fans
Commercial	• Wholesale & retail trade • Private & public offices • Education • Health • Hotels & restaurants • Other commercial	• Space heating[3] • Space cooling[3] • Water heating • Cooking • Lighting • Refrigeration • IT and multimedia • Other equipment
Industry	• Chemicals & petrochemicals • Iron & steel • Petroleum refineries • Food & tobacco • Pulp & paper • Non-metallic minerals • Machinery • Non-ferrous metals • Other industry	• Process heating • Machine drives • HVAC • Process specific • Compressed system • Gas compressors • Process cooling • Lighting • Other
Road Transport[4]	• Passenger transport • Freight transport	• Heavy goods vehicle • Light duty vehicle • Private cars • Public road transport

[3] Ventilation related energy end-use are assessed under space heating and space cooling categories.
[4] Note that trams, metro, rail and inland navigation are not included in the scope of this assessment.

3 Assessment methodology

3.1 Overview of assessment methodology

The assessment utilises a bottom-up energy accounting framework to quantify the technical and economic saving potential across the respective sectors/subsectors within each Member State. Figure 1 presents the overview of methodology applied for this assessment, which include the 6 following steps:

Step 1: Setup Energy Saving Opportunities, which consist of 4 sub steps (1a – 1d)

Step 2: Establish Member State subsector end-use profile and energy related input data

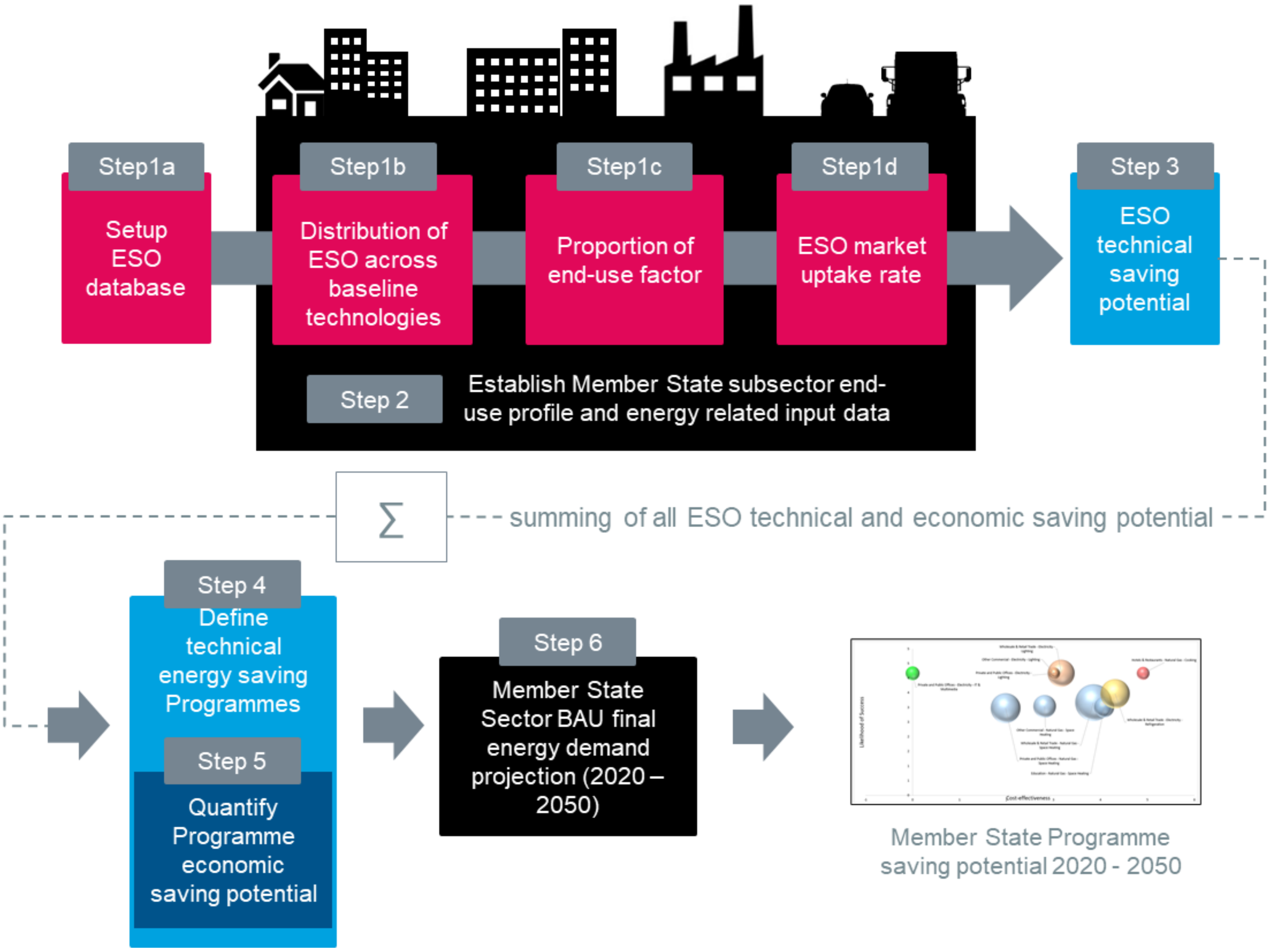
Step 3: Quantify ESO technical saving potential

Step 4: Define technical energy saving Programmes

Step 5: Quantify Programme economic saving potential

Step 6: Member State sector BAU final energy demand projection (2020 – 2050)

Figure 1. Overview of assessment methodology framework

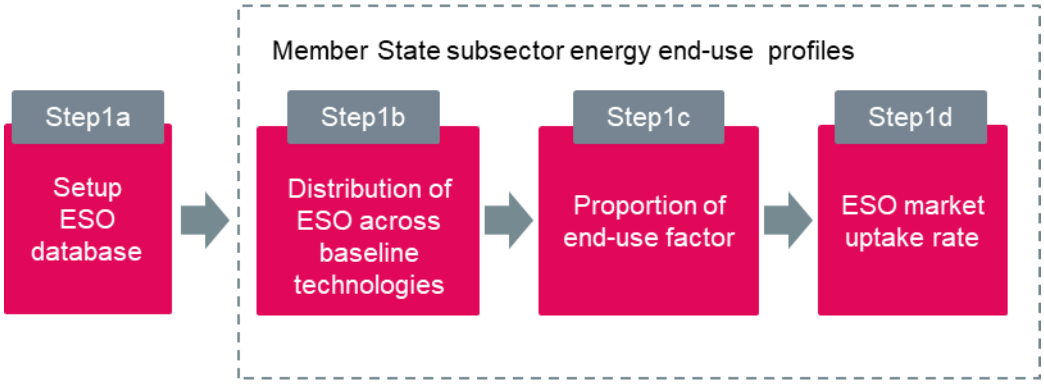


3.2 Step 1: Setup Energy Saving Opportunities (ESOs)

Step 1 consists of four building blocks as presented in Figure 2 to define all the associated Energy Saving Opportunities (ESOs).

At Step 1a, an existing ESO database is setup to define all the relevant Energy Saving Opportunities (ESOs) to be applied in the assessment. Steps 1b, 1c and 1d are parameters within step 1a, that are adjusted depending on the Member State subsector energy profile applied. The outputs of step 1 will quantify the technical energy saving potential for each specific ESO applied across the relevant sub-sectors. Steps 1a – 1d are repeated for every ESO in the database, and the technical energy saving potential for each ESO can be aggregated to account for the technical saving potential (and eventually the economic saving potential in step 5. This forms the primary basis of the bottom-up methodology applied in this assessment, ensuring that all energy saving potential are attributed to a specific energy saving measure.

Figure 2. The four building blocks of quantifying energy saving potential through ESOs



3.2.1 Step 1a: Setup ESO database

Energy efficiency and energy saving measures used in this assessment are classified as Energy Saving Opportunities (ESOs). A library of ESOs are setup to capture the technical and financial performance of different energy efficiency and energy saving measures, including management best practices (e.g. behavioural measures). The following sources were utilised to setup the ESOs:

- **Industrial**. ICF's Industrial Energy Efficiency Database (IEED) were applied. This database was used in the DG ENER *Study on Energy Efficiency and Energy Saving Potential in Industry and on Possible Policy Mechanisms* (2015), and further elaborated in the DG CLIMA study *Industrial innovation and decarbonisation opportunities to 2050* (2018).
- **Residential and Tertiary**. ICF's Demand Side Management (DSM) database will be used. The database has been developed based on evidence collected through the successful implementation of 150 DSM programmes for more than 50 utilities and program administrators around the world[5]. ICF's DSM database has been updated to ensure EU compatibility, through application of relevant baselines and measures[6].

[5] https://www.icf.com/work/energy/demand-side-management

[6] ICF reviewed the Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings (2012/C 115/01) to ensure alignment between the ICF DSM database and listed measures in the regulation.

- **Road transport**. ESOs were selected based on the review of Member State NECPs and through consultation of experts. This assessment only accounts for energy saving potential from the improved vehicle efficiency improvement and tyre efficiency gains. ESOs for the sub-categories of vehicle (Light Duty Vehicle, Heavy Goods Vehicle, passenger vehicle and public road transport) are presented across different aggregated vehicle efficiency improvement levels. These aggregated levels of vehicle efficiency improvement are made up of a list of possible technical and operational sub-measures (e.g. ICT fuel management system, aerodynamic wheel covers, reduced idling, route optimisation, etc.), which are applied in various combinations to achieve the aggregated vehicle efficiency improvement level defined.

Energy savings for heat pumps are accounted as follows:

- Replacement of fossil fuel combustion heating system with electrical heat pumps are included for residential and commercial sector. In such cases, the energy savings accounts for the net final energy savings by switching to electrical heat pumps, i.e. accounting for the additional electrical consumption of heat pumps. The ambient heat captured by heat pumps are not treated as an energy product and does not attribute to the final energy savings within this assessment.

The following categories are excluded from the ESOs under this assessment:

- Novel or emerging technologies for industrial processes (e.g. increased production of high-quality steel from scrap metal, methanol-to-olefins production, low carbon cement production, oxy-fuel combustion).
- Renewable energy sources[7].
- Fuel switching to biofuel and H2.
- Road transportation modal shifts (e.g. modal shift from private passenger vehicles to public transport, increased cycling, etc.).
- Switching from Internal Combustion Engine Vehicles (ICEV) to Zero Emission Vehicles (i.e. battery electric vehicle and fuel cell vehicle)

Each ESO contains the following input parameters which are pre-defined within the ICF database:

Sector. Categorised according to the sectors setup for this assessment, i.e. residential, commercial, industry and road transport.

Sub-sector. Categorised according to the sub-sectors setup for this assessment (expanded in Table 5).

Fuel type (energy carrier). Energy type categorised into electricity, natural gas, coal, refined petroleum products, and biomass (referenced as 'other' fuel).

Applicable end-use category. Defined in accordance with the categories of energy end-use for each subsector (presented in Table 5).

Baseline technology. Baseline technologies are established for each end-use category, as presented in Table 5, including its nominal installed capacity. The baseline technology provides the reference point to quantify the energy saving potential for the associated ESO applied. Where possible[8], specifications of the baseline technology are compared with Ecodesign Directive and the Minimum Energy

[7] Solar heating is an exception, it has been accounted for in the residential and commercial sector assessment.

[8] Efforts are taken to align the specifications of the baseline technology with MEPS stated under Ecodesign Directive. However, this may not be completely harmonised with MEPS due to the difference in our baseline technology categorisation and classification of ESO parameters.

Performance Standards (MEPS) are applied as the minimum performance level. Each end-use category may also contain several baseline levels. Taking lighting for example, a small proportion of the baseline technology would be incandescent bulbs, while a larger proportion would be Compact Fluorescent Lamps. For space heating, a proportion of the baseline technology would be standard-efficiency boilers, and the remaining made up of mid-efficiency boilers.

Equivalent annual energy savings for each ESO. The level of savings for each ESO corresponds to the energy saving achieved when switching or addressing the baseline technology with the respective ESO. The energy savings are quantified on an equivalent annual energy saving basis (in kWh/year and/or % of energy savings per annum) as a result of implementing the ESO. The savings are calculated based on nominal rating of the end-use baseline technology along with assumptions of its nominal annual energy consumption. The following here provides an example for space heating in a single family house:

ESO Parameter	Description
ESO name	High Efficiency Boiler
Sector	Residential
Sub-Sector(s)	Single family house
Energy carrier (fuel type)	Natural gas
Energy end-use category	Space heating
ESO definition	Boiler with High Efficiency Boiler (95% efficiency rating)
Baseline technology	Boiler with efficiency rating of 90% efficiency
Baseline technology annual energy consumption	26,000 kWh/yr
Equivalent annual energy savings	1,300 kWh/yr (5%/yr)

Lifespan of ESO. The life span of each ESO is defined with reference to its associated baseline technology.

Full capital cost / incremental cost. The full capital cost of an ESO includes the material, installation, operation and maintenance cost of implementing the specific ESO. The assessment also defines an incremental cost for each ESO, i.e. the cost difference between the ESO and the associated baseline technology it is replacing. Incremental cost includes the cost difference in material, operation and maintenance cost. It does not include the installation cost. All cost reference is denominated in EUROs, with reference to 2018 price points[9]. ESOs are applied according to the following categories, which defines their respective cost treatment:

- **New/additional technology**. This category of ESOs are implemented as a new/additional technology (e.g. replacing or supplementing existing fossil based hot water heating system with active solar water heating system). For this category, full capital cost of the ESO is applied.
- **Retiring existing baseline technology (RET)**. RET category of ESOs are implemented immediately by retiring existing baseline technology (e.g.

[9] Where on older price points are applied, the ESO cost are inflated at a nominal rate up to 2018.

replacing a functioning boiler with a new premium efficiency boiler). For RET category, the full capital cost of the ESO is applied.

- **Replace on Burnout (ROB)**. ROB category of ESOs are implemented to replace end-of-life baseline technologies (e.g. replacing an end-of-life boiler with a new premium efficiency boiler). For the ROB category, the incremental cost of the ESO is applied.

Where ESOs are classified RET or ROB, it is assumed under this assessment that they are evenly split between the two categories, i.e. 50% of the ESO uptake rate are implemented with full capital cost of the ESO, while the remaining 50% are implemented with ESO incremental cost. Table 4 (in section 3.2.2) provides an example of ESOs with the RET and ROB classification.

Power Purchase Parity (PPP). The ESO cost are adjusted between Member States by applying a Purchasing Power Parity (PPP) factor to adjust the base cost, which allows for the equalisation of the purchasing power between Member States. PPP factors are differentiated for the industrial, residential, commercial (tertiary), and transport sectors. For example, the 2017 residential sector PPP in France is 1.16. This means that 1 Euro for the European Union is equivalent to 1.16 Euros in France. As such, the average 'cost' for a residential sector ESO in France is increased by a factor of 1.16, to obtain the ESO cost in France.

ESO cost reduction over time[10]. The cost of ESOs takes maturity of technologies into account. Technology costs may reduce over time due to multiple factors; including national energy policy implementation, improved economics of scale, improved learning as manufacturers gain design and production experience, and maturity of supply chain. This effect is modelled using a High, Medium, Low or Constant definition to adjust for incremental cost reductions over time.

- High category assumes that the incremental cost will reduce linearly to zero, from the base year to 2050. Taking LED technology for example, it is anticipated that costs will continue to reduce at a significant rate through 2050. As such, a High category is applied, whereby the incremental cost will decrease linearly to zero by 2050 (i.e., LED will become the baseline technology). Other examples include lighting controls and high efficiency lighting fixtures.

- Medium category assumes that the incremental cost will reduce linearly by 60%, from the base year to 2050. This category is typically applied to ESOs with high remaining cost reduction potential. Examples include higher efficiency heat pumps, solar heating and specialised electronic control system.

- Low category assumes that the incremental cost will reduce linearly by 20%, from the base year to 2050. This category is typically applied for ESOs whereby the installation cost is usually higher than the material cost, as such offering very low potential for cost reduction. Examples include insulation, air filtration and draft proofing kits.

- Constant category assumes no further cost reduction potential from base year to 2050. This category assumes that the associated ESO is already well established and offers no further cost reduction potential. Examples include chillers, motors, higher efficiency convection ovens.

An illustrative example of the above-mentioned input parameters are presented in Table 3.

[10] Ongoing national policy and measures can influence the ESO cost reduction over time.

Table 3. Illustrative example of an ESO input parameters for split air conditioning

ESO Parameter	Value
ESO name	High Efficiency Split Air Conditioning (AC)
Sector	Commercial (Tertiary)
Sub-Sector(s)	Education, Hotel & restaurants, private and public offices, wholesale & retail trade, health, other commercial.
Energy carrier (fuel type)	Electricity
Energy end-use category	Space cooling
ESO definition	Split AC/HP unit with Energy Efficiency Ratio (EER): 11.69
Baseline technology	Split AC/HP unit with Energy Efficiency Ratio (EER): 11.2 Capacity: 10 Refrigeration Tonne
ESO lifespan	15 years
Equivalent annual energy savings	2,910 kWh/yr (28%/yr)
Applied cost	Incremental cost of EUR 2,500
ESO cost reduction over time	Medium (i.e. incremental cost is reduced linearly to EUR 1,000 by 2050)

3.2.2 Step 1b: Distribution of ESO across baseline technologies

For multiple ESOs applicable to a similar baseline technology, a distribution factor is applied across the overlapping ESOs to quantify the weighted average of energy saving impact these multiple ESOs have on the baseline technology. This avoids double counting of energy savings with reference to the same baseline technology. This distribution is referred to as the 'distribution by efficiency/model' factor in the assessment.

Table 4. Example case for applying a weighted average energy saving potential across ESOs with similar baseline technology through a distribution factor

Baseline technology: Mid-efficiency non-condensing gas boiler	
Relevant fuel type (energy carrier): Natural gas	
Sector: Commercial	
Subsector: Private and public offices	
End-use: Space heating	
Applicable ESOs	**Distribution by efficiency/model factor**
Premium efficiency condensing gas boiler (RET[11])	40%
Premium efficiency condensing gas boiler (ROB[12])	40%
Air Source Heat Pumps (new)	20%

[11] RET refers to baseline technologies which are retired immediately, to be replaced by the associated ESO.

[12] ROB refers to baseline technologies which are at its end-of-life and replaced by the associated ESO.

