Sensitivity analysis to Estonian electricity demand scenarios

Study

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Background

The previous 2022 study “Estonian electricity demand scenarios” determined Estonian electricity demand scenarios for household, services, industry and transportation sector up to 2050. The result was the creation of electricity demand scenarios providing yearly energy demand values and peak power values, the sensitivity analysis of different factors affecting electricity demand and creation of hourly load profiles. The electricity demand scenarios express yearly energy demand values and peak power values on different levels.

In 2023, it became apparent that the study 'Estonian Electricity Demand Scenarios' needs an update due to significant changes in the assumptions made back in 2020-2021. The Russian invasion of Ukraine has led to major difficulties and global disruptions in the energy market. As a response, the European Union's 'REPowerEU' strategy aims to accelerate and expand the transition to clean energy through dedicated funding. In Estonia, this funding is being directed towards preventing potential supply disruptions caused by the energy crisis associated with the war in Ukraine. This includes transitioning to new energy sources and making investments to ensure supply security, supported by the European Regional Development Fund and 'NextGenerationEU' funds. Currently, pilot projects are underway to explore the feasibility of substantially replacing natural gas and liquid fuel consumption with renewable energy sources in Estonia. Additionally, the adoption of heat pumps in district heating systems, which would contribute to reducing gas consumption, is under consideration in several regions. Furthermore, Estonia will introduce a car tax in 2025 aimed at reducing the negative environmental impact of transportation through taxation. In summary, the update of this study is necessary to obtain more accurate results and sensitivity analysis outcomes for various assumptions, which were not as thoroughly assessed in the previous study. The study updates the previous model's results on two levels:

- Level 1: end user demand without local generation. On this level local production (solar power generation) and vehicle to grid is not considered.

- Level 3: transmission network demand. This level also takes into account additional electricity generation from distribution networks, so large distinct solar farms and CHPs connected to the distribution network. Power generation in the transmission system network is not in the scope of this study. Level 3 does not include the transmission network losses.

The study is conducted in accordance with the contract No 1.1-4/2023/352. The Employer is Elering AS and contractor is Energex Energy Experts OÜ. **The object of the Contract is to complement the original Estonian electricity demand scenarios with additional sensitivity analysis. The aim of the sensitivity analysis is to assess the impact of faster electrification of the heating and transport sectors in 2030 on electricity consumption in Estonia.**

The contractors are grateful and would like to say thank you to Elering AS and to District Heating Network market participants for the valuable collaboration and contribution.

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Executive summary

Chapter 1. analyses the potential for electrification of heat consumed in local and district heating. Unlike the previous model, this model does not limit electrification to small district heating networks and natural gas consumption, but takes into account the total heat consumption of Estonia.

Chapter 1.1 summarises the results of the interviews with market participants. The chapter concludes with a list of nine barriers to electrification. The transition to electrifying district heating networks in Estonia is set to begin within the next decade, with a significant shift expected post-2025 as funding from the Estonian Environmental Investment Centre for biomass boiler installations ceases and existing biomass boilers approach the end of their efficient lifespan by 2040. Market participants anticipate increased collaboration with the Electrical System Operator and the Competition Authority, emphasizing the need for clear communication regarding future legislative perspectives, pricing models, electricity grid capacity, and environmental regulations.

Key challenges in implementing heat pumps include legislative hurdles and unpredictable input resource prices. The slow progression of electrification, with major investments planned for 2030-2035, reflect these complexities. Current heat production pricing principles present obstacles to adopting climate-neutral and storage technologies. The Competition Authority's pricing model, focused on natural gas prices and standardized consumption patterns, is misaligned with climate neutrality goals. This misalignment also extends to the regulatory uncertainty in the pricing and working hours of electric boilers and the unregulated pricing of waste heat.

Many Estonian heating networks already use renewable base loads, with long-term investments made in existing equipment, particularly biomass boilers. Consequently, a shift to heat pumps, if it occurs, will be gradual, respecting the utility of functioning equipment.

Electricity price volatility, seen as a risk due to limited heat storage options, necessitates investments in storage solutions, even at the expense of temporary consumer cost increases. Fixed pricing models are considered crucial by some heat producers for the successful electrification of heating networks.

Operational challenges for heat pumps arise from current heating schedules and the limited availability of free or excess thermal energy sources. While high-temperature solutions exist, their feasibility is constrained by their Technology Readiness Level or higher investment costs compared to available alternatives. This landscape portrays the complexities and gradual evolution of Estonia's journey towards electrifying its district heating networks.

Chapter 1.2 includes a summary of heat consumption and fuels used in different sectors. In total, 5.5 TWh of heat consumption is estimated for local heating and 5.4 TWh for district heating. The consumption of natural gas is not taken into account as it has already been electrified in the previous model. Since renewable and biofuel sources currently account for 68% of heat consumption, there is potential to electrify the remaining 32% that relies on fossil fuels. However, within this 68%, there are older biomass-operated devices, fireplaces, and stoves, which could also be subject to further electrification to some extent. Service and Industry sector has the highest fossil fuel consumption.

It is possible, at the national level, to regulate the reduction of fossil fuel consumption and pollution due ineffective heating methods, but restricting the use of natural gas boilers, biomass stoves and furnaces has not previously found support in Estonia. The cost of fuel has a profound and immediate impact on the behaviour of private consumers. If the price of biofuels increases more rapidly over time than the cost of electricity, the power grid will experience much quicker heat pump adoption for the base thermal load. Many rural buildings, located outside of district heating networks, are already equipped with heat pumps to maintain indoor warmth, and biofuels are reserved for use during peak load times, aligning with the overall electricity demand.

Chapter 1.3 gives an overview of the historical sales of heat pumps and forecasts their future growth in numbers and electricity consumption. The model does not take into account the electricity growth resulting from the diffusion of heat pumps, as the sales volumes of heat pumps and the associated electricity consumption growth are strongly correlated with the gross domestic product, on the basis of which a separate baseline consumption growth is calculated. The chapter analyses the competitiveness of heat pumps and concludes that, in the case of local heating, heat pumps are competitive in terms of base load generation. Results indicate that there are situations today for local heating where heat pumps are more cost-effective than heating furnaces or stoves and considering the recent growth trend in the sales of heat pumps, it can be safely assumed that the base electricity consumption model already assumes increase in electricity consumption due to heat pumps. For district heating, the uptake of heat pumps is limited as alternative fuels are currently cheaper.

Chapter 1.4 presents the assumptions and values of the updated model and presents sectoral electricity consumption growth. Based on fixed assumptions, prices, and production volumes, electricity is not yet competitive. However, the new ETS2 carbon price will apply to petrol, diesel and heating fuels such as natural gas whose climate warming emissions have continued to rise over the years despite attempts to decarbonise. The expected scenario envisions that half of the thermal energy demand for local and district heating is projected to be met through electrification by 2050 but district heating is using electricity for only peak and summer loads. The ambitious scenario expects district heating to electrify the base loads. The extreme scenario involves rapidly integrating electricity to ensure the whole heating system to handle both the base and peak loads.

Currently, electric boilers are the most suitable solution for district heating networks with a cogeneration plant that allows electric boilers to be operated when electricity production with steam turbine is not profitable and additionally allows electric boiler to produce heat without electricity network fees. Market participants believe that electrification is taking place more in larger district heating networks, where CAPEX costs are better distributed among many consumers. Based on this, it can be assumed that electrification of peak load and summer load (22% of the annual consumption) may already be an ongoing process, but a significant difference between the price of wood chips and electricity is needed for electrification of base load, and today's wood chip boilers are likely to be operated until 2040.

The projection shows that district heating, especially in service sector, is expected to constitute a larger share of the total electricity consumption compared to local heating. However, local heating sees more substantial contributions from the industry and household sectors. In 100% electrification, total electricity consumption reaches 4022 GWh by 2050, with household and service sectors leading the demand. The peak power demand exhibits a steep rise, with demand surging to 3578 MW by 2050.

Chapter 2. describes the electrification of the cooling energy. The projection of cooling capacity and electricity consumption in Estonia considers the impact of both current and new buildings. Future energy efficiency strategies in building design could significantly change energy consumption patterns. At present, the integration of local cooling capabilities in existing residential and commercial buildings remains unlikely. Similarly, new constructions currently lack cooling capabilities, though this may evolve in the future. A notable trend in building renovations is the potential integration of solar panels to meet energy efficiency standards. These panels can power cooling systems during peak demand, an approach known as solar cooling. Solar panels can offset the energy requirements of cooling systems, maintaining stable electricity consumption. Industry experts suggest that district cooling systems can reduce electricity consumption by 70%-85% compared to local devices. The service sector is expected to see a continued increase in cooling capacity, but a complete shift to district cooling is unlikely. Energy labels on buildings could drive more widespread adoption of district cooling, allowing for more energy use while maintaining energy efficiency.

The electrification of cooling estimates the possible increase in electricity consumption due to cooling solutions. However, the model's accuracy is limited by the lack of comprehensive data on cooling system installations in buildings. The challenge in the electricity consumption model lies in differentiating the increase due to cooling from overall growth attributed to the national economy. Therefore, cooling electricity consumption is not added to the electrification model, as base growth model reflects the expansion of district cooling and district heating networks and its correlation with GDP growth.

The model predicts the percentage of buildings with installed cooling systems, focusing on those with "A," "B," or "C" energy labels. It also considers buildings with solar panels, ensuring no additional grid electricity is needed for their cooling systems.

By 2050, cooling demand is expected to rise across all building types, with the service sector experiencing the most significant increase in peak power and energy demand. This sector's cooling demand may more than double from 2035 levels, far outstripping the growth in apartment buildings and single houses. The service sector might require around 477 MW_e of peak electric power, significantly more than apartment buildings (303 MW_e) and single houses (178 MW_e). The projected electricity consumption for services/commercial buildings, apartment buildings, and single houses by 2050 is approximately 584 GWh, 115 GWh, and 67 GWh, respectively.

It is recommended that the network operator supports the development of district cooling to avoid overloading the network with local cooling equipment. District cooling significantly reduces the electricity demand for cooling. This highlights the growing need for efficient cooling solutions, energy management strategies and district cooling regulations and policies in Estonia's building sector.

Chapter 3. describes the sales statistics and market volumes of vehicles and trucks in Estonia and Europe. Historical trends are used in the number of registered vehicles and the historical trends in the share of electric vehicles in other European countries with more developed electric vehicle markets to forecast the growth of electricity consumption. The results of the new model suggest that both the top-down and bottom-up approaches achieve a similar result, so the result of the old model are of the same order of magnitude and still relevant.

It has been observed that different European countries have followed a similar EV adoption increase rate, i.e., when the adoption of EVs starts to increase in a country, it tends to increase at a similar rate to other countries. Hence, the projections in this document take the historical increase in EV sales in more developed European EV markets as input. It is assumed that the sales of EVs shall increase in Estonia at a similar rate, but the sales increase is delayed for a number of years. The changes in the size of the entire fleet of vehicles has been projected based on Estonian historical vehicle registration statistics. That is, it is assumed that the levels of deregistration and registration of vehicles in certain age brackets remains similar, which results in the increase of the national fleet. The projected fleet of electric (EV) and internal combustion engine (ICE) cars and vans is shown on Figure 0.1, where an expected and a progressive scenario are proposed.

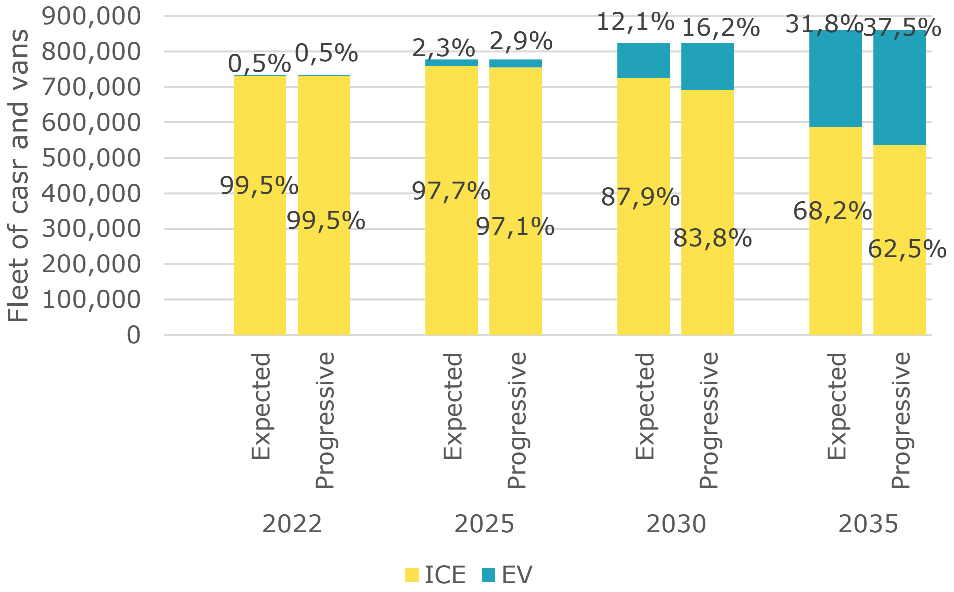


Figure 0.1. Cars and vans fleet projections

The number of all trucks was forecasted based on historical registration and deregistration data for trucks of certain age. The share of electric trucks in the fleet was predicted by utilizing proposed values on share of new electric trucks sold in the coming years proposed by a report by the International Council on Clean Transportation [1].

If the acceleration of road transport electrification continues, then in the coming years the electricity consumption from EVs shall be significant. Cars and vans shall contribute the majority of electricity consumption, as can be observed on Figure 0.2. Personal vehicles are a relatively energy intesive mode of travel.

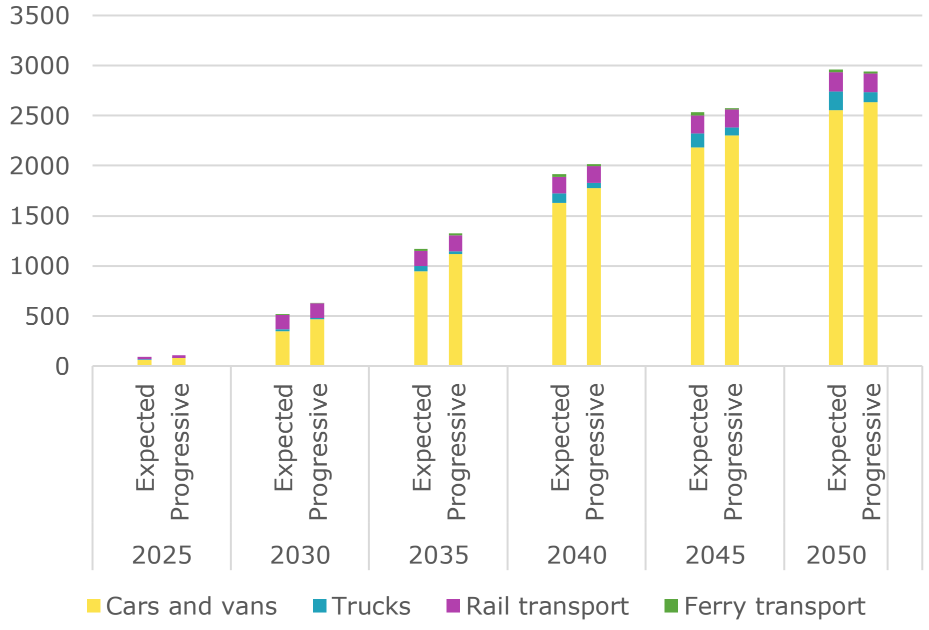


Figure 0.2. Electricity consumption in the transport sector

Chapter 4. presents solid results of the new model and comparisons with the old model. Different scenarios yield an expected (Scenario 11), ambitious (Scenario 13, 22, 23) and extreme (Scenario 24) electrification outcomes as some scenarios have marginal differences and fall within the same magnitude.

The expected scenario envisions a gradual adoption of electric vehicles in Estonia, aligning with historical trends observed in other European countries, culminating in the exclusive sale of zero-emission vehicles by 2035. The ambitious scenario, however, anticipates a swift transition, with Estonia quickly matching the EV uptake of leading European nations, aiming for 80% of new vehicle sales to be zero-emission by 2030 and reaching 100% by 2035. Essentially, the scenario represents a more accelerated path towards electrification of transport compared to the expected scenario.

Expected scenario envisions that half of the thermal energy demand for local and district heating is projected to be met through electrification by 2050 but district heating is using electricity only for peak and summer loads. Ambitious scenario expects district heating to electrify the base loads. Extreme scenario involves rapidly integrating electricity to ensure the whole heating system to handle both the base and peak loads.

The expected scenario, according to the authors, is one that proceeds with today's policies, whereas the ambitious scenario assumes that the country will seriously commit to climate neutrality policies and significantly reduce the consumption of fossil fuels. Extreme scenario is to establish an upper boundary for the possible growth of electricity consumption on average climatic year.

In summary, the average results of these scenarios are presented.

Consumption and peak load of the expected electrification model:

- Electricity consumption difference in 2035: 693 GWh, 303MW.
- Electricity consumption difference in 2050: 2285 GWh, 1,5 GW.
- Final consumption in 2035: 11 TWh, 2,2 GW.
- Final consumption in 2050: 16,8 TWh, 4,2 GW.
- Network Transmission demand in 2035: 9,3 TWh, 2,2 GW.
- Network Transmission demand in 2050: 13,3 TWh, 4,4 GW.

Consumption and peak load of the ambitious electrification model:

- Electricity consumption difference in 2035: 927 GWh, 404 MW.
- Electricity consumption difference in 2050: 2953 GWh, 2,1 GW.
- Final consumption in 2035: 11,2 TWh ja 2,2 GW.
- Final consumption in 2050: 17,5 TWh ja 4,8 GW.
- Network Transmission demand in 2035: 9,5 TWh ja 2 GW.
- Network Transmission demand in 2050: 14 TWh ja 4,5 GW.

Consumption and peak load of the extreme electrification model:

- Electricity consumption difference in 2035: 1271 GWh, 586 GW.
- Electricity consumption difference in 2050: 4500 GWh, 3,3 GW.
- Final consumption in 2035: 11,5 TWh, 2,5 GW.
- Final consumption in 2050: 19 TWh, 6 GW.
- Network Transmission demand in 2035: 9,9 TWh, 2,4 GW.
- Network Transmission demand in 2050: 15,6 TWh, 6,1 GW.

Figure 0.3 depicts annual electricity consumption trends in the electrification model.

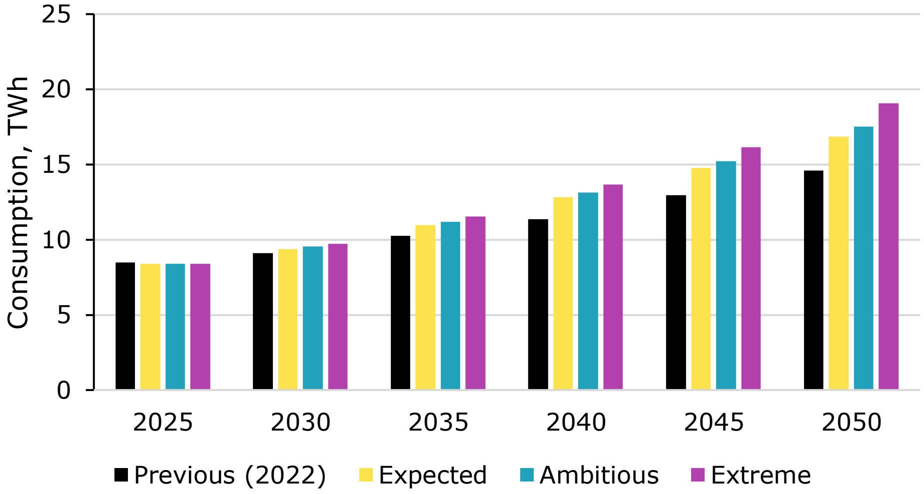


Figure 0.3. Annual Consumption in the Electrification Model

Figure 0.4 illustrates the peak electricity consumption in the electrification model over time.

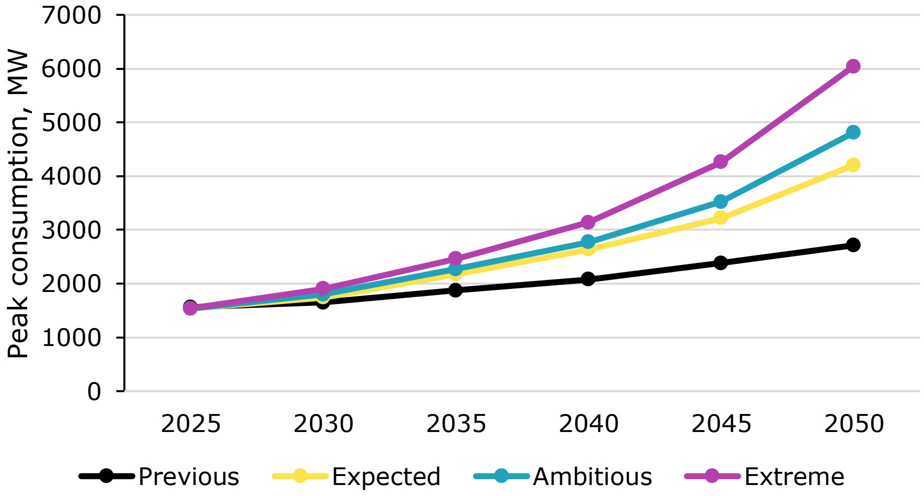


Figure 0.4. Peak Consumption in the Electrification Model Scenarios

Figure 0.5 the average annual consumption for a climatic year under the Ambitious Electrification Scenario, broken down by different consumption categories such as Loss, Buildings, Local heating, District heating, Natural gas, Transport, Generation, and Base.

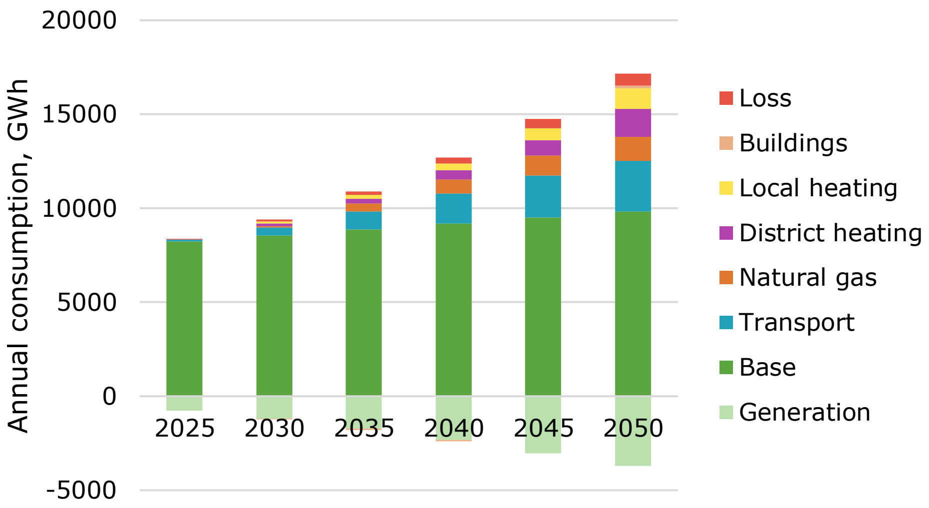


Figure 0.5. Average Climatic Year Consumption Under the Ambitious Electrification Scenario

Kokkuvõte

Peatükk 1. analüüsib lokaal- ja kaugkütte tarbitud soojuse elektrifitseerimise potentsiaali. Erinevalt eelmisest mudelist ei piira see mudel elektrifitseerimist väikeste kaugküttevõrkude ja gaasi kasutavate tootmisseadmetega, vaid arvestab kogu Eesti soojuse tarbimist.

Peatükk 1.1 annab kokkuvõtte turuosalistega tehtud intervjuudest. Üheksa elektrifitseerimist takistavat faktorit on loetletud peatüki kokkuvõttes. Eestis algab üleminek kaugküttevõrkude elektrifitseerimisele järgmise kümnendi jooksul. Märkimisväärset üleminekut oodatakse pärast 2025. aastat, sest siis lõpeb Eesti Keskkonnainvesteeringute Keskuse poolt biomassi katelde paigaldamise rahastamine ja 2040. aastaks lähenevad olemasolevad biomassi katlad oma efektiivse eluea lõpule. Turuosalised ootavad suuremat koostööd elektrisüsteemi halduri ja Konkurentsiametiga, rõhutades vajadust selge teabevahetuse järele seoses tulevaste seadusandlike perspektiivide, hinnakujundusmudelite, elektrivõrgu võimsuse ja keskkonnaalaste eeskirjadega.

Soojuspumpade kasutuselevõtu peamisteks takistusteks on seadusandlikud barjäärid ja sisendressursside hinnakõikumised. Elektrifitseerimine edeneb aeglaselt ning olulised investeeringud on kavandatud alles perioodiks 2030–2035. Kliimaneutraalsete ja energiasalvestustehnoloogiate kasutuselevõttu pärsivad Konkurentsiameti soojuse tootmise hinnastamispõhimõtted, mis pole kooskõlas kliimaneutraalsuse sihtidega. Probleemiks on ka elektrikatelde töötundide ja heitsoojuse hinnastamise regulatiivne ebakindlus.

Paljud Eesti kaugküttevõrgud on hiljuti teinud toetuste abil pikaajalisi investeeringuid biomassikateldesse, et toota soojuse baaskoormust taastuvenergiaga. Seetõttu toimub üleminek soojuspumpadele järkjärgult alles olemasolevate seadmete eluea lõpus.