Taking the example presented in Table 4, the baseline technology for space heating within private and public offices (commercial sector) is a 'mid-efficiency non condensing gas boiler'. This baseline technology contains 3 possible ESOs which can be applied; premium efficiency condensing boilers (RET)[13], premium-efficiency condensing boilers (ROB)[14] and air-source heat pumps. In this example, we attribute a baseline distribution factor of 40% to the two premium efficiency boilers and 20% to air-source heat pumps. As a result, the weighted average of the energy saving of the 3 ESOs on the baseline is apportioned according to the distribution factor. In practice, this also reflects building owner's choice based on available market options when replacing their existing heating technology. For ESOs which applies to one single baseline technology, the total energy saving potential of the ESO is accounted for, i.e. an equivalent 100% distribution factor applied.

3.2.3 Step 1c: Proportion of end-use factor

This factor defines the proportion of energy savings that an ESO has on the baseline technology in consideration of: (i) the applicable end-use energy consumption represented by the baseline technology in the subsector profile; and (ii) fuel mix ratio for the fuel type(s) associated with the baseline category. This enables the assessment to differentiate the energy saving potential according to the applicable end-use consumption and the energy saving for each fuel type are accounted separately.

3.2.4 Step 1d: ESO market uptake rate

The ESO uptake rates[15], from the base year to 2050, are projected according to the 3 following parameters/reference points:

ESO existing penetration rate (%) defines how the starting point at 2020, i.e. how much of the ESO has already been implemented in the sector. The existing market penetration rate takes into consideration the maturity of technology, capital, operating expenditures and complexity in implementation and operation of the specific ESOs.

ESO market Penetration rate by 2030 (%) specifies the projection of ESO uptake by 2030 with reference to the ESO existing penetration rate.

ESO market penetration rate by 2050 (%). Specifies the projection of ESO uptake by 2050 with reference to the ESO market penetration by 2030.

The assessment assumes a linear uptake trend across the three points, i.e. a linear uptake trend from 2020-to-2030, and 2030-2050.

The 2030 and 2050 penetration rates are applied based on best available Member State sources (technical literature, statistical database, journals, etc.). In absence of reliable Member State data, projections are supplemented with assumptions applying the closest alternative technology category, regional projection trends, and Ecodesign preparatory study data (where applicable). The projections applied generally erred on conservative assumptions.

3.3 Step 2: Establish Member State subsector end-use profile and energy related input data

For each Member State, the energy-related input data are collected to establish its country profile. The input data consists of the following parameters:

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[13] New refers to the immediate replacement of the baseline technology, whereby full capital cost applies to the ESO.

[14] Replacement refers to the replacement of an end-of-life baseline technology, whereby an incremental cost applies to the ESO, but not the full capital cost.

[15] Ongoing national policy and measures can influence the ESO penetrations rates.

Subsector end-use profiles. Country research was conducted across the 27 Member States to obtain best available data to establish the relevant subsector end-use profile[16] as presented in Table 5. The sources of these data were obtained from various in-country technical reports. Where specific Member State sources were unavailable, an EU representative data was applied. In each end-use category, the associated baseline technology options are also categorised, which forms the principal basis of quantifying the energy savings from each energy efficiency and energy saving measure. Each of this baseline categories are tagged onto the associated Energy Saving Opportunities (as described in step 1, section 3.2).

Table 5. Breakdown of sector/sub-sector energy end-use profile

Sector/ Sub-Sector	End-use category	Types of fuel	Baseline technology categories
Residential/ 1. Single family houses, 2. Multi-family apartments.	Space heating	Natural gas, electricity, refined petroleum product, coal and biomass.	Boilers, air heaters, heat pumps, insulation, air infiltration, glazing, draft proofing.
	Hot water heating	Natural gas, electricity.	Boilers, hot water tank, washing machine, dishwasher, shower, faucet.[17]
	Lighting	Electricity.	CFL, incandescent.
	Cooking	Electricity, natural gas.	Ovens.
	Appliances	Electricity.	Clothes dryers, refrigerators, televisions, PCs.
	Fans and pumps	Electricity	Ventilation complete with ducting system, pool pumps
	Cooling	Electricity	Heat pumps, insulation, air infiltration, glazing, draft proofing.
Commercial/ 1. Education 2. Hotel & restaurants 3. Private and public offices 4. Wholesale & retail trade	Space heating	Natural gas, electricity, refined petroleum product, coal and biomass.	Boilers, fans and pumps, motors, air heaters, heat pumps, electric heaters, insulation, air infiltration, glazing, draft proofing, building control.
	Hot water heating	Natural gas, electricity, refined petroleum product, coal and biomass.	Boilers, pumps, insulation, hot water tank, commercial laundry, electric water heaters, shower, faucet, building control

[16] Country research was conducted up to the end-use category level for each subsector. The baseline technology categories are standardised and applied across all Member States based on ICF ESO database.

[17] Hot water usage in washing machines and dishwashers are classified as domestic hot water usage in this assessment.

Sector/ Sub-Sector	End-use category	Types of fuel	Baseline technology categories
5. Health 6. Other commercial.	Cooling	Natural gas, electricity, refined petroleum product, coal and biomass.	Chillers, fans and pumps, motors, heat pumps, make-up air units, insulation, air infiltration, glazing, draft proofing, building control.
	Lighting	Electricity	Metal halide, linear lamps, high bay, CFL, incandescent.
	Cooking	Electricity, natural gas	Broilers, convection ovens, Steam cooker, fryers, griddles, hot food holding cabinets.
	Refrigeration	Electricity	Commercial refrigerators, walk-in cooler, walk-in freezers, commercial icemaker, glass door coolers, motors, compressors.
	IT & Multimedia	Electricity	Power modules.
	Other equipment	Electricity	Commercial pool pumps
Industry/ 1. Iron & steel 2. Chemicals & petrochemicals 3. Petroleum refineries 4. Paper & pulp 5. Non-ferrous metal 6. Non-metallic mineral	Process heating	Natural gas, electricity, refined petroleum product, coal and biomass.	Process heating systems (indirect and direct), Process heating control systems, design optimization, waste heat recovery
	Machine drives	Electricity	Motors, pumps, fans/blowers, machine drives.
	HVAC	Electricity	Comfort heating system, comfort cooling system, ventilation system.
	Gas compressors	Natural gas	Natural gas fired compressors

Sector/ Sub-Sector	End-use category	Types of fuel	Baseline technology categories
7. Food & beverage 8. Machinery	Compressed systems	Electricity	Compressed air system
	Process cooling	Electricity	Chillers, cooling towers, refrigerant compressors
	Lighting	Electricity	Indoor, outdoor.
	Process specific	Natural gas, electricity, refined petroleum product, coal and biomass.	Bespoke industrial specific processes.
	Other	Natural gas, electricity, refined petroleum product, coal and biomass.	Sub-metering, process integration, Energy Management System.
Road transport/ 1. Passenger transport 2. Freight transport	Private cars	Refined petroleum product, electricity	Average vehicle efficiency, average efficiency tyres.
	Public road transport	Refined petroleum product, electricity	Average vehicle efficiency, average efficiency tyres.
	Light duty vehicles	Refined petroleum product, electricity	Average vehicle efficiency, average efficiency tyres.
	Heavy goods vehicles	Refined petroleum product, electricity	Average vehicle efficiency, average efficiency tyres.

Primary fuel tariff. Member State sector fuel tariff prices are collected based on the sources summarised in Table 6. Where the projection trends diverge between the sources, the fuel tariff price projection to 2050 were based on the projections applied under the EU Reference Scenario 2016.

Table 6. Sources for EU27 sector fuel tariff

Energy carrier	Source
Natural gas	Eurostat 2018
Electricity	Eurostat 2018
Coal	2017 Harmonised EU assumptions for NECP
Refine Petroleum Product (RPP)	2017 Harmonised EU assumptions for NECP
Other (biomass)	2018 Heat Roadmap Europe Future Price Review

Primary fuel conversion factor. The quantification of primary fuel demand is calculated based on a fuel conversion factor of the final energy carrier. These Member State fuel conversion factors (final energy to primary energy) for the respective energy carrier are sourced from EU2018 cost-optimal reports[18].

Power Purchase Parity. EU Power Purchase Parity (PPP) is applied to adjust pricing levels across EU27 with regards to the cost of implementing specific Energy Saving Opportunities within the respective Member State (further elaborated in Section 3.2. The resulting cost will have an impact on the overall economic potential assessment. The EU Purchase Power Parity are sourced from Eurostat.

Member State discount rates[19]. Discount rates are applied to assess the incremental cost of Energy Saving Opportunities through to 2050 and performing the cost-effectiveness test of energy saving Programmes (see step 5, section 3.6). Discount rates were primarily sourced from Member State 2018 cost optimal reports.

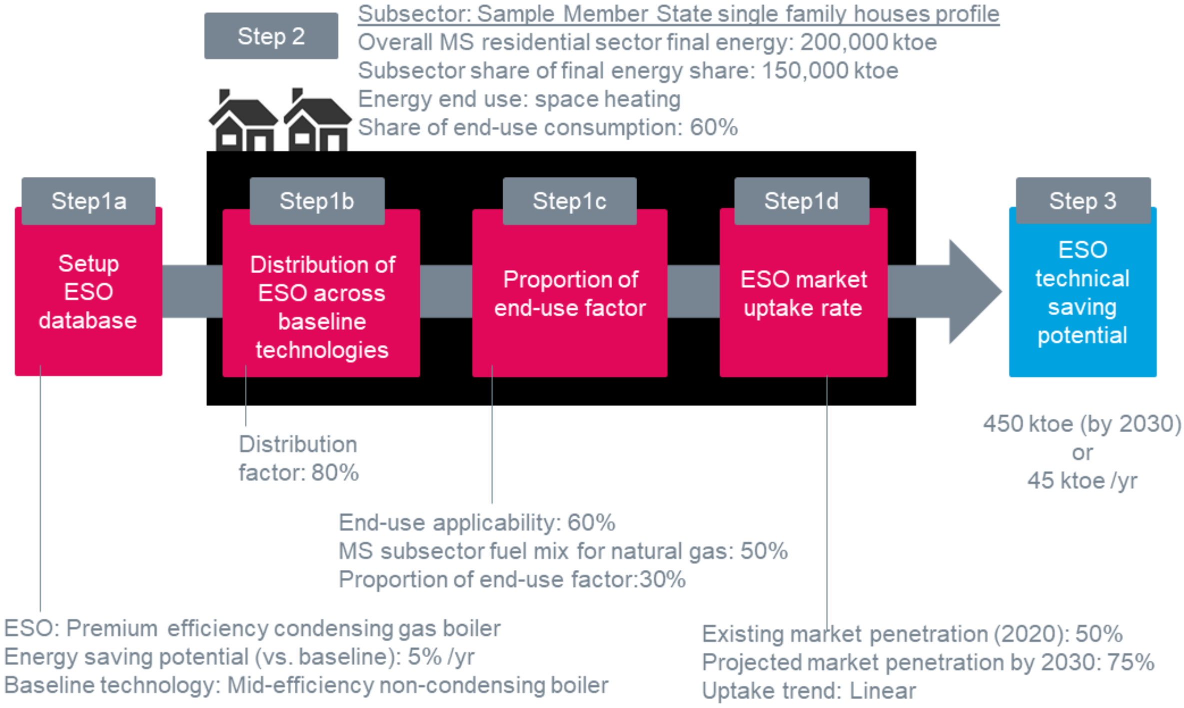
3.4 Step 3: Quantify ESO technical saving potential

The technical energy saving potential is the level of energy savings that could be achieved if the baseline technology of energy using equipment, products or processes within the respective sectors were replaced with additional energy saving measures or higher technical efficiency ESOs, by implementing the suite of ESOs within the respective Programme at a pre-defined uptake rate. Figure 3 expands on the technical potential quantification approach for each ESO.

[18] EU countries' 2018 cost-optimal reports, DG ENER, 2020

[19] Ongoing national policy and measures can influence the Member State sector discount rates over time.

Figure 3. Technical saving potential quantification for sample Member State subsector



Referring to the example presented in Figure 3, the ESO in consideration is a premium efficiency condensing gas boiler, with an energy saving potential of 5%/year, in comparison with the baseline technology. Examining the sample Member State subsector profile, share of final energy for single-family-houses amounts to 150,000 ktoe and 60% attributed to space heating. Applying the ESO to the subsector profile, the following parameters are quantified (through steps 1b – 1d):

- Distribution of ESO across baseline technologies: 80%, i.e. the baseline category represents 80% of space heating technology for single-family-houses.
- End use applicability (referring to the subsector profile) is 60%, and the sample Member State sector fuel mix for natural gas is 50%. The resulting proportion end-use factor amounts to 30%.
- Existing market penetration rate (2020) is 50%, projected penetration linear uptake rate by 2030 is 75%, i.e. net uptake of 25%.

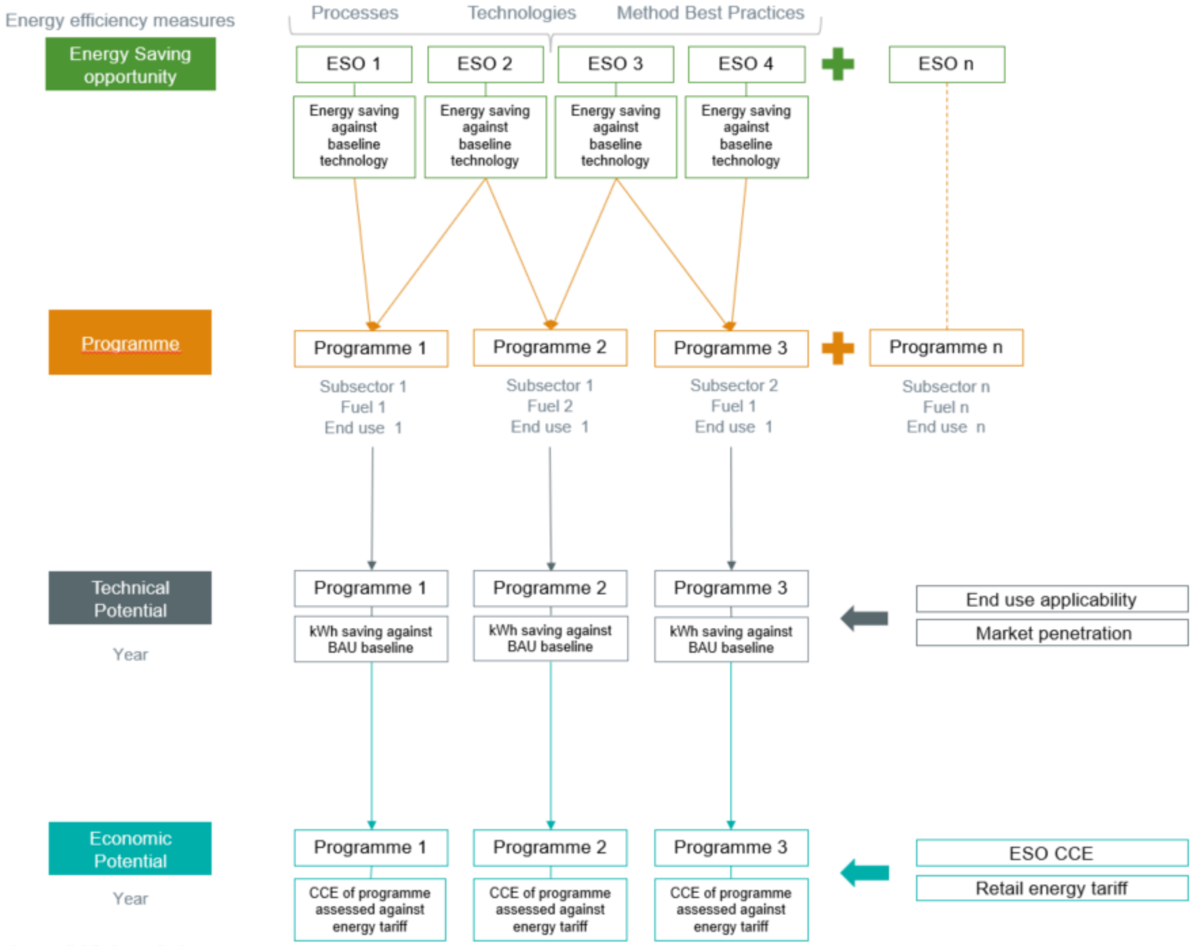
Applying steps 1 – 3, the projected technical saving potential of premium efficiency condensing gas boiler (the ESO) for single-family-houses (the subsector) in the sample Member State is 450 ktoe of natural gas (the fuel type) by 2030.

Steps 1 – 3 are repeated across all ESOs within the ICF ESO database and the technical potential savings are aggregated in total for the relevant subsector.

3.5 Step 4: Define energy saving programmes

This assessment presents the technical and economic energy saving potential on a Programmatic level. Programmes are defined as a group of relevant ESOs (as defined in step 1) which could be applied to a similar sub-sector, energy end-use and type of fuel. The resulting technical and economic energy saving potential are quantified with reference to the application of these relevant aggregated ESOs under the Programme. Figure 4 presents ESOs build-up framework under a Programme. At this step, ESOs are categorised and attached to the respective Programmes according to the following setup: *(i) the relevant sub-sector*; *(ii) the applicable fuel type (energy carrier)*; and *(iii) the applicable end-use category*; as expanded in Table 5.

Figure 4. Programme setup structure to assess technical and economic saving potential at a programmatic level



For example, a 'Single family house – Natural Gas – Space Heating' Programme consist of 28 ESOs (including upgrading of boiler unit, draft proofing measures, installation of thermal curtains, installation of adaptive thermostats, improvement of insulation system, etc.) which can be applied to improve the energy performance specific to natural gas related space heating performance in single family houses. The resulting energy saving potential quantifies the aggregated technical and economic saving potential attributed to the 28 ESOs.

Table 7 provides a further example of programmes assessing the energy saving potential for the iron and steel industry. There are 405 programmes setup for industry, 80 for residential, 120 for commercial (tertiary) and 40 for road transport sector.