Elektrifitseerimise suurimaks riskiks on elektrienergia hinna kõikumine. Selle riski maandamiseks on tarvis investeerida salvestustehnoloogiasse, mis tähendab, et tarbijate jaoks soojuse hind kasvab. Soojusetootjate hinnangul on kaugküttevõrkude elektrifitseerimise eelduseks võimalus pikaajaliselt fikseerida elektrienergia hind.

Soojuspumpade kasutamine on piiratud tarbijate küttegraafikute tõttu, mis eeldab kõrget temperatuuri ning soojuspumpadega kõrgete temperatuuride saavutamiseks ei ole piisavalt heitsoojust, mis seda efektiivselt võimaldaks. Kuigi on olemas kõrge temperatuuriga lahendused, piirab nende teostatavust nende tehnoloogiline valmidustase või kõrgemad investeerimiskulud võrreldes olemasolevate alternatiividega. Peatükk kirjeldab Eesti kaugküttevõrkude elektrifitseerimise keerukust ja järkjärgulist arengut.

Peatükk 1.2 sisaldab kokkuvõtet erinevate sektorite soojuse tarbimisest ja kasutatavatest kütustest. Kokku arvestatakse lokaalkütte puhul 5,5 TWh soojuse tarbimist ja kaugkütte puhul 5,4 TWh soojuse tarbimist. Arvesse ei võeta maagaasi tarbimist, kuna see on elektrifitseeritud juba eelmises mudelis. 68% tarbitud soojusest on toodetud biokütustest, mis tähendab, et on potentsiaal elektrifitseerida 32% soojuse tarbimisest, mis on toodetud fossiilsetest kütustest. 68% piires on täna kasutuses ka vanemaid biomassiga töötavaid seadmeid, mida eluea lõppedes võiks samuti elektrifitseerida. Teenindus- ja tööstussektoris on fossiilkütuste tarbimine kõige suurem.

Riiklikul tasandil on võimalik reguleerida fossiilkütuste tarbimist ja ebatõhusatest kütteviisidest tingitud saaste vähendamist, kuid maagaasikatelde, biomassi ahjude ja pliitide kasutamise piiramine ei ole seni Eestis toetust leidnud. Kõige enam mõjutab kütuse hind eratarbijate käitumist. Kui biokütuste hind tõuseb aja jooksul kiiremini kui elektrienergia hind, võetakse soojuspumbad elektrivõrgus palju kiiremini kasutusele põhilise soojuskoormuse tarbeks. Paljud väljaspool kaugküttevõrke asuvad maapiirkondade hooned on juba varustatud soojuspumpadega, et säilitada siseruumide soojust. Biokütused on reserveeritud kasutamiseks tippkoormuse ajal.

Peatükk 1.3 annab ülevaate soojuspumpade ajaloolisest müügimahust ning prognoosib nende tulevast arvulist ja elektrienergia tarbimise kasvu. Mudelis ei arvestata soojuspumpade kasutuse levikust tulenevat elektrienergia kasvu, kuna soojuspumpade müügimahud ja sellega kaasnev elektrienergia tarbimise kasv on tugevas seoses sisemajanduse koguproduktiga, mille põhjal arvutatakse eraldiseisev baastarbimise kasv. Peatükis analüüsitakse soojuspumpade konkurentsivõimet ning jõutakse järeldusele, et lokaalkütte korral on soojuspumbad konkurentsivõimelised baaskoormuse tootmisel. Analüüsi tulemused näitavad, et tänapäeval on lokaalkütte puhul olukordi, kus soojuspumbad on juba kuluefektiivsemad kui ahjud või küttekolded, ning arvestades soojuspumpade müügi hiljutist kasvutrendi, võib julgelt eeldada, et elektritarbimise baasmudelis on juba elektritarbimise suurenemine tänu soojuspumpadele. Kaugkütte puhul on soojuspumpade kasutuselevõtu levik piiratud, kuna alternatiivsed kütuseliigid on hetkel odavamad.

Peatükk 1.4 esitab uuendatud mudeli eeldused ja väärtused ning esitab sektoripõhilise elektrienergia tarbimise kasvu. Tänaste eelduste põhjal ei ole elekter kaugküttevõrgus veel hinna poolest konkurentsivõimeline. Muudatused Euroopa Liidu heitkogustega kauplemise süsteemis mõjutavad kõige enam fossiilseid kütuseid, mille kliimasoojenemisega seotud heitkogused on aastate jooksul jätkuvalt kasvanud. Seda hoolimata püüdlustest vähendada süsinikdioksiidi heitkoguseid. Eeldatav stsenaarium näeb ette, et pool lokaalsest ja kaugkütte tarbitavast soojusest elektrifitseeritakse 2050. aastaks, kuid kaugküttes kasutatakse elektrit ainult tipp- ja suvise koormuse puhul. Ambitsioonikas stsenaarium näeb ette, et kaugkütte baaskoormus elektrifitseeritakse. Äärmuslik stsenaarium hõlmab elektriliste lahenduste kiiret integreerimist, et elektrifitseerida nii baas- kui ka tippkoormus.

Elektrikatlad on hetkel kõige sobivamad koostöös koostootmisjaamaga. See võimaldab elektrikatlaid kasutada siis, kui elektritootmine auruturbiiniga ei ole kasumlik ning lisaks võimaldab elektrikatlal toota soojust ilma elektrivõrgu tasudeta. Turuosalised usuvad, et elektrifitseerimine toimub pigem suuremates kaugküttevõrkudes, kus kapitalikulud on paremini jaotatud paljude tarbijate vahel. Sellest lähtuvalt võib eeldada, et tippkoormuse ja suvise koormuse (22% aastasest tarbimisest) elektrifitseerimine võib olla juba käimasolev protsess, kuid baaskoormuse elektrifitseerimiseks on vaja olulist erinevust hakkpuidu ja elektri hinna vahel ning tänased hakkpuidukatlad töötavad tõenäoliselt kuni 2040. aastani.

Kaugkütte elektrifitseerimine avaldab kõige suuremat mõju teenindussektorile, mis panustab kõige mahukama tarbimisega. Lokaalkütte elektrifitseerimisel kasvab tööstus- ja kodumajapidamiste sektoris elektrienergia tarbimine. Täieliku elektrifitseerimise korral ulatub elektrienergia kogutarbimine 2050. aastaks 4022 GWh-ni, kusjuures juhtivad on kodumajapidamiste ja teenindussektori nõudlused. Elektrienergia tippnõudlus suureneb järsult, ulatudes 2050. aastaks 3578 MW-ni.

Peatükk 2. kirjeldab jahutusenergia elektrifitseerimist. Eesti jahutusvõimsuse ja elektritarbimise prognoosis on arvesse võetud nii praeguste kui ka uute hoonete mõju. Tulevasete hoonete projekteerimisel võivad energiatarbimise mustreid oluliselt muutuda. Praegu on lokaalsete jahutusvõimsuste integreerimine olemasolevatesse elamutesse ja ärihoonetesse endiselt ebatõenäoline. Samuti praegu puuduvad uutes ehitistes jahutusvõimalused, kuigi ka see võib tulevikus muutuda. Hoonete renoveerimisel on päikesepaneelidega võimalik saavutada nõutud energiatõhususe näitajad. Päikesepaneelid võivad tippnõudluse ajal ka jahutussüsteeme varustada, mida tuntakse kui päikesejahutus. Päikesepaneelid võivad kompenseerida jahutussüsteemide energiavajadust, tagades stabiilse elektritarbimise. Valdkonna eksperdid väidavad, et kaugjahutussüsteemid võivad vähendada elektritarbimist 70-85% võrreldes lokaalsete seadmetega. Teenindussektoris on oodata jahutusvõimsuste jätkuvat suurenemist, kuid täielik üleminek kaugjahutusele on ebatõenäoline. Hoonete energiamärgised võivad soodustada kaugjahutuse laialdasemat kasutuselevõttu. See võimaldab suuremat energiakasutust, säilitades samal ajal energiamärgisele vastava energiatõhususe.

Peatükis on ka hinnatud hoonete jahutuslahendustest tulenevat võimalikku elektritarbimise kasvu. Siiski piirab mudeli täpsust põhjalike statistiliste andmete puudumine hoonete jahutussüsteemide paigaldamise kohta. Elektritarbimise prognoosimise mudeli probleem seisneb selles, et jahutusest tingitud elektrienergia tarbimise suurenemist ei ole võimalik eristada üldisest majanduskasvust, mis on tingitud SKP-st. Seetõttu ei ole elektrifitseerimise mudelisse lisatud jahutusega seotud täiendavat elektritarbimist, kuna esialgne SKP-st tuletatud baas mudel võib juba kajastada kaugjahutuse- ja kaugküttevõrkude laienemist.

Jahutusenergia elektrifitseerimise mudel on koostatud eeldustega, et A-, B- või C-energiamärgisega hooned paigaldavad jahutussüsteemid. Ühtlasi on määratud eeldused, et osa päikesepaneelidega hooneid suudavad toita enda jahutussüsteeme selliselt, et jahutuseks ei ole vaja täiendavat võrguelektrit.

2050. aastaks suureneb eeldatavasti jahutusnõudlus kõigis hoonetüüpides, kusjuures teenindussektoris suureneb kõige rohkem jahutuse tippvõimsus ja -energiavajadus. Selle sektori jahutusnõudlus võib 2035. aasta tasemega võrreldes rohkem kui kahekordistuda, ületades märkimisväärselt korterelamute ja üksikelamute jahutusest tingitud elektrienergia tarvet. Teenindussektor võib tarbida elektrienergia tipptaset umbes 477 MW_e, mis on oluliselt rohkem kui korterelamute (303 MW_e) ja üksikelamute (178 MW_e) tarbimine. Prognoositav jahutusest tingitud elektritarbimine teeninduse, korterelamute ja üksikelamute puhul on 2050. aastaks vastavalt ligikaudu 584 GWh, 115 GWh ja 67 GWh.

Autorid soovitavad, et võrguoperaator toetaks kaugjahutuse arendamist, et vältida elektrivõrgu ülekoormamist lokaalsete jahutusseadmetega. Kaugjahutus vähendab oluliselt jahutusega seotud elektrienergia tarbimist. See näitab, et Eestis on üha suurem vajadus tõhusate jahutuslahenduste, energiamajandusstrateegiate ning kaugjahutuse eeskirjade ja poliitika järele.

Peatükk 3. kirjeldab Eesti ja Euroopa sõidukite ja veokite müügistatistikat ja turumahtu. Elektrienergia tarbimise kasvu prognoosimisel lähtutakse registreeritud sõidukite arvu muutumise ajaloolistest trendidest ning teiste arenenuma elektrisõidukite turuga Euroopa riikide ajaloolisest elektrisõidukite osakaalude trendidest. Uue mudeli tulemuste järgi võib väita, et nii *top-down* kui ka *bottom-up* lähenemisega saavutatakse sarnane tulemus, seega vana mudeli tulemus on samas suurusjärgus ja jätkuvalt asjakohane.

Täheldatud on, et erinevates Euroopa riikides on elektrisõidukite müügi osakaal kasvanud sarnasel kiirusel, st kui elektrisõidukite kasutuselevõtt riigis suureneb, siis kasvukiirus on seni olnud Euroopa riikides sarnane. Seega on käesolevas dokumendis esitatud elektrisõidukite prognoosides võetud aluseks arenenumate elektrisõidukite turgude ajalooline elektrisõidukite müügi kasv. Eeldatakse, et elektriautode müük kasvab Eestis samasuguse kiirusega, kuid müügi kasv algab teatud viivitusega. Kogu sõidukipargi muutusi on prognoositud Eesti ajaloolise sõidukite registreerimisstatistika põhjal, st eeldatakse, et teatud vanuseklasside sõidukite registrist kustutamise ja registreerimise tase jääb sarnaseks. Selle tulemusel jätkab riigi sõidukipark kasvamist.

Registreeritud veoautode hulga muutumist prognoositi veoautode varasemate registreerimis- ja registrist kustutamisandmete põhjal. Elektriveokite osakaal sõidukipargis prognoositi International Council on Clean Transportation aruandes [1] pakutud stsenaariumite põhjal.

Kui maanteetranspordi elektrifitseerimine jätkuvalt kiireneb, siis on elektriautode elektritarbimine lähiaastatel märkimisväärne. Joonisel 0.2 on näha, et sõiduautod ja kaubikud moodustavad suurema osa elektritarbimisest, kuna isiklik sõiduk on suhteliselt energiamahukas liikumisviis.

Peatükk 4. esitab uue mudeli tulemused ja võrdleb neid vana mudeliga (2022). Erinevad stsenaariumid annavad oodatava (stsenaarium 11), ambitsioonika (stsenaarium 13, 22, 23) ja äärmusliku (stsenaarium 24) elektrifitseerimise tulemuse. Ambitsioonikas stsenaarium on mitme stsenaariumi keskmine, sest nende stsenaariumite tulemused jäid samasse suurusjärku.

Eeldatav stsenaarium näeb ette elektrisõidukite järkjärgulist kasutuselevõttu Eestis, mis on kooskõlas teistes Euroopa riikides täheldatud ajalooliste suundumustega ja kulmineerub ainult nullilähedaste sõidukite müügiga 2035. aastaks. Ambitsioonikas stsenaarium näeb ette kiiret elektrifitseerimist, mille puhul Eesti jõuab kiiresti Euroopa juhtivate riikide elektriautode kasutuselevõtu tasemele, seades eesmärgiks, et 2030. aastaks on 80% uute sõidukite müügist nullilähedane. Aastaks 2035 saavutatakse 100%. Sisuliselt kujutab see stsenaarium endast eeldatava stsenaariumiga võrreldes kiiremat teed transpordi elektrifitseerimise suunas.

Eeldatav stsenaarium näeb ette, et pool lokaalkütte ja kaugkütte tarbitud soojusest elektrifitseeritakse 2050. aastaks. Kaugkütte puhul kasutatakse elektrienergiat ainult tipp- ja suvise koormuse jaoks. Ambitsioonikas stsenaarium eeldab, et elektrifitseeritakse ka kaugkütte baaskoormus. Äärmuslik stsenaarium hõlmab elektrienergia kiiret integreerimist ja elektrifitseeritakse nii baas- kui ka tippkoormus.

Autorite hinnangul saavutatakse oodatav stsenaarium juba tänase poliitikaga, samas kui ambitsioonikas stsenaarium eeldab, et riik pühendub tõsiselt kliimaneutraalsuse poliitikale ja vähendab oluliselt fossiilkütuste tarbimist. Ekstreemne stsenaariumi mõte on tuvastada elektritarbimise võimaliku kasvu ülemine piir.

Kokkuvõttes esitatakse nende stsenaariumide keskmised tulemused.

Eeldatava elektrifitseerimismudeli tarbimine ja tippkoormus:

- Aasta 2035 elektrienergia tarbimise vahe: 693 GWh, 303MW.
- Aasta 2050 elektrienergia tarbimise vahe: 2285 GWh, 1,5 GW.
- Aasta 2035 lõpptarbimine: 11 TWh, 2,2 GW.
- Aasta 2050 lõpptarbimine: 16,8 TWh, 4,2 GW.
- Ülekandevõrgu nõudlus aastal 2035: 9,3 TWh, 2,2 GW.
- Ülekandevõrgu nõudlus aastal 2050: 13,3 TWh, 4,4 GW.

Ambitsioonika elektrifitseerimismudeli tarbimine ja tippkoormus:

- Aasta 2035 elektrienergia tarbimise vahe: 927 GWh, 404 MW.
- Aasta 2050 elektrienergia tarbimine vahe: 2953 GWh, 2,1 GW.
- Aasta 2035 lõpptarbimine: 11,2 TWh ja 2,2 GW.
- Aasta 2050 lõpptarbimine: 17,5 TWh ja 4,8 GW.
- Ülekandevõrgu nõudlus aastal 2035: 9,5 TWh ja 2 GW.
- Ülekandevõrgu nõudlus aastal 2050: 14 TWh ja 4,5 GW.

Tarbimine ja tippkoormus äärmuslikus elektrifitseerimismudelis:

- Aasta 2035 elektrienergia tarbimise vahe: 1271 GWh, 586 GW.
- Aasta 2050 elektrienergia tarbimise vahe: 4500 GWh, 3,3 GW.

- Aasta 2035 lõpptarbimine: 11,5 TWh, 2,5 GW.
- Aasta 2050 lõpptarbimine: 19 TWh, 6 GW.
- Ülekandevõrgu nõudlus aastal 2035: 9,9 TWh, 2,4 GW.
- Ülekandevõrgu nõudlus aastal 2050: 15,6 TWh, 6,1 GW.

Joonis 0.3 kujutab elektritarbimise aastaseid trende elektrifitseerimise mudelis.

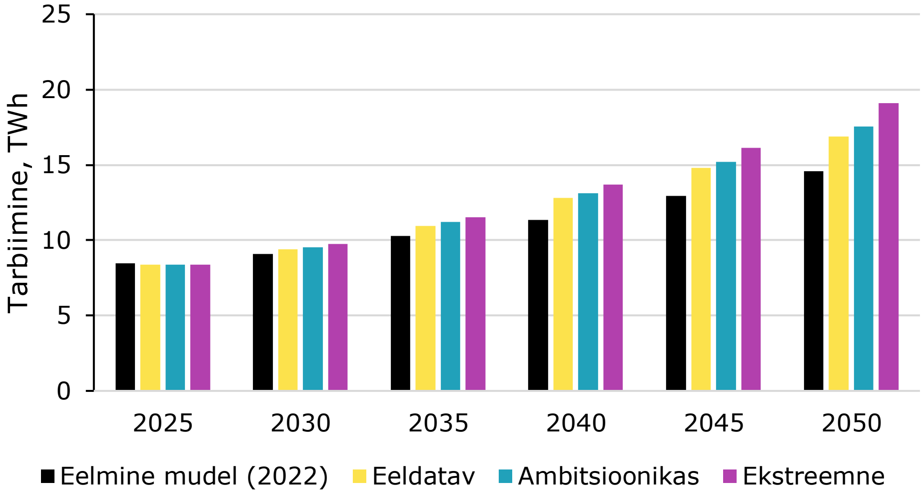


Figure 0.3. Annual Consumption in the Electrification Model

Joonis 0.4 illustreerib elektrifitseerimise mudeli tipptarbimist aja jooksul.

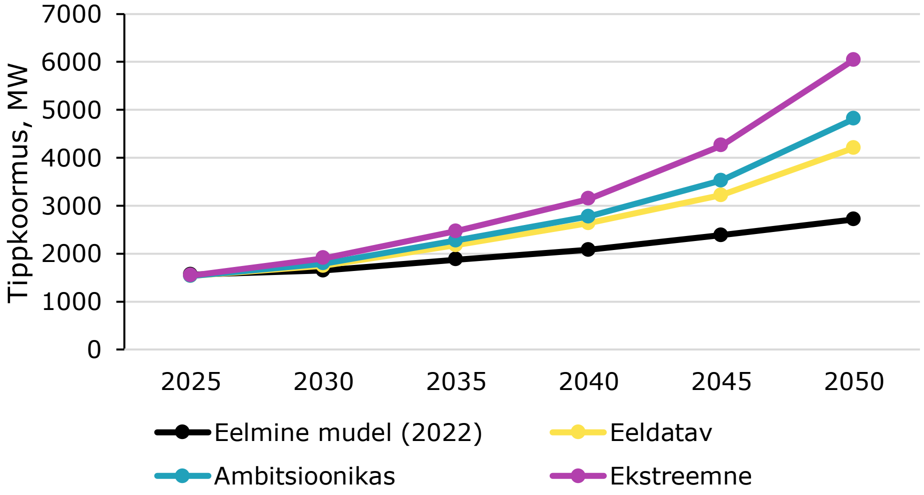


Figure 0.4. Peak Consumption in the Electrification Model Scenarios

Joonis 0.5 näitab keskmist aastast tarbimist kliima-aastal ambitsioonika elektrifitseerimise stsenaariumi all, jaotatuna erinevate tarbimiskategooriate vahel nagu kadu, hooned, kohalik küte, kaugküte, maagaas, transport, tootmine ja baas.

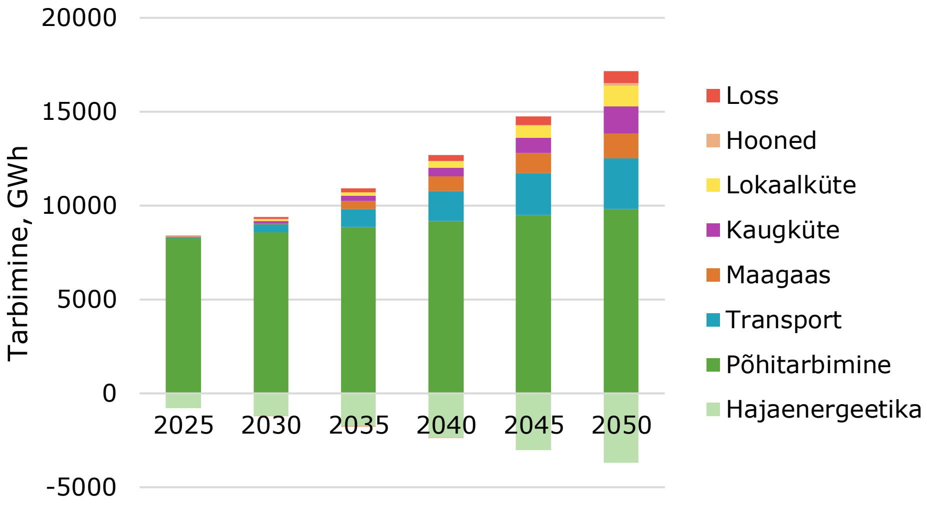


Figure 0.5. Average Climatic Year Consumption Under the Ambitious Electrification Scenario

1. Electrification of thermal energy

The previous “Estonian electricity demand scenarios” study’s model evaluated the electrification of rural areas with district heating networks, with the data derived from a study focused on the use of heat pumps in rural district heating networks in Estonia. The previous model evaluated the electrification of rural areas with district heating networks, with the data derived from a study focused on the use of heat pumps in rural district heating networks in Estonia. 16 GWh was chosen as the threshold as all networks with consumptions under this level can be considered as rural. Only rural areas were considered because heat pump integration is especially important in these areas. Therefore, the total of 498,5 GWh of heat consumed annually was modelled to be electrified. It was expected that rural district heating networks will be shut down or electrified due to demographic movement to bigger cities which causes higher renovation costs and heat production prices within rural district heating networks. Both base and high electrification scenario models expect all under 16 GWh district heating networks to be converted to other methods by 2050. Over 50 GWh district heating networks were not included in the electricity demand model.

The updated model addresses significant changes, notably the impact of the Russian invasion of Ukraine on the global energy market and the subsequent European Union's 'REPowerEU' strategy. It focuses on Estonia's transition to new energy sources, exploring more ambitious and faster implementation of renewable alternatives and district heating innovations, backed by European Regional Development Fund and 'NextGenerationEU' funds.

The authors agreed that the electrification of district heating networks will begin in the next ten years because Estonian Environmental Investment Centre is funding biomass boiler installations for district heating companies. It is expected that the funding will stop after 2025 and the most of previously built biomass boilers will reach the end of their efficient lifespan by 2040.

1.1 Market participants

The current study included conducting interviews with major heat producers. Interviews were conducted with the following companies: Utilitas Tallinn, Danpower Eesti, SW Energia, Eesti Jõujaamade ja Kaugkütte Ühing (Estonian Association of Power Plants and District Heating).

Main topics of the interview in detail:

- To what extent is there a plan to electrify heat production (specifically, burning natural gas and biomass) with heat pumps and electric boilers in the near future?
- What volume of thermal storage facilities is planned to be constructed, including those with electric heating elements?
- When and for what load purpose would electricity be used (peak or base load)?
- What preconditions need to be met for the electrification of the district heating network?
- When could district heating potentially transition from biomass to electricity?

Market participants view on electrification of heat networks

The electrification process is in progress, but it's advancing gradually, with initial targets set for 2030-2035. Whether heat pumps can be used for base load or other purposes depends on the specific district heating network. However, currently, district heating networks are not swiftly transitioning to heat pumps for base load in the next 5-10 years. This is because investments are typically made when existing fossil fuel boilers reach the end of their operational lifespan. At that point, network providers must decide whether to reinvest in a boiler or transition toward electrification.

Heat producers have varying perspectives on the adoption of storage solutions, and specific quantities remain undisclosed. The implementation speed of concrete solutions is significantly influenced by input resource prices. When resource prices, such as biomass and gas, reached their peak, producers began to contemplate and implement heat pump solutions more rapidly. Load-frequency reserve market could potentially speed up the implementation process. While the energy companies attempted to implement electric solutions, it was not always possible to connect to the electric grid, due to the lack of available capacity.

When the natural gas prices were low, it was challenging for the heat providers to make innovative investments. Under the current principles of calculating heat production prices, market participants find it challenging to implement climate-neutral and storage technology solutions. This is because any solutions that even slightly increase heat prices are discouraged by the Competition Authority. Market participants' primary criticism is that the Competition Authority's comparison of various heat production solutions to natural gas prices does not align with climate neutrality goals and may no longer be relevant or feasible in the future.

Possibilities: areas where heat pumps could be considered at faster pace

Currently, there are many small non-renewable boilers in smaller district heating networks. Boilers with a capacity of about 1 MW are problematic because wood chip solutions are too expensive, pellet has volatile pricing, and the best renewable alternative is not known. Heat pumps could be used to cover the base load if it utilizes waste heat to produce thermal energy. Boreholes cannot be ruled out, but it requires more experiments and case studies. However, most of the existing district heating systems operate with supply temperature above 80–100 °C which hinders the use of heat pumps.

District networks could consider employing heat pumps as a summer base load when the networks are primarily used for heating domestic hot water. During this period the consumption patterns are predictable and utilizing boilers on low loads is not efficient, thus using heat pumps together with storage solutions increases the networks overall efficiency. Also, Load-frequency reserve market could provide an alternative solution for peak loads. However, as minimum bidding starts at 1 MWe, it could reduce the potential application in the smaller networks. Due to lower annual consumption the investment cost is allocated to fewer consumers, as some consumers have local electric solutions for heating water. Thus, the investment would increase the thermal energy price more than it would in a higher consumption network.

District heating companies are also exploring innovative solutions like using sea water or wastewater as heat source. For wastewater there are existing technical solutions, and the project timelines are shorter. Projects utilizing seawater are technically more difficult and need innovation in technical aspects and the project must be coordinated with several authorities thus the project timelines will be longer, the market participants expect solutions to be implemented around 2030. Because in Estonia there are only few examples of using heat pumps in district heating networks, the market participants have a wait and see approach.

Conclusion

The market participants expect greater collaboration with the Electrical System operator and with the Competition Authority. Clear communication about the future perspectives of legislation, pricing models and electricity grid capacity, environmental regulations is needed.

The main factors hindering the implementation of heat pumps are described. Some of these factors need legislative changes and can be resolved with communication with the Competition Authority, while others like input resource prices are difficult to predict and regulate. The main consensus among the heat providers is that the electrification process is underway, but it is progressing slowly, with the first large-scale investments set for 2030-2035.

Hindering factors of the electrification of heating networks in Estonia

1. Regulatory issues regarding heat pricing

Under the current principles of calculating heat production prices, market participants find it challenging to implement climate-neutral and storage technology solutions. This is because any solutions that even slightly increase heat prices are discouraged by the Competition Authority. Market participants' primary criticism is that the Competition Authority's comparison of various heat production solutions to natural gas prices does not align with climate neutrality goals and may no longer be relevant or feasible in the future. Another pricing issue is that the Competition Authority assumes standardized consumption patterns, including specific working hours. Predicting working hours for electric boilers is complex and falls into a regulatory grey area. It should ideally remain the entrepreneur's risk, although the revenue they generate also carries risks. Additionally, the pricing of waste heat is not regulated by the Competition Authority.

2. The heat producers have invested into other technologies

Many heating networks in Estonia already have access to reasonably priced renewable base loads. Producers have made long-term investments, so even if they decide to transition to heat pumps in the future, the change will occur gradually. There's no compelling reason to cease using functional equipment, particularly in the case of biomass boilers.

3. Electricity price volatility

Heat providers view electricity price volatility as a risk because of the limited heat storage options available. Investments that may temporarily increase costs for consumers are necessary to develop storage solutions. Some heat producers consider fixed prices as essential for the electrification of the heating network.

4. Resource prices

A primary concern raised by heat producers is the cost of input resources, particularly the price of wood chips, which significantly influences investment decisions. If existing solutions like biomass boilers and natural gas remain competitive, producers are reluctant to switch to new technologies.

5. Temperature limitations

The current heating schedules pose challenges for heat pumps, specifically regarding the availability of free or excess thermal energy sources that a heat pump can utilize. Complications arise when temperatures drop to -10 degrees Celsius, making the use of air-source heat pumps economically challenging due to their reduced efficiency. District heating networks vary, and while some have access to heat sources such as wastewater, seawater, or geothermal energy, it's not universally feasible across all networks.

6. Lowering the heat networks temperature is not possible in some of the networks

In Estonia, numerous district heating networks operate without heat exchangers (open networks). This situation implies that reducing the temperature in these networks could result in insufficient heating for consumers at the far end of the network. This issue is mainly a concern in smaller district heating areas, where heat producers estimate that roughly half of the consumers are directly connected to the network. Overhauling these networks is expensive, and consumers are often reluctant to invest in more efficient solutions. Also, to lower the heating temperatures in addition to heat exchangers new radiators are also needed, but consumers are reluctant to make changes.

7. Heat pumps cannot provide high enough temperature

There are existing solutions for achieving high temperatures, but for certain technologies, it's not currently feasible due to their Technology Readiness Level (TRL), or the investment costs are significantly higher when compared to available alternatives.

8. The heat storage possibilities are limited

Heat consumption patterns are dependent on weather conditions. It is difficult to time heat production and consumption according to the electricity prices and participate in the regulatory market, heat is produced when it is need. Heat storage typically involves large water tanks, which complicates the implementation of storage solutions on a large scale in district heating networks where abundant space for storage solutions is non-existant.

9. Expanding the electric grid may be slow

Transitioning to heat pump systems isn't always a swift process, mainly due to electric grid restrictions caused by the limited available grid capacity.

1.2 Heating in Estonia

1.2.1 CHP and District Heating producers

Statistics Estonia provides fuel consumption by electricity, heat and combined heat and power (CHP) producers. The annual fuel consumption of CHP producers is at 6658 GWh (Figure 1.1), while heat producers alone consume 2714 GWh annually (Figure 1.2). When combined, the total annual fuel consumption of CHP and heat producers reaches 9372 GWh (Figure 1.3). In the context of climate neutrality plans, district heating network operators have the potential to replace natural gas consumption, oil shale and coke oven consumption and other non-renewable fuels with biofuels or electricity. The consumption of oil shale and oil sands fuels is predominantly concentrated in Ida-Virumaa County, with the Iru waste incineration unit contributing to municipal waste consumption.

According to Statistics Estonia, the annual normalized district heating network heat output is 6451 GWh. District heating network losses in the district heating network must be subtracted to calculate thermal energy consumption. The additional energy consumption caused by network losses has not been accounted for in the electrification of consumer consumption, as these losses are borne by the producer. The Competition Authority has mandated a 0.5% reduction in district heating network losses every two years, aiming for a total reduction of 11.5% by 2031. Additionally, the introduction of local devices is anticipated to further decrease network losses in smaller district heating systems.

Subsequent sections will delve into household, services, and industry sector fuel consumption, as well as district heating network thermal energy consumption.

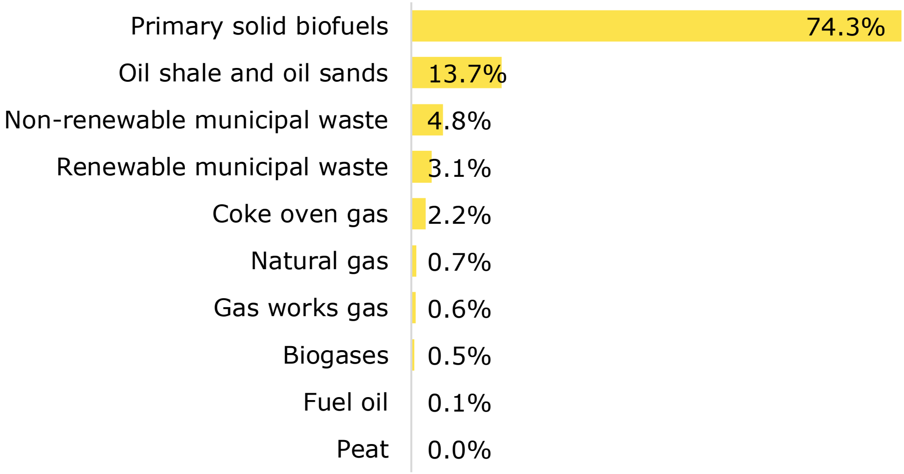


Figure 1.1. Fuel consumption of combined heat and power producers

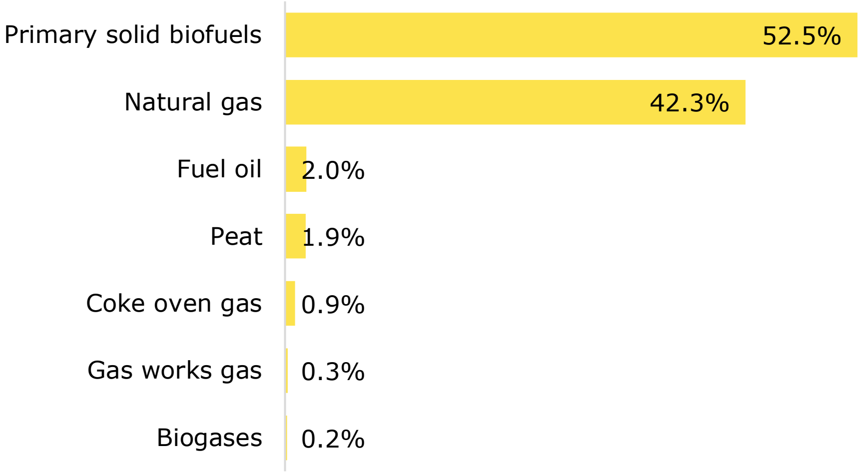


Figure 1.2. Fuel consumption of heat producers only

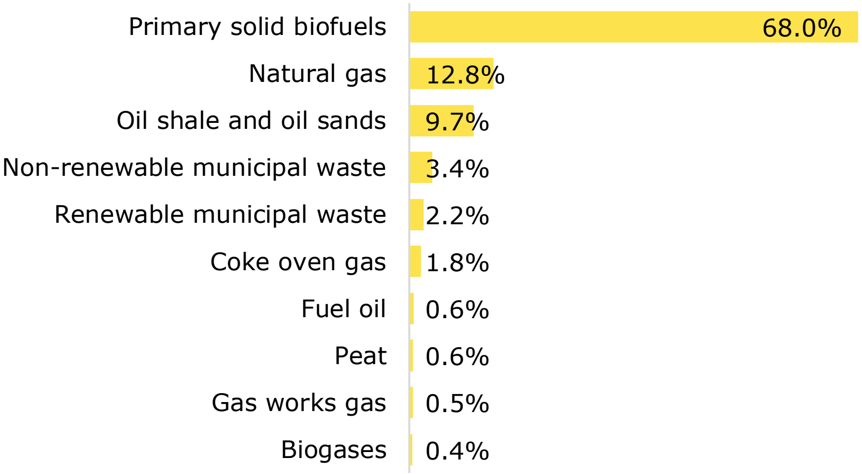


Figure 1.3. Combined total fuel consumption of CHP and heat producers

The values displayed here represent the total fuel consumption. **The potential for electrification of CHP and Distric heating sector fuel use is as follows:**

- natural gas 1195 GWh (13%),
- fossil fuels 1712 GWh (19%),
- biofuels 6465 GWh (68%).

It is crucial to note that the subsequent figures in the following chapters have been tailored for each sector, with adjustments made to account for boiler efficiency and network transmission losses. The consumption by sectors is reported based on data from the Statistics Estonia, with the underlying assumption that the sectoral consumption data excludes heat generated in the condensation mode of CHP systems.

1.2.2 Households

Annual normalized local heating fuel consumption in household sector is 5187 GWh. Households mostly rely on solid biofuels and natural gas (Figure 1.4).

Due to the lack of data, it is not possible to assess the proportion of fuels burned in stoves, furnaces, or boiler equipment. EU standard EN 15544 stipulates that the efficiency of stoves and furnaces should be at least 78%. Before the standard, the efficiency of existing stoves and cookers ranged between 60-70%. The district heating network regulation specifies that the efficiency of solid fuel heat production should not be less than 80% and for new equipment, not less than 85% [2]. Assuming an average efficiency of 75%, then the net heat consumption in local heating is 3326 GWh. When adding natural gas consumption (690 GWh) to this, local heating energy consumption exceeds the district heating network consumption in household sector. Household sector annual normalized district heating thermal energy consumption is 3660 GWh.

It is possible to regulate the reduction of fossil fuel consumption and pollution due ineffective heating methods at the national level, but restricting the use of natural gas boilers, biomass stoves and furnaces has not previously found support in Estonia. Although, there are examples in the world where this has already been done [3] [4]. The cost of fuel has a profound and immediate impact on the behaviour of private consumers. If the price of biofuels increases more rapidly over time than the cost of electricity, the power grid will experience much quicker heat pump adoption for the base thermal load. Many rural buildings, located outside of district heating networks, are already equipped with heat pumps to maintain indoor warmth, and biofuels are reserved for use during peak load times, aligning with the overall electricity demand.

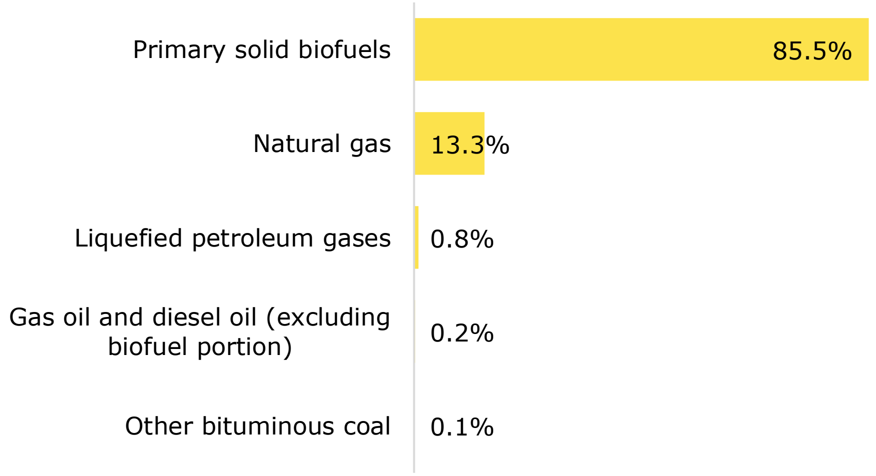


Figure 1.4. Household sector fuel consumption

The potential for electrification of service sector fuel use is as follows:

- natural gas 690 GWh (13%),
- fossil fuels 61 GWh (1%),
- biofuels 4436 GWh (86%),

Households connected to district heating network:

- natural gas 467 GWh,
- fossil fuels 690 GWh,
- biofuels 2504 GWh .

1.2.3 Services

The annual normalized local heating fuel consumption in the service sector is 1320 GWh (Figure 1.5). The service sector primarily relies on gas and liquid fuels because they are easier to operate, maintain, and have lower investment costs. Additionally, the boiler efficiency for liquid and gaseous fuels, depending on the water temperature, must range from 87.5% to 97%, which is more efficient than a solid fuel boiler. Moreover, biofuels require a fuel depot, for which commercial real estate typically lacks sufficient space. This is the primary reason why the service sector has the greatest potential to replace its fuel consumption with district heating or heat pumps. Additionally, some service buildings could utilize their excess heat from heat recovery ventilation and supermarket refrigeration and cooling units for the base thermal load. As previously mentioned, the use of natural gas and different fuel oils could be regulated by the state.

Service sector annual normalized district heating thermal energy consumption is 1332 GWh.

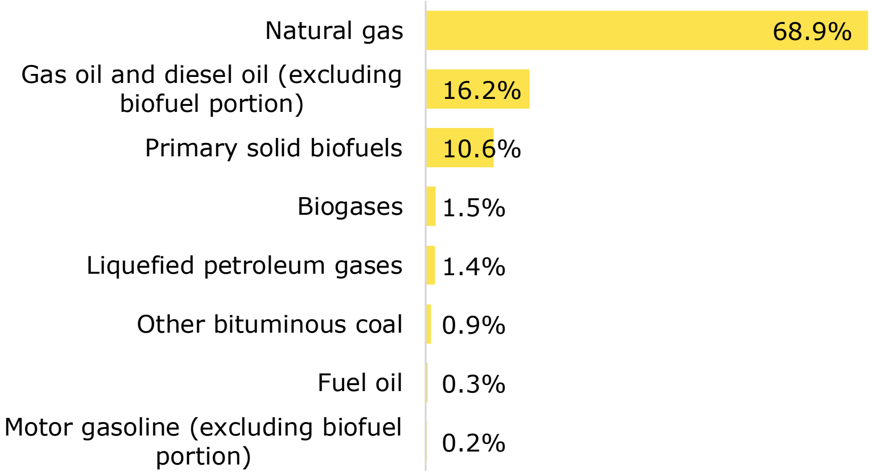


Figure 1.5. Services sector fuel consumption

The potential for electrification of service sector fuel use is as follows:

- natural gas 910 GWh (69%),
- fossil fuels 251 GWh (19%),
- biofuels 159 GWh (12%),

Services connected to district heating network:

  - natural gas 170 GWh
  - fossil fuels 251 GWh,
  - biofuels 911 GWh.

1.2.4 Industries

The annual normalized fuel consumption in the industry sector is 1773 GWh (Figure 1.6). The industry sector exhibits the most diverse fuel consumption patterns. However, among the 16 industry sectors, 11 primarily rely on natural gas. Solid biofuels are predominantly used in the paper, pulp, and printing sector, while gas oil and diesel oil find the most extensive use in the construction sector. The food and beverages sector stands out as the most diverse in terms of fuels used and has the highest consumption. This sector relies on liquid and gaseous fuels to respond promptly to fluctuations in production loads.

Within the industry sector, annual normalized district heating consumption is 477 GWh. This usage may involve separate industries producing heat for their subsidiaries. For instance, a sawmill may transport wood chips and sawdust to a subsidiary responsible for providing heat to the sawmill's kiln dryers.

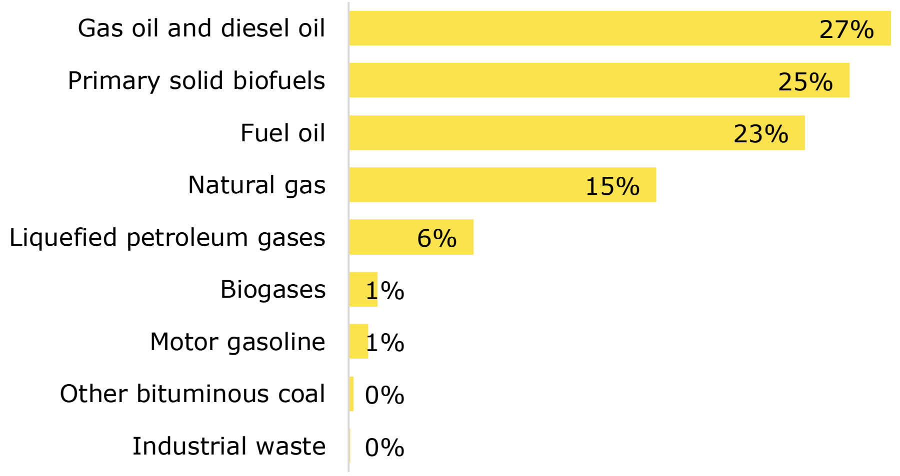


Figure 1.6. Industry sector fuel consumption

The potential for electrification of industrial fuel use is as follows:

- natural gas 115 GWh (16%),
- fossil fuels 428 GWh (58%),
- biofuels 198 GWh (27%),

Industries connected to district heating network:

- natural gas 61 GWh,
- fossil fuels 90 GWh,
- biofuels 326 GWh.

1.3 Heat pumps

The number of heat pumps has steadily increased over the past ten years (Figure 1.7) [5] [6]. The most widely used heat pumps are Air-To-Air heat pumps (AAHP) because they are easy to install. In recent years, Air-To-Water heat pumps (AWHP) have been gaining popularity. Compared to Ground-Source heat pumps (GSHP), they are easier to install, which is now the least common type of heat pump. The significant advantage of Air-To-Water heat pumps compared to Air-To-Air is their higher Coefficient of Performance (COP) and the ability to produce hot water for domestic use, replacing electric boilers. The growth of Ground-Source heat pumps is limited by building thermal systems' capacity, available land, and legislation, making them more suitable for rural areas. The lack of available land in urban areas is the primary reason to prefer Air-To-Water heat pumps.

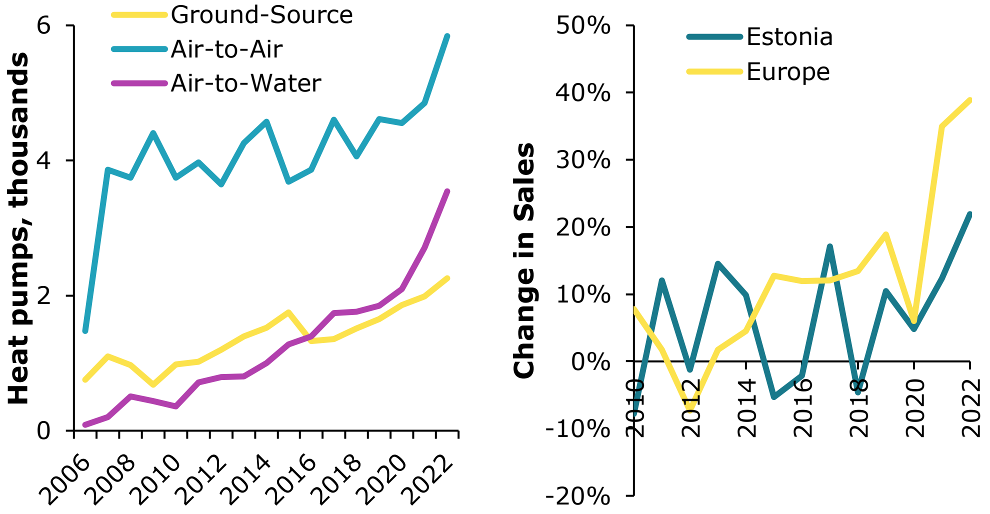


Figure 1.7. Heat pump data

In the Nordic countries, heat pumps have been in the market earlier as a secondary heating source, offering convenience compared to solid fuels. Additionally, the need for cooling has increased with warmer summer weather. In conclusion, as the population's wealth increases, devices that provide comfort (heat pumps) become more accessible and see more usage. This implies that it's relatively accurate to predict the acquisition of heat pumps based on GDP. Correlation analysis indicates a strong linear relationship (0.96 after removing outliers) between the number of purchased heat pumps and Gross Domestic Product (GDP) (Figure 1.8).

Given that the base electricity consumption model estimates overall growth due to the expansion of the national economy, it becomes difficult to isolate the specific increase in electricity consumption attributed to heat pumps. This is because the base electricity consumption model already assumes increase in electricity consumption due to organic growth of the economy.

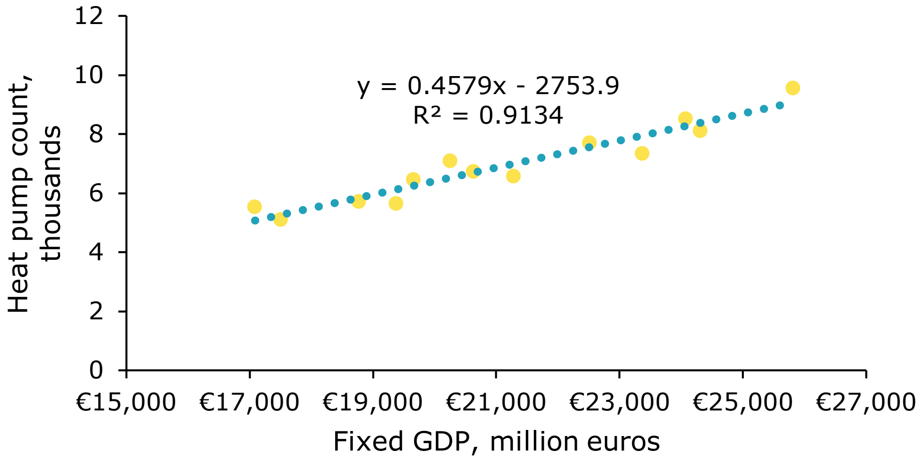


Figure 1.8. Heat pump regression analysis

1.3.1 Heat pump consumption model

Two different methodologies have been chosen for predicting the use of heat pumps based on historic data [5].

- In the fast electrification model, linear regression has been used to forecast that the acquisition of heat pumps grows each year.
- In the base electrification baseline model assume an average growth over a 5-year period, rather than annually. This replicates the previous study's base consumption model - overall growth due to the expansion of the national economy.

The difference between these two models is 1.6 times. Fast electrification model estimates 458 000 heat pumps installed by the year 2050, while the base electrification model estimates 284 000 heat pumps (Figure 1.9).

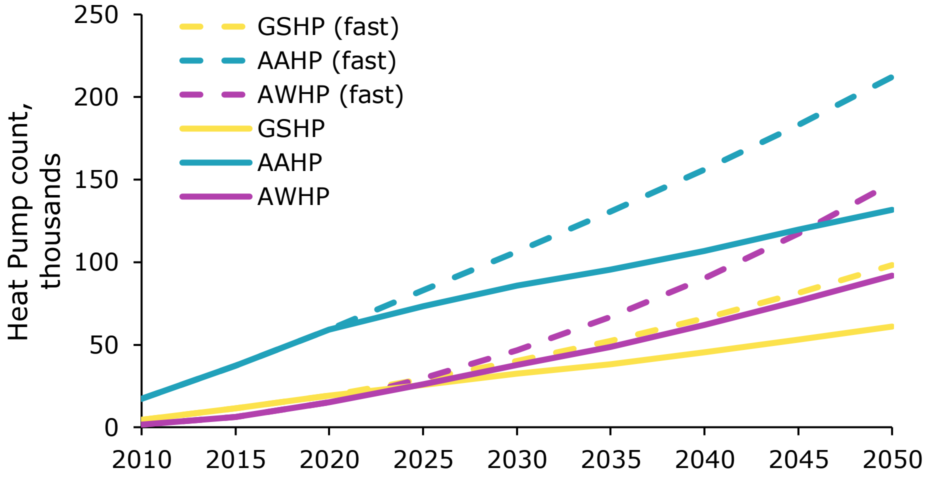


Figure 1.9. Installed heat pump forecast

To assess the peak consumption of installed heat pumps and electricity consumption, assumption was based on the building requirement to achieve a required energy class "C" (160 kWh/(m^2y)) [7]. The energy class sets limits on electricity consumption, and if specific consumption of equipment and lighting consumes 38 kWh/(m^2y) of electricity [8], we can calculate how much energy remains for heating and cooling. In the methodology for calculating the energy label, electricity consumption is considered with a value of 2, meaning each 1 kWh of electricity consumed is considered as 2 kWh [9]. The calculation is based on an average household, considering 30.1 m2 per inhabitant with an average of 2.35 inhabitants. The calculation uses an average climatic year model, from which the COP and electricity consumption of the heat pump are computed for each hour. Based on the assumptions, the calculated peak consumption of average household heat pump is 3.7 kW_e, and the annual average consumption is 0.41 kW_e.