Table 7. Example of programmes for the Iron and Steel Industry

Program Name	ESO name
Iron and Steel - Natural Gas - Process Specific	Coke Dry Quenching (CDQ)
	BOF Waste Heat and Gas Recovery
	Continuous Casting
	Sinter Plant Waste Heat Recovery
	Stove Waste Gas Heat Recovery
Iron and Steel - Electricity - Process Specific	State-of-the-Art Power Plant
	Coke Dry Quenching (CDQ)
	BOF Waste Heat and Gas Recovery
	Continuous Casting
	Scrap Pre-Heating
	Sinter Plant Waste Heat Recovery
	Top Gas Recovery Turbine (TRT)
	Stove Waste Gas Heat Recovery
Iron and Steel - RPP - Process Specific	Coke Dry Quenching (CDQ)
	BOF Waste Heat and Gas Recovery
	Continuous Casting
	Sinter Plant Waste Heat Recovery
	Stove Waste Gas Heat Recovery
Iron and Steel - Coal - Process Specific	Coke Dry Quenching (CDQ)
	BOF Waste Heat and Gas Recovery
	Continuous Casting
	Sinter Plant Waste Heat Recovery
Iron and Steel - Other - Process Specific	Optimized Sinter Pellet Ratio (Iron Ore)
	Stove Waste Gas Heat Recovery

3.6 Step 5: Quantify Programme economic saving potential

For each Programme setup (in step 4), an economic test for cost-effectiveness using a Cost of Conserved Energy (CCE) methodology is conducted across all associated ESOs within the Programme. CCE represents the lifetime cost of providing an energy service using an efficient technology measure that otherwise would be provided by an inefficient baseline technology. It is the cost incurred to save 1 kWh of energy (specific to a technology and usage pattern). The lower the CCE, the more economical the Programme becomes.

Programmes are deemed to be cost-effective if their respective CCE is lower than the applicable fuel (e.g., electricity, gas, coal, etc) tariff for the applicable sector of the given Programme, i.e. it is cheaper to save 1kWh of energy in comparison to paying for the additional 1kWh of energy from the utility supplier.

In this assessment, Programme CCEs are calculated by aggregating all the cost and benefit of all associated ESOs within the Programme, resulting in an aggregated programme CCE output. The aggregated programme CCE is calculated using the following equation:

$$CCE = \frac{I}{E}\,\frac{d}{1-(1+d)^{-n}}$$

Where,

I = Sum of all ESO incremental cost or full capital cost within a programme (EUR)

E = Sum of all ESO technical energy saving potential within a Programme (kWh)

n = Programme assessment period (30)

d = discount rate (%)

We have taken a standard 30-year assessment period in account for every Programme. ESOs with a shorter lifespan will have its cost-benefit accounted for across multiple lifecycles, making up the 30-year assessment period. For example: (i) A gas boiler with a nominal lifespan of 15 years, is replaced with a new one upon its end-of-life, therefore having its cost and benefit accounted across 2 lifecycles to make up the 30-year assessment period; (ii) Building recommissioning which is carried out at a five-year interval, will have its cost and benefit accounted across 6 cycles to make up 30-year assessment period.

For ROB ESOs, implemented to replace an end-of-life baseline technology, the incremental cost is applied. For RET ESOs, retiring a functioning baseline technology on an immediate basis, the full cost of the measure is applied in the CCE.

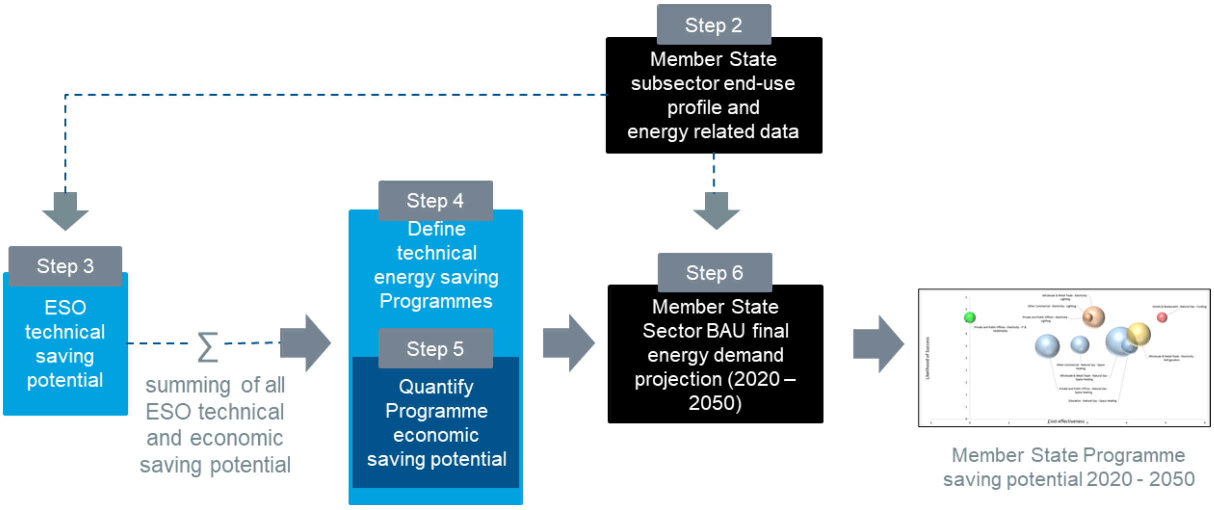
There are some Programme CCEs which are close to the fuel tariff price. Over the assessment period, these Programmes may become cost-effective due to increase in fuel tariff rates, surpassing the Programme CCE.

3.7 Step 6: Member State sector BAU final energy demand projection (2020 – 2050)

Step 6 of the assessment defines the business-as-usual (BAU) final energy demand baseline for each sector in each Member State from 2020 - 2050. It provides the overall reference point for the projected technical and economic saving potential in this assessment through to 2050, as carried out in steps 3 to 5 (summarised in Figure 5).

The BAU projections are broken down to subsector level by applying the outputs of step 2 (section 3.3). All the technical and economic Programme savings are organised according to the Member State’s subsector, fuel type and energy end-use.

Figure 5. Energy savings with reference to BAU projections from 2020 - 2050



Base year data. Eurostat 2018 sector final energy demand data was applied as the base year data for residential, commercial and road transport sector. For industrial sector, Eurostat 2017 final energy demand data was applied as the base year data[20]. For cost analysis purposes, all associated metrics refers back to 2018 as the base reference year.

Projections to 2050. BAU projections from the base year to 2020 and beyond (to 2050) applies the respective year-on-year sectoral growth rates projected under the EU Reference Scenario 2016. As the assessment quantifies the energy saving potential with reference to BAU, applying the projections under the EU Reference Scenario 2016 would enable some consistency when comparing the outputs with other related EU research and studies. The BAU are presented from 2020 onwards (rather than the base year) for ease of reference and comparison with Member State National Energy and Climate Plans (NECPs). As such, base year of this assessment has been projected to 2020 in line with EU Reference Scenario 2016, and the results presented in this assessment accounts only for energy savings from 2020 onwards. However, all associated cost (energy tariff, ESO cost, operation cost, etc.) are still with reference to, and inflated from, the original base year applied for this assessment (i.e. 2018).

3.8 Assessment outputs

For each Member State, the results of the assessment across the 4 sectors are presented in a Member State profile report (refer to the 'Annex Report'). In each Member State profile report, the following details are presented.

3.8.1 Technical and economic saving potential charts

The top 10 Programmes with the highest likelihood of success are presented in a bubble chart as illustrated in Figure 6. The energy saving potential are grouped into energy saving Programmes (as detailed in step 4, section 3.5). Each energy saving programme is organised according to the subsector, end-use and primary fuel saving categories. The energy saving potential are presented according to the following 3 parameters. Each of the parameter is given a score of 0 to 5; 0 indicating least cost-effective / least likely to succeed and 5 indicating most cost-effective / most likely to succeed. Further explanation of the parameters as follows:

[20] Eurostat 2018 data recategorized the final energy demand of blast furnace and petroleum refineries under 'energy sector', whereas 2017 data categorised these consumption under the 'industry sector'. As this assessment includes the final energy demand for blast furnace and petroleum refineries, 2017 data was applied.

Size of the bubble. The bubble size indicates the magnitude of (technical and economic) energy saving potential for the respective programme, i.e. a larger sized bubble presents a higher energy saving potential than a smaller sized bubble.

Cost-effectiveness axis. All cost-effective programmes (passing the CCE test as described in section 3.6) are shortlisted and allocated a cost-effectiveness score on a linear scale of 0 – 5 based on its CCE output. Shortlisted programme with the lowest CCE output will be allocated a cost-effectiveness score of 5 (i.e. most cost-effective) and programmes with the highest CCE will be allocated a score of 0 (i.e. least cost effective). The top-10 most cost-effective Programmes are then presented in the output bubble chart.

Likelihood of success. Each ESO is assessed for its likelihood of success based on two sub-parameters: (1) programme complexity and (2) policy feasibility. The average score of the two above-mentioned sub-parameters make up the final score of the likelihood of success.

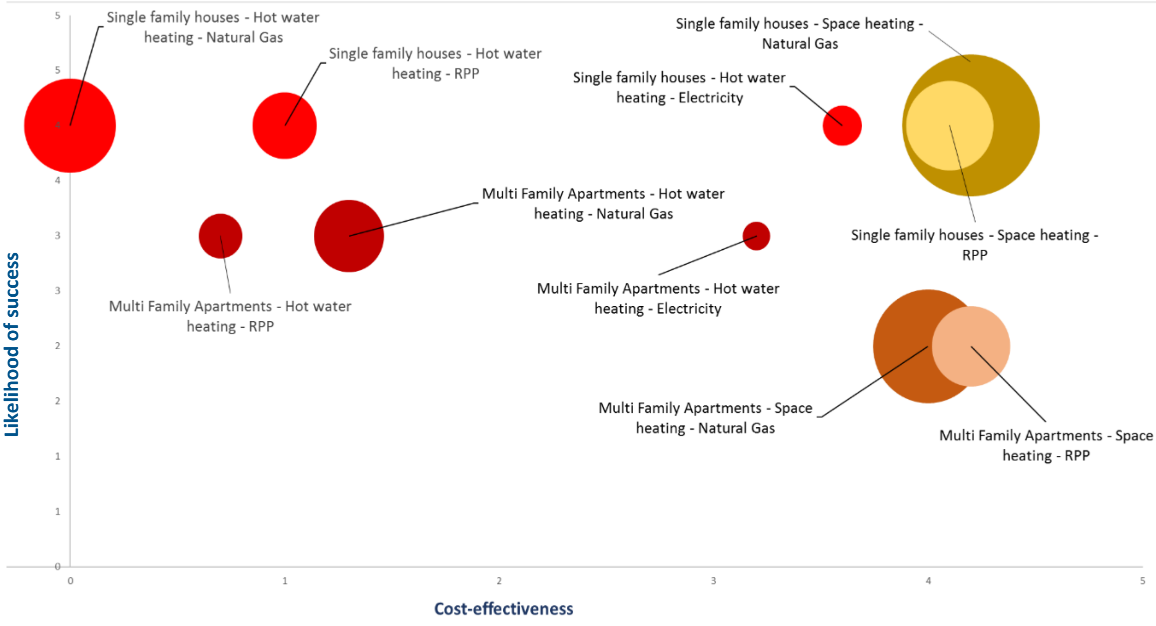
- **Programme complexity** measures the technical complexity of implementing the associated ESOs associated with the Programme. For the residential sector, this is focussed on the intrusiveness of the ESO. For commercial and industrial sector, this is emphasised on business disruption and resource intensity. The qualitative assessment has been undertaken by ICF technical experts assuming a 'typical installation' scenario across the sectors. To maintain consistency, only a scoring of 1 (low), 3 (medium) and 5 (high) are applied.
- **Policy feasibility** takes into account if there are sufficient policy measures within the Member State to support further uptake of the specific Programmes. The scoring for this parameter is obtained directly from Odyssee-Mure database[21]. A scoring of 1 – 5 is applied, 1 being least successful, and 5 being most successful.

Taking Figure 6 for example, Space heating Programmes for single family houses utilising natural gas and RPP presents the highest energy saving potential, likelihood of success and are highly cost effective. On the other hand, space heating Programmes for multi-family apartments utilising natural gas and RPP has a high energy saving potential and are cost-effective, however the likelihood of success is lower in comparison to the previous mentioned space heating programme for single family house. This is mainly attributed to the complexity of implementing more resource intensive space heating ESOs (e.g. improved glazing, installation of better heating system infrastructure, improved construction standards) in multi-family apartments in comparison with single family houses. Hot water heating programme for single family house utilising natural gas presents a relatively high energy saving potential and high likelihood of success, however they are less economic due to its low cost-effectiveness score.

Based on the scoring criteria explained above, the outputs of the likelihood of success utilises a standardised scale and criteria across all sectors and Members States, and therefore the likelihood of success may be reasonably compared across sectors and Member State. However, the cost-effectiveness and bubble chart size are scaled specifically to the Member State specific cost metrics and sector specific energy saving potential. As such, the bubble chart does not compare well between sectors or Member States.

[21] Methodology of Odyssee Mure can be accessed here: http://www.measures-odyssee-mure.eu/successful_info.asp

Figure 6. Assessment outputs presenting technical and economic energy saving potential



The scoring for economic Programmes are presented with all ESOs aggregated at Programme level, i.e. quantified based on the weighted average of CCE metrics for all ESOs associated with the Programme. As such, the economic Programme cost-effectiveness score may consist a mixture of high and low cost-effective ESOs within it.

3.8.2 Top 10 Energy Saving Opportunities

Our assessment also presents the top 10 ESO which based on the highest technical saving potential. This result presents the total potential energy saving impact on the sector attributed to the specific standalone ESO.[22]

3.8.3 Recommendations from the assessment

Recommendations to facilitate EU and national policy makers on developing or implementing further measures to support the uptake of potential energy savings quantified under this assessment are also provided in the 'Annex Report'. The list of recommendation takes the following factors into account:

- Assessment of Member State draft NECPS (submitted in 2019);
- The Commission's feedback on Member State draft NECPs;
- A brief analysis of PAMs under each Member State's draft NECP;
- Technical and economic potential savings from the assessment output.

[22] Comparing the output results between Note that the top 10 ESOs may not always correspond with the top energy saving Programmes.

3.8.4 Limitations of this assessment

The following list highlights some limitations of the approach and results of the assessment.

1. **Future projection trends**. The future BAU projection trends are conducted with reference to the projections under EU Reference Scenario 2016. As such, our assessment results may not compare well to alternative scenarios (e.g. transition to Zero Emissions Vehicles, increase of cooling demand).
2. **Conversion of final energy to primary energy savings based on constant factor**. The Member State final energy to primary energy conversion factor for each fuel type remains constant throughout the assessment period (2020 – 2050). As such, there are limitations in presenting the fuel type (energy carrier) savings as it excludes external factors influencing the change in sector fuel mix (e.g. fuel switching, increase in renewable generation, etc.)
3. **Approach to economic saving potential**. The economic savings approach applies a comparison between CCE and fuel tariff price. It provides a consistent approach in comparing the cost effectiveness. While it accounts for the cost in consideration of the measure lifespan, it does not take other nominal financial metrics which may be more widely applied (e.g. payback, ROI, IRR). As a result, the economic saving potential would appear higher in comparison with other nominal financial metrics. The cost benefit period applied for the CCE assessment is 30 years, considerably longer than typical the investment term acceptable to financial providers.
4. **Subsector share of final energy and end-use**. The breakdown of Member State subsector energy demand and energy end-use are limited to the high-level Member State data research carried out when the subsector profiles are being setup.
5. **ESO scope and uptake rates**. The scope of this assessment excludes fuel switching ESOs, therefore does not account for the longer-term uptake of such measures (e.g. increase in renewable energy resources, transition to Zero Emission Vehicles, etc.). Due to the wider coverage of sectors, a linear uptake rate has been applied to all ESO uptake curves to ensure assessment consistency across all sectors. However, the assessment does account for a portion of fossil fuel boiler to be replaced with heat pumps.
6. **Road transport ESOs excludes mode switching**. In relation to the preceding point, our road transport assessment does not account for mode switching, which limits the technical saving potential for the sector.
7. **Programme level economic savings**. The economic results are presented on a Programme level. The option to unbundle the ESO economic details are not presented in this assessment.
8. **Comparison of technical and economic saving output bubble charts**. The output energy saving bubble charts does not compare well between sectors or Member States, as the scale and metrics are customised to the specific Member State and sector.

4 Summary of EU energy saving potential

Figure 7 presents the aggregated EU-level technical and economic saving potential for the 4 sectors. In general, this assessment applied a steeper ESO uptake rate (as discussed in Section 3.2.4, Step 1d) from 2020 – 2030, in anticipation of Member State action plan towards achieving the 'Clean Energy Package for all Europeans' framework 2030 targets for energy efficiency. As a result, the economic and technical saving potential projects a steeper decrease of final energy consumption from 2020 – 2030, reflecting a high market penetration rate for most ESOs by 2030. The uptake potential from 2030 onwards would be limited to the remaining uptake potential for each ESO, therefore reflecting a gradual decrease from 2030 – 2050. The resulting *technical saving potential*[23] is projected to reduce the Business-as-Usual (BAU) final energy consumption by 22.6% (from 887MTOE to 687 MTOE] by 2030 and by ~33% (from 870 MTOE to 584 MTOE] by 2050. In the same projection period, the economic saving potential[24] is projected to reduce the BAU final energy consumption by 15.5% (from 887 MTOE to 749) by 2030 and ~25% (from 870 MTOE to 654 MTOE) by 2050.