Table 1.1. Heat pump power calculation

Parameter	**Value**
Specific consumption, kWh/(m^2y) ("C" label)	160
Average electricity consumption, kWh/(m^2a)	38
Electricity conversion factor	2
Heating consumption, kWh/(m^2y)	83
Weighted average COP (Coefficient of Power)	2,97
Power to Heat, kWh/(m^2y)	123
Surface area, m^2	71
Heating consumption, kWh/y	8727
Heating degree hours, Kh	96386
Peak thermal power, kW	3,7
Peak power, kW_e	1,2
Annual heating period, h	7505
Average power, kW_e	0,41
Average power, %	0,33
Electricity consumption, kWh/y	3065

1.3.2 Heat pump electrification

The following tables (Table 1.2-Table 1.5) present the results of the heat pump consumption model at 5-year intervals. Peak consumption occurs only during extremely cold temperatures when the COP is low, and the thermal load is high.

The average consumption best describes the increase in electricity consumption due to the electrification of heat pumps. The model used today's average heat pump COP data. Since future building energy consumption is expected to decrease, and equipment efficiency is expected to improve, the results are likely to be somewhat higher than reality.

Table 1.2. Fast electrification peak power

Year	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Ground-Source	36	50	65	82	101	123
Air-to-Air Heat	104	133	163	195	229	265
Air-to-Water	37	58	83	113	146	185
TOTAL, MW	**177**	**241**	**312**	**390**	**477**	**572**

Table 1.3. Fast electrification average power and total consumption

Year	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Ground-Source	12	16	21	27	33	40
Air-to-Air Heat	34	43	53	64	75	87
Air-to-Water	12	19	27	37	48	60
TOTAL, MW	**58**	**79**	**102**	**127**	**156**	**187**
Total, GWh	**434**	**591**	**765**	**956**	**1170**	**1405**

Table 1.4. Base electrification peak power

Year	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Ground-Source	32	40	48	56	66	76
Air-to-Air Heat	91	107	119	133	150	164
Air-to-Water	33	47	61	77	96	115
TOTAL, MW	**156**	**195**	**228**	**267**	**312**	**355**

Table 1.5. Base electrification average power and total consumption

Year	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Ground-Source	10	13	16	18	22	25
Air-to-Air Heat	30	35	39	44	49	54
Air-to-Water	11	15	20	25	31	37
TOTAL, MW	**51**	**64**	**75**	**87**	**102**	**116**
Total, GWh	**383**	**478**	**560**	**656**	**765**	**872**

1.3.3 Primary energy cost comparison

Table 1.6 provides the results of the calculation for the energy price of firewood. The calculation is based on the variable cost only (OPEX). A stere, or "ruumimeeter" in Estonian, is equivalent to one cubic meter of stacked wood with air pockets and is a common unit used by firewood producers.

the electricity prices from the past year (2022-2023) and the COP values derived from the average climatic year temperature were used to calculate the average thermal energy cost for heat pumps.

The weighted average heat production cost (electricity cost divided by COP) of the heat pump, based on the heat load, is 57.2 €/MWh (170 €/MWh electricity). The same primary energy cost would be achieved with the firewood priced at 62 € per stere (primary energy cost at 1450 kWh/stere and 75% efficiency). In the last 12 months, the heat production cost of the heat pump has been lower than this for 5236 hours. The sharp increase in firewood prices in recent years has made heat pumps more competitive at base thermal loads. At the time of report writing, the price of firewood is 80 € per stacked cubic meter. When the price of firewood reaches 261 € per stacked cubic meter, it becomes more cost-effective to produce heat with a heat pump throughout the entire heating season.

Table 1.6. Firewood thermal energy price calculation

Firewood price, €/st	**62**	**80**	**261**
Energy price, €/MWh	43	55	180
Primary energy cost, €/MWh	57	74	240
Cheaper electricity price hours, h	5236	6269	7505

Figure 1.10 illustrates the load profile of an average C-class label household (71 m^2) and the distribution of heat production between the heat pump and the fireplace, based on the assumptions made in previous chapters. The results indicate that during the previous heating season, with a price of 80 € per stacked cubic meter of firewood, it would have been more cost-effective to produce the base thermal load (77%) with a heat pump and rely on the heating furnace exclusively for peak loads (23%). This is particularly relevant during extremely low ambient temperature periods when the heat pump's COP is diminished, and when electricity prices are higher.

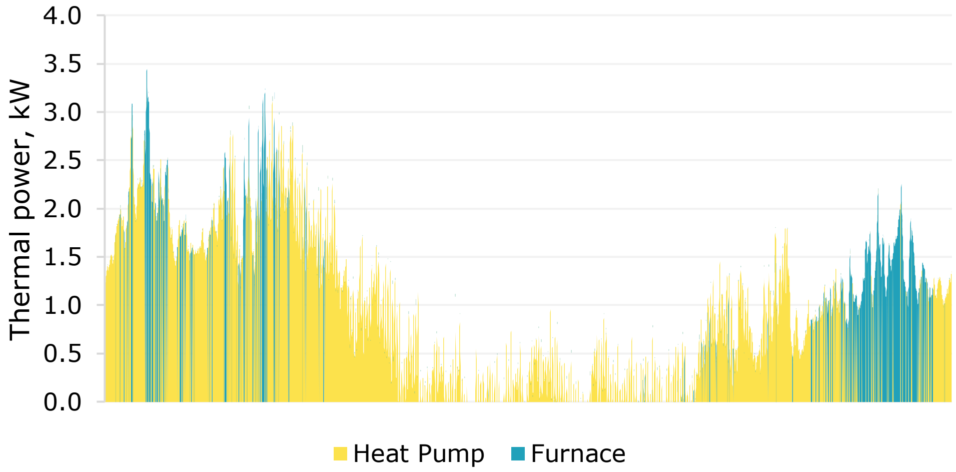


Figure 1.10. Optimal heating for average household based on the price of electricity

In conclusion, the results indicate that there are situations today where heat pumps are more cost-effective than heating furnaces or stoves and considering the recent growth trend in the sales of heat pumps, it can be safely assumed that the base electricity consumption model already assumes increase in electricity consumption due to heat pumps.

1.3.4 Power to Heat potential

To evaluate the competitiveness of electrification, the following OPEX (Table 1.7) and CAPEX (Table 1.8) assumptions have been made. The fuel and electricity prices are based on the data from the last 12 months (October 2022 – October 2023) (Figure 1.12), and the medium voltage network fee has been added to the electricity price.

Table 1.7. OPEX assumptions

Fuel	**Fuel cost, €/MWh**	**Efficiency**
Wood Chips	25	86%
Pellet	57	90%
LPG	63	92%
Shale oil	65	91%
Natural gas	73	94%
Heat Pump	151	300%
Electricity	151	100%

Table 1.8. CAPEX assumptions

Fuel	**Specific investment cost, €/MW**	**Amortization, yr**
Wood Chips	1 000 000	20
Pellet	350 000	20
LPG	160 000	20
Shale oil	160 000	20
Natural gas	200 000	20
Heat Pump	550 000	15
Electric boiler/heater	60 000	7

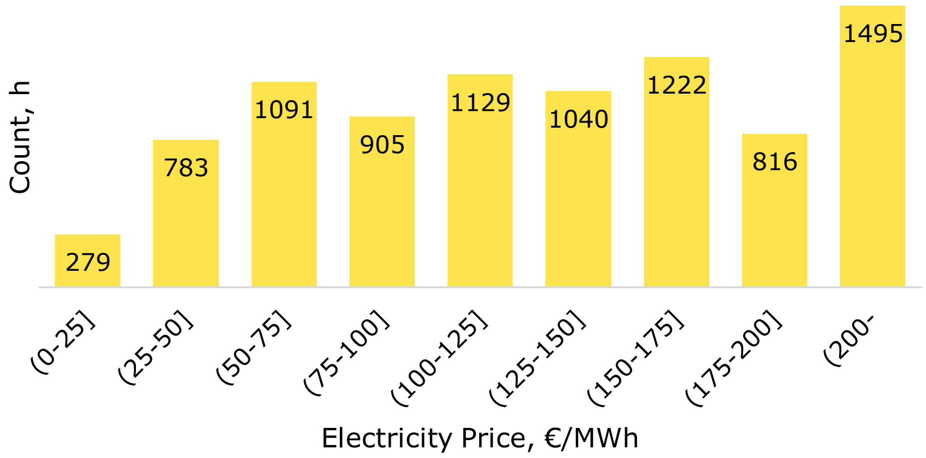


Figure 1.11. Electricity market price profile (2022-2023)

The calculation of the thermal price is based on the heat price calculation principles by the Competition Authority, which combines variable and fixed costs. The variable cost consists of fuel price, electricity price, and pollution charges. The fixed cost includes operating costs and depreciation costs of equipment investments. The WACC for investments is 7.46%.

Figure 1.12 and Figure 1.13 illustrate the heat production prices for the base load and peak load, respectively. The model optimized the price for the base load boiler at 78% of the annual consumption, while for the peak load boiler, it was optimized at 22%.

According to the previously set assumptions, wood chips are the cheapest fuel option for base load, while LPG is the cheapest option for peak load. Typically, the cheapest solution for smaller district heating networks has been shale oil, or natural gas in larger networks with a gas grid connection.

Many wood chip boilers are purchased with local subsidies that reduce investment costs by 50%, further decreasing the heat price. However, this subsidy is not shown in the figure to compare prices without subsidy.

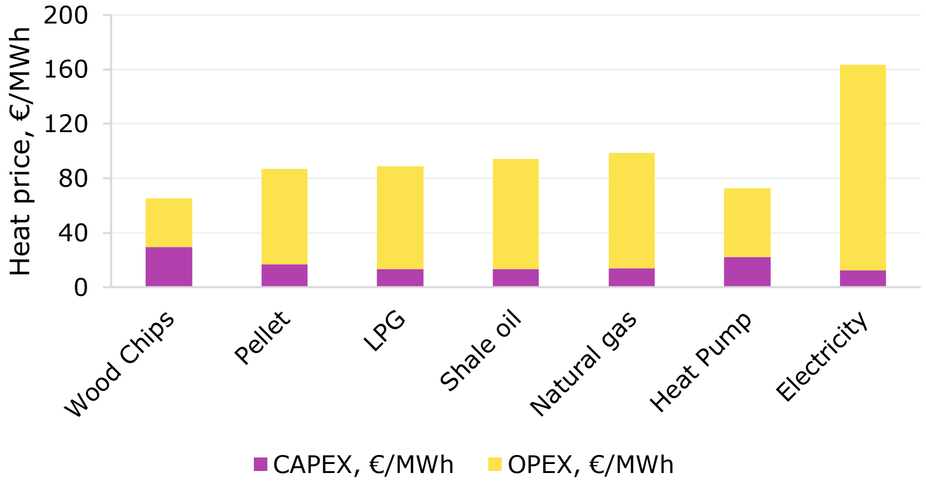


Figure 1.12. Heat production price for the base load

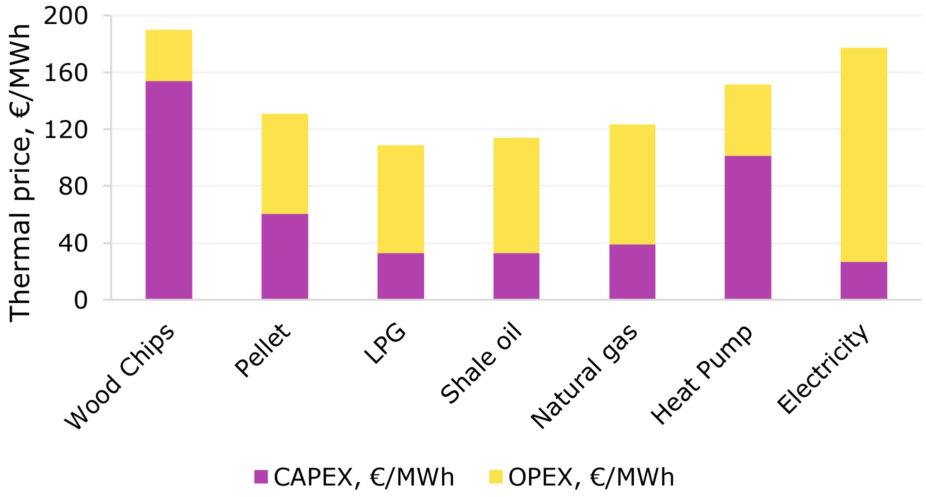


Figure 1.13. Heat production price for the peak load

The price difference between wood chips and heat pumps is only 11%. However, this calculation is based on an average electricity price of 151 €/MWh and at COP 3. Heat pumps have not been widely used in district heating networks due to high temperatures. Additionally, wood chip prices have been more stable than electricity prices and usually both see an increase in price at the same time.

With the given assumptions, LPG is the cheapest option for peak load, with a 39% price difference compared to heat pump prices. Although heat pumps or electricity could be used to produce heat when electricity prices are low, peak loads correlate with extremely low ambient temperatures, which also correlates with high electricity prices. Therefore, LPG has an advantage as it can be bought and stored throughout the year at a lower price. Table 1.9 presents the impact of CO_2 and LPG prices on peak load price. The calculations suggest that LPG and heat pump solutions would achieve equal prices:

- At a given LPG and electricity price, the CO_2 price must increase to €240/t (182%).
- At €85/t CO_2 price, the LPG price must increase to €91/MWh (+44%).
- At €25/t CO_2 price, the LPG price must increase to €102/MWh (+62%).

Table 1.9. Impact of CO_2 and LPG prices on Peak Load price

CO_2 / LPG price	**63 €/MWh**	**91 €/MWh**	**102 €/MWh**
25 €/t	109	140	152
85 €/t	121	152	164
240 €/t	152	182	194

In conclusion, based on fixed assumptions, prices, and production volumes, electricity is not yet competitive. However, the new ETS2 carbon price will apply to petrol, diesel and heating fuels such as natural gas whose climate warming emissions have continued to rise over the years despite attempts to decarbonise.

1.3.5 District heating network model

The biggest advantage of using electricity is its speed and simplicity. The load of a wood chip boiler cannot be quickly regulated without damaging its efficiency. Therefore, a static calculation that fixes the electricity price for the entire heating season does not allow for the evaluation of opportunities for heat production due to fluctuations in electricity prices. To assess whether a heat production solution would differ from a static calculation at low electricity prices, three different scenarios for electrification have been developed. Scenarios are compiled for a district heating network with an annual consumption of 59 GWh. All scenarios exclude the depreciation price of the district heating network grid as it would be the same for all the solutions.

- Scenario 1 (Control): The base and peak loads are produced with the cheapest solution that ensures the lowest fixed costs for the boilers.
- Scenario 2 (Electricity): The district heating network purchases an electric boiler and uses it when it is cheaper than the base and peak load boilers.
- Scenario 3 (Heat Pump): The district heating network purchases a heat pump solution and uses it when it is cheaper than the base and peak load boilers.

Figure 1.14 represents the scenario 1 heating load profile. The cheapest option for the given scenario is a wood chip boiler with a capacity of 9233 kW, which produces 78% of the annual output, and an LPG peak load boiler with a capacity of 19 MW (maximum load), which produces 22% of the annual output. **The cost of producing heat for such a district heating network is 75 €/MWh.**

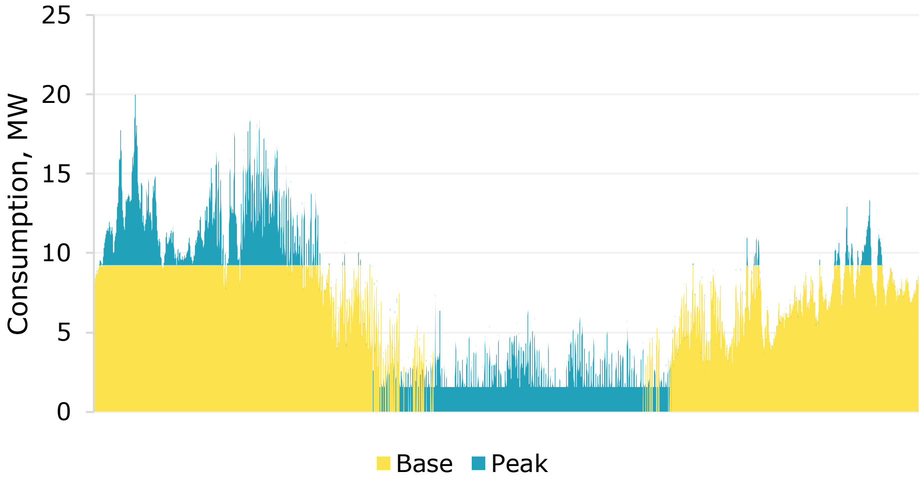


Figure 1.14. Scenario 1 heating load profile

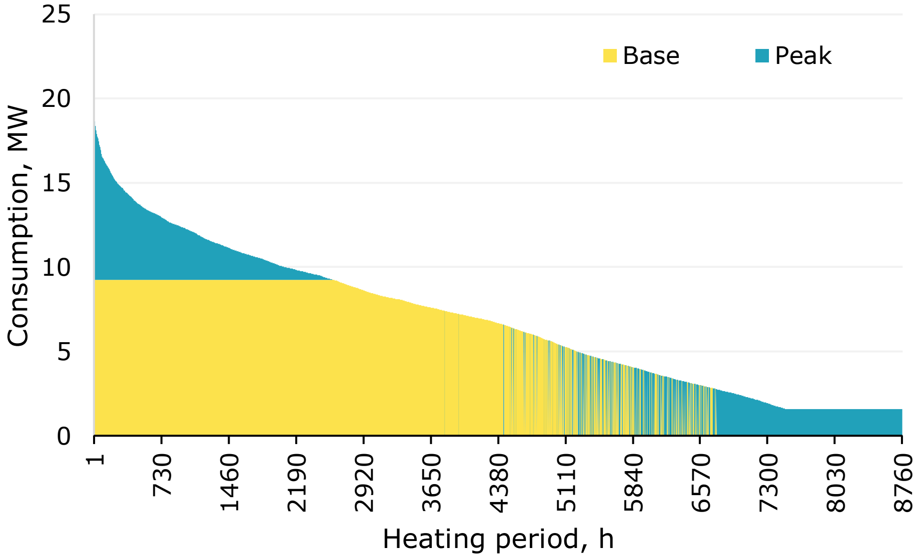


Figure 1.15. Scenario 1 heating load profile sorted by consumption

Figure 1.16 represents the scenario 2 heating load profile. The cheapest price for the consumers is provided with the following setup:

- a wood chip boiler with a capacity of 9233 kW, which produces 78% of the annual output,
- a LPG peak load boiler with a capacity of 10 766 kW, which produces 14% of the annual output,
- an electric boiler with a capacity of 10 267 kW, which produces 8% of the annual output.

The cost of producing heat for such a district heating network is 63,5 €/MWh, which is cheaper than scenario 1. A lower price is achieved by purchasing a lower-capacity peak load boiler, which reduces the share of CAPEX in the heat price. However, since the modelled district heating network's peak load is 19 MW, there is no independent boiler that can produce 19 MW thermal output. This means that Scenario 2 jeopardizes consumer supply security to achieve a cheaper price. Yet, from a strategic standpoint, this approach secures the N-1 contingency.

This means that two working boilers are always required to produce peak loads. In the proposed solution, adding a 19 MW or 2 x 9,5 MW LPG boiler would no longer offer a cheaper price compared to Scenario 1. However, a cheaper price can be maintained with a 19 MW electric boiler. This means that the heat price at peak load depends on the electricity price of the power grid. Since the electricity price is beyond the control of the heat producer, such a solution is economically risky for both the producer and consumer.

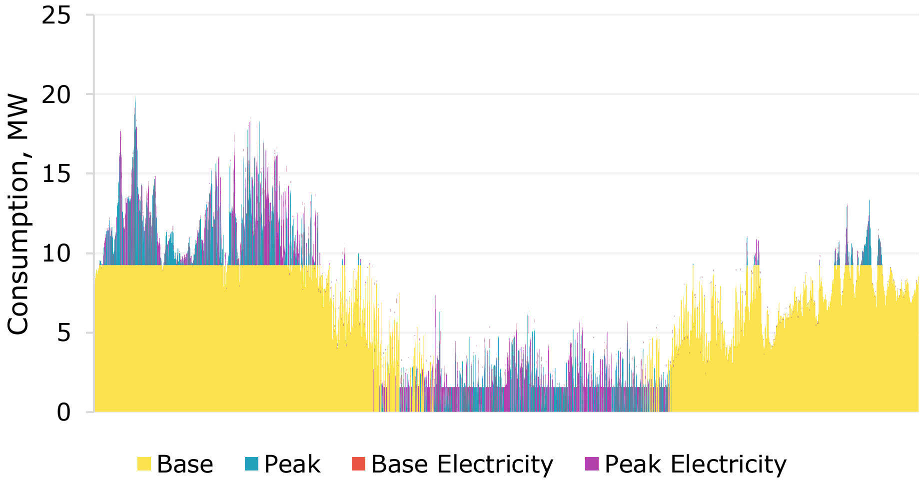


Figure 1.16. Scenario 2 heating load profile

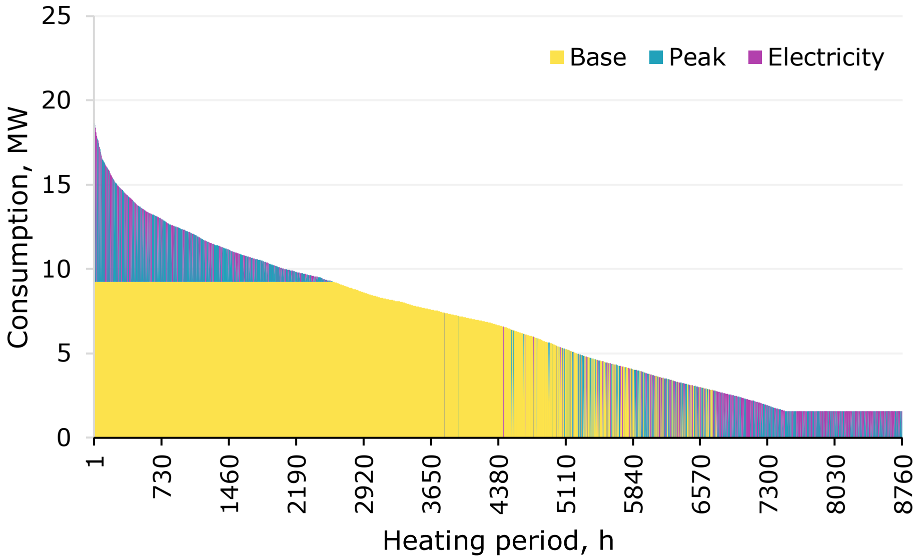


Figure 1.17. Scenario 2 heating load profile sorted by consumption

Figure 1.18 represents the scenario 3 heating load profile. The cheapest price for consumers can be achieved by using heat pumps instead of electric boilers in the same capacity setup as Scenario 2. Heat pumps would produce 21% of the annual output, reducing the LPG peak boiler usage to 2% of the annual output. The cost of producing heat for such a district heating network is 73.5 €/MWh, which is marginally cheaper than Scenario 1. However, this solution shares the same risks as Scenario 2, but has higher costs due to the higher CAPEX of heat pumps.

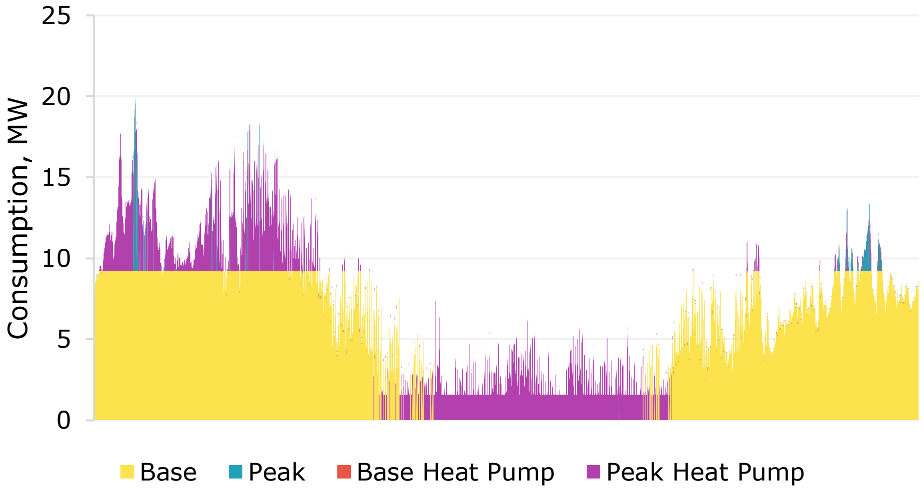


Figure 1.18. Scenario 3 heating load profile

Conclusion

To summarize, it is important to be aware that investments in district heating networks are made for up to 20 years, and this modelling is based on a specific electricity price profile, which will certainly not be the same for the next 20 years. The unpredictability of electricity prices is the main risk because district heating companies are not rushing to electrify the heat production.

Currently, electric boilers are the most suitable solution for district heating networks with a cogeneration plant that allows electric boilers to be operated when electricity production with steam turbine is not profitable and additionally allows electric boiler to produce heat without electricity network fees.

Market participants believe that electrification is taking place more in larger district heating networks, where CAPEX costs are better distributed among many consumers. Based on this, it can be assumed that electrification of peak load and summer load (22% of the annual consumption) may already be an ongoing process, but a significant difference between the price of wood chips and electricity is needed for electrification of base load, and today's wood chip boilers are likely to be operated until 2040.

1.3.6 Technological developments of heat pumps

Heat pumps efficiency is dependent on the heat source, heat sink and the working fluid. [10] During winter ground or external water-sources typically are warmer than ambient air, thus consuming less electricity and yielding a higher COP. However air-source heatpumps have a lower investment costs, thus they are more common. Worldwide almost 85% of all heatpumps sold are air-sourced [11].

Heat pump technology has seen significant advances during the last decades. The Swiss Office of Energy estimated that since the early 1990s the COPs have increased more than 70% for air-to-water heat pumps in Switzerland. Modern industrial heat pumps have high efficiency: when the temperature lift is in the range of 30–50 °C the COP is >3, for higher temperature lifts the COP is generally lower. There are some technical possibilities to limit the loss of efficiencies like intermediate heat exchangers and cascaded cycles. But while they improve efficiency they also result in higher investment cost [11].

IEA states that the heat pump research is currently focused on smart and flexible sytems, noise reductions, higher efficiencies, and lowering environmental footprints by the materials and refrigerants used [11].

Refrigerants are of importance in heat pump technology. European Parliament passed a regulation no 517/2014 on fluorinated greenhouse gases. From 1st of january 2020 the usage of industrial grade fluorinated greenhouse gases with a global warming potential of more than 2500 GWP (Global Warming Potential) is prohibited for service and maintenance, when the amount of refrigerat is >40 CO2 equivalent tonnes. Examples of refrigerants with GWP >2500 are 404A, 507A, 422A, 422D. Until 1st of January 2030 reuse of refridgerants is allowed during maintenance under scertain conditions. The legistlation restricts the implementation of new systems or replacing old systems with refrigerants with high GWP [12] [13].

Under the existing regulations it is important that the solutions implemented would be future proof and that companies actively seeks environmentally sustainable solutions. One of the refrigerants with low significantly lower GWP compared to fluorinated refrigerants is R744 (Carbon dioxide). Two studies found that for domestic water heating heat pump systems with R744 the COP is 3,5–4,5 [14] [15].

1.3.7 Industrial Heat Pump Technology

The potential for heat pumps varies by sector, the IEAs estimates of the heat needs across all temperature ranges that could be met by industrial heat pumps are: 65% in paper industry, 40% in food industry, 25% in chemical industry. [11] The potential of using waste heat is larger when additional heat sources from neighbouring facilities could be used – In case of industrial parks. In Estonia so far the are not many industrial parks where these synergies could be met but in Ida-Virumaa county many are proposed. Ida-Virumaa Investment agency is leading Narva, Kiviõli, Jõhvi, Kohtla-Järve industrial park projects. This could be potential locations for further using waste heat [16].

Table 1.10 shows the technology readiness level of industrial heat pump technologies by temperature range. For temperatures over 200 °C at present direct electrification is generally preferable over heat pumps [11].

Table 1.10 Industrial Heat Pump technology readiness by temperature range [11]

Temperature	**Technology readiness level (TRL)**
<80 °C	TRL 11: Proof of market stability
80–100 °C	TRL 10: Commercial and competitive, but large- scale deployment not yet achieved
100–140 °C	TRL 8-9: First-of-a-kind commercial applications in relevant environment
140–160 °C	TRL 6-7: Pre-commercial demonstration
160–200 °C	TRL 8-9: First-of-a-kind commercial applications for small-scale mechanical vapor compression systems and heat transformers TRL 4-5: Early to large prototype
>200 °C	TRL 4: Early prototype

**Representation using the IEA extended TRLs : 1 – initial idea to 11 – proof of stability*

The Heat Pump Potential in Estonia (PEC – primary energy consumption)

In 2018 a joint report Heat Pump Potential in the Baltic States mapped out various high-temperature heat sources available. The analysis covered sources with an installed capacity over 10 MW, as utilizing smaller heat sources would probably not be justified. For excess heat that is below 90 ° C using a heat pump or electric boiler is necessary to rise the temperature to match the district heating network supply temperature [17].

174 high temperature heat sources identified were: industrial excess heat (PEC 18 867 GWh) and existing CHP plants (PEC 14 029 GWh). The dominant industries in Estonia are chemical, cement, refinery, and wood sectors, collectively accounting for PEC of 16,011 GWh. Additionally, the asphalt and food industries contribute 1,449 GWh with 63 and 10 heat sources, respectively. Some of industries brought out are seasonal e.g. asphalt production, meaning that the available excess heat might not match the heating profile [17]. In Annex 1 an overview of temperatures needed for various industrial processes are shown with technology readiness levels. The temperature ranges are wide and vary grately by process.

Based on the authors' experience in energy audits, it is possible to successfully implement heat pumps in the industrial sector. However, from the manufacturer's perspective, the primary concern is achieving a return on investment and energy savings.

In the paper and wood industries, the use of heat pumps is challenging because the production process yields sawdust and scrap wood, which can be used to produce heat for drying at a significantly lower cost than electricity. In Estonia, there is one exceptional wood industry that uses heat pumps for drying sawn timber at low temperatures (42 °C), but most wood drying processes operate at temperatures of 90-160 °C. Using lower temperatures extends the drying time of products and requires a specific business plan, thus retrofit solutions often do not meet the owners' or shareholder expectations. Manufacturers are exploring the use of heat pumps for heat recovery from wood dryers, but due to inexpensive waste fuels (wood chips, sawdust), these projects often do not achieve the desired profitability, and the waste heat remains unused.

In the chemical and plastics industries, operations are carried out at excessively high temperatures, limiting the potential use of heat pumps. Achieving higher temperatures with heat pumps often requires a large amount of high-temperature waste heat, which is not often readily available in a controllable manner to replace steam boilers.

In the food industry, the use of heat pumps depends on the products to be dried, evaporated, pasteurized, sterilized, and boiled, as these processes require high temperatures. If it is possible to process products under pressure, it is possible to lower the water boiling temperature, which improves the potential for using heat pumps. Food industry is heaviliy regulated to reduce the risk to the food safety, this makes implementing newer technical systems more complex.

Heat pumps are primarily taken into use during technical system renovations, where electric boilers and electric radiators are replaced to increase the efficiency of hot water production and building heating. For industrial processes, investments have already been made in the acquisition of steam boilers, so the expansion of heat pump use is reasonable only after the boilers reach the end of their service life.

1.3.8 The potential of utilizing waste heat with heat pumps

Table 1.11 shows the excess heat potential in Estonia. Theoretical potential shows all potential and practical potential considers heat sources with distance less than 1 km to a district heating area.

Table 1.11 Excess heat potential in Estonia [17]

Excess heat potential in Estonia, GWh	**Theoretical**	**Practical**
Industrial excess heat (total)	3370	2923
Industrial excess heat (direct supply)	2247	-
Industrial excess heat (supplied via HP)	1123	-
Boilers and CHP plants (flue gas HP)	590	511
Power plants	26 057	6521

The study also analysed low-temperature heat sources like seawater, ambient air, sewage water among others– sources with temperatures close to ambient temperature, which means that the temperatures are below 30 °C. Low temperature heat sources that are near a district heating area are a potential place to utilise large-scale heat pumps for heating. In Estonia there are in total 184 district heating areas, most areas have some sort of potential access to low-temperature heat source as is shown in Table 1.12. [17].

Table 1.12 Low temperature heat source potential in Estonia [17]

Number of district heating areas with access to (< 1 km)	
Seawater	22
Sewage treatment plant	44
Large river	104
Large lake	19

The study forecast significant heat pump usage rise in Estonia. Under the Base scenario, the distribution of heat supply sources in Estonia is projected to be approximately 61% from large-scale heat pumps, 23% from biomass-based plants, and 7% from natural gas-fired plants The study also analysed the impact of carbondioxide and biomass prices on usage of heat pumps and it was found that if the price of biomass is low and biomass is highly available it could predominantly displace the usage of heat pumps. While high carbon dioxide prices do not create a significant additional traction to heat pumps. [17].

The heat pump potential study prognosed that it is expected that heat pump usage increases after 2030 [17]. While the study focused on using the industrial excess heat potential and also low temperature heat sources for district heating, similar trend is to be expected in overall usage of heat pumps. This is similar to the answers given from the market participant interviews.

1.4 Electrification potential

Assumptions

Since renewable and biofuel sources currently account for 68% of heat consumption, there is potential to electrify the remaining 32% that relies on fossil fuels. However, within this 68%, there are older biomass-operated devices, fireplaces, and stoves, which could also be subject to further electrification to some extent. Consequently, the scenario has achieved a target value of 50% electrification. In addition, an extreme scenario is created to forecast maximum consumption limit that would be achieved with 100% electrification. The two electrification scenarios for household and service sector local and district heating use the following assumptions:

- In the balanced heating scenario, 50% of thermal energy consumption for local and district heating will be electrified by 2050.
- In the extreme heating scenario, 100% of thermal energy consumption for local and district heating will be electrified by 2050.
- In both scenarios, the base thermal load will be supplied by a heat pump with a COP of 3. Three different consumption scenarios are generated with different base and peak production parameters for district heating. **Local heating will always use a heat pump for the base thermal load and biofuels for the peak thermal loads.**
    - In the Market-based Electric Boiler scenario, 8% of annual thermal consumption is supplied by an electric boiler.
    - In the Heat Pump for Peak Load Only scenario, 22% of annual thermal consumption is supplied by an heat pump.
    - In the Heat Pump for Base Load Only scenario, 78% of annual thermal consumption is supplied by a heat pump.
    - In the Heat Pump scenario, 100% of annual thermal consumption is supplied by a heat pump.

The previous study’s model assumed that industry natural gas consumption would be electrified. Scenarios are based on the “Estonian Gas Market Study – Consumption Forecast Until 2050” study. The new industry electrification model adds fossil fuel and biofuel electrification potential with two scenarios replicating the natural gas consumption electrification rate:

- In the base electrification scenario, 28% of fossil fuel energy consumption will be electrified by 2050.
- In the fast electrification scenario, 31% of fossil fuel and biofuels energy consumption will be electrified by 2050.
- In both scenarios, thermal energy will be produced by heat pumps with a COP of 3.

The chosen values and percentages for named scenarios are based on the calculations presented in the previous chapters. The following chapters provide an analysis of the electrification potential based on given assumptions. This updates the forecast from an earlier study concerning the electrification of the district heating network. It's crucial to understand that this analysis does not include the base electricity consumption increase scenario where there's an increase in electricity consumption by heat pumps, which is directly linked to GDP growth. Therefore, the 2025 district heating electrification forecast projects an output of 0 GWh and 0 MW

1.4.1 Base scenario electrification

The following is a list of potential electrification base scenario figures and tables containing the results.

Figure 1.19 presents the electricity consumption levels for various technical solutions following the electrification of the base scenario.

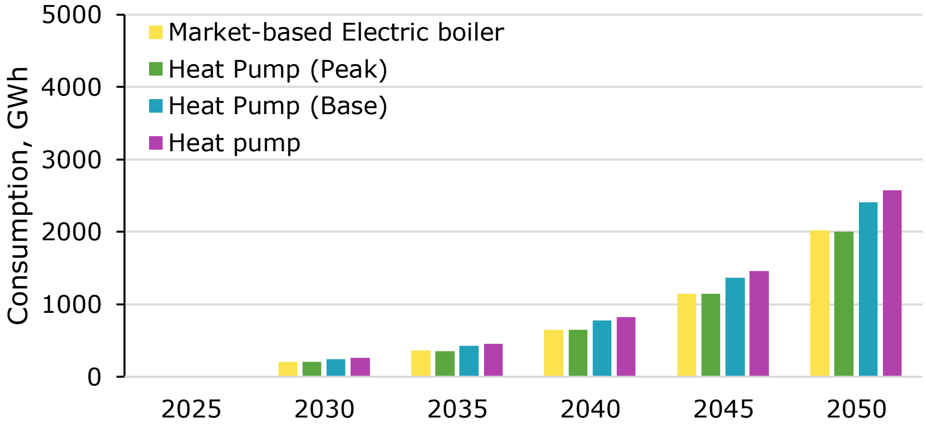


Figure 1.19. Electricity consumption in the base scenario for heating electrification

Figure 1.20 displays the peak load of the base scenario solutions. The purpose of the comparison is to ensure that the axes of the base scenario graphs are equal to those of the fast scenario graphs.

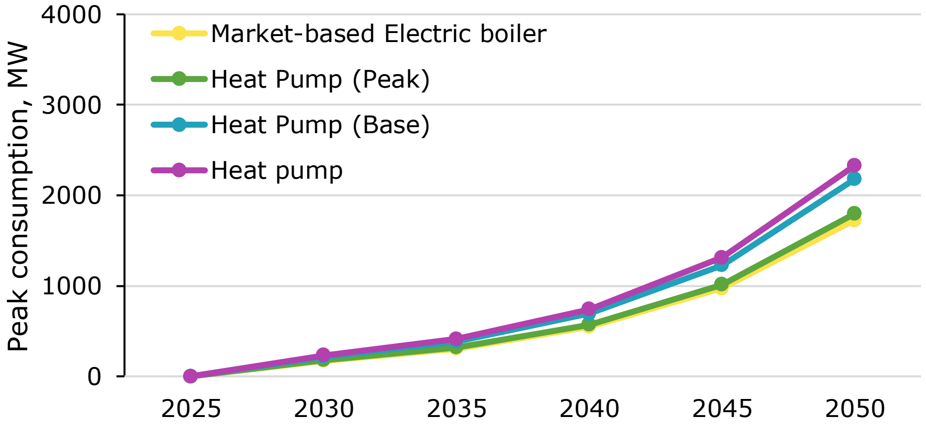


Figure 1.20. Peak consumption in the base scenario for heating electrification

Table 1.13 presents the projected electricity consumption for peak heat pump scenarios extending to the year 2050, comparing local heating (LH) and district heating (DH). It suggests a gradual increase in total consumption 2006 GWh in 2050. The service sector is expected to be the most significant contributor, followed by households and industry. For peak power demand in MW, a similar trend is observed, with an increase to 1796 MW in 2050, where again the service sector leads the demand.

The projection shows that district heating, especially in services, is expected to constitute a larger share of the total electricity consumption compared to local heating. However, local heating sees more substantial contributions from the industry and household sectors.

Table 1.13. Electricity consumption of peak and summer heat pump scenario (base)

Electrification	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total, GWh	**0**	**201**	**357**	**648**	**1142**	**2006**
LH, GWh	0	82	145	269	470	816
DH, GWh	0	119	212	379	672	1190
Industry	**0**	**13**	**22**	**52**	**82**	**121**
LH, GWh	0	11	18	43	68	100
DH, GWh	0	2	4	9	14	21
Household	**0**	**69**	**123**	**219**	**389**	**692**
LH, GWh	0	40	72	128	228	405
DH, GWh	0	29	51	91	162	287
Service	**0**	**119**	**212**	**377**	**671**	**1193**
LH, GWh	0	31	55	98	175	311
DH, GWh	0	88	157	279	496	882
Peak, MW	**0**	**180**	**319**	**571**	**1013**	**1796**
LH, MW	0	69	123	221	392	693
DH, MW	0	110	196	349	621	1104
Industry	**0**	**3**	**4**	**10**	**16**	**24**
LH, MW	0	2	4	8	13	20
DH, MW	0	0	1	2	3	4
Household	**0**	**65**	**116**	**206**	**366**	**651**
LH, MW	0	38	68	120	214	380
DH, MW	0	27	48	85	152	270
Service	**0**	**112**	**199**	**355**	**631**	**1122**
LH, MW	0	29	52	93	165	293
DH, MW	0	83	147	262	466	829

** LH – Local Heating, DH – District Heating*

Table 1.14 presents the same indicators when heat pumps are used across both base and peaks loads for both district and local heating. Here, the overall consumption is higher, indicating that continuous operation of heat pumps significantly increases electricity usage. By 2050, consumption is expected to reach 2571 GWh, with household and service sectors being major consumers. The peak power demand follows a similar trend, with the highest demand from the household sector, reaching 1040 MW in 2050.

In alignment with earlier observations, the projection reaffirms that district heating, predominantly in the service sector, will occupy a larger portion of the overall electricity consumption relative to local heating. Nonetheless, it is evident that local heating continues to receive significant uptake within the industry and household sectors.

Table 1.14. Electricity consumption of heat pump scenario (base)

Electrification	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total, GWh	**0**	**258**	**457**	**827**	**1460**	**2571**
LH, GWh	0	110	195	358	629	1097
DH, GWh	0	148	262	468	831	1474
Industry	**0**	**13**	**22**	**52**	**82**	**121**
LH, GWh	0	11	18	43	68	100
DH, GWh	0	2	4	9	14	21
Household	**0**	**111**	**197**	**350**	**622**	**1106**
LH, GWh	0	65	115	205	364	647
DH, GWh	0	46	82	145	258	459
Service	**0**	**134**	**239**	**425**	**756**	**1344**
LH, GWh	0	35	62	111	197	350
DH, GWh	0	99	177	314	559	993
Peak, MW	**0**	**233**	**414**	**739**	**1311**	**2327**
LH, MW	0	96	170	305	541	957
DH, MW	0	137	244	434	771	1370
Industry	**0**	**3**	**4**	**10**	**16**	**24**
LH, MW	0	2	4	8	13	20
DH, MW	0	0	1	2	3	4
Household	**0**	**104**	**185**	**329**	**585**	**1040**
LH, MW	0	61	108	192	342	608
DH, MW	0	43	77	137	243	432
Service	**0**	**126**	**225**	**400**	**711**	**1263**
LH, MW	0	33	59	104	185	330
DH, MW	0	93	166	295	525	934

** LH – Local Heating, DH – District Heating*

The difference in electricity consumption between the two scenarios is not as substantial as might be expected, despite the additional base load usage in Table 1.15. This is likely due to the fact that heat pumps operate with a higher COP during base load conditions, which are typically milder temperature ranges where heat pumps can operate more efficiently. In contrast, during peak load conditions, which are associated with more extreme temperatures, the COP is lower, meaning that more electricity is required to deliver the same amount of heating. Consequently, even though heat pumps are used more frequently in the scenario depicted in Table 1.15, the overall energy efficiency during base load operations moderates the increase in electricity consumption.

District heating, particularly within the service sector, emerges as a predominant consumer of electricity, pointing towards an increasing reliance on centralized heating solutions in commercial and public spaces. Conversely, local heating is more prominently utilized in industrial and residential sector.

1.4.2 Fast scenario electrification

The following is a list of potential electrification fast scenario figures and tables containing the results. The projections in this chapter describe an accelerated adoption rate for electrification within both local and district heating systems.

Figure 1.21 presents the electricity consumption levels for various technical solutions following the electrification of the fast scenario.

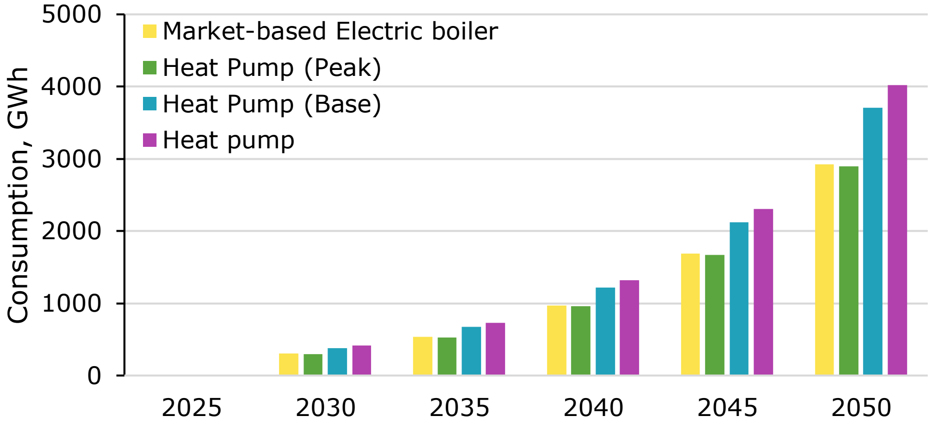


Figure 1.21. Electricity consumption in the fast scenario for heating electrification

Figure 1.22 displays the peak load of the fast scenario solutions.

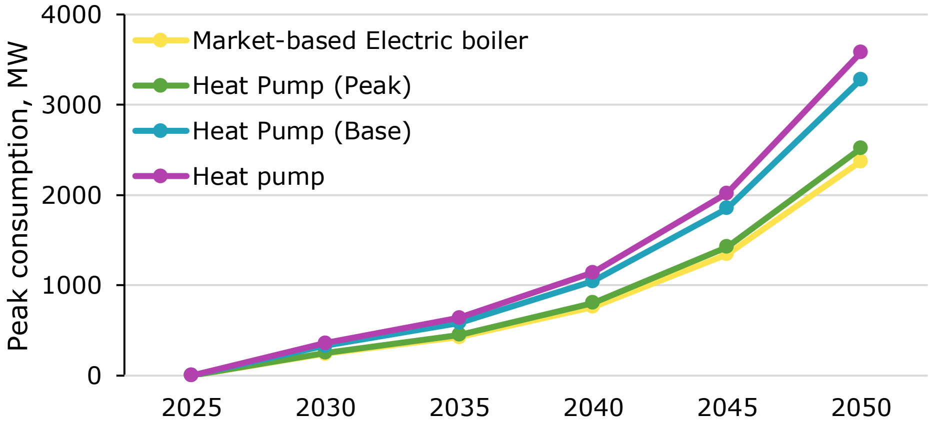


Figure 1.22. Peak consumption in the fast scenario for heating electrification

Table 1.15 shows the fast scenario growth values of electricity consumption resulting from the use of market-based electric boilers and local heating heat pumps in district heating networks. The growth in consumption is more pronounced in this scenario, consuming 2893 GWh in 2050. The service sector again shows the highest demand, indicating its potential scale and reliance on electric boilers. The peak power demand also reflects a significant increase, particularly in the service sector, escalating to 1162 MW by 2050.

In the fast scenario presented, the gap between local heating and district heating consumption narrows significantly when compared to the base scenario.

Table 1.15. Electricity consumption of market-based electric boiler scenario (fast)

Electrification	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total, GWh	**0**	**299**	**528**	**959**	**1669**	**2893**
LH, GWh	0	144	253	466	798	1357
DH, GWh	0	155	275	493	871	1536
Industry	**0**	**37**	**62**	**130**	**196**	**273**
LH, GWh	0	31	51	108	162	226
DH, GWh	0	6	11	23	34	47
Household	**0**	**138**	**246**	**438**	**778**	**1384**
LH, GWh	0	81	144	256	455	809
DH, GWh	0	57	102	182	323	575
Service	**0**	**124**	**220**	**391**	**695**	**1236**
LH, GWh	0	32	57	102	181	322
DH, GWh	0	91	162	289	514	913
Peak, MW	**0**	**254**	**450**	**805**	**1424**	**2517**
LH, MW	0	112	199	358	630	1108
DH, MW	0	141	251	447	794	1409
Industry	**0**	**7**	**12**	**26**	**38**	**54**
LH, MW	0	6	10	21	32	44
DH, MW	0	1	2	4	7	9
Household	**0**	**130**	**231**	**412**	**732**	**1301**
LH, MW	0	76	135	241	428	761
DH, MW	0	54	96	171	304	540
Service	**0**	**116**	**207**	**367**	**653**	**1162**
LH, MW	0	30	54	96	170	303
DH, MW	0	86	153	272	483	859

** LH – Local Heating, DH – District Heating*

Table 1.16 presents the same indicators when heat pumps are used for both district and local heating. The total electricity consumption here is markedly higher, reaching 4022 GWh by 2050, with household and service sectors leading the demand. The peak power demand exhibits a steep rise as well, with demand surging to 3578 MW by 2050, which is significantly higher than in the previous scenarios.

Table 1.16. Electricity consumption of heat pump scenario (fast)

Electrification	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Total, GWh	**0**	**412**	**729**	**1316**	**2304**	**4022**
LH, GWh	0	200	353	643	1114	1920
DH, GWh	0	212	376	672	1189	2102
Industry	**0**	**37**	**62**	**130**	**196**	**273**
LH, GWh	0	31	51	108	162	226
DH, GWh	0	6	11	23	34	47
Household	**0**	**221**	**393**	**700**	**1244**	**2212**
LH, GWh	0	129	230	409	727	1293
DH, GWh	0	92	163	290	517	919
Service	**0**	**154**	**273**	**486**	**864**	**1537**
LH, GWh	0	40	71	127	225	401
DH, GWh	0	114	202	359	639	1136

Electrification	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Peak, MW	**0**	**360**	**639**	**1140**	**2021**	**3578**
LH, MW	0	165	293	525	928	1637
DH, MW	0	194	346	615	1093	1941
Industry	**0**	**7**	**12**	**26**	**38**	**54**
LH, MW	0	6	10	21	32	44
DH, MW	0	1	2	4	7	9
Household	**0**	**208**	**370**	**658**	**1170**	**2080**
LH, MW	0	122	216	385	684	1216
DH, MW	0	86	154	273	486	864
Service	**0**	**145**	**257**	**457**	**813**	**1445**
LH, MW	0	38	67	119	212	377
DH, MW	0	107	190	338	601	1068

** LH – Local Heating, DH – District Heating*

1.4.3 Conclusion

The analyses across chapters convey a consistent trend where district heating, especially in service sectors, is projected to claim a greater portion of electricity consumption. However, the fast scenario indicates a marked shift, with local heating—predominantly in industrial and residential areas—gaining ground, suggesting a future where the distinction in electricity usage between the two systems becomes less pronounced.