Figure 7. Projection of EU27 technical and economic final energy saving potential

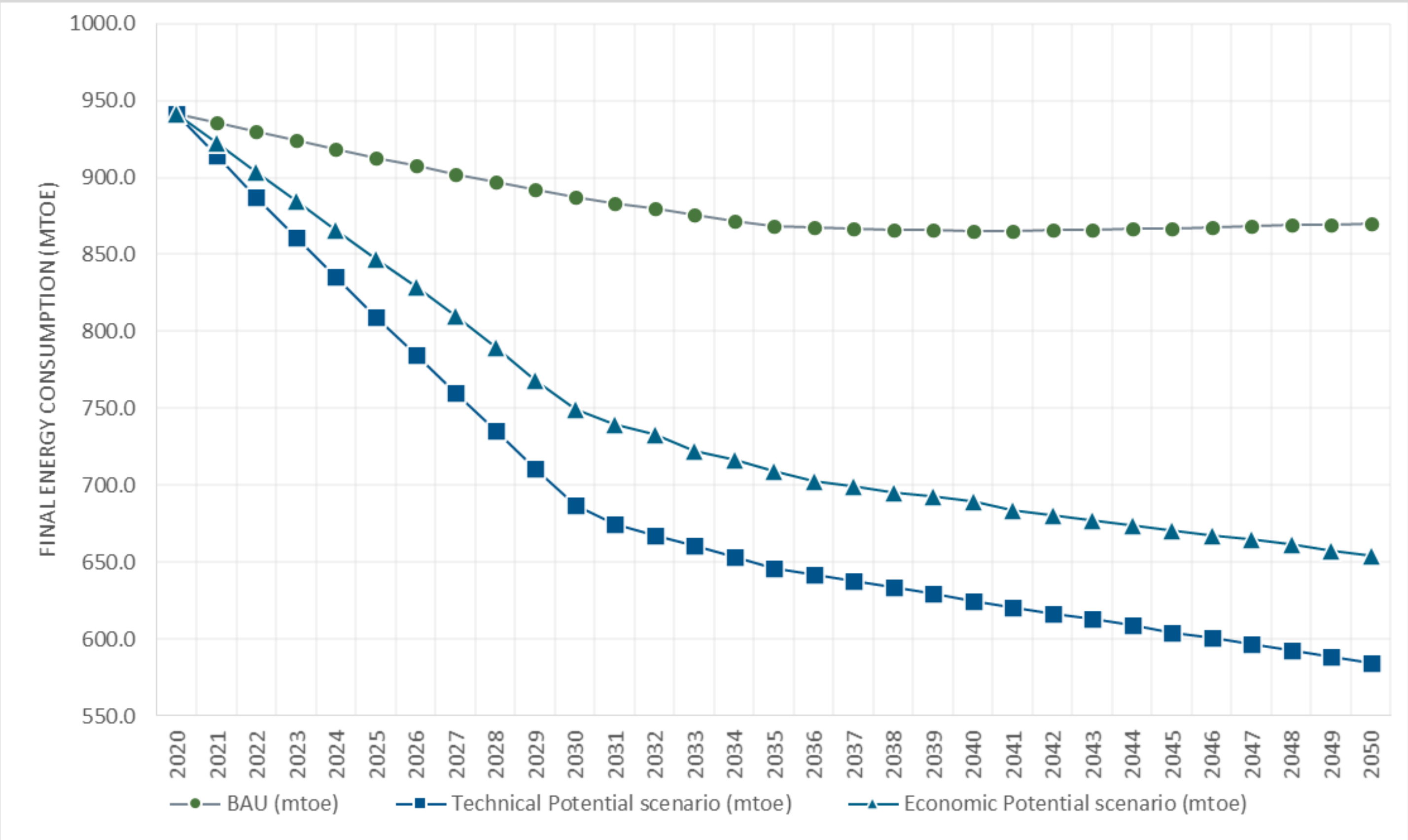


Table 8 provides a breakdown of the technical and economic final energy saving potential across the EU27 Member States. Germany, France, Italy, Spain, Poland, Netherlands, Belgium, Sweden, Austria and Romania make up the top 10 Member State with the highest amount of technical saving potential amounting to 82% of total EU technical potential savings. The same 10 Member states also make up the top 10

[23] **Technical saving potential** estimates the level of energy saving potential that would occur if all processes, equipment and related infrastructure are upgraded with Energy Saving Opportunities (ESOs) that are technically feasible, regardless of any economic constraints, at a predefined uptake rate.

[24] **Economic saving potential** estimates the level of energy saving potential that would occur if all processes, equipment and related infrastructure are upgraded with ESOs which are cost effective.

Member State with the highest economic saving potential amounting to 84% of total EU economic potential savings.

Table 8. Breakdown of EU27 technical and economic final energy saving potential by 2030

Member State	Technical saving potential by 2030 [MTOE]	% of total EU technical savings	Economic saving potential by 2030 [MTOE]	% of total EU economic savings
Germany	43,194.34	21.58%	36,900.79	26.76%
France	28,776.63	14.38%	18,633.40	13.52%
Italy	27,310.42	13.65%	17,747.41	12.87%
Spain	16,028.02	8.01%	10,270.61	7.45%
Poland	13,349.20	6.67%	5,849.48	4.24%
Netherlands	9,862.14	4.93%	7,481.35	5.43%
Belgium	8,056.77	4.03%	6,717.70	4.87%
Sweden	6,230.80	3.11%	5,577.35	4.05%
Austria	5,952.80	2.97%	4,561.92	3.31%
Romania	5,663.77	2.83%	2,220.72	1.61%
Czech Republic	5,415.10	2.71%	2,472.97	1.79%
Finland	4,395.27	2.20%	3,578.03	2.60%
Hungary	4,243.56	2.12%	1,488.53	1.08%
Greece	3,307.38	1.65%	2,058.49	1.49%
Portugal	3,057.57	1.53%	2,227.01	1.62%
Denmark	2,900.32	1.45%	2,486.96	1.80%
Ireland	2,564.01	1.28%	1,987.01	1.44%
Slovakia	2,325.84	1.16%	1,403.68	1.02%
Bulgaria	1,945.87	0.97%	1,068.07	0.77%
Croatia	1,457.85	0.73%	727.73	0.53%
Slovenia	861.32	0.43%	537.82	0.39%
Luxembourg	914.70	0.46%	701.72	0.51%
Lithuania	909.47	0.45%	523.73	0.38%
Latvia	637.80	0.32%	282.72	0.21%
Estonia	494.07	0.25%	219.05	0.16%
Cyprus	218.11	0.11%	105.63	0.08%
Malta	76.40	0.04%	39.86	0.03%

Figure 8 presents the breakdown of EU technical final energy saving potential across the 4 sectors from 2020 – 2050. Residential sector presents the highest technical saving potential at 36%, closely followed by the industrial sector at 34%. Road transport and commercial sector has the potential to contribute equally at 15% each to make up the remaining technical saving potential. Figure 9 presents the breakdown of EU economic final energy saving potential across the 4 sectors.

Figure 8. EU level technical final energy saving potential across the 4 sectors

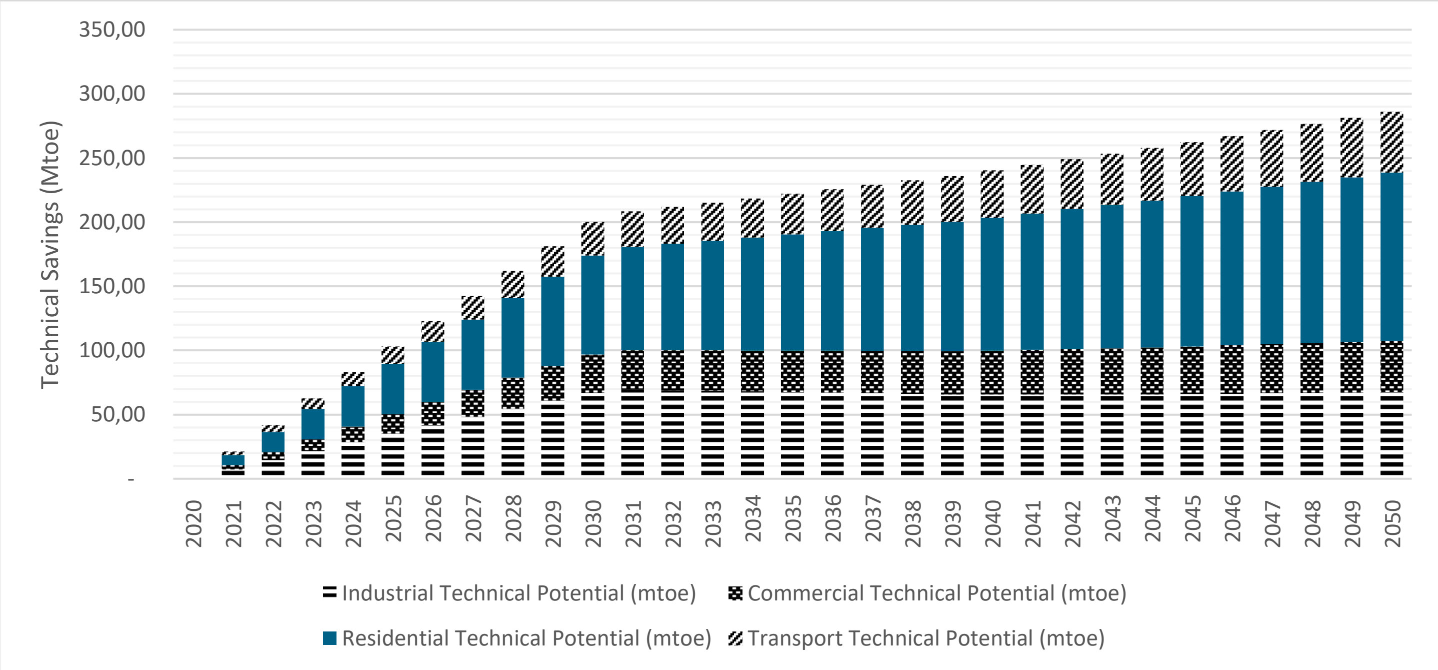
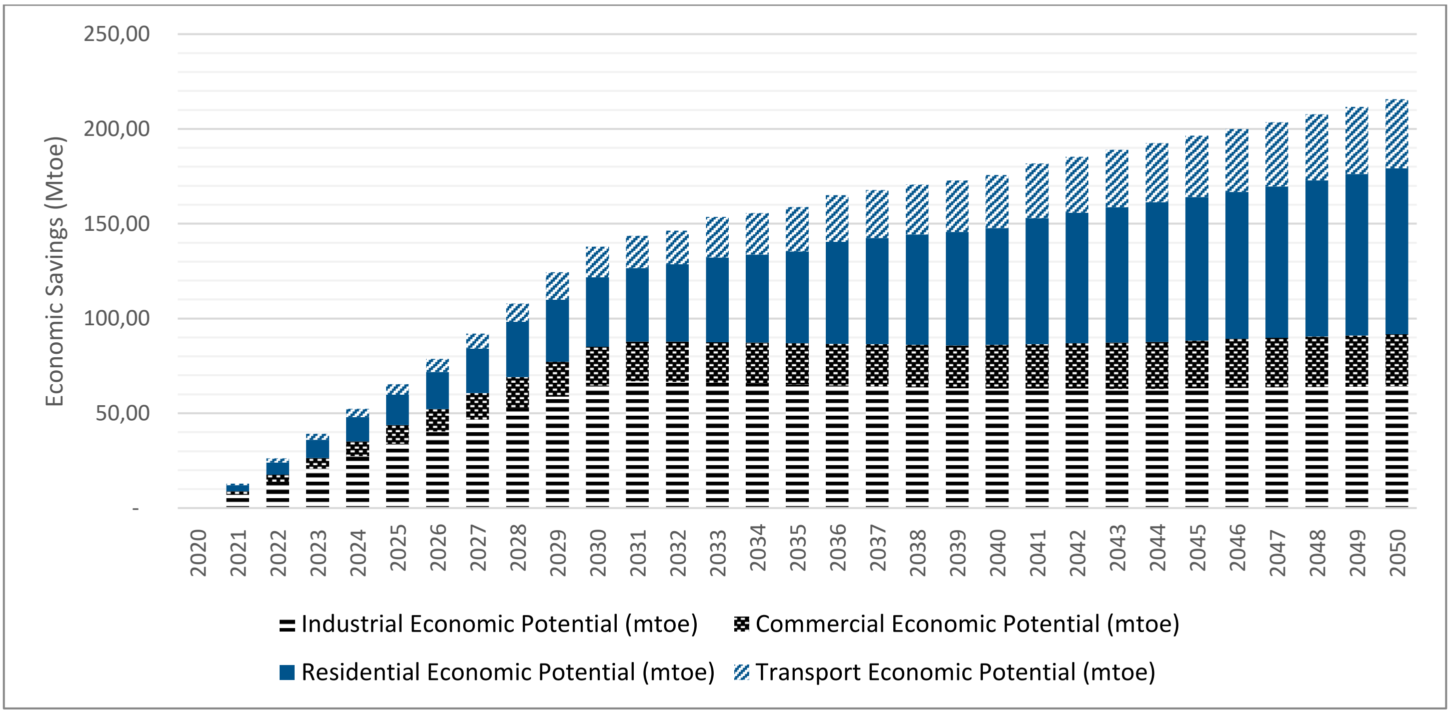


Figure 9. EU level economic final energy saving potential across 4 sectors

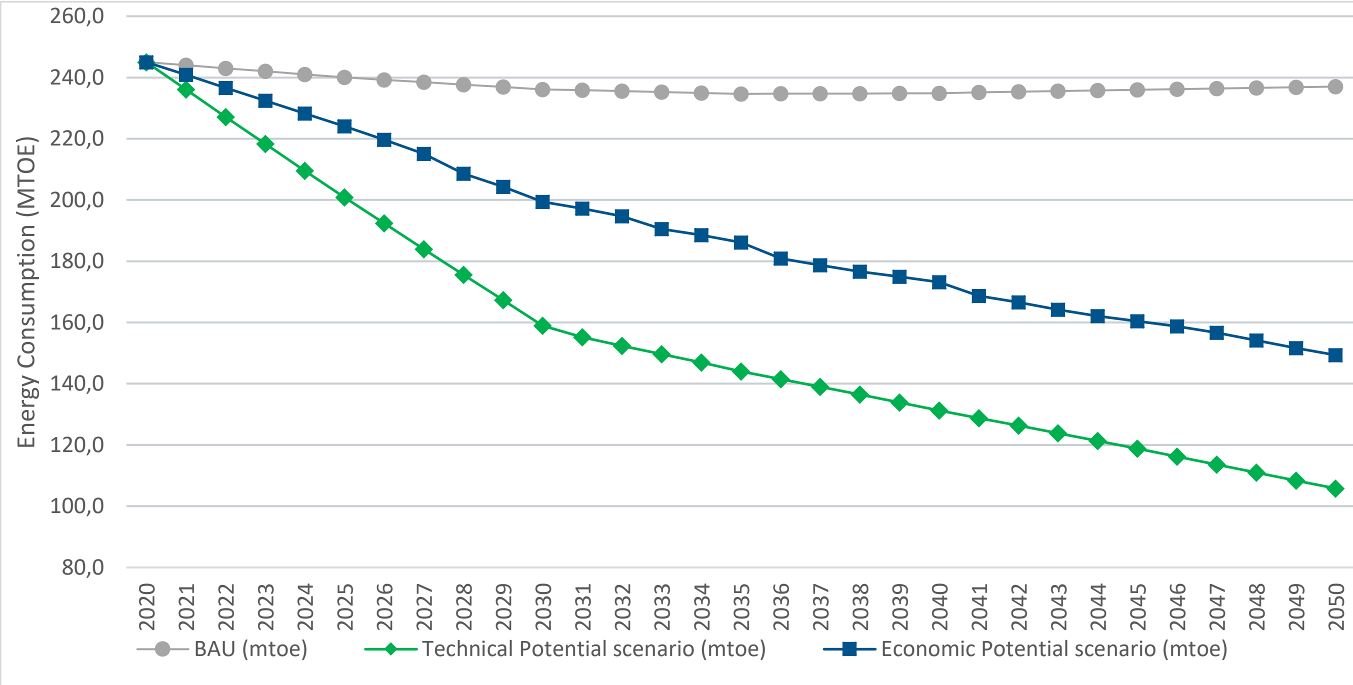


4.1 EU residential sector final energy saving potential

Figure 10 presents the EU27 residential sector technical and economic saving potential from 2020 – 2050. By 2030, EU residential sector has a technical saving potential of 33%, reducing BAU final energy consumption by 77 MTOE, and an economic saving potential of 15%, reducing BAU final energy consumption by 36 MTOE.

Germany, Italy, France, Spain, Poland, Netherlands, Belgium, Romania, Hungary and Czech Republic make up the top 10 Member State with the highest technical final energy saving potential, amounting to 85% of overall EU residential sector savings.

Figure 10. EU27 residential sector final energy consumption technical and economic savings projection



The technical and economic final energy saving potential for the residential sector, broken down by residential end-use categories, is presented in Table 9. Space heating presents highest amount of technical and economic energy saving potential. The highest saving potential for space heating in EU is attributed to improved wall/attic/basement insulation, reducing air infiltration, high performance windows, thermal curtains, adaptive thermostats and high-efficiency heat recovery ventilators, amounting to 38% (~15MTOE) energy savings for space heating category. Uptake of efficient heat pumps presents the next most significant energy savings amounting to 23% energy savings of space heating category.

Renovation of residential buildings, which consist of space heating and domestic hot water heating improvement measures, presents significant energy saving potential.

A key assumption within the assessment is definition of the baseline technology for each ESO from which the energy saving potential is calculated. This is particularly relevant for wall insulation ESOs where the baseline technology is an adequately insulated home (R-10 rated) as this is assumed to be the average energy efficiency performance of homes across the member state. The various residential typologies across the member state is accounted for within the energy consumption baseline. Should the baseline technology be reprofiled to take into account solid wall housing stock (with much poorer insulation level), the technical potential for space heating savings across the EU could increase between 3.4 MTOE – 5.1 MTOE by 2030.

Table 9. EU27 residential sector 2030 final energy saving potential broken down by residential end-use categories

Residential end-use category	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Space heating	40,187	26,698
Hot water heating	32,564	5,656
Lighting	2,645	2,645
Appliances	1,557	1,504
Cooking	81	81
Cooling	78	75
Fans and pumps	2	0

Technical recommendations for the EU residential sector

The following technical recommendations here presents a list of key Energy Saving Opportunities (ESOs) with high collective energy saving impact within EU27 residential sector based on the outputs of this assessment.

Efficient heat pumps play a crucial role. The use of heat pumps for space heating is a more efficient in comparison to conventional fossil boiler system, from a heat generation perspective. In addition, application of heat pumps also provide the sector with the capability to decarbonise heat in transition to carbon neutral or zero carbon heat generation. This assessment projects an energy saving potential of 9.2 MTOE[25] from the uptake of highly efficient heat pumps, accounting for the net benefit of higher uptake of heat pumps (i.e. higher electrical consumption offsets against the overall energy saving benefit of replacing fossil fuel boilers with heat pump). As the baseline technology for space heating is predominantly fossil fuel boiler, the energy saving potential for heat pumps only consider a portion of these fossil fuel boilers being replaced with heat pumps in accordance with the distribution factor (as outlined in section 3.2.2).