Amidst these projections, it's crucial to approach the interpretation of local heating electrification with caution. The complexities introduced by the intertwining factors of national economic growth and the inherent uncertainties in forecasting models necessitate a careful analysis. The anticipated overall growth in electricity consumption complicates the task of isolating the increase attributable solely to the electrification of local heating. Therefore, while the projections provide valuable insights, they should be considered as part of a larger, dynamic framework subject to variabilities and economic trends.

2. Electrification of cooling

2.1.1 Definitions

- Coefficient of Performance (COP) of a heat pump, refrigerator or air conditioning system is a ratio of useful heating or cooling provided to work (energy) required.
- The Energy Efficiency Ratio (EER) is ratio of output cooling energy to input electrical energy.
- Seasonal coefficient of performance (SCOP) is a metric that measures the energy efficiency of a heat pump over an entire heating season.
- Seasonal energy efficiency ratio (SEER). The SEER rating of a unit is the cooling output during a typical cooling-season divided by the total electric energy input during the same period. Users must be cautious when referencing American data sheets that often provide EER values. These figures are based on the unit's capacity measured in BTUs. To convert the American EER to the equivalent EU EER, divide it by 3.414. A SEER of 13 is approximately equivalent to an EER of 11, and a COP of 3.2 [18] [19].
- European seasonal energy efficiency ratio (ESEER) is calculated by combining full and part load operating Energy Efficiency Ratios (EER), for different seasonal air or water temperatures, and including for appropriate weighting factors.

2.1.2 Baseline

In 2021, a KPMG analysis used building floor area data from 2015 and estimated the theoretical cooling demand to be 313 GWh. Electricity consumption for cooling depends on the COP (Coefficient of Performance) of cooling equipment [20]. Based on average COP of 3, the theoretical consumption of electricity for such cooling demand is approximately 104 GWh. In the 2022 strategy conducted by Trinomics, it was estimated that the electricity used for cooling in 2021 was approximately 325 GWh [21].

The electricity consumption has doubled between the two analyses, with a 5-year gap in the data used. Both methodologies relied on building floor area and rule-of-thumb guidelines for estimating cooling energy consumption. Detailed information about cooling is lacking because consumers do not have the capability to differentiate cooling energy, and the statistical agency does not distinguish cooling consumption separately. Consequently, the rapid increase in cooling demand can be attributed to the growing GDP allowing people to invest in comfort due to the frequent heat waves caused by climate change.

2.1.3 Model Assumptions

Based on various academic and research papers [22] [23] [24] [25] [26] [27] [28] [29] [30], the energy consumption for cooling in residential buildings is 40 W/m^2, while for commercial buildings, it's 65 W/m^2. Electricity consumption is correspondingly 11 W/m^2 and 19 W/m^2. The annual average energy consumption is 3 kWh/m^2 for residential buildings and 20 kWh/m^2 for commercial buildings. The extremes of electricity consumption and power depend significantly on the COP (Coefficient of Performance) of cooling equipment. The average SCOP (Seasonal Coefficient of Performance) for heat pumps and chillers is 3.5, but during the summer period, the EER (Energy Efficiency Ratio) value for cooling can range from 4 to 9. However, efficiency improves significantly when water cooling is used, but cooler climatic region market opts for air cooled chillers [31] [32].

In interviews with district cooling market participants, the values referenced in the academic works of 40-65 W/m^2 are more of a design maximum to ensure uniform cooling in all spaces. This aligns with the values designed for district cooling, but practical experience shows that actual peak consumption is 70% of the designed value. District cooling networks utilizing external heat sources such as rivers, lakes, or seas have the potential to achieve an annual average EER (Energy Efficiency Ratio) of up to 10.

Climespace, a subsidiary of Engie, manages Europe's largest district cooling network, which comprises six major plants in the central district cooling system with a total capacity of 215 MW and four more plants outside the central network, resulting in a total cooling capacity of 285 MW. This extensive network delivers chilled water sourced from the River Seine and cooled to serve five million square meters of space in hotels, offices, government buildings, theatres, and museums. This results cooling capacity of 57 W/m^2 [33].

Local heat pump equipment suppliers, focusing on residential consumers, offer devices for cooling with a cooling capacity of 90 W/m^2 and electric power of 12 W/m^2, with SEER 7.5. The electricity consumption for cooling amounts to up to 3.5 kWh/m^2. It should be noted that suppliers of local heat pump equipment currently primarily sell heat pumps for heating purposes, so the cooling capacity depends on the heating capacity, making it somewhat oversized in that regard [34] [35] [36].

In conclusion, the extreme cooling power consumption model uses the following assumptions:

- Specific electricity power of 11 W/m^2 for single and apartment buildings. It is calculated from cooling capacity of 40 W/m^2 divided by COP of 3.5.

- Specific electricity power of 19 W/m^2 for commercial and service buildings. It is calculated from cooling capacity of 65 W/m^2 divided by COP of 3.5.

2.1.4 Initial model consumption

Figure 2.1 illustrates the electrical power at peak load. Figure 2.2 presents the forecast for electricity consumption. **Both figures depict the extreme scenario where all buildings will require cooling by 2050.** Below are some reasons why we should critically evaluate this extreme forecast.

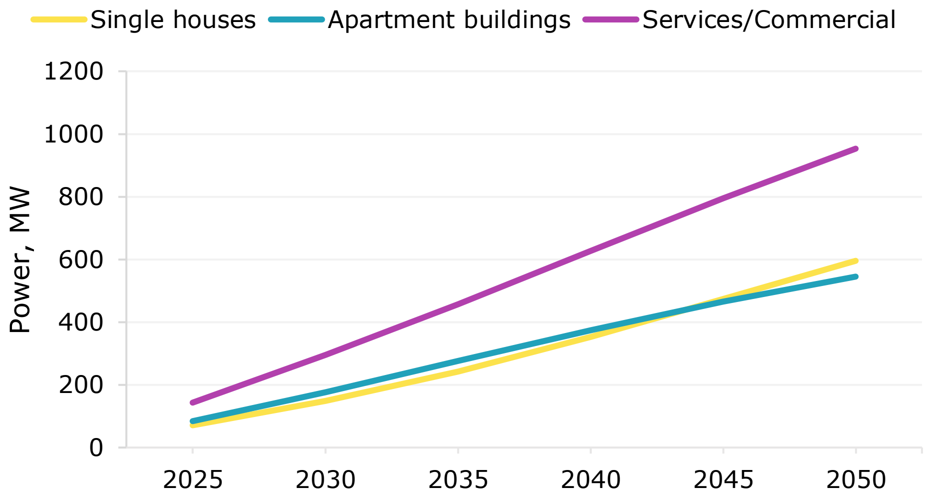


Figure 2.1. Extreme peak power consumption of cooling

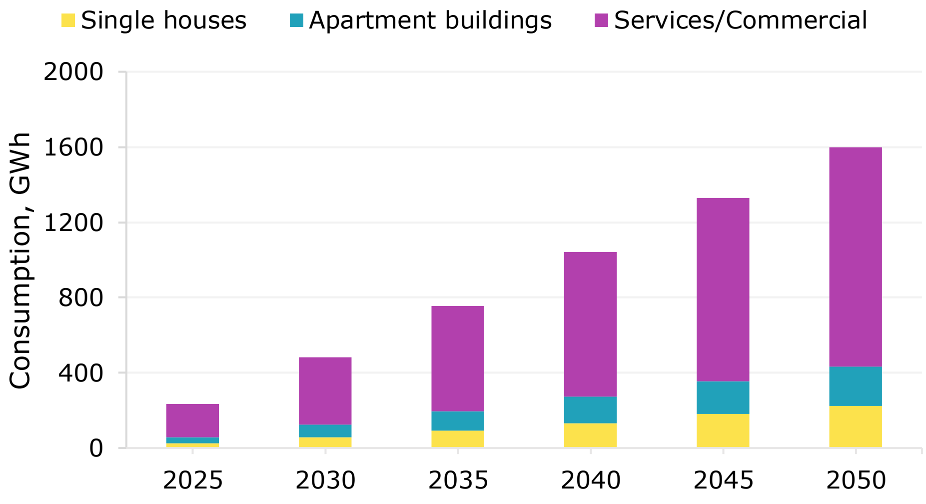


Figure 2.2. Extreme cooling electricity consumption potential

Inaccuracies in Assumptions
Cooling capacity and electricity consumption have been projected based on current and new buildings. Therefore, constant cooling loads have been used. The design and architecture of buildings significantly influence the need for mechanical cooling and other energy services. While factors like cost, aesthetics, and space use are often prioritized in design decisions,

energy efficiency is a crucial consideration. The future building energy efficiency strategies could significantly alter energy consumption per unit area [33].

The primary driver of cooling demand is climate, particularly air temperature and humidity. Furthermore, the forecast does not account for the fact that cooling loads will increase with rising ambient temperatures as the model does not have an ambient temperature forecast which accounts climate change. The primary climatic factor influencing the need for space cooling is air temperature, with humidity also playing a role [33].

Since the electricity consumption model anticipates overall growth due to the growth of the national economy, it becomes challenging to distinguish the increase in electricity consumption due to cooling because an unknown portion of cooling is already included in the overall electricity consumption growth.

Furthermore, in the context of building renovations, there is a strong likelihood of integrating solar panels to attain the required energy efficiency. These solar panels can effectively supply electricity to cooling systems during peak demand periods, a concept referred to as solar cooling. With solar panels generating up to 150 W/m^2 of power, surpassing the energy demands of cooling systems, this approach guarantees that the overall electricity consumption remains unaltered by cooling systems [33].

Market Uncertainty
Currently, it is unlikely that all existing residential and apartment buildings will establish local cooling capabilities. Present-day new developments do not include cooling capabilities. Although this may change in the future, local cooling implies a higher real estate cost that residents must be willing to bear, and establishing this capability may deter price-sensitive buyers.

Regulatory Constraints
The establishment of local cooling equipment within urban areas is restricted in environmentally sensitive and heritage-protected areas. Legalizing heat pumps may be a significant barrier limiting the growth of local cooling use in existing buildings in these protected areas [37].

District Cooling
District cooling networks distribute chilled water from a central plant to buildings and industrial sites. Typically, this chilled water is produced using technologies like commercial air conditioning, albeit on a larger scale. In some locations, natural sources like groundwater, rivers, or the sea may partially or fully chill the water – a method known as "free" or natural cooling. Heat from various sources, including district heating, industry, geothermal, or solar thermal, can also be used with absorption chillers. District cooling systems often include storage. This reduces capacity requirements, enhances energy efficiency, and provides flexibility, such as producing chilled water during low electricity price periods. Integrated designs that combine heating, cooling, and thermal storage can achieve high system efficiencies [33]. Market participants argue that, compared to local devices, district cooling with external heat source can reduce electricity consumption by up to 70%-85% [38]. Without external source the savings

are up to 30%. It is in the interest of the electrical grid operator to support the development of district cooling to prevent overloading the grid with local cooling equipment.

It is most likely that the service sector's cooling capacity will continue to grow [39] [40] [41]. However, it is unlikely that the whole service sector will convert to district cooling. Market participants project that the district cooling potential (cooling capacity) in Estonia for 2030 could reach approximately 120 MW_c and 150 MW_c in 2040. The planned district cooling capacities are 80-90 MW_c for Tallinn, 30 MW_c for Tartu, and 7 MW_c for Pärnu. Based on the average estimated EER of 10, this would require approximately 12 MW_e of electric power.

Regular comparable local cooling system has an annual average EER of 3. The district cooling system built in 2016 with a cooling capacity of 13 MW_c has an annual average EER of 10. Another district cooling system established in 2019 with a cooling capacity of 10 MW_c has an annual average EER of 7. The greater the availability of free cooling from an external source, the higher the EER value that can be attained. Electrical chillers operate from April to October, while the remainder of the year relies on free cooling, with pumps being the primary energy consumers.

Energy labels

In addition, buildings’ energy labels can incentivize more buildings to consider district cooling. This is because the energy carrier conversion factors used in energy label calculations favour district cooling with conversion factors ranging from 0.2 to 0.4, while electricity is at 2. Consumption of more efficient energy carrier enables buildings to consume more energy while achieving or maintaining the required energy label [42].

2.1.5 Revised model consumption

The revised power consumption model is based on the following assumptions:

- The model establishes the percentage of buildings that install cooling systems. Cooling systems are installed in buildings with energy labels "A," "B," or "C".

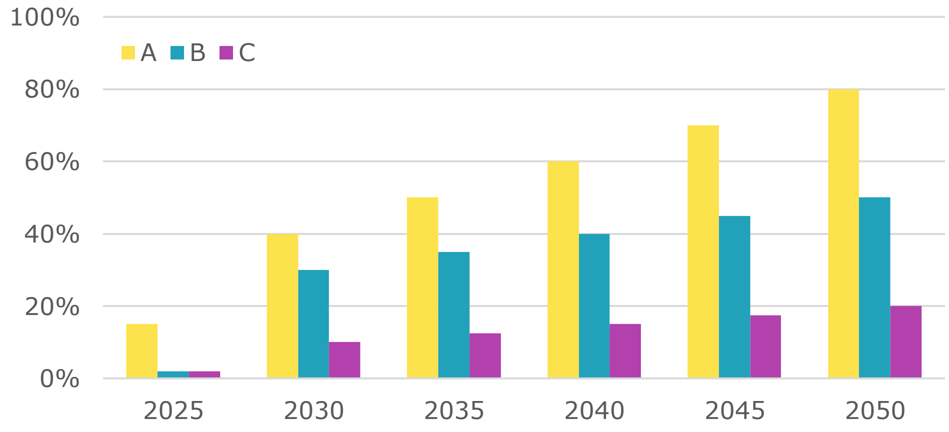


Figure 2.3. Assumptions About Cooling Capacity Based on Energy Efficiency Labels

- The model anticipates that energy labels for the renovated and new buildings.

Figure 2.4. Energy Efficiency Labels: Renovated Buildings (Left) and New Buildings (Right)

- The model sets the proportion of buildings with an "A" energy label that install cooling systems and can sustain their "A" rating thanks to PV panels. It also establishes the percentage of buildings that, with solar panels, ensure that the energy consumed by their installed cooling systems does not require additional electricity from the grid.

- The model estimates a ratio of district cooling to local cooling primarily at the county level and computes the electrical energy consumption of local cooling. District cooling electrical energy consumption is not calculated separately, as it is assumed to be already accounted for in the base model. Such assumption is made because district cooling in Estonia has expanded within district heating networks which correlates with the overall growth of the GDP. Particularly as no significant changes are expected in this sector, this factor of basic growth has already been incorporated into the base consumption model projections. In addition, by combining heating and cooling systems, it's possible to utilize waste heat from cooling processes for heating purposes and vice versa which can significantly improve overall energy efficiency.

Figure 2.5 depicts the electrical power at peak load in the revised model and Figure 2.6 displays the electricity consumption forecast. When compared to the extreme model, the revised model shows a significant reduction, with peak load electrical power and consumption both being halved.

When interpreting the model results, it's important to keep in mind that it is an estimation, and producing an accurate estimate is not possible due to the lack of a comprehensive building database regarding energy labels and the installation of cooling systems. To create a better model, Statistics Estonia would need to initiate the tracking of energy labels assigned to buildings over time and request buildings to begin separately measuring cooling energy consumption.

The revised model projected increase in electric power and electrical energy consumption of cooling systems for different types of buildings in the future. The data suggests that cooling demand will rise significantly from 2025 to 2050, especially for services/commercial buildings, which will consume more power and energy than single houses and apartment buildings combined. This implies that cooling systems will have a large impact on the power grid and that more efficient and sustainable solutions are needed to meet the growing cooling needs.

Regarding the peak power and energy consumption for cooling:

- The cooling demand is projected to increase for all building types.
- Services/commercial buildings will experience the highest increase in peak electrical power and energy demand, followed by apartment buildings, with single houses having the least increase.
- By 2050, services/commercial buildings are expected to require a peak electric power of approximately 477 MW_e, which is substantially higher than single houses (178 MW_e) and apartment buildings (303 MW_e). Services/commercial buildings could consume electricity around 584 GWh, while apartment buildings and single houses are projected to consume 115 GWh and 67 GWh, respectively.
- By 2050, the demand for cooling in services/commercial buildings is projected to more than double from the levels in 2035, with peak power consumption and energy use escalating significantly. The increase in this sector far outpaces that of apartment buildings and single houses, which are also set to experience a considerable rise in cooling needs. Apartment buildings will see their peak demand and energy usage grow to over three times, and single houses to nearly four times their respective 2035 figures.

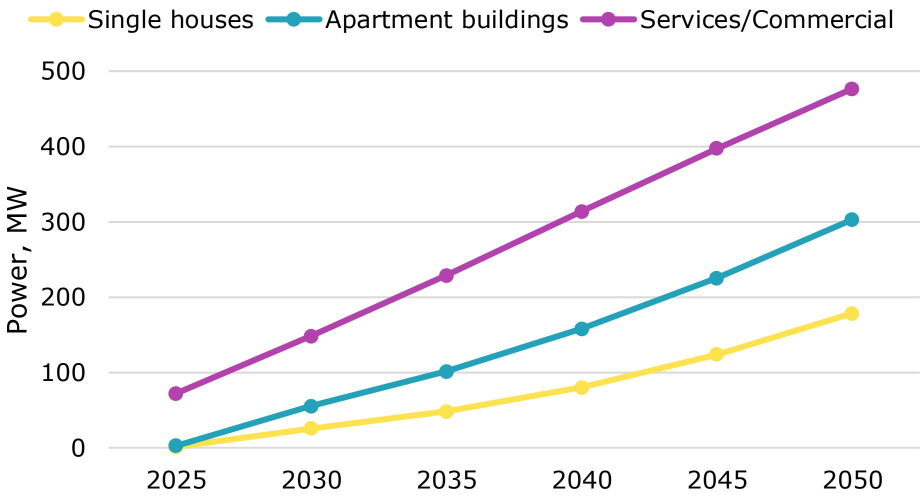


Figure 2.5. Potential peak power consumption of cooling

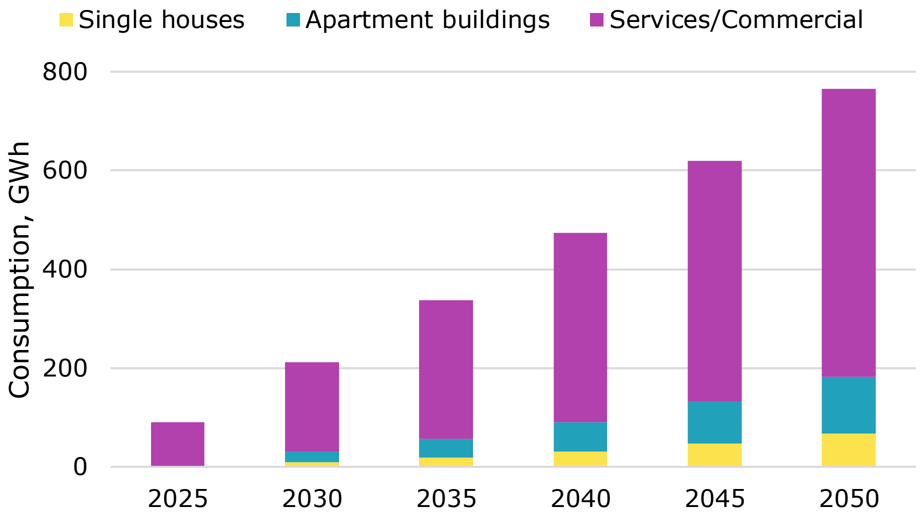


Figure 2.6. Cooling electricity consumption potential

Table 2.1. Potential peak power consumption of cooling (MW$_e$)

Building type	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Single houses	1	26	48	80	124	178
Apartment	3	55	101	158	225	303
Services/Commercial	72	148	229	314	398	477
Total, MW$_e$	**76**	**229**	**378**	**552**	**747**	**958**

Table 2.2. Cooling electricity consumption potential (GWh$_e$)

Building type	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Single houses	0	10	18	30	47	67
Apartment	1	21	38	60	85	115
Services/Commercial	88	181	281	384	487	584
Total, MW$_e$	**90**	**212**	**337**	**474**	**619**	**766**

3. Electrification of transport

3.1 General

3.1.1 Overview of electrification in automotive industry

Nowadays the source of 29% of the EU total greenhouse gas emissions is transportation. The largest contributors being passenger cars (15%) and heavy-duty vehicles (5%) [43]. Despite emissions decreasing by 32% in various sectors since 1990, the transportation sector has seen instead a 33% increase in emissions over the same period [44] [45]. The sector has undergone a significant transformation with far-reaching consequences throught the widespread adoption of electric vehicles (EVs). With mounting concerns about climate change and air pollution, the shift towards Evs has become both a response and a global necessity. Electrification offers the potential to decrease greenhouse gas emissions while improving energy efficiency and lessening our dependence on fossil fuel reserves. Furthermore, it fosters innovation, driving advancements in battery technology, charging infrastructure, and sustainable transportation solutions. Beyond environmental benefits, electric vehicles offer a quieter, smoother, and more technologically advanced driving experience. They also present an economic opportunity since governments and industries worldwide investing heavily in the EV ecosystem. The electrification of the automotive sector is fundamentally more that just a trend; it is a fundamental transformation that shapes the future of mobility, offering a cleaner, smarter, and more sustainable way forward for both individuals and societies.

3.1.2 Sales of electric vehicles in Europe

In the following table (Table 3.1) the share of electric passenger vehicles in the sales of all new passenger vehicles in European countries are described. Prior to the year 2016, in most European countries the share of EVs from sales of all new passenger vehicles hovered around a few percent and hence that data has been truncated from the table. The only clear exception to this is Norway. A clear uptrend of sales can be seen in recent years. However, Estonia is clearly in the bottom of the sales charts.

Table 3.1. Share of electric vehicles in new passenger cars

	2016	2017	2018	2019	2020	2021	2022
Norway	15%	20%	29%	41%	53%	64%	79%
Sweden	1%	1%	2%	4%	10%	19%	33%
Iceland	-	3%	4%	8%	24%	27%	-
Netherlands	1%	2%	5%	14%	21%	20%	24%

Liechtenstein	2%	3%	3%	5%	11%	18%	21%
Denmark	1%	0%	1%	2%	7%	13%	21%
Finland	0%	0%	1%	2%	4%	10%	18%
Germany	0%	1%	1%	2%	7%	14%	18%
Switzerland	1%	2%	2%	4%	8%	13%	17%
Austria	1%	2%	2%	3%	6%	14%	16%
Malta	0%	0%	3%	4%	4%	8%	15%
Luxembourg	-	-	-	-	5%	10%	15%
Ireland	0%	0%	1%	3%	4%	8%	15%
France	1%	1%	1%	2%	7%	10%	14%
Portugal	-	1%	2%	3%	6%	9%	12%
United Kingdom	0%	1%	1%	-	-	11%	-
Belgium	0%	0%	1%	2%	3%	6%	10%
Romania	0%	0%	0%	1%	2%	6%	10%
Latvia	0%	0%	0%	1%	3%	3%	7%
Slovenia	0%	0%	1%	1%	3%	4%	6%
Lithuania	0%	0%	0%	0%	1%	5%	6%
Hungary	0%	1%	1%	1%	2%	4%	4%
Italy	0%	0%	0%	1%	2%	5%	4%
Spain	0%	1%	1%	1%	2%	3%	4%
Cyprus	0%	0%	0%	0%	0%	1%	3%
Estonia	0%	0%	0%	0%	2%	2%	3%
Croatia	0%	0%	0%	0%	1%	3%	3%
Greece	-	-	-	-	-	2%	3%
Poland	1%	1%	0%	0%	0%	1%	3%
Türkiye	0%	0%	0%	0%	0%	1%	1%

In Table 3.2 we can observe the registrations of new vehicles in Estonia in last years. If we exclude the year 2020, which was exceptional due to the COVID-19 pandemic, registrations of passenger vehicles has stayed on a similar level. We can observe that although the share of EVs in cars imported to Estonia is still relatively small, their share is quickly increasing. By 1st October 2023, more EVs had been registered than during the entirety of 2022. This is a clear indication of accelerating demand.

Table 3.2. Registrations of passenger vehicles (M1(G)) in Estonia

	2018	**2019**	**2020**	**2021**	**2022**	**2023***
Used	24 090	25 376	19 965	26 637	29 177	18 675
including EVs	34	88	120	289	479	759
New	26 311	27 591	19 294	22 611	20 563	17597
including EVs	83	77	344	487	693	1029
Total	**50 401**	**52 967**	**39 259**	**49 248**	**49 740**	**36 272**

** 1st October 2023*

In Table 3.3 entire fleet of Estonian passenger vehicles is presented, this includes only vehicles with an active registration, vehicles which had a suspended registration, were excluded. As one can observe, it is likely that by the end of 2023, the fleet of EVs in Estonia will nearly double.