Further emphasis on domestic hot water heating savings. Further emphasis should be given to the technical energy saving potential for domestic hot water heating. Although share of domestic hot water final energy usage is lower in comparison to space heating, the higher technical saving potential for domestic hot water is mainly due to the higher energy saving potential for a selection of ESOs, attributed by its low existing market penetration rate within EU, thus presenting a higher market uptake potential for these domestic hot water ESOs by 2030. Domestic hot water heating ESOs with highest energy saving potential in EU include domestic hot water tank insulation, utilisation of tankless water heaters (on-demand heater), high-efficiency condensing hot water boilers, gas storage heaters, washing machine and dishwasher[26]. This assessment projects an energy saving potential of 8MTOE[27] from the uptake of these ESOs.

However, its economic potential is significantly lower as the related ESOs are deemed to be uneconomical, mainly due to a combination of higher replacement/installation cost and a lower lifespan, in comparison with ESOs related to space heating.

[25] Final energy savings per annum by 2030 with reference to baseline projections.

[26] Hot water usage in washing machines and dishwashers are classified as domestic hot water usage in this assessment.

[27] Final energy savings per annum by 2030 with reference to baseline projections.

Consumer choice and behaviour could contribute to high level of savings. A significant portion of energy savings for domestic hot water heating can be attributed to consumer choice and behaviour. Fitting of low-flow shower heads and faucet aerators could potentially contribute to approximately 5MTOE[27] of energy savings. Behavioural measures (e.g. reducing hot water temperature setting, reducing wash cycles, eco-mode settings for wet appliances) could contribute to approximately 4MTOE[27] of energy savings.

Encourage replacement of non-efficient heating appliances. Heating appliances tend to remain functional beyond its anticipated product lifespan. This assessment projects an energy saving of approximately 9MTOE[27] for replacing non-efficient heating appliances (including domestic wet appliances) with highly efficient units. Further incentives are required to encourage consumers to replace functional heating appliances with low efficiency rating. Replacement of boilers with higher efficiency condensing boilers also present a significant energy saving potential, as existing stock of non-condensing boilers within EU remains high (>80million units[28]).

New dwellings have high energy saving potential. To avoid double counting of renovation ESO benefits with other individual ESOs on space heating and domestic hot water heating, this assessment only accounts for renovation of new dwellings[29], and assumes that old dwellings will account for the energy performance benefits based on uptake of individual (space heating and hot water heating) ESOs. New dwelling construction ESOs are defined at two levels[30]; improvement of new dwelling energy performance by 20% and 30% compared to its current energy profile. Both ESOs contribute to a significant portion of the technical and economic saving potential for space heating and domestic hot water energy end-use. With regards to the rate of improvement, this assessment assumes that by 2030, approximately half of the new dwellings will improve have their energy performance improved by 20% energy performance improvement and the remaining half will have a 30% improvement level. The assessment also assumed a 'Medium' cost reduction trajectory for relevant construction costs in anticipation of the improvement to the NZEB supply chain to deliver wider implementation of NZEBs. While significant effort has been focussed on deep renovation of existing old building stock, new dwellings within the EU building stock also presents high energy saving potential. This assessment projects that renovation of new dwellings could contribute to approximately 11 MTOE[27] of energy savings.

Active solar hot water heating system have high energy saving potential. Active solar water heating system consist of solar collectors that capture radiation heat and utilises an auxiliary or backup water heating system when hot water supply cannot be supplied by the solar collector system. This assessment projects that active solar water heating could potentially contribute to approximately 3 MTOE[27] of energy savings.

Waste water heat recovery system have high energy saving potential. This ESO recovers heat from domestic hot water heating to preheat cold water mains feed to the hot water heating system, resulting in lower energy consumption to heat up water in residential buildings. This assessment projects a potential energy saving of approximately 4.5 MTOE[27] of energy savings which, mainly due to high potential uptake of such systems within EU and its relatively low current market penetration rate.

[28] Pezzutto, S.et al; Assessment of the Space Heating and Domestic Hot Water Market in Europe— *Energies* **2019**, *12*, 1760

[29] Residential buildings with primary energy rating of 90 – 150 kWh/m2/a

[30] ESO for 20% improvement denoted as "Energy Efficient Homes (20% above code)" and ESO for 30% improvement denoted as "Net-Zero-Ready Homes".

Policy recommendations for the EU residential sector

The following section here presents a list of policy recommendations in view of encouraging further uptake of Energy Saving Opportunities (ESOs) and complementary measures to realise the energy saving potential for the EU residential sector.

Active monitoring and enforcement actions for Article 10a of EED. The updates on Article 10a of EED on the provision of billing information for heating, cooling and domestic hot water is a positive step towards empowering consumer choice and encouraging better informed decisions on residential energy performance. Specific attention should be focussed on how Member States are ensuring that accurate billing information are made available to consumers in practice.

Empowering consumer choice requires easier access to trustworthy, up-to-date and simplified information for consumers. Further standardisation and simplification of complex energy parameters is required to ensure consumers understand energy improvement options and their upfront and life-cycle costs when they are undertaking building renovation decisions. Standardization of energy parameters is also key to provide reliable information to financing institutions willing to invest in building energy interventions.

Additionally, a standardised approach to communicate the right information to enable consumers to make like-for-like comparisons of available options (e.g. life-cycle cost vs. upfront cost, equivalent monetary savings and limitations of efficient solutions) will empower consumers to embark on energy performance improvement opportunities. Dedicated tools to inform and help consumer decision making will be useful.

Consumer trust is another element which is crucial in supporting consumer choice. Robust accreditation systems for energy-related professionals are needed to build consumer trust in energy-related installers. Additionally, such accreditation must also ensure that accredited professionals are aligned with EU energy saving objectives and competent in providing customers with the appropriate advice on optimal solutions rather than reverting back to the simplest or cheapest option.

A framework to manage data security and energy performance data sharing. As with the roll out of smart meters under EED, specific efforts must be taken to address data security concerns to unlock the wider potential of data application (e.g. data capture, storage and predictive analytics). The benefits of applying smart meter data should be widely demonstrated perhaps to further motivate consumers to consent to data release.

It is crucial for LTRS to address non-technical barriers to deep renovation. The shift of national Long-Term Renovation Strategy (LTRS) from EED to EPBD and the expansion of LTRS requirements (on Member States preparing LTRS action plans and measurable indicators) is a constructive step. A variety of non-technical barriers persist for deep renovation. Other financial incentives should be developed to encourage uptake of energy renovations. Incentives could include tax rebates, inheritance tax relief, or other market-based mechanisms. Provisions under the EU Green Deal needs to allocate further attention and funding capacity for non-public building renovation.

Renovations are usually triggered by non-energy needs, such as lifestyle changes, aesthetics, floor space usage, etc., referred to here as mainstream renovation works. Methods (complementary to Article 7 of EPBD) of embedding energy performance improvements in mainstream renovation, otherwise overlooked, should be explored and disseminated. The objective is to ensure that the market embeds energy performance improvements automatically rather than for regulatory compliance purposes. For instance, for householders, increasing 'active ageing'[31] renovation trends are good triggers to promote energy performance improvement within such renovation activities, as they are highly complementary to the health and wellbeing of an ageing population. Continued support is required to further disseminate deep renovation solutions which are cost-effective and less intrusive. This may include further identification, dissemination or mainstreaming of proven and effective retrofit solutions to ensure the wider market - both the supply-side and demand-side - are aware of such solutions.

Further support required on improving solar thermal heating supply chain. Solar thermal plays an integral role in meeting objectives of all key policies (EED, EPBD and RED) and could significantly contribute to zero carbon heating for NZEBs. However, it is currently not a cost-effective solution, mainly due to the high installation cost and the relatively low generation capacity (i.e. low savings). Further emphasis to mainstream the supply and installation of solar thermal could provide the necessary drive to improve the supply chain and cost effectiveness of solar thermal. Further R&D support would be required to support solar thermal product offering (e.g. integrated panels to maximise surface area) to underpin its potential contribution.

Capacity building of heat pump supply chain. While the role of Ecodesign and energy labelling regulation is playing its part in the supporting the effective rollout of heat pumps, further emphasis should be given to build up the capacity of heat pump supply chain resources to support wide scale implementation of heat pumps. This may include optimal sizing, design, retrofitting and installation of heat pumps for space heating, Unlike fossil fuel boilers, heat pumps require continuous operation to work effectively without switching it on or off. Communication of appropriate operation of heat pump is important in realising the energy saving benefits. Consideration should also be given to better educate consumers on the impact of heat pumps on household utility bills, i.e. consumers will notice a significant rise int heir energy consumption. Nevertheless, the overall energy saving (for non-electrical energy consumption) will offset against the increase in the electrical energy consumption.

[31] Active ageing refers to older generation building occupiers undertaking renovations to adapt their homes to their aging lifestyle needs. Energy efficiency renovations could be undertaken along these renovations.

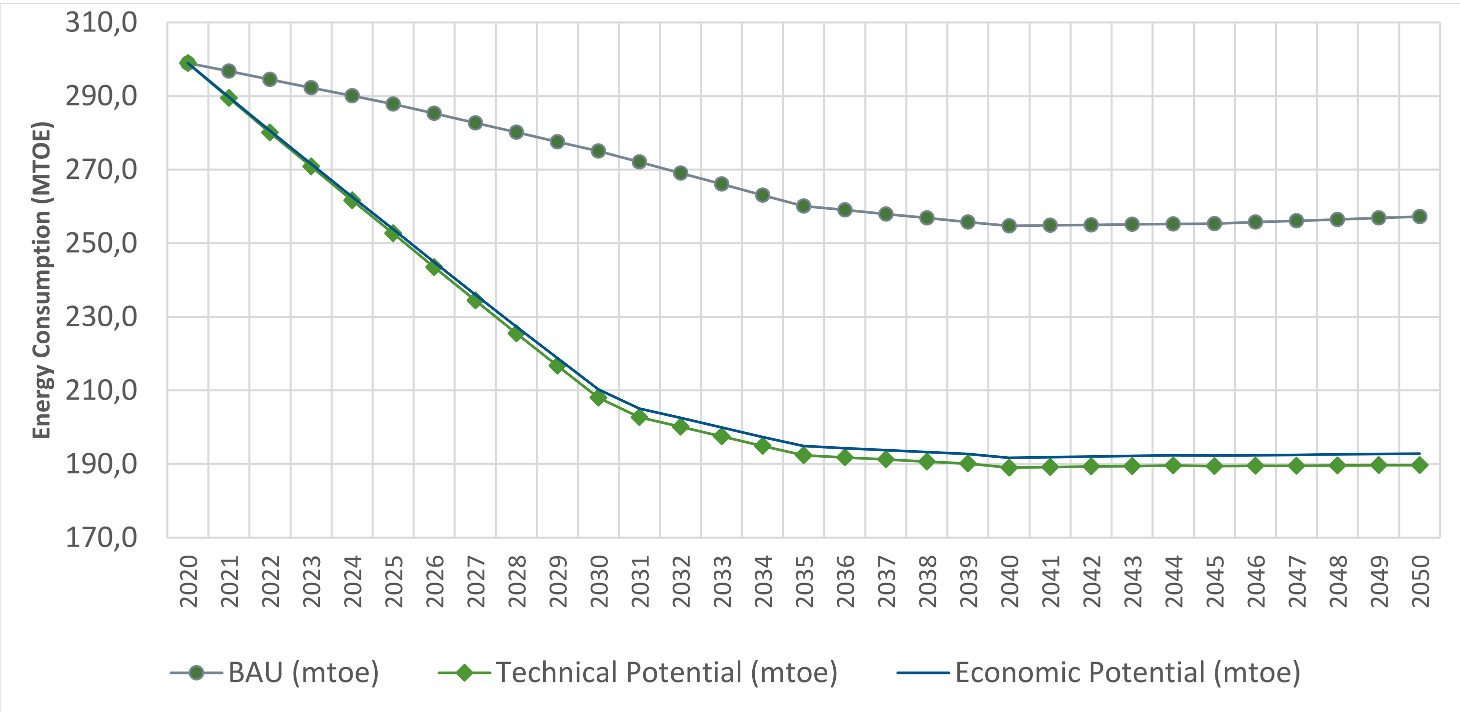
4.2 EU industrial sector final energy saving potential

Figure 11 presents the EU27 industrial sector technical and economic saving potential from 2020 – 2050. By 2030, EU industrial sector has a technical energy saving potential of 24.4%, reducing BAU final energy consumption by 67 MTOE, and an economic saving potential of 23.5%, reducing BAU final energy consumption by 64.7 MTOE.

Germany, France, Italy, Spain, Poland, Netherlands, Belgium, Sweden, Austria and Finland make up the top 10 Member State with the highest technical energy saving potential, amounting to 79% of overall EU industrial sector final energy savings.

Overall, the economic saving potential for industrial sector is very close to its technical saving potential. This is mainly attributed to the long lifespan of industrial Energy Saving Opportunities (ESOs), which resulted in a lower Cost of Conserved Energy (CCE) across the sector. Industrial primary energy tariffs are also lower in comparison with the other sectors. As such, a high proportion of industrial related ESOs have CCEs which are lower than the respective primary fuel tariff, deeming them to be cost-effective ESOs.

Figure 11. EU27 industrial sector final energy consumption technical and economic savings projection



The technical and economic final energy saving potential for the industrial sector, broken down by industrial subsector, is presented in Table 10. The highest potential contribution of technical final energy saving potential is fairly equal between Chemical & Petrochemicals (15%), iron & steel (14%) and petroleum refineries (13%). The remaining technical potential is made by food & drink (10%), pulp & paper (10%), non-metallic mineral (9%) and machinery (6%). Other industrial sectors cumulatively could contribute to up to 19% of the industrial sector technical saving potential.

Table 10. EU27 industrial sector 2030 final energy saving potential broken down by energy intensive subsectors

Industrial subsector	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Chemicals and Petrochemicals	10,599	9,851
Iron and Steel	9,802	9,210
Petroleum refineries	8,859	8,783
Paper, Pulp and Print	7,025	6,878
Food and Tobacco	6,522	6,477
Non-Metallic Minerals	5,886	5,439
Machinery	4,175	4,114
Non-ferrous Metals	2,512	2,439
Other industries	11,615	11,508

Table 11 presents the above technical and economic final energy saving potential by 2030 broken down by industrial sector end-use categories. Process heating presents the largest technical and economic saving potential. Machine drives, HVAC, compressed system, process cooling, gas compressors and lighting has equal technical and economic saving potential. Process specific category has a high technical potential, however most ESOs related to this end-use category are deemed uneconomical.

Table 11. EU27 industrial sector 2030 final energy saving potential broken down by industrial end-use categories

Industrial end-use category	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Process Heating	45,719	45,719
Machine drives	12,717	12,717
HVAC	3,963	3,963
Process Specific	1,874	110
Compressed System	1,131	1,131
Other	531	-
Lighting	462	462
Gas Compressors	303	303
Process Cooling	294	294

Some critical industrial scenarios; namely electrification of heat, fuel switching to low carbon sources, availability of carbon free electricity or H2 and carbon capture storage; are not included in this assessment. The impacts of such scenario has to be compared on a scenario-to-scenario basis.

Technical recommendations for the EU industrial sector

The following here presents a list of key fundamental recommendations in support of effective implementation of key Energy Saving Opportunities (ESOs) with high collective energy saving impact within EU27 industrial sector based on the outputs of this assessment.

Submetering of significant energy users. To develop an energy picture of a facility, plant operators need accurate, real-time energy data to evaluate the performance of individual processes, pieces of equipment, departments and benchmark energy levels at multiple facilities. Sub-meters enables facilities to analyse various issues, including the profiling of individual or aggregated loads on equipment to pinpoint peak usage, so operational staff can employ load controlling devices to set high/low thresholds, control loads and reduce energy costs; allowing facilities to identify exact energy costs by production line, production run, individual piece of equipment or the entire facility, which enables the accurate allocation of energy costs to individual products or customers; monitoring usage and identifying potential failures, thus allowing facility managers to take proactive steps to schedule repairs before the equipment fails, thus avoiding costly and unexpected downtimes; and enabling organisations to separate production costs from other departments to support accurate budgeting. Sub-metering is often viewed as a cost component instead of contributing factor to energy savings. However, it plays a vital role in supporting implementation of ESOs and validating its benefits, underpinning the business case of energy efficiency investments.

Energy Management System with clear energy performance improvement. Energy Management System (EnMS) enables enterprises to establish systems and processes necessary for the purpose of improving energy performance, including energy efficiency, and consumption. It is defined as a set of interrelated or interacting elements to establish an energy policy, energy objectives, processes and procedures to achieve those objectives. Unlike other voluntary management system standards, the accepted norm for EnMS includes demonstrated energy performance improvement. Practitioners, auditors and certification / accreditation schemes globally continue to struggle with consistently ensuring EnMS are truly driving performance improvement. Nevertheless, EnMS remain crucial in energy efficiency improvement and further emphasis is required to realise its potential within energy intensive industries.

Dedicated practitioners to manage energy. Dedicated resource/experts are required to ensure that there is real and credible expertise involved in managing an organisation’s EnMS. This requires a defined set of competencies that must be met and documented for EnMS experts. While training and certification of EnMS auditors (consistent with international standards such as ISO 17024) does produce understanding of what satisfies the requirements of ISO 50001, it does not result in an understanding of the practical aspects of how to develop and implement an EnMS. ISO does not have standards for EnMS (or other management system) implementation experts. Thus, EnMS development and implementation expert requirements / also described as “practitioner” requirements is a practical minimum for such an approach. Clear training, experience and certification minimums would be desirable for practitioners. Selected models of EnMS practitioner expertise do exist. Efforts to develop an internationally applicable EnMS practitioner recognition began under the Global Superior Energy Performance Partnership program with that program evolving into the Certified Practitioner in Energy Management Systems program[32].

[32] Certified Practitioner in Energy Management Systems (CPEnMS) https://ienmp.org/certifications/cp-enms/

Policy recommendations for the EU industrial sector

The following section here presents a list of policy recommendations in view of encouraging further uptake of Energy Saving Opportunities (ESOs) and complementary measures to realise the energy saving potential of EU industrial sector.

Article 8 of EED could incentivise industry to set its own energy performance improvement targets. Mandatory audit schemes under Article 8 of EED has already gone through its second phase. In the following phases, industries should be encouraged to identify and set energy performance targets to ensure that findings from the energy audits (or EnMS) are thoroughly assessed by the board level, and implemented where feasible. Financial incentives could be setup to further drive action on energy performance improvement and clear reduction in energy consumption.

Supporting EnMS with high impact schemes. The potential for EnMS within EU energy intensive industries could be sufficiently exploited with further high impact schemes. These schemes may include:

- Financial assistance in EnMS certification. Financial assistance can be provided to organizations that commit to implementation of an EnMS. The means of financial assistance may be as a percentage of documented costs for a specified set of implementation activities/ or to a specified maximum amount for any one organization.
- Provision of EnMS experts / practitioners. When experts in EnMS implementation are provided, this support can be in the form of providing funding for participating organizations to directly hire as employees experts in EnMS, or to hire contractor experts in EnMS. A key part of having EnMS experts that will support organizations is to ensure that there is real and credible expertise provided. This requires a defined set of competencies that must be met and documented for EnMS experts.
- EnMS implementation tools. Providing a variety of tools that are in the common language(s) of the nation for use in industry are a way to support EnMS adoption. Tools can include general templates that can be adapted (e.g. spreadsheets for calculating energy performance improvements relative to baseline, examples for each required procedure under ISO 50001) can be of the greatest help to organizations that have not historically had a comprehensive EnMS.
- EnMS peer-to-peer networks. Peer networks provide a means for sharing of expertise, learning experiences and best practices. Industry peer networks can begin with/be supported by trade associations. A peer network can also be location driven, where a number of industries in a common geographic area (e.g. town or state) are engaged. A peer network can also be facilitated by an EnMS expert / government entity that provides pooled expertise/ expertise shared across the network. The activities of a network are generally built around a shared learning experience as the organizations work to develop and implement EE and EnMS efforts.
- Recognition programmes on energy performance improvement. Not all jurisdictions provide incentives that are directly tied to full certification to ISO 50001. For some organizations the motivation for EnMS implementation is driven only by internal drivers but for others a form of recognition of development and implementation of an EnMS is a driver. Recognition can be of a "self-declaration" by the implementing organization, or it can be recognition of documented participation in a peer reviewed format (e.g. the CEM has an awards program that recognizes leaders with a certified EnMS) or there can recognition of progress made towards full EnMS implementation.
- Financial incentives for energy saving or energy performance improvement achievements. Financial incentives can be in the form of tax relief when an EnMS has been documented as having been implemented. A common form of trigger for

tax relief is a demonstration of completion of EnMS implementation via certification by an independent third party. For ongoing tax relief the certification would need to be maintained. Rebates are generally for industries/ enterprises above a defined "size" (e.g. annual energy consumption). Rebates could be a proportion of related energy costs or can be a reduction of any other aspect of the overall tax burden for the industry.

Sector specific transition roadmap and managing carbon lock in. In view of the further development of EU's new industrial strategy, significant consideration should be given in managing industrial technology and carbon lock in factors. These factors should be thoroughly assessed along with a mitigation plan for key long-term assets (e.g. hydrogen infrastructure, district heating, CCS). The transition to a carbon neutral bloc would need dedicated measures and instruments to facilitate transition of these long-term assets to carbon neutral options (e.g. fuel switching capabilities, retrofitting capabilities, supporting low carbon infrastructure). Sector specific roadmaps may be required to ensure the transition is appropriate for each sector.

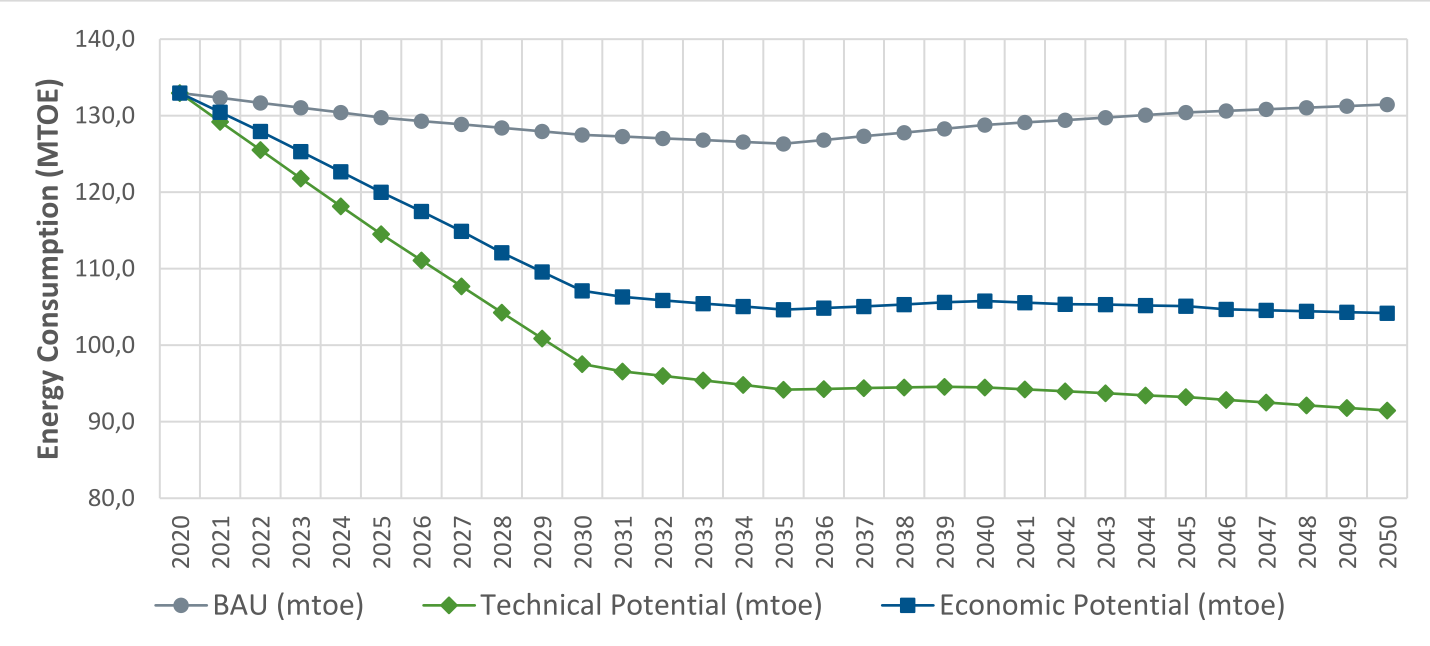
Incentives for implementation of novel technologies driving carbon neutral economy. While it is crucial for EU policy and mechanisms to remain technologically neutral, technologies with a significant role in driving energy intensive processes towards carbon-neutral approach should be incentivised or accelerated. For instance hydrogen electrolysis, hydrogen based steel making, electrolysis of iron ore, zero-carbon Ethylene production (via low carbon Methanol-to-Olefins route), low carbon cement, electrification of process heat.

4.3 EU commercial sector final energy saving potential

Figure 12 presents EU27 commercial sector technical and economic saving potential from 2020 – 2050. By 2030, EU commercial sector has a technical saving potential of 23%, reducing BAU final energy consumption by 30 MTOE, and an economic saving potential of 16%, reducing BAU final energy consumption by 20 MTOE.

Germany, Italy, France, Spain, Poland, Netherlands, Belgium, Sweden, Greece and Czech Republic make up the top 10 Member State with the highest technical final energy saving potential, amounting to 83% of overall EU commercial sector savings.

Figure 12. EU commercial sector final energy consumption technical and economic savings projection



The technical and economic final energy saving potential for the commercial sector, broken down by its subsector, is presented in Table 12. Wholesale & retail trade has the potential to contribute highest technical final energy saving potential at 34% of overall sector energy savings. This is followed by private and public offices (18%), education (15%), Healthcare (10%) and hotels & restaurant (9%). Other commercial sectors cumulatively have the potential to address up to 14% of the sector's technical saving potential.

Table 12. EU 2030 final energy saving potential broken down by commercial subsectors

Commercial subsector	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Wholesale & Retail Trade	10,102	7,938
Private and Public Offices	5,381	2,143
Education	4,486	3,401
Other Commercial	4,162	2,628
Health	3,047	2,217
Hotels & Restaurants	2,778	2,048

Table 13 presents the above technical and economic final energy saving potential by 2030 broken down by commercial sector end-use categories. Space heating presents the largest technical and economic saving potential; however, the economic saving potential is significantly reduced as most ESOs under this end-use category is deemed to be uneconomical. This is due to the lower lifespan assumed for the ESOs within this sector, therefore increasing the capital cost over the assessment period. Space heating ESOs with the highest energy saving potential include high efficiency cold climate air-source heat pumps, adaptive thermostats and high-performance glazing.

With regards to improvement of building energy systems, ESOs with the highest energy saving potential are building recommissioning and installation of advanced Building Automation System/Controllers.

Lighting and refrigeration present equal technical and economic saving potential (whereas for space cooling it is almost equal) as the relevant ESOs under these end-use categories are all deemed to be economical measures.

Table 13. EU27 commercial sector 2030 final energy saving potential broken down by commercial end-use categories

Commercial subsector	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Space Heating	12,861	5,501
Water Heating	6,575	4,822
Lighting	6,546	6,546
Refrigeration	2,104	2,104
Space Cooling	965	861
Cooking	516	391
IT & Multimedia	321	86
Other Equipment	68	63

Technical recommendations for the EU commercial sector

The following technical recommendations here presents a list of key Energy Saving Opportunities (ESOs) with high collective energy saving impact within EU27 commercial sector based on the outputs of this assessment.

Regular building recommissioning. Building Recommissioning (defined under this assessment) involves readjustment, recalibration and refinement of applicable settings on key components of building space heating and water heating system. Building systems often require frequent adjustments in responding to the changing in building energy requirements to maintain the equipment's intended optimum technical performance level. Recommissioning of these building systems often only require fine adjustment of its settings and may sometimes require mechanical adjustments. Nevertheless, building recommissioning is highly economic and effective in achieving energy savings. This assessment projects an energy saving potential of approximately 2MTOE[33] through increased regular building recommissioning.

Advanced Building Automation System and Controllers. Advanced Building Automation System and Controllers (BASCs), defined under this assessment, accounts for energy savings through the utilisation of automated central controller systems that monitor and control the energy performance of significant energy users for space heating and water heating systems according to the actual needs and changes to the building environment. The effectiveness of advanced BASCs is dependent on appropriate system design, scope and extent of controllers installed on key components of the building system. In addition, implementation of advanced BASCs forms a crucial interim step in enabling smart building capabilities. This assessment projects an energy saving potential of approximately 1.5MTOE[33] through increased implementation of advanced BASCs within EU commercial buildings.

Efficient high bay lighting. High bay lighting is generally applied for luminating spaces with floor-to-ceiling height of 8m or over. High bay lightings are more commonly applied in environments requiring uniform and high illumination of useful space. The fittings are also more robust and often applied in harsher environments, where higher concentration of air particulates may shut out weaker (low bay) lighting source and damage to less robust fittings. Efficient high bay lighting requires a replacement/modification of the light fitting to utilise LED luminaires. Although efficient high bay lighting is common in most of the commercial sector, this assessment projects energy an additional energy saving potential of approximately 2.5MTOE[33] beyond the baseline projection.

Lighting controls and LED lighting fixture. LED lighting and control sensors (occupancy and daylight) are commonly applied within the sector. Nevertheless, this assessment projects an additional energy saving potential of approximately 3MTOE[33] beyond the baseline projection.

Building renovation. This assessment defines improvement of existing non-residential building at two levels[34]; renovation improvement with energy performance improvement of 25% and 40%. Both ESOs contribute to a significant portion of the energy saving potential for space heating and hot water heating energy end-use. This assessment assumes that by 2030, approximately half of the commercial buildings will carry out potential renovation with 40% energy performance improvement and the remaining half will carry out renovation with 25% improvement level, resulting in a projected energy saving potential of 4MTOE[33].

High efficiency cold climate air-source heat pump presents high energy saving potential and a route for electrification of heat. Air-source heat pumps are designed to operate at its nominal outdoor temperature ratings. Efficiency of heat pumps reduces as outdoor temperature drops. High efficiency cold climate heat pumps are designed specifically to operate at low outdoor temperature while retaining high efficiency. Heat pumps forms part of the solution for electrification of heat. Further emphasis could be given to the technical energy saving potential for high efficiency cold climate air-source heat pumps in line with increased renewable capacity. This assessment projects a net final energy reduction potential of 3MTOE[33], considering an upgrade of existing heat pumps to high-efficiency units.

[33] Final energy savings per annum by 2030 with reference to baseline projections.

[34] ESO for 40% improvement denoted as “New Construction - 40% Better” and ESO for 25% improvement denoted as “New Construction - 25% Better”.

Policy recommendations for the EU commercial sector

The following section here presents a list of policy recommendations in view of encouraging further uptake of Energy Saving Opportunities (ESOs) and complementary measures to realise the energy saving potential of EU commercial sector.

Active monitoring and enforcement actions for Article 8, 14 and 15 of EPBD. The updates on Article 8 of EPBD on the definition of Technical Building Services is a positive step towards mainstreaming attention on building heating and air-conditioning services. Specific attention should be focussed on how Member States are defining, enforcing and monitoring the requirements of Article 8.1 and 8.9 in practice. This will have significant and immediate energy saving impact collectively for EU27.

Article 14.1 and 15.1 of EPBD has been updated to allow Member States to define the necessary measures to establish regular inspections of heating and air conditioning systems. Inspection should include recommissioning of existing Technical Building Systems. Recommissioning should be carried out when there is a change in the building use or environment (e.g. occupancy changes, reconfiguration of internal space, etc.) even though no changes has been made on the heating or air conditioning system.

Continue and increase effort in enabling and transitioning to NZEB and smart buildings in LTRS. The expansion of Article 8 of EPBD to include a scheme for rating of smart readiness in buildings is a significant step forward in enabling future buildings to integrate into the smart building ecosystem. Further dissemination of best practice in smart building design will support wider awareness and accelerate the uptake of smart solutions. Such support could include development of clear standards for smart buildings and relevant supporting criteria (e.g. minimum requirements standards for smart buildings and Building Technical System). At a minimum, standards should include the buildings' role in Demand Side Management, energy storage, distributed energy generation and integration with zero emission vehicle infrastructure.

Facilitate the wider exploitation of buildings energy performance data with a framework to manage data protection. The updated Article 14.4 and 15.4 of EPBD on requirements for Member State to lay down requirements for building automation system is another significant step forward. These requirements will generate a rich source of actual performance data which could be utilised for wider and deeper benchmarking of building energy performance. The application of digital analytics to improve building energy performance is a relatively new. Its ability to generate actual data (as opposed to modelled data) will help building owners/users to operate buildings more efficiently. Such data also provides a rich stream of insights which can not only be used by demand response aggregators, amongst others, but also fed into national databases and other research projects, enabling clearer and more accurate monitoring of large-scale energy performance, particularly from new technologies and construction methods. Further dissemination of best practices, or case studies of successful application, will help to stimulate its wider adoption. Nevertheless, a framework to manage appropriate data sharing and data security should be developed imminently to facilitate the data utilisation potential.

Linking of EED Article 8 with EPBD Article 8, 14 and 15. The expansion of Article 8, 14 and 15 in EPBD; which goes into significant details on Building Technical System, building automation and the transition framework to smart buildings; requires further link up with Article 8 of EED on energy audits and energy management system. Annex VI of EED could potentially be revised to layout clear details on the minimum audit requirements for Technical Building Services.

4.4 EU road transport sector final energy saving potential

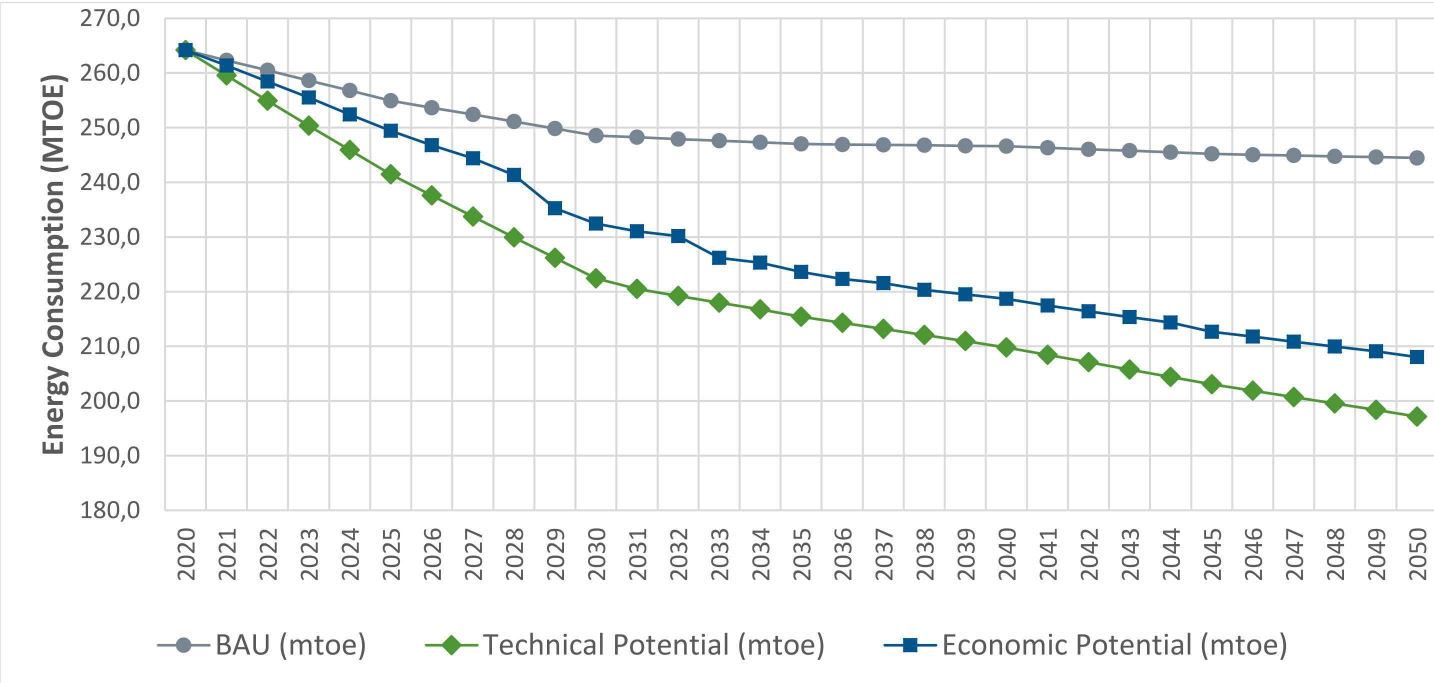
Figure 13 presents EU27 road transport sector technical and economic saving potential from 2020 – 2050. By 2030, EU27 road transport sector has a technical saving potential of 10.5%, reducing BAU final energy consumption by ~26 MTOE, and an economic saving potential of 6.5%, reducing BAU final energy consumption by ~16 MTOE.