Table 3.3. Status of passenger vehicles in Estonia

	2019	**2020**	**2021**	**2022**	**2023***
All passenger vehicles	621 804	624 614	634 039	649 592	659 127
including EVs	1 359	1 750	2 424	3 422	5 105

** 1st October 2023*

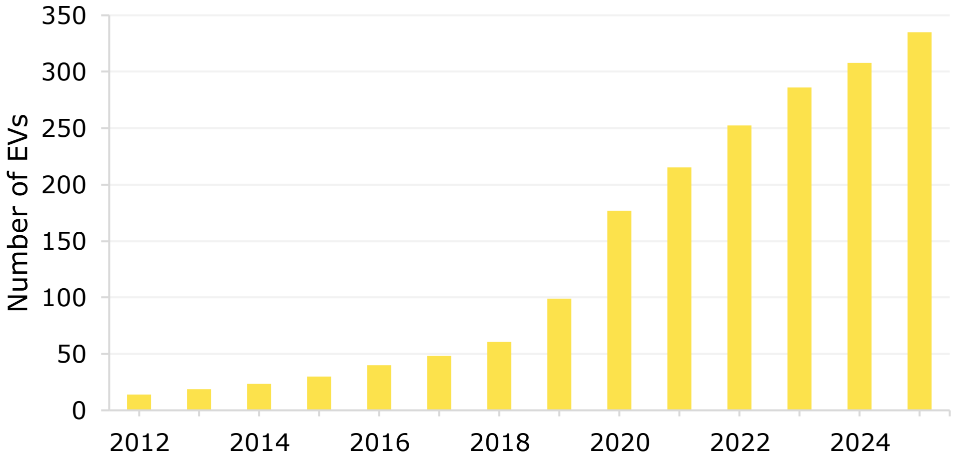
3.1.3 EV manufacturers' supply outlook

The overarching aim of European car manufacturers within the framework of cutting emissions and expanding their EV market share is to spearhead a sustainable automotive revolution. They key objective is to achieve 90% reduction in transport emissions by the year 2050 [46]. In line with this, the new EU CO_2 standards will require the average emissions of new cars to come down by 55% and of the new vans by 50% by 2030 [47].

The European Commission has mandated the cessation of new thermal vehicle marketing starting in 2035. Furthermore, it dictates the end of sales for new cars excluding those for businesses. [48]This directive is in accordance with the new EU law, which necessitates that all new cars sold from 2030 must have CO_2 emissions that are 55% lower than those in 2021 [49]. The end of sales of new heavy-duty vehicles used to transport people or goods and using mostly fossil fuels is also announced for 2040.

Listing plan of major European car manufacturers

Prominent figures in the European construction industry are embracing the concept of "eco-friendly transportation" as can be seen in Figure 3.1 and Figure 3.2. This coincides with the entrance of a determined new Chinese manufacturer seeking to establish a foothold in the European market [50].



Going into more detail, Volkswagen's "New Auto" plan for 2030 includes to become of the top five selling brands in Europe adopting a quite aggressive strategy by setting a target of 80% EV sales in Europe and 55% in North American by 2030 [51]. Its intention is to launch at least three more electric models before 2025 and and approximately 70 all-electric models by 2030, 20 of these being already in production [52].

Stellantis Group, which consists of Italian–American conglomerate Fiat Chrysler Automobiles and the PSA Group (Peugeot, Citroën, DS, Opel, Vauxhall), have set a course for the year 2030 to have 100% of sales in Europe and 50% in the US to be battery electric vehicles (BEV). [53] The plan is expected to be executed via 3 giga factories. The launching of two new battery chemistries from 2024 is also included.

Renault Group intends to possess the greenest mix in the European market in 2025 with over 65% of electric and electrified vehicles in the sales mix and up to 90% electric vehicles in the Renault brand mix in 2030 [54]. Two giga factories are planned to be built in France, the first by 2024 and the latter by 2026.

Mercedes has announced that from 2030 onward they will become entirely an electric brand. This will be accomplished by the shorter term aims which include that from 2022 Mercedes-Benz had battery electric vehicles in all segments the company serves. From 2025 onwards, all newly launched vehicle architectures will be electric-only, and customers will be able to choose an all-electric alternative for every model the company manufactures [55]. The full electrification plan would require at least 200GWh battery capacity which roughly means 8 giga factories worldwide announced by the CEO.

Overall, the recent market trend towards EVs in Europe has been remarkable. In 2020, Europe not only exceeded China but also claimed the position of the largest glabal market for EVs in both sales volume and market share as can be seen in Figure 3.3. Despite an overall decline in car sales across Europe during that year due to the pandemic, EV registrations had more than doubled, surging to 1.4 million units, constituting 10% of the market. In contrast, China and the United States recorded lower figures, with 6% and 2% respectively. This trend has persisted into 2021, with EVs continuing to experience significant growth in Europe, accounting for 15% of cumulative sales through May. Europe's substantial lead in the EV market asserting its influence on the global stage.

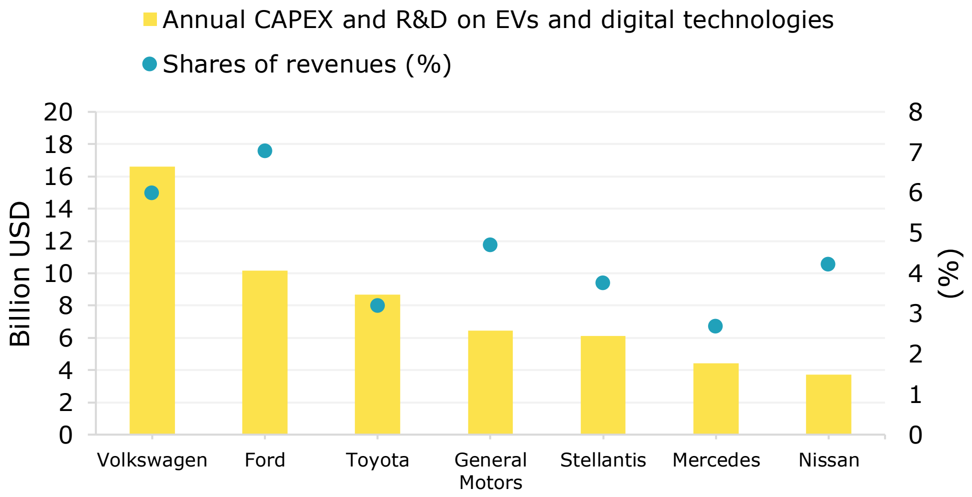


Figure 3.1. Annual CAPEX and R&D spending commitments on EVs and digital technologies by selected automakers for the year 2019-2022 [56] [56]

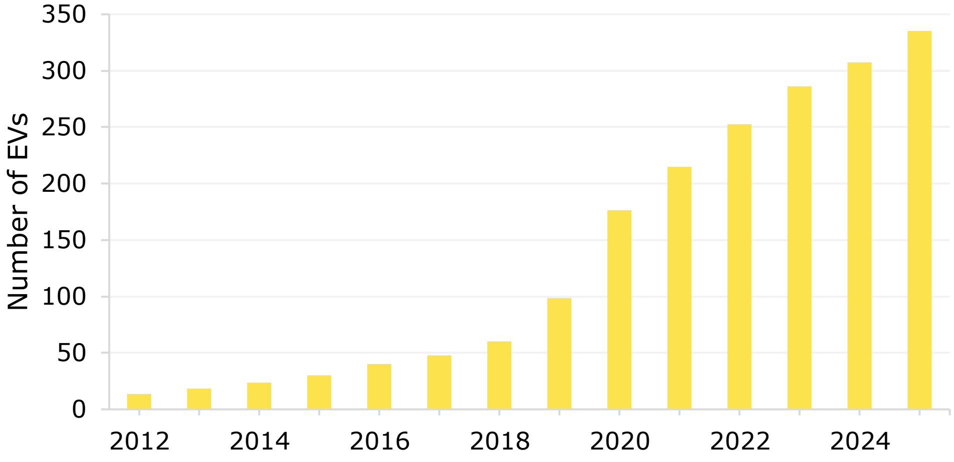


Figure 3.2. Number of EVs (PHEVs and BEVs) models launched and planned to be launched until 2025 by OEM group in Europe [50] [57]

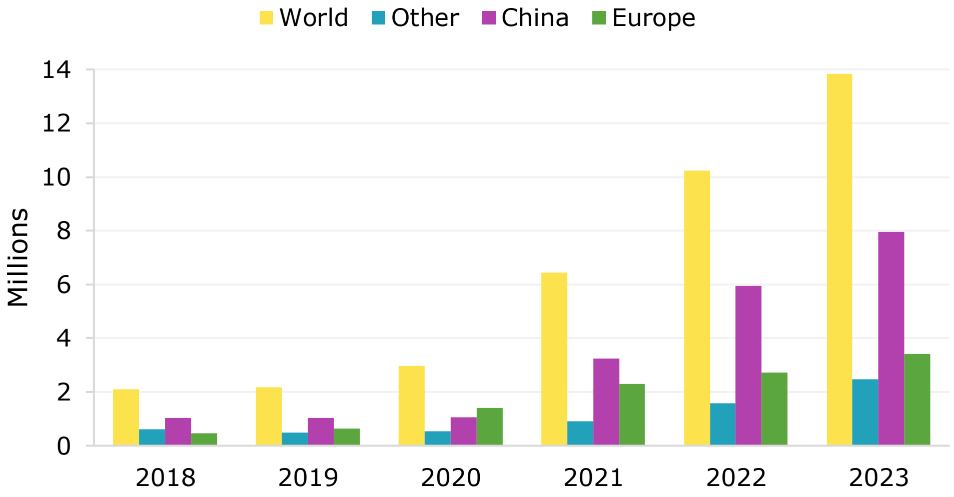


Figure 3.3. Electric car sales per region for the years 2018-2023 [56] [56]

Battery technology Advancements

European car manufacturers are actively investing in research and development to enhance the efficiency, energy density and affordability of batteries. These advancements have the potential to make mass production of electric vehicles more viable. Improved battery technology does not only allow longer driving ranges but also helps lower production costs thus making electric vehicles more accessible to a wider range of consumers. As a result, the supply outlook for cars in Europe is expected to improve as manufacturers become better equipped to meet the increasing demand.

When we analyse the supply of cars in the European market, it is important to consider the various factors that shape the automotive industry. One crucial aspect is the market capitalization of car companies, which has an impact on the growth and transformation of the industry. Market capitalization does not only indicate stability and investment capacity but also provides insights into investor sentiment, competitive positioning, and growth prospects. In this context it plays a role in determining car manufacturers' ability to meet the increasing demand for electric vehicles.

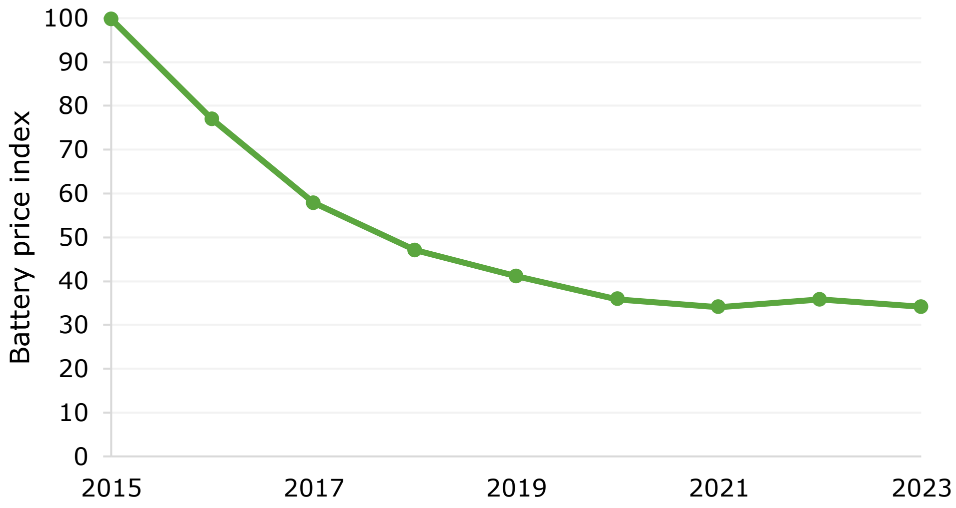


Figure 3.4. Battery price index of lithium-ion battery for the years 2015-2023 [56] [56]

Potential challenges

- Battery range

The transformative transition is not without its challenges. In this section, we delve into the multifaceted obstacles and potential roadblocks that may slow down the adoption of EVs and hinder their market penetration when compared to their conventional internal combustion engine (ICE) counterparts. We can break down these challenges into different aspects. These would include EVs' technology that should compete with the already established technology of internal combustion regarding for instance range and refuelling but also infrastructure, consumer behaviour and economic considerations. As regards to the latter, the initial cost of purchase especially without the available EU subsidies is a significant barrier to the adoption of electric vehicles for the majority of Europeans. Data on this aspect is presented in the following Economic viability section.

Another issue to contend with is the limited range of electric vehicles, despite advancements in battery technology displayed in Figure 5. The average driving range of electric vehicles worldwide for 2021 was 349 km, increased by almost 106 km from 2016. However, as one could deduce, there exists the potential for the range distance to increase even more.

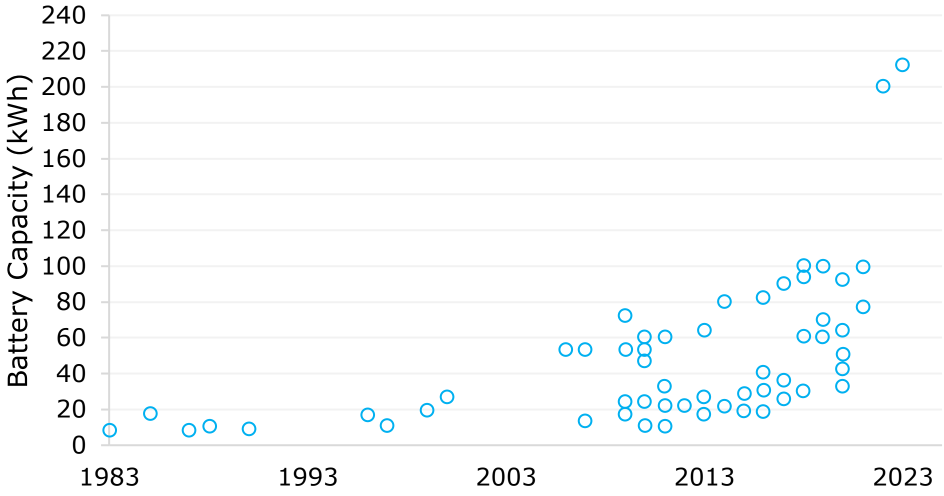


Figure 3.5. Development of batteries' capacity from 1980 till 2025 [58] [58]

- Charging infrastructure

Despite the fact that demand for charging can be met by home charging, accessible public charging stations are highly needed. Thus, the charging infrastructure should be driven in two directions: increase in the number of public charging points as well as of the installations of the appropriate technology for fast charging. The necessity of the latter cannot be easily argued because people would not prefer EVs if their stop time during long trips would be over 30 to 45 minutes.

More than half of the world's public slow chargers were located in China as of the end of 2022. Europe comes in second with 460.000 slow chargers overall in 2022, up 50% from the previous year. In Europe the overall fast charger stock numbered over 70.000 by the end of 2022, an increase of around 55% compared to 2021 as one can see in the following Figure 3.6 [56]. For EV adoption to be widely accepted, public charging infrastructure must be set up in advance of an increase in EV sales.

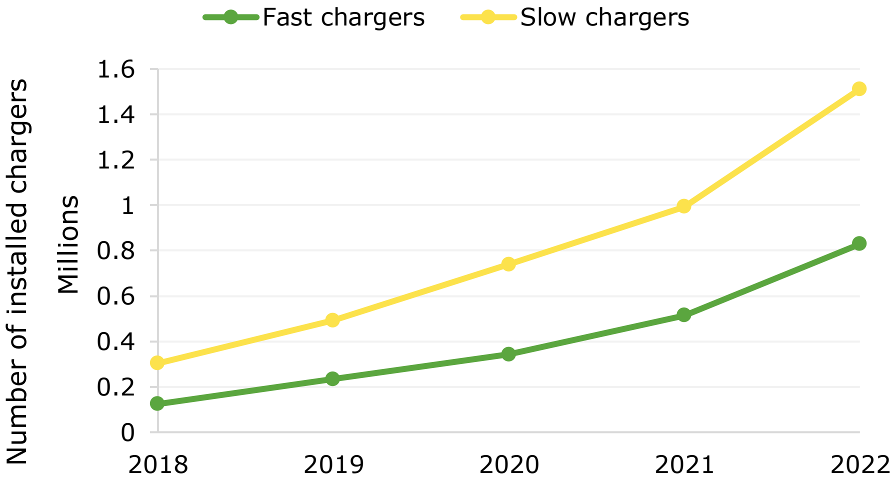


Figure 3.6. Publicly accessible light-duty vehicle charging stations installed in Europe 2018–2022 [56]

In the year 2022, the market share of Zero Emission Vehicles (ZEVs) - comprising of Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles, witnessed a notable surge across all markets. The share was globally increased from 6% to 10.6%, in the EU from 9 to 12.5%, in non-EU EEA countries from 61.4% to 77.2% (26% of this share derives from Norway) and from 0.1 to 7.3% in other Europe for the years 2021 and 2022 respectively [1].

Table 3.4. New sales share projections for Zero Emission Vehicles by scenario and vehicle type; Baseline scenario: Represents the status quo, recently adopted policies; Momentum scenario: Considers the implementation of national and subnational government policies related to electric vehicles (EVs); Ambitious scenario: Considers international commitments made by countries [1]

		2030	**2035**	**2040**	**2045**	**2050**
Baseline	Cars	24%	34%	36%	38%	41%
	Buses	17%	22%	26%	33%	43%
	Trucks	8%	12%	13%	15%	18%
Momentum	Cars	40%	57%	61%	62%	63%
	Buses	29%	40%	46%	51%	57%
	Trucks	19%	27%	34%	35%	37%
Ambitious	Cars	65%	89%	98%	100%	100%
	Buses	73%	94%	100%	100%	100%
	Trucks	46%	71%	94%	100%	100%

3.1.4 EV demand outlook

In this chapter, a comprehensive exploration is undertaken to examine the competitive dynamics that shape the outlook for EVs in comparison to their well-established counterparts, the ICE vehicles. Throughout this analysis, multiple factors, including economic viability will be considered. Through the examination of these crucial dimensions, valuable insights are aimed to be offered into the present and future competitiveness of electric vehicles within the swiftly evolving automotive industry.

A study [59] on behalf of the Federal Ministry for Digital and Transport in Germany compared the total costs of EV cars and internal combustion engines cars (ICE) [59]. The research demonstrates that battery-electric cars provide a financial benefit over combustion engine vehicles in the long run, despite higher initial purchase and charging infrastructure expenses. This advantage is due to lower energy costs, environmental incentives, tax exemptions, and GHG quota exemptions. Medium-sized electric cars reach cost parity in three years, while smaller ones take five to eight years. The availability of efficient charging infrastructure is critical, with home charging, particularly with photovoltaic systems, significantly reducing costs compared to relying solely on public stations. This highlights the potential for significant long-term savings with electric vehicles and the significance of accessible home charging solutions. Generally, BEVs have a higher initial investment but significantly lower running costs.

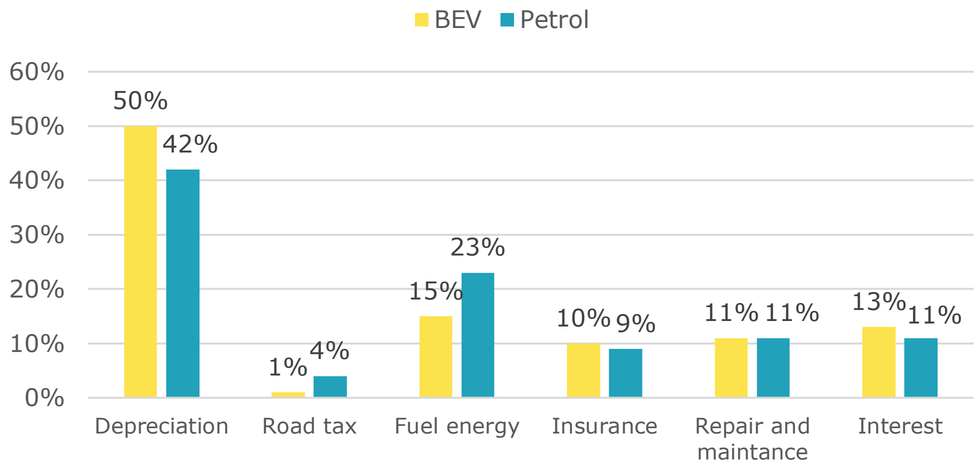


Figure 3.7. Breakdown of total cost of ownership in BEVs and in petrol vehicles [60]

3.1.5 Electric heavy duty vehicles' competitiveness outlook

The competition in the heavy truck business is changing rapidly. Companies are starting to care more about being environmentally sustainable and this chapter looks at the competitive situation of electric heavy trucks. These are the heavy-duty vehicles leading the change to more sustainable transportation. The electric heavy truck market's current state will not be assessed but a lot of focus will be placed on the comparison with other technologies vying for dominance in the sector. Our objective is to provide a comprehensive view of the competitive landscape, shedding light on the potential of electric heavy trucks and their role in shaping the future of sustainable heavy-duty transportation in Europe [61].

The urgent demands set by global climate targets require a steady but continuously growing pace for the transition of heavy trucks to zero emission vehicles. More specifically Table 3.5 shows the share of sales required for members of the Zero Emission Vehicles Transition Council to achieve.

Table 3.5. Zero Emission Vehicles shared required by year for ZEVTC members to align with Paris Agreement goals [62]

Vehicle type	**2025**	**2030**	**2035**	**2040**	**2045**
Bus (>3.5 tonnes)	7%-30%	75%-90%	90%-100%	100%	100%
Medium truck (3.5 to 16 tonnes)	3%-12%	40%-50%	75%-90%	100%	100%
Heavy truck (>16 tonnes)	2%-9%	30%-41%	60%-75%	90%-100%	100%
All HDVs (sales-	3%-12%	40%-56%	69%-83%	94%-100%	100%

Vehicle type	2025	2030	2035	2040	2045
eighted average per country)					
All HDVs (sales-eighted average for all ZEVTC members)	3%-12%	40%-56%	69%-83%	94%-100%	100%

According to the study report “Fuel Cells Hydrogen Trucks: Heavy-Duty’s High Performance Green Solution” [63] fuel cell hydrogen technologies are more competitive than the alternatives such as diesel e-fuels and BEV (Battery Electric Vehicles). Due to lower annual mileage, BEV trucks also indicate a lower flexibility in routes. Additionally, the document states that BEV technology is the most commercially attractive zero-emission option, and Fuel Cell Electric Vehicles (FCEV) at scale become comparable to diesel in 2030. However, FCH trucks have the highest total cost of ownership in 2023 compared to other zero-emission technologies yet show a significant cost-down potential at scale. Overall, study suggests that FCH and battery electric trucks see robust adoption across all considered market segments. A strong policy push is needed for the entire transport chain, including OEMs, hydrogen and infrastructure providers, truck operators, and logistics users.

FCH trucks have some advantages over EVs in certain areas. For instance, FCH trucks have longer ranges, fast refueling, and payload capacity comparable to diesel vehicles. They also have clear cost-down potential over the years and additional potential in cases of high energy needs. However, FCH trucks have some weaknesses as well. They are dependent on local hydrogen refueling infrastructure, in the short-term the high cost of powertrain for FCH trucks, and uncertainty on second life use and value today. Additionally, the cost of hydrogen is high, resulting in high fuel costs (OPEX) at current market prices. Projections show an increase in FCEV market to overall sales share of 17% in 2030 FCEV [63]. The great potential of FCH trucks within the entire market also reflects the necessary transitional development path to achieve the goals of reducing carbon dioxide emissions before the year 2050.

Especially in trucks, battery swapping can have huge advantages over ultra-fast charging. First of all, the shift can last up to 5 minutes, which would be difficult and expensive to achieve with cable-based charging, which requires a very fast charger connected to a medium or high voltage network and expensive battery management systems and battery chemistry. With this method extension of battery capacity, performance and life is achievable. Additionally, the construction cost of the station is likely to be higher for a truck battery change because the vehicle is bigger and batteries are heavier. Another significant obstacle is the requirement that batteries are standardized to a specific size and capacity. Truck OEMs are likely to be perceived as a challenge to competitiveness as battery design and capacity is a key differentiator among electric truck manufacturers [56].

Heavy-duty vehicles encompass diverse types and applications, each evolving differently in technology, market readiness, and cost-effectiveness. Therefore, analyzing each segment and type of Heavy-Duty Vehicles (HDV) could provide more insightful conclusions.

Urban buses provide the segment of HDV with the highest degree of adoption of zero-emission technology to date because their load and routes are predictable as well as their access to enroute charging. In the majority of markets with accessible data, zero-emission buses have attained a state of essential cost competitiveness. They have either reached a level of parity with internal combustion engine (ICE) buses in terms of total cost of ownership (TCO) or are projected to achieve this equilibrium by the year 2025 as is shown in the Table 3.6.

EV trucks have a significant positive environmental impact when compared to other trucking solutions. Conversion to zero-emission trucks allows for a total reduction of NOx pollutants, and particulate matter can also be reduced due to more efficient driving patterns, including regenerative braking for electric vehicles. The positive environmental impact of zero-emission vehicles will be significant in urban areas, where truck emissions directly affect citizens' health. That is why electrification of buses is highly beneficial for EU cities.