ESOs for EU road transport sector were selected from literature review and limited assessment of the draft NECPs. This selection was based on the expected savings that can be achieved, but also on the feasibility to develop a sound methodology to estimate the savings potential for 2030. The key measures accounted under this assessment are increasing technical vehicle and tyre energy efficiency.

Other key measures were also identified, i.e. electrification of transport, modal shift to environmental friendlier modes and a measure related to driving behaviour (lower speed on motorways). However, this assessment has omitted these other measures for modal shifts, fuel switching[35] (e.g. electrification of road transport, switch to Zero Emission Vehicles) and non-technical[36] ESOs (e.g. motorway speed reduction), which has reduced the technical saving potential significantly.

Germany, France, Italy, Spain, Netherlands, Austria, Belgium, Sweden, Romania and Poland make up the top 10 Member State with the highest technical final energy saving potential, amounting to 83% of overall EU transport sector savings.

Figure 13. EU road transport sector final energy consumption technical and economic savings projection



The technical and economic final energy saving potential for the transport sector, broken down by end-use categories, is presented in Table 14. Private cars present the highest technical saving potential; however, ~60% of this potential are deemed uneconomical. Heavy goods vehicles and light duty vehicles presents a strong level of technical and economic saving potential. The technical and economic saving potential

[35] Modal shifts and fuel switching were omitted as the modelling process is unable to account for the impact of fuel switching.

[36] Non-technical measures have been excluded from the assessment due to insufficient cost estimates.

under public road transport are equal, as all related ESOs under this end-use category are deemed to be economical.

This assessment has quantified the energy saving potential for improvement of vehicle efficiency at different aggregated improvement levels. For each vehicle type, there are different aggregated level(s) of improvement defined:

- Passenger transport: Improved aggregated vehicle efficiency of 3%, 4% and 6%.
- Public transport: Improved aggregated vehicle efficiency of 3%
- Light duty vehicle: Improved aggregated vehicle efficiency of 3%, 4% and 6%
- Heavy goods vehicle: Improved aggregated vehicle efficiency of 15%, 20%, 25%, 30% and 32.35%.

The aggregated improvement levels defined above are based on the combination uptake of different dynamic sub-measures, as defined in Table 15. This combination of sub-measures make up the aggregated vehicle efficiency improvement level.

To avoid double counting (and overlaps) of energy saving, this assessment allocated these aggregated improvement levels at an equal distribution across the number of vehicles which will carry out these improvement levels. Taking Light Duty Vehicle for instance; 33% of vehicles will carry out improvement of aggregated vehicle efficiency at 3%, 33% at 4% aggregated improvement level and the remainder 33% at 6% aggregated improvement level.

The criteria for establishing the three target levels as above mentioned were based on a top down assessment to establish the level of ambition in setting target levels. The key criteria for setting the target levels is to meet overall climate goals set for the transport sector in the most cost-effective manner. This equates to a 54-67% reduction of emissions when compared to 1990 by 2050. A 54-67% reduction could be done by each transport mode (HGV, LCV, Private Cars) however this is will not be the most cost-effective pathway. Further detail of how these target levels have been set can be found within CE Delft 2017 report[37]. The targets were set following a consultation with DG CLIMA.

All improvement levels are quantified with reference to the baseline specification. For private cars, the baseline refers to the average energy efficiency (MJ/pkm) for passenger cars as defined in EU Reference Scenario 2016. For the CO2 standards for cars and vans, it is assumed, based on current reduction trends, that the 2020/21 CO2 targets for the fleet of new vehicles set out in the Regulation[38] are achieved and remain constant afterwards (for cars 95gCO2/km by 2021, for vans 147gCO2/km by 2020).

[37] CE Delft 2017 report: https://www.cedelft.eu/en/publications/download/2420

[38] Regulation (EU) 2019/631 setting CO2 emission performance standards for new passenger cars and for new vans in the EU.

Table 14. EU27 road transport sector 2030 final energy saving potential broken down by road transport end-use categories

Road Transport end-use category	Technical saving potential [KTOE]	Economic saving potential [KTOE]
Private cars	14,531	5,602
Heavy goods vehicles	6,517	6,029
Light Duty Vehicles	4,313	3,750
Public road transport	726	726

Technical recommendations for the EU road transport sector

The following here presents a list of key fundamental recommendations in support of effective implementation of key Energy Saving Opportunities (ESOs) with high collective energy saving impact within EU27 road transport sector based on the outputs of this assessment.

Improvement of vehicle efficiency. Vehicle efficiency improvement for passenger cars are possible through technical measures, such as improving aerodynamics, motor efficiency, light-weighting, etc. For Light Duty Vehicle and Heavy Goods Vehicle, the vehicle efficiency can be improved through a range of technical measures; mass reduction, auxiliary systems (LED lighting, AC efficiency, cooling fan), transmission efficiency and advanced driver assistance systems.

Table 15 presents a list of possible technical and operational sub-measures which make up the aggregated vehicle efficiency improvement level. In combination, these measures are expected to generate an aggregated energy saving levels as defined in the above section.

Table 15. Specific measures contributing to improvement of LDV and HGV aggregated efficiency improvement

Measure	Energy saving potential	End-user cost	Source
Low rolling resistance tyres	2-4%	no addinional costs	CE Delft (2014)
TPMS (tyre pressure management system)	0.5-2.5%	€450-€1000	CE Delft (2014)
Frequently aligning axes and wheels	0-4.5%	€ 700	CE Delft (2014)
Installing nets on top of open empty containers	3.5-5.5%	labor costs	CE Delft (2014)
Side-shields for trailers	2.7-6%	€ 3,250	CE Delft (2014)
Aerodynamic wheel covers	0.5-1.5%	€125 per axis	CE Delft (2014)
ICT: fuel management systems	1-8%	€ 3,500	CE Delft (2014)
Improved aerodynamics	Up to 3-5% of energy use	n/a	IEA (2018)
Lower rolling resistance tyres	10% to 30% reduction of rolling resistance and about 3-5% of total energy use	n/a	IEA (2018)
Reducing idling	Up to 2.5%	n/a	IEA (2018)
Route optimization	5%-10% intra-city, 1% long haul	n/a	IEA (2018)
High Capacity Vehicles (HCVs)	Up to 20%, primarily in long haul, risk of rebound	n/a	IEA (2018)

Driver training and feedback	3% to 10%	n/a	IEA (2018)
Platooning	5% to 15%	n/a	IEA (2018)
Last mile delivery optimization	5% to 10%, depends on degree of implementation	n/a	IEA (2018)
Supply chain collaboration/co-loading	Up to 15%	n/a	IEA (2018)
Matching cargo and vehicles via IT	5% to 10% in urban areas	n/a	IEA (2018)
Urban consolidation centres	20%-50% in urban centres (all measures combined, including vehicle techs)	n/a	IEA (2018)
Physical internet	Up to 20%	n/a	IEA (2018)

Policy recommendations for the EU transport sector

The following section here presents summary of policy recommendations in view of the level of ambition for energy saving potential for EU road transport vehicles with Internal Combustion Engines with reference to the various efficiency improvement levels.

Level of ambition for vehicle efficiency improvement targets of passenger vehicle and LDV. Under the BAU scenario, the target levels for passenger cars (95 g/km NEDC) and Vans (147 g/km NEDC) would continue beyond 2020/2021. This assessment established three scenarios (3%, 4% and 6% efficiency improvement for passenger cars and LDV) on annual reduction of the CO2-norms post 2021. However, the annual reduction needs to be corrected for the difference in type approval (TA) and real world (RW) emission reduction, with a difference of 48 g CO2/km[39] for passenger vehicles and 39.5g CO2/km for LDV. After this correction, the emission reductions are 16-28% for new passenger vehicles in 2030 (Table 16), and 19 – 34% for new LDV in 2030 (Table 17).

Table 16. Correction of Type Approval (TA) and Real World (RW) emission reduction for passenger vehicles

Efficiency improvement	baseline 2030 g CO2/km TA (NEDC)	2030 gCO2/km TA	baseline 2030 g CO2/km RW	2030 g CO2/km RW	%emission reduction RW
3% annual reduction	95	72	143	120	-16%
4% annual reduction	95	66	143	114	-20%
6% annual reduction	95	54	143	102	-28%

[39] CE Delft (2017)

Table 17. Correction of Type Approval (TA) and Real World (RW) emission reduction for LDV.

Efficiency improvement	baseline 2030 g CO2/km TA	2030 g CO2/km TA	baseline 2030 g CO2/km RW	2030 g CO2/km RW	%emission reduction
3% annual reduction	147	112	186.5	151	-19%
4% annual reduction	147	102	186.5	141	-24%
6% annual reduction	147	84	186.5	124	-34%

The maximum energy savings potential assessed[38] is higher than the proposed CO2-norm for passenger cars in 2030 by the European Parliament, which is a 37,5% reduction to the 95 g CO2/km norm in 2021. This would translate to 59 g/km in the NEDC.

For passenger vehicles, the 3% and 4% improvement levels suggested in this assessment is less ambitious, while the 6% improvement level reflects a more ambitious target.

For LDV, the 3% improvement level suggested in this assessment is less ambitious, while the 4% and 6% improvement level reflect a more ambitious target.

Level of ambition for vehicle efficiency improvement targets of HGV. Heavy Goods Vehicles (HGV) are not yet regulated for their CO2-emissions but there is a legislative proposal setting the first ever CO2-emission standards for HGV in the EU. The proposed targets for average CO2 emissions from new lorries are 15% lower than in 2019 for 2025 and at least 30 % lower in 2030 than in 2019.

The background studies that were made in support of the proposal for CO2-standards for HGV provide information about maximum energy savings potentials for trucks and related costs. TNO (2018) made an overview of all technologies available for increasing fuel efficiency of trucks. JRC (2018) used this information to develop cost curves, which were used as input in the PRIMES-TREMOVE model for impact assessment.

For HGV, BAU was assumed to be the 2016 average energy efficiency of HGV in the EU reference scenario. The vehicle efficiency improvement levels are defined at 15%, 20%, 25%, 30% and 32.35% reduction compared to this baseline. The CO2 standard for HGV in 2030 is are expressed as 30% reduction compared to the EU average in the period 1 July 2019 – 30 June 2020, a somewhat different baseline which makes the comparison a bit more difficult. Assuming that the average CO2-emissions of HGV did not change much between 2016 to date, the 32.35% level is quite close to the CO2-standards, whereas the other improvement levels (15, 20, 25%) are less ambitious.

Annex 1 Energy saving potential for Data Centres

Electricity consumed in data centres (including enterprise servers and storage, telecommunication equipment) accounts for a large proportion of electricity consumed in the EU commercial sector and continues to grow in both capacity and importance.

Real-time video streaming, online gaming and mobile devices are predicted to rise from 60% to 80% of data traffic by 2020[40]. By the same year, European energy consumption in data centres is predicted to be 103 TWh[41].

The data centre market has continued to expand at an unprecedented rate and operators in 2019 are consistently building three times the capacity as they did in 2016 to provide for large US-based cloud providers like Amazon, Google and Microsoft[42].

The largest data centre markets in Europe currently are Frankfurt, London, Amsterdam and Paris, collectively known as FLAP. FLAP markets are growing at 12% compound annual growth rate (CAGR), 4% higher than established markets[43].These cities are experiencing large data centre growth where policy has not developed at the same rate. As a result of this trend, in summer 2019 Amsterdam banned the establishment of any new data centres until 2020 while it awaits new regional policy[44]. Growth in London has slowed due to US providers making large purchases in 2018 and needing little in 2019.

Take-up of colocation capacity has continued to exceed previous figures. Colocation capacity across Europe has strongest growth in Frankfurt. Frankfurt has been fastest growing market in Europe. It added 44 MW of data centre capacity in the first half of 2019, a large part of a total 98 MW take-up in Europe, London, Amsterdam and Paris[6]. Data centre providers have diversified, meaning there are no longer few providers accounting for most growth.

US providers are set to continue to grow their operations in Europe. Google plans to spend €3bn expanding its European cloud-based operations over the next two years. It will open cloud-based services in Poland and to build further data centres in the Netherlands, Ireland and Belgium.[45]

In terms of regulation, the European Energy Performance of Buildings Directive (EPBD) mandates Member States to comply with cost-optimal minimum efficiency requirements for buildings.

The Ecodesign Directive covers servers and data storage products. New Ecodesign regulations for servers and online storage devices will be implemented in March 2020. Under these regulations, IT manufacturers will be required to declare their operating condition classes and thermal performance.

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[40] Bertoldi, P. A market transformation programme for improving energy efficiency in data centres. In Proceedings of the MELS: Taming the Beast, ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, USA, 17–22 August 2014

[41] Bertoldi, P.; Hirl, B.; Labanca, N. Energy Efficiency Status Report 2012. Electricity Consumption and Efficiency Trends in the EU-27. European Commission, Joint Research Centre 2012. Available online: http://publications.jrc.ec.europa.eu/repository/handle/JRC69638 [Accessed 23/10/2019]

[42] Europe lost for space as competition hots up. Mark Ballard, September 3rd 2019 https://www.datacenterdynamics.com/news/europe-lost-space-competition-hots/ [Accessed 25th October 2019]

[43] State of the European Data Centres Market, Eric Boonstra, Iron Mountain https://www.ironmountain.co.uk/resources/general-articles/s/state-of-the-european-data-center-market [Accessed 25/10/2019]

[44]More control over the establishment of data centers in Amsterdam and Haarlemmermeer https://www.amsterdam.nl/bestuur-organisatie/college/wethouder/marieke-doorninck/persberichten/regie-vestiging-datacenters-amsterdam/ [Accessed 25/10/2019]

[45] Google open Polish cloud region, September 27th 2019, Sebastian Mass https://www.datacenterdynamics.com/news/google-open-polish-cloud-region/ [Accessed 25th October 2019]

Energy Star certified equipment is available in Europe. Energy Star ratings apply to servers, their power supplies and they indicate that the equipment is best practice in energy efficiency.

A European Code of Conduct (CoC) for Data Centres was created in 2008. This is a voluntary code to promote best practice in the sector. There is no minimum efficiency requirement for the sector due to the wide variation in type of data centres and their type of ownership; e.g., owned, operated, colocation provider. The majority of data centres compliant with the Code of Conduct are in the UK[4].

There is an upward trend in use of free cooling in data centres. In a recent survey by Uptime Institute, 45% of respondents said they considered a small number of European customers to be deploying direct free air cooling and 63% of respondents considered a small number of European customers to be deploying indirect free cooling[46]. An average of 29% of respondents said that *most* of their European customers were deploying free cooling.

The most widely used metric for data centre energy performance is PUE (power usage effectiveness). The ideal PUE is 1. Average global PUE figures have been decreasing since 2006, when the global average was 2.5, and the European average is now 1.7[47]. In 2019 however, for the first time, they slightly increased from 1.58 to 1.67[48].

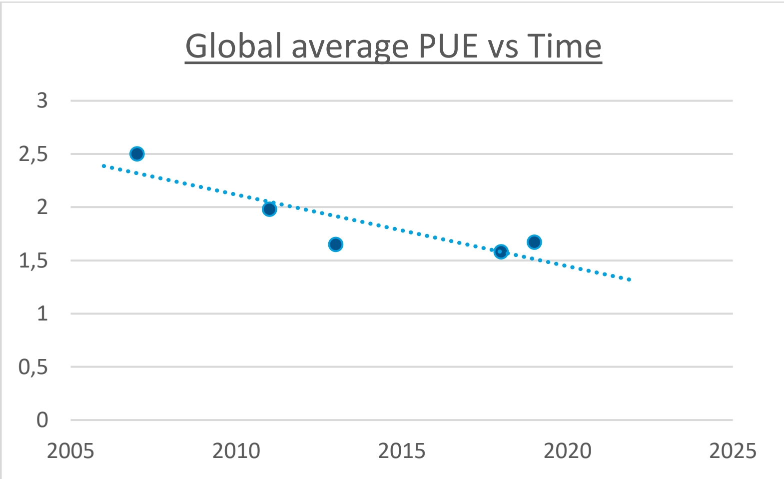

Figure A1.1 Global average PUE vs Time. Source: Uptime Institute

If no energy efficiency improvements occur, energy consumption is assumed to grow slightly slower than market growth; i.e., 3% per year through 2050. The slower growth of energy consumption compared to growth of markets reflects the growth in hyperscale cloud platforms for US providers like Google, who are achieving PUEs lower than average; i.e., 1.12[48].

The biggest infrastructure efficiency gains have already happened, and further improvements will require significant investment and effort, with increasingly diminishing returns[49].

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[46] Data Center Free Air Cooling Trends, Rabih Bashroush, Uptime Institute, September 2019 https://journal.uptimeinstitute.com/data-center-free-air-cooling-trends/

[47] The Current State of Data Center Energy Efficiency in Europe, Open Compute Project, August 16th 2018, https://www.opencompute.org/documents/the-current-state-of-data-center-energy-efficiency-in-europe-ocp-white-paper

[48] Is PUE actually going UP? May 2019 Andy Lawrence, Uptime Institute https://journal.uptimeinstitute.com/is-pue-actually-going-up/ [Accessed 23/0/2019]

[49] Uptime Institute, 2018 Global Data Center Survey quoted in 'Uptime's Data Center Survey Shows Increased Downtime and More Efficient Power User', Christine Hall, August 9th 2018,

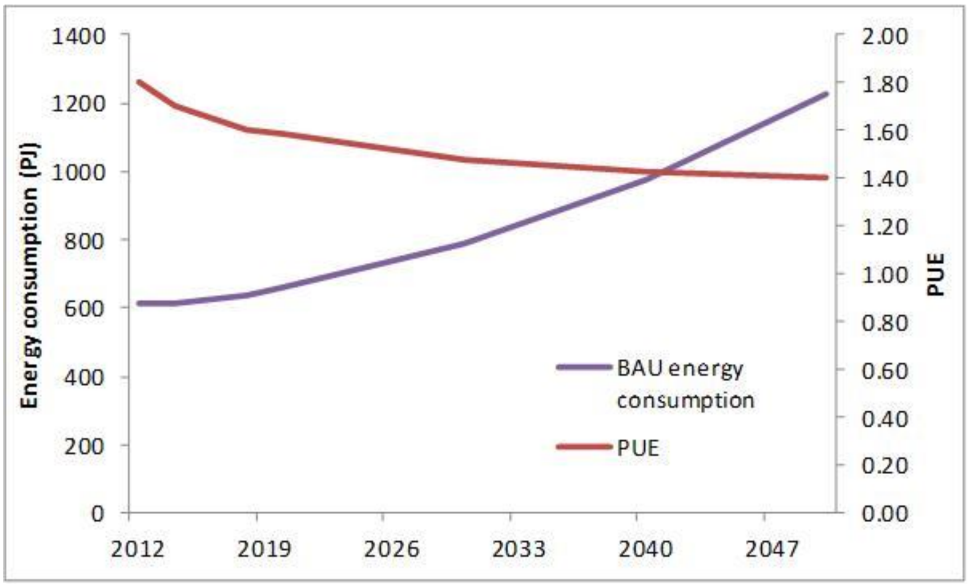
Table A1.2 presents estimated improvements in PUE through 2050. Between 2013 and 2018, PUE improved at an average rate of -0.8% per year. It is assumed that this rate of improvement will continue through 2030 and will halve between the years 2030 to 2050 (-0.4% per year).

These assumptions have been overlain to develop an estimate for business-as-usual (BAU) energy consumption through 2050 (Table A1.2;Figure A1.2), which reflects a continuation of current industry trends (without regulations).

Table A1.2 Energy consumption trend for the information and communications sector based on projected market energy consumption assuming a continuation of current industry PUE improvements through 2050.

	2020	2030	2040	2050
PUE (continuation of current market progress)	1.7	1.5	1.3	1.1
Energy consumption reflecting a continuation of PUE trends (PJ)	751	1009	1356	1823

Figure A1.2 Projected energy consumption and PUE trend for data centres



It is assumed that PUE in 2030 and 2050 is 1.5 and 1.1 respectively. The energy consumption for the sector is assumed to be 1009 PJ (24.1 Mtoe) in 2030, and 1823 PJ (43.5 Mtoe) in 2050.

Large energy savings in the market have already been made through cooling technologies. The emphasis now is on the IT itself and as it makes technological advancements, energy consumption will increase at a slower rate for this growing sector.

Technological advancements such as the change from hard disk drives to solid-state drives (flash memory) are expected to drive significant power and cost savings[50].

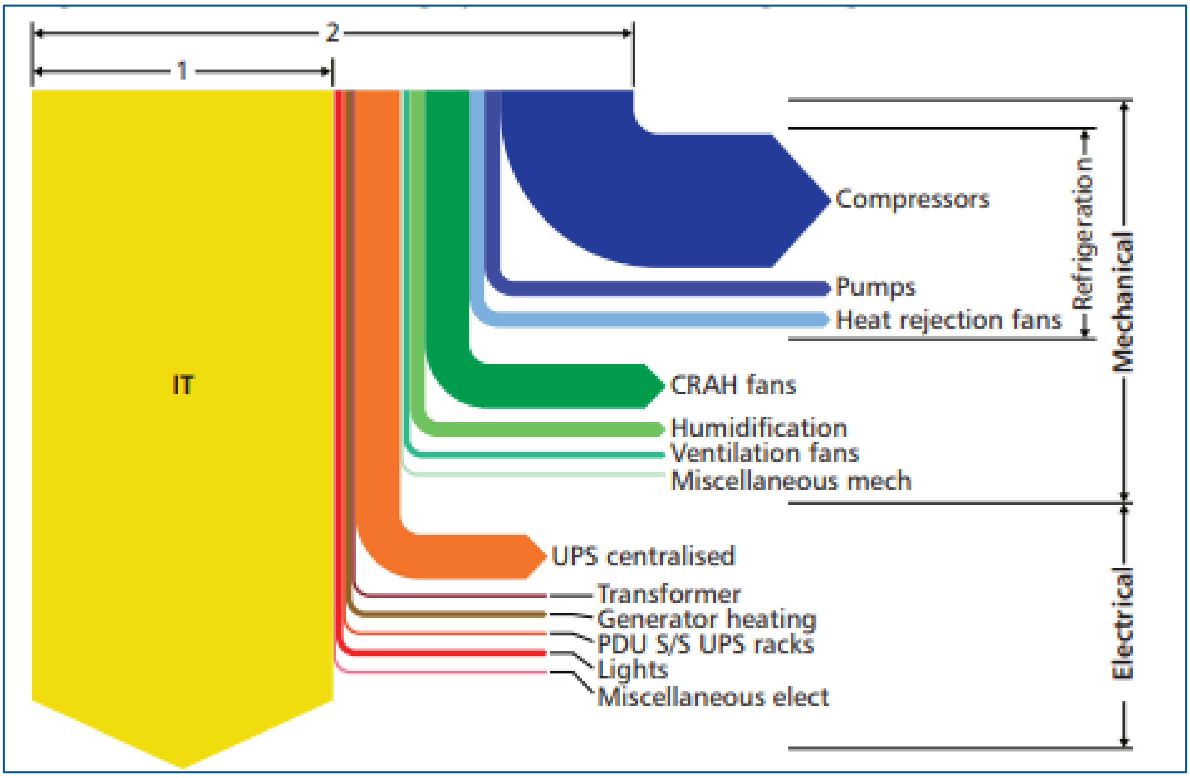
https://www.datacenterknowledge.com/uptime/uptimes-data-center-survey-shows-increased-downtime-and-more-efficient-power-use [Accessed 04/11/2019]

[50] Be aware of these 5 Data Center Trends in 2018, Bill Kleyman, Jan 17 2018 https://www.datacenterknowledge.com/manage/be-aware-these-5-data-center-trends-2018 [Accessed 05/11/2019)

A1.2 Energy usage profile

Figure A1.3 presents typical energy consumption in legacy data centres, with a PUE of 2. The numbers across the top of the diagram represents the PUE value, and the associated energy use composition. As noted, a large proportion of energy use in legacy data centres is associated with cooling.

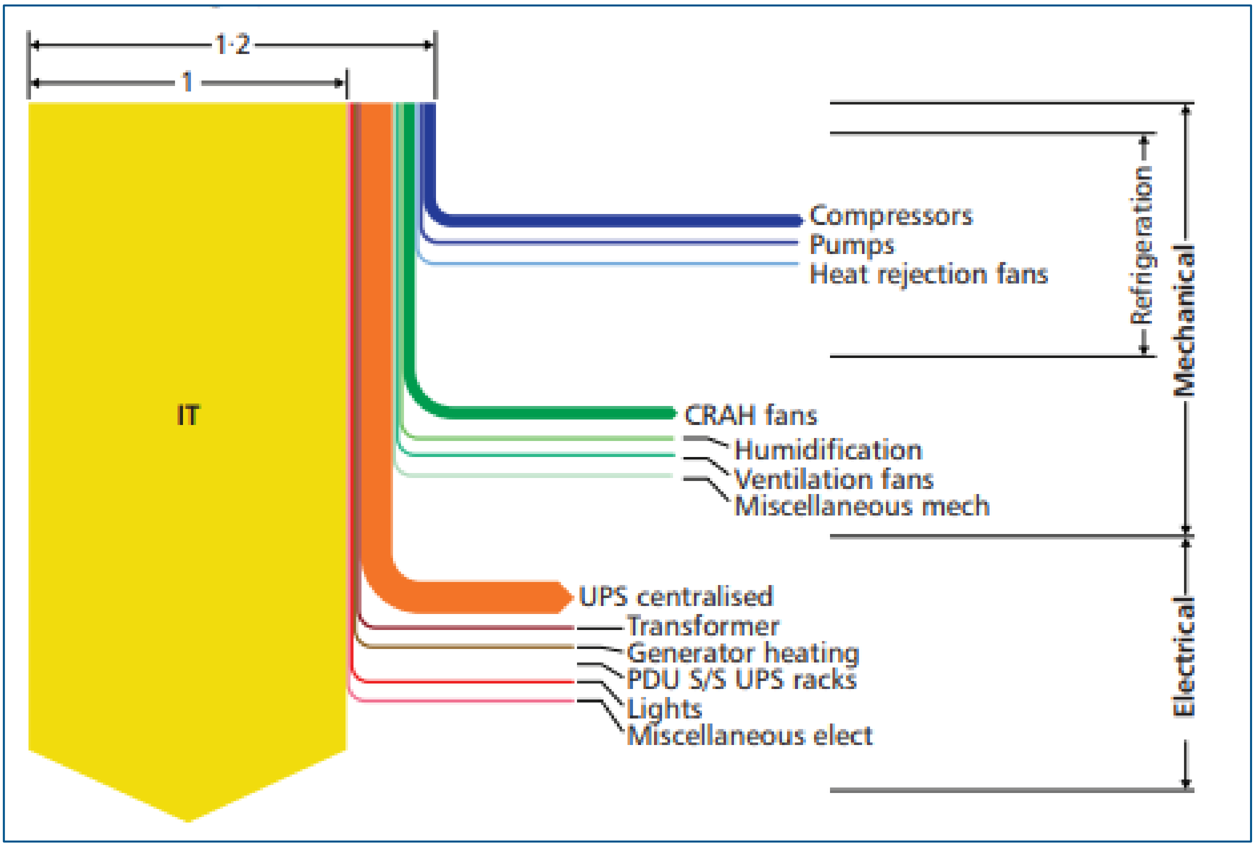
Figure A1.3 Typical Power Distribution, Legacy Data Centres[51]



[51] CIBSE KS18 Data centres: an introduction to concepts and design 2012. Available at cibse.org

Figure A1.4 shows that in new data centres (PUE = 1.2), the cooling load is largely reduced by minimising the need for compressors and adopting free cooling instead.

Figure A1.4 Typical Power Distribution, New Data Centres e.g. PUE 1.2



A1.3 Opportunities

Table A1.3[52] highlights some of the equipment and infrastructure approaches to improving energy efficiency in data centres.

Table A1.3 Energy efficiency improvement in data centres

Best Practices	Opportunities	Typical Investment[53]	Typical Cost Savings
Efficient Equipment	Adopt Minimum Energy Performance Requirements (EU Energy Star, Ecodesign or SPECPower)	€€€	For IT legacy equipment, savings could be between 30% to 50%
	Specify equipment equivalent to ASHRAE Class A2 (operable in higher temperature and humidity conditions)	€€€	Up to 4% of legacy costs per degree change

[52] ICF analysis

[53] High-level estimate (for 10,000ft^2 data centre): € = <€50,000, €€ = €50,000 to €500,000, €€€ = >€500,000

Best Practices	Opportunities	Typical Investment[53]	Typical Cost Savings
			Up to 50% of legacy costs for humidity adjustment[54]
Consolidate and Optimize	Use Virtualization to Consolidate and Optimize the exploitation of Physical Devices	€€€	63% reduction in total cost of ownership (i.e., financial impact over the product life cycle)[55]
	Implement Cloud Computing to shave peaks, by balancing data center workloads	€€	29% compared to an internal IT system[56]
Power Generation & Distribution	High Voltage DC (HVDC) to reduce to step down loss/conversion	€€€	Between 5% to 10% of facility power
	Install PV panels where cost-effective and maximize auto consumption of DC power, avoiding DC-AC-DC losses	€€	DC-AC-DC can involve 30-40% of losses (PV produce DC, converted to AC for the grid, then reconverted to DC for computing use
	Use efficient Uninterruptable Power Supplies (UPS) to match load to demand	€€€	Capital and operational savings of 20%
Heating & Cooling	Increase temperature ranges to decrease the workload on the HVAC systems	€	Up to 4% of legacy costs per degree change
	Increase humidity set points to decrease workload on humidification and cooling systems	€	Up to 50% of legacy costs[57]
	Hot/cool aisle thermal containment	€€	30% of legacy costs
	Replace air conditioners with air handlers and economizers	€€	Up to 50% of legacy costs

[54] http://advice.cio.com/michael_bullock/cool_ways_to_save_money_in_the_data_center?page=0%2C

[55] Storage Networking Industry Association (2008), *Building the Green Data Centre; Towards Best Practices and Technical Consideration*

[56] http://broadcast.rackspace.com/hosting_knowledge/whitepapers/Cloudonomics-The_Economics_of_Cloud_Computing.pdf

[57] http://advice.cio.com/michael_bullock/cool_ways_to_save_money_in_the_data_center?page=0%2C

Best Practices	Opportunities	Typical Investment[53]	Typical Cost Savings
	Variable speed fan drives	€€€	4 to 10 months return on investment (ROI)[58]
	Use free cooling	€€	
	Blanking Plates. Use empty but fully blanked cabinets (or solid doors) to prevent re-circulated air.	€	1-2% of energy savings per blanking plate[59]
	Zoned conditioned areas. E.g. tighter conditioning in zone with UPS.	€€€	Up to 4% of legacy costs per degree change Up to 50% of legacy costs for humidity adjustment[60]
Lighting	Advanced Lighting Technology	€€	Up to 70% of legacy lighting consumption depending on lighting technology
	Occupancy Control	€	Up to 80% of lighting load depending on occupancy
Waste heat recovery	Waste heat recovery through district heating or internal utilization.	€€€	>50% waste heat recovery from Data Centre. Payback period 4 years expected for a medium data centre with 1.97 PUE selling heat to district heat network[61]
	Liquid cooling server	€€	Up to 90% waste heat recovery from Data Centre.
	Upgrading of low-grade waste heat with high temperature heat pumps	€	Increasing low grade waste heat to ~140°C to expand the possible utilization of waste heat.

[58] SNIA (2008), *Building the Green Data Centre; Towards Best Practices and Technical Consideration*

[59] Properly Deployed Airflow Management Devices https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center/properly_deployed_airflow_management_devices [Accessed 04/11/2019]

[60] http://advice.cio.com/michael_bullock/cool_ways_to_save_money_in_the_data_center?page=0%2C

[61] Waste heat from data centers: An investment analysis. Matti Parssinen, et al., January 2019, Sustainable Cities and Society, Elsevier https://www.sciencedirect.com/science/article/pii/S2210670718314318 [Accessed 04/11/2019]

Best Practices	Opportunities	Typical Investment[53]	Typical Cost Savings
	Production of cooling energy	€€	Up to 90% savings in cooling energy required in Data Centres. Approximately

A1.4 Barriers

Varying ownership and management of data centres continues to be a challenge to its energy efficiency, Service level agreements for colocation data centres continue to restrict efforts to improve energy efficiency. Capital investment for retrofit measures is also a barrier.

Lack of knowledge of the operating conditions of different IT equipment often leads to design for the most stringent operating conditions and therefore higher energy demand for air conditioning.

Waste heat recovery for data centres presents a significant potential for remaining energy saving potential. However, implementation of waste heat recovery for data centres remain low due to the following critical barriers:

- **Application of low grade waste heat is limited**. Waste heat are recovered at low temperature (28 – 35°C) which narrows the possible application of waste heat. This typically limits the utilisation of waste heat to nearby greenhouses, swimming pools, and heating of buildings nearby.
- **Integration with heat network requires lots of planning**. Heat network facilities are essential to wider uptake of waste heat utilisation from Data Centres. If a heat network is unavailable, further planning and investment is required on the transportation of heat to nearby heat users. This process is commercially and technically complex as it involves multiple stakeholders committing to the overall scheme.**High investment and operation cost for waste heat recovery solutions**. Apart from heat transportation, other waste heat recovery solutions (e.g. liquid cooled IT system, upgrade of waste heat through heat pumps, etc.) requires significant investment with marginal returns.

A1.5 The Future

The largest improvements in PUE have already been made by addressing the greatest opportunity to reduce energy usage: cooling in data centres. Despite the expected slowing of energy efficiency improvements over the years, current trends do not explain why the average global PUE has increased slightly this year from the last. In the future, improvements to energy efficiency in data centres can be expected but at slower rates.

One of the opportunities to reduce cooling loads further is through the latest Ecodesign regulations, which could be adopted in March 2020, for servers and online storage devices. The impact of this is that IT manufacturers will have to declare the operating conditions of their equipment and this may increase utilisation of energy saving opportunities such as zoning of cooling to different temperatures. Technological advancements in IT equipment, e.g. upgrading hard disk drives to solid-state drives, are expected to reap energy savings by generating less heat and using less power.

Trends continue for large US providers such as Microsoft, Google and Amazon to buy data centre space in Europe. The roll-out of 5G networks around 2021 has the potential to increase energy costs but also send more data for the same amount of energy.

Annex 2 Energy saving potential for heat pumps (residential)

In the earlier version of this modelling assessment, energy savings through the application of heat pumps for residential sector was omitted. Annex 2 was developed as an addendum to Member State Annex Report, specifically to quantify the additional energy saving potential through application of heat pumps in residential sector. Table A2.1 presents the annual energy saving potential for heat pumps across EU27 Member States by 2030.

Table A2.1 Summary of additional energy saving potential through heat pumps for residential sector

Member State	Technical Potential Saving (by 2030) [kTOE/year]
Austria	274.69
Belgium	454.32
Bulgaria	43.22
Croatia	78.67
Cyprus	3.49
Czech Republic	354.32
Denmark	236.72
Estonia	38.69
Finland	232.49
France	1,079.64
Germany	2,380.84
Greece	76.86
Hungary	343.70
Ireland	134.17
Italy	753.74
Latvia	40.19
Lithuania	62.32
Luxembourg	31.70
Malta	0.42
Netherlands	374.65
Poland	1,258.50
Portugal	18.21
Romania	348.17
Slovakia	102.33
Slovenia	32.41
Spain	221.47
Sweden	237.96
Grand Total	**9,213.87**

Note:

1. The savings presented in this assessment accounts for a portion of fossil fuel boilers (baseline technology for space heating) to be replaced with heat pumps, i.e a portion of the baseline technology for space heating will be electrified through the application of heat pumps.

2. The energy savings for heat pumps account for the net benefit, i.e overall energy savings accounts for higher electrical consumption.

3. The technical energy saving potential presented here is in addition to the technical energy saving potential presented in the Member State Annex Report residential sector results, to account for the overall Member State technical energy saving potential including the implementation of high efficiency heat pumps.

4. The additional energy savings presented in Table A2.1 are not included in the accompanying 'Member State Annex Report', which presents the energy saving profile for the 27 Member States (plus UK).

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