Table 3.6. Heavy Duty Vehicles sales shares, Total cost of ownership parity year and ZEV market readiness for urban buses [62]

Vehicle type	ZEV share in 2020 bus sales	TCO parity year	Market readiness
US (including California)	0.6%	2022-2025	Mature market
Canada	1.7%	2022-2025	Mature market
EU, UK, Norway	6.4%	2022	Mature market
India	0.6%	2022	Mature market
Japan	NA	NA	Small-scale commercialization
Mexico	5.3%	2030	Mature market
Republic of Korea	1.6%	NA	Mature market

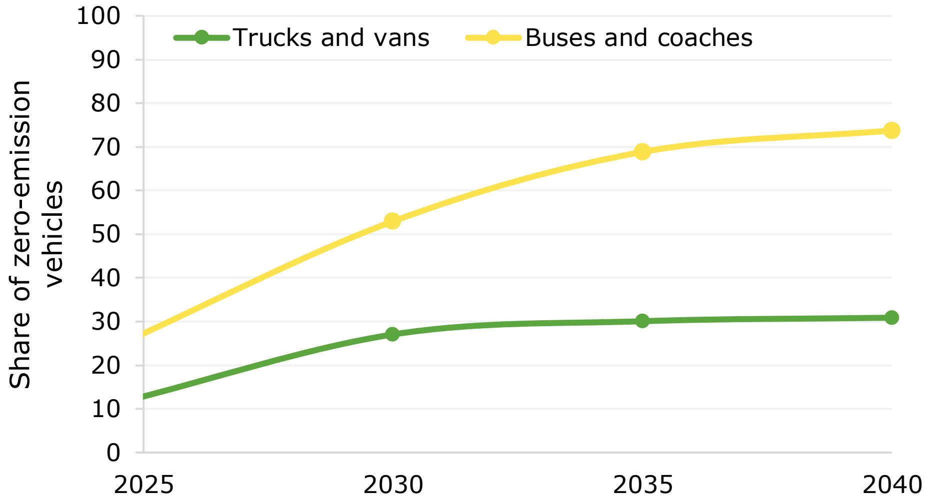


Figure 3.8. Share of zero-emission heavy-duty vehicles in the EU for different scenarios [62] [62]

The total cost of ownership that is compared in Figure 3.9 is composed of:

- the environmental compliances:
  - penalties for the emission of noise and pollutants in inner cities;
- the energy costs;
  - diesel;
  - electricity;
  - grid utilization fees;
  - charging and coupling devices;
  - grid connection costs;
  - constructional measures;
- the battery system;
  - cells;
  - packaging;
  - system components;
- the maintenance costs;
- the vehicle assets.

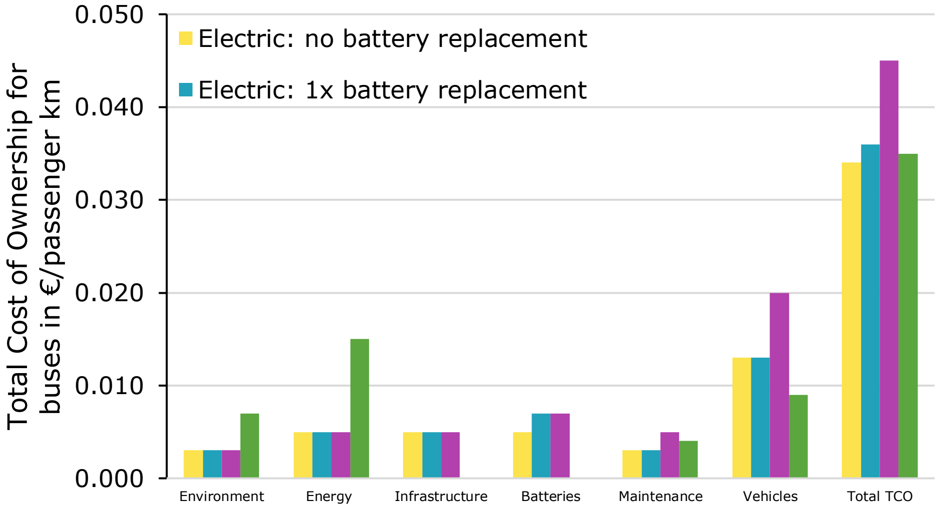


Figure 3.9. TCO comparison in EUR/passenger-km [64]TCO comparison in EUR/passenger-km for buses [64]

3.2 Sensitivity

3.2.1 Description of scenarios in the previous model

Previous study considered the increased use of electric vehicles in road transport, electrification of rail transport and ferries.

It was assumed that the share of distance travelled by electric vehicles is equal to the number of electric vehicles on each year. To find the distance travelled for all cars and vans, buses, trucks, and motorcycles on Estonian roads from 2025 up to 2050 with 5-year increments, the model takes as input historical distance travelled in million km and the change in distance travelled, in % per a 5-year period, for all vehicles during the time-series in these categories. The total number of vehicles in each category for each year is calculated by taking the historical number of vehicles in each category and the change in the number of vehicles, in % per a 5-year period as input.

To find the distance travelled by electric vehicles for each specified year, the model takes as input the share of distance travelled by electric vehicles in each category and multiplies it by the distance travelled by all vehicles in each category. To find the number of electric vehicles for each year, the model takes as input the share of electric vehicles in all vehicles in each category and multiplies it by the number of all vehicles in each category.

Share of all vehicles in each category in each county from 2025 up to 2050 with 5-year increments is predicted by applying a linear regression using the least squares method. The model takes as input historical and projected population of each Estonian county up to the year 2050, historical data on vehicles registered in each county and dummy variables for the counties.

The assumptions for the base scenario were based on research produced by Civitta [65] [66] and adjusted based on feedback from the contracting entity Elering. It is assumed that the share of distance travelled by electric vehicles is equal to the number of electric vehicles on each year. Table 3.7 presents the previous model base scenario consumption values. On average 88% on consumption is increased due to road transport.

The ferry transport model allocates annual energy consumption into hourly segments using consumption profiles that consider daily and seasonal variations, with distinct patterns for summer and other months. It was assumed that the Virtsu – Kuivastu line is set to transition to electric ferries, with half of its services going electric starting in 2030 and reaching full electrification by 2035. It is assumed that half of Rohuküla-Heltermaa trips are electrified my 2035 and the line is fully electrified by 2040. Ruhnu and Sõru-Triigi ferries are assumed to be electrified by 2040. The model's hourly consumption is based on standard ferry schedules and historical data, with adjustments for monthly seasonality and average daily trips during summer and other seasons.

Table 3.7. Consumption in the base scenario

Year	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Consumption, GWh	192	517	994	1341	2159	2991
Road transport, GWh	165	365	818	1144	1951	2772
Rail transport, GWh	27	145	156	167	178	190
Ferry transport, GWh	0	7	20	30	30	30

To calculate the electricity consumption of the national rail network, an overall change in train-km by passenger trains and an additional increase in different lines separately was assumed. The assumption was based on a study by the ITF [67]. Efficiency (electricity use per train-km) is calculated based on historical energy consumption data by Statistics Estonia [68] and train-km data by Ministry of Economic Affairs and Communications [69].

The main assumption of freight transport on Rail Baltic (**Error! Reference source not found.**) is the amount of freight transported during the time-series, which is based on the projection by EY [70]. However, in the model, the freight flows have been shifted into the future compared to EY's projection, as the Rail Baltic project has experienced some delays. The energy consumption of trains of Rail Baltic is based on the analysis by Piterina and Masharsky [71]. Railway length is the length of Rail Baltic within Estonia. For passenger transit on Rail Baltic, electricity consumption is calculated according to the methodology proposed by Piterina and Masharsky [71], where the number of train pairs per day is the base assumption of the projection.

Table 3.8. Rail Baltic assumptions

	2025	**2030**	**2035**	**2040**	**2045**	**2050**
Freight, million t	**0**	**5,1**	**5,45**	**5,8**	**6,1**	**6,4**
Railway length, km	**0**	**213**	**213**	**213**	**213**	**213**
Electricity use, kWh/t-km	0	0,05	0,05	0,05	0,05	0,05
Freight, million t-km	0	1088	1162	1237	1301	1365
Passenger trainpairs/day	**0**	**8**	**8**	**8**	**8**	**8**
Railway length, km	0	213	213	213	213	213
Train capacity, seats	0	402	402	402	402	402
Electricity use, kWh/seat-km	0	0,033	0,033	0,033	0,033	0,033
Electricity consumption, GWh/y	**0**	**100**	**103**	**107**	**110**	**114**

3.2.2 Description of new sensitivity scenarios

Two new scenarios were drawn up for the transport sector. The new scenarios were created based on the base scenario of the orevious model. Compared to previous scenarios, the main differences are in the assumptions made for the expected changes in the composition of the Estonian fleet of vehicles.

In Table 3.9 we describe the assumptions made for the low and high scenarios for the electrification of passenger vehicles and vans (vehicles in the categories M1, M1G, N1 and N1G). The entire fleet of cars and vans was forecasted based on historical trends of registration and deregistration of vehicles in Estonia.

The scenarios are the following:

- Expected scenario – expected transition to electric transport. Estonia follows the historical trend of adopting EVs in other European countries with some delay depending on the development of the EV sector in a specific country. In 2035, only zero-emission vehicles will be sold as new. The market for used cars follows the trend set by the sales of new cars.
- Progressive scenario – a progressive shift to electric transport. Estonia catches up with other leading European countries in the popularity of zero-emission vehicles quicker. By 2030, 80% of new vehicles sold are zero-emission vehicles and by 2035 only zero-emission vehicles are sold new. The market for used cars follows the trend set by the sales of new cars.

To predict the share of EVs in Estonia, an analysis of the sales of new EVs in selected countries in Europe was conducted based on more developed EV market, that is Norway, Iceland, Netherlands, Sweden, Austria, Germany, Denmark, Switzerland, Finland, France and Portugal. A starting year was selected in each of the countries, when the level of EV sales was similar, that is from 1,7% to 3,3% of the sales of new vehicles (in Norway 5,3%). In Figure 3.10 We can observe the share of sales of new EVs as a share of the sale of all passenger vehicles in the previously mentioned European contries. We estimate that Estonia in 2023 is in a similar phase of EV adoption as these selected countries each were a few years ago.

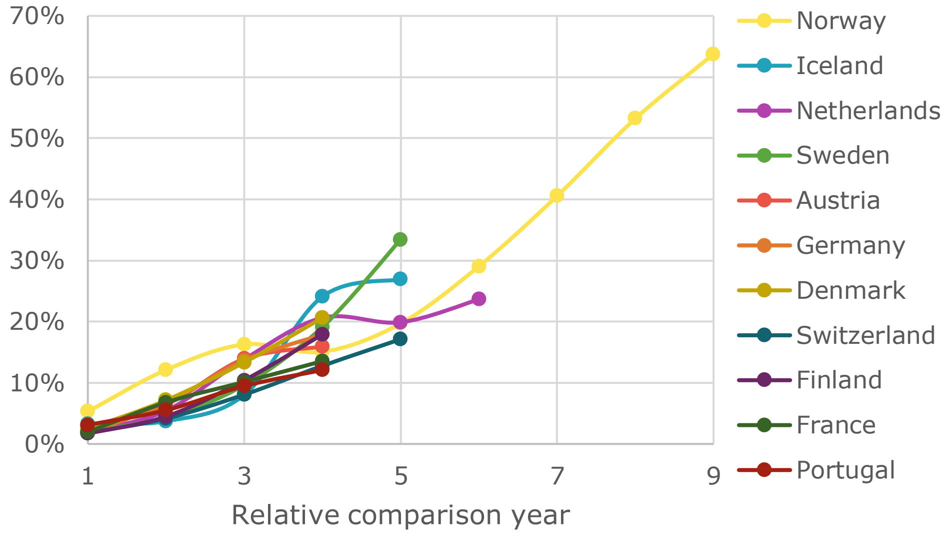


Figure 3.10. Share of sales of new electric passenger vehicles in selected European countries based on a comparable starting point

Using the data on Figure 3.10 as input, we conducted a simulation using the Monte Carlo method to determine likely sales numbers of new EVs in the coming years (Figure 3.11). As the European minimum and maximum we display the the dynamics of electic vehicle sales using a similar starting year (with regard to the share of sales of EVs in all vehicles). The starting year was selected in each of the countries, when the level of EV sales was similar, that is from 1,7% to 3,3% of the sales of new vehicles (in Norway 5,3%).

As we can observe from the graph, the modelled expected scenario follows approcimately the mean EV adoption rate in other European countries and the progressive scenario follows the maximal EV adoption rate in Europe and also accelerates after the year 2026. The progressive scenario is very ambitious, to achieve even faster growth, an extremely expensive intervention measure would likely be required.

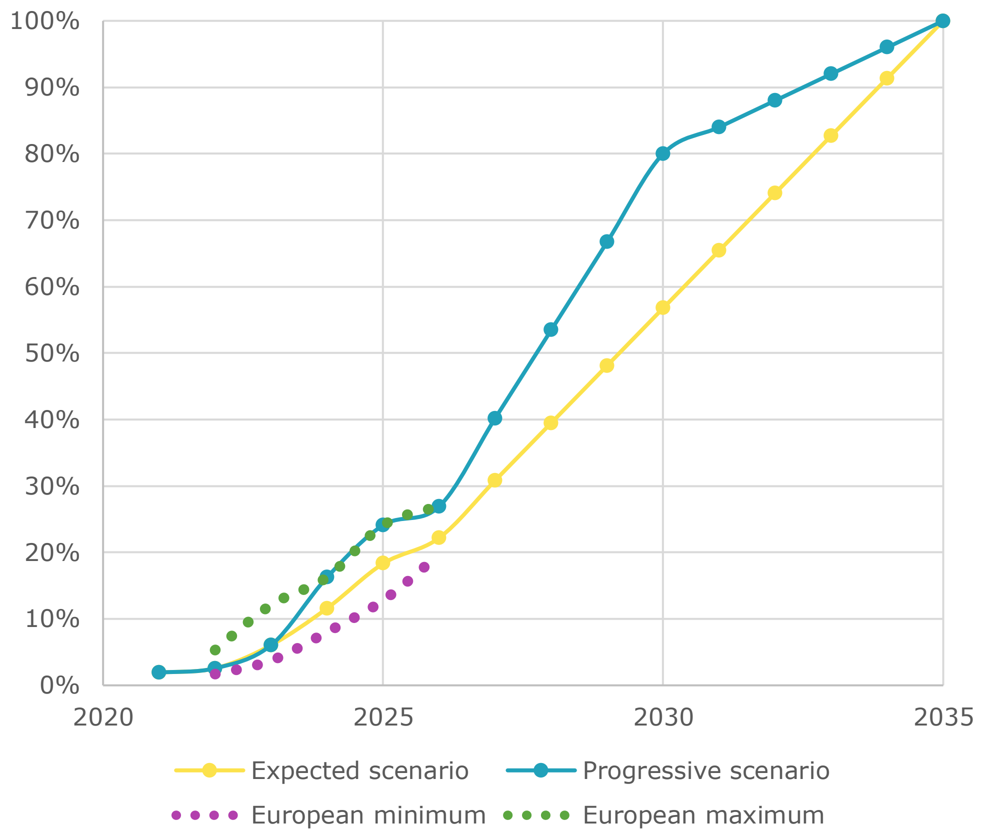


Figure 3.11. Predicted share of sales of EVs as a share of new cars sold

Table 3.9. Estonian fleet of cars and vans

	2022	2025	2030	2035	2040	2045	2050
All cars and vans	733 507	776 947	825 191	859 859	884 119	902 636	919 827
Expected scenario							
EVs (low)	3 415	18 165	99 799	273 049	474 001	642 151	759 622
Share of Evs (low)	0,5%	2,3%	12,1%	31,8%	53,6%	71,1%	82,6%
Progressive scenario							
EVs (high)	3 415	22 581	133 649	322 380	517 382	677 052	782 196
Share of Evs (high)	0,5%	2,9%	16,2%	37,5%	58,5%	75,0%	85,0%

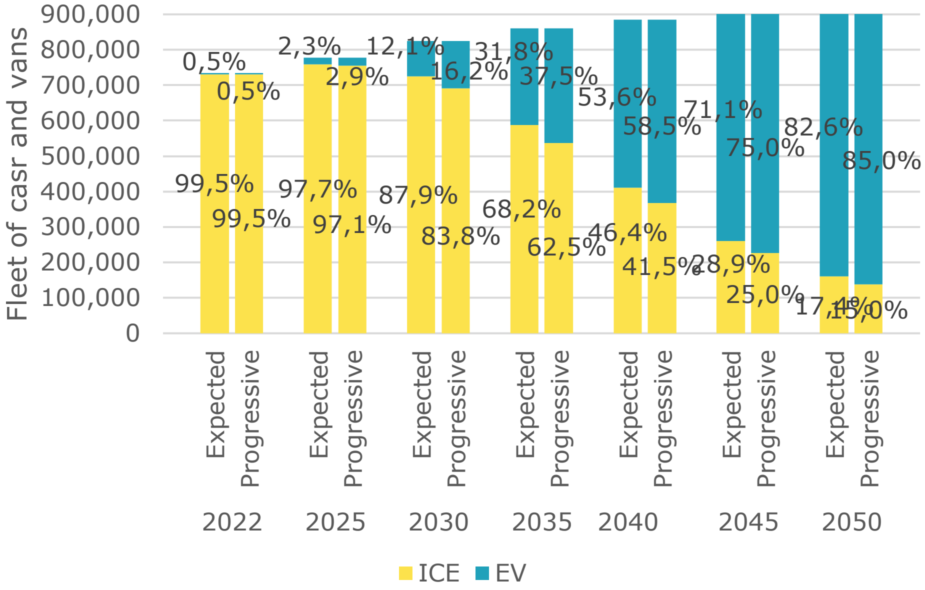


Figure 3.12. Fleet of internal combustion engine (ICE) and electric cars and vans

In Table 3.10 two scenarios for electric trucks is presented. First, the number of all trucks (vehicles in categories N2 and N3) has been presented. The number of all trucks was forecasted based on historical registration and deregistration data for trucks of certain age. The share of electric trucks in the fleet was predicted by utilizing proposed values on share of new electric trucks sold in the coming years proposed by a report by the International Council on Clean Transportation [1] These values have been utilized to predict the changes in the fleet in the coming years (see shares of sales in Table 3.4 and Figure 3.13).

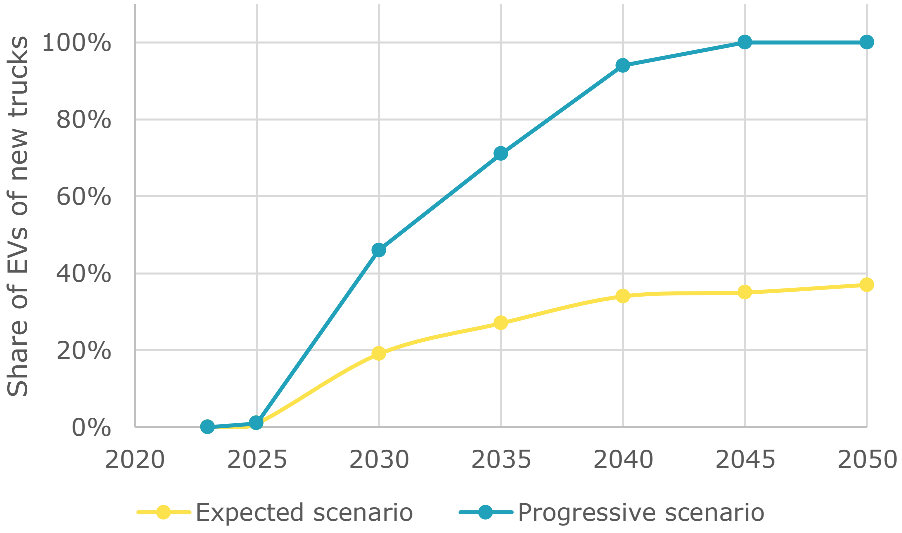


Figure 3.13. Share of electric truck sales of all truck sales

Table 3.10. Predicted Estonian truck fleet

Year	**2022**	**2025**	**2030**	**2035**	**2040**	**2050**
All trucks	27 076	27 023	26 981	27 124	27 423	28 030
Expected scenario						
EVs	0	15	604	1 831	3 483	6 847
Share of EVs	0,0%	0,1%	2,2%	6,8%	12,7%	24,4%
Progressive scenario						
EVs	0	15	1 414	4 547	9 021	18 699
Share of EVs	0,0%	0,1%	5,2%	16,8%	32,9%	66,7%

In calculating the electricity consumption for vehicles, we use the study by Transpordiamet [72] as input. The data includes all kilometers travelled in Estonia, even foreign vehicles, so the mileage of foreign trucks driving on Estonian roads is included in the analysis. However, the mileage data is divided into categories according to the statistics on the fleet of Estonian vehicles.

3.2.3 Results of sensitivity scenarios

The electricity consumption of electric vehicles has been forecasted by considering the distance traveled and the charging method, with distinct profiles for household slow charging, public fast charging, and smart charging options, including vehicle-to-grid (V2G) technology. Smart charging adjusts consumption patterns for workdays and weekends, while V2G is evaluated for its potential to reduce grid energy demand and provide demand-side response services. Seasonal variations are accounted for with monthly coefficients.

Electricity use is calculated daily and hourly for each county, factoring in the year, vehicle type, and charging method. For cars and vans, the model multiplies the distance traveled by the efficiency and proportion of each charging type, averaged over the year. Similarly, the hourly consumption incorporates the time of day and seasonality, while for buses, trucks, and motorcycles, a separate formula considers the distance traveled and a yearly charging share, again adjusted daily and hourly.

The tables present projections for energy consumption and peak power requirements for cars and vans versus trucks over a 25-year period, under two different scenarios: low (Table 3.11) and high (Table 3.12).

The trend across both scenarios indicates a significant increase in energy consumption and peak power requirements for both cars and vans and trucks as time progresses. However, the rate of increase is much steeper for cars and vans compared to trucks.

In the low scenario, the consumption for cars and vans reaches 2558 GWh by 2050, while for trucks, it goes up to 183 GWh. In terms of peak power, cars and vans increase to 654 MW, whereas trucks reach 55 MW by 2050.

Table 3.11. Consumption and peak power in the expected scenario

Year	2025	2030	2035	2040	2045	2050
Cars and vans						
Consumption, GWh	64	350	948	1628	2184	2558
Peak, MW	21	97	226	380	510	654
Trucks						
Consumption, GWh	0	18	48	94	141	183
Peak, MW	0	5	15	28	43	55

The high scenario shows a similar pattern but with higher absolute values. For cars and vans, consumption grows to 2634 GWh by 2050, while peak power increases to 673 MW. For trucks, the consumption grows to 99 GWh, with peak power reaching 30 MW.

Table 3.12. Consumption and peak power in the progressive scenario

Year	2025	2030	2035	2040	2045	2050
Cars and vans						
Consumption, GWh	80	468	1119	1778	2303	2634
Peak, MW	26	130	267	415	538	673
Trucks						
Consumption, GWh	0	11	29	54	78	99
Peak, MW	0	3	9	16	24	30

The difference between the low and high scenarios for cars and vans is notable, suggesting that under more aggressive assumptions, the growth in energy demand and peak power is considerably larger for cars and vans than for trucks. The data suggests that while the energy needs for trucks will grow, the scale of increase is dwarfed by the growth expected for cars and vans, indicating a potentially larger impact on energy infrastructure from personal and smaller commercial vehicles compared to larger transport vehicles.

4. Model improvements

To model faster electrification than previously assumed, a new model was created to update the inputs for district heating and transportation models, which were previously formulated in the electricity demand scenario.

A faster and wider approach to heating electrification was modeled. Previously, only the electrification of smaller district heating networks was considered. Now, the electrification of both local and district heating is being considered. Two scenarios were created:

- Electrification of local and district heating peak and summer thermal loads.
- Electrification of local and district heating all thermal loads.

Additional scenarios were created for cars, vans, and heavy-duty vehicles based on vehicle sales/registration forecasts and fleet renewal.

- Expected transition to electric transport (low) - Estonia follows the historical trend of other European countries. By 2035, only zero-emission vehicles will be sold. The used car market follows the shift in Central European new car markets.
- Progressive transition to electric transport (high) - Estonia is catching up with other leading European countries in the popularity of zero-emission vehicles. By 2030, 80% of zero-emission vehicles will be sold, and by 2035, only zero-emission vehicles will be sold. The Estonian used car market prefers low-emission vehicles.

The model was updated in MS Excel. Results files combine sectors' results and calculate electricity demand scenarios providing yearly energy demand values and peak power values both annually and hourly. Electricity demand was updated on two levels:

- Level 1: end user demand without local generation. On this level local production (solar power generation) and vehicle to grid is not considered.
- Level 3: transmission network demand. This level also considers additional electricity generation from distribution networks, so large distinct solar farms. Power generation in the transmission system network is not in the scope of this study.

Previous model results are in Table 4.1 and Table 4.2.

Table 4.1. Average climate year end consumer consumption (level 1)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	2 191	2 318	2 547	2 772	2 997	3 206
Service	GWh	3 398	3 570	3 975	4 312	4 583	4 798
Industry	GWh	2 602	2 635	2 657	2 806	3 008	3 306
Transport	GWh	281	586	1 095	1 469	2 366	3 269
Total	**GWh**	**8 472**	**9 109**	**10 274**	**11 359**	**12 954**	**14 579**
Peak	MW	1561	1649	1875	2080	2384	2713
Summer Peak	MW	992	1078	1201	1303	1473	1658
Lowest	MW	527	592	687	782	927	1087

Table 4.2. Average climate year transmission network demand (level 3)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	1968	1963	2018	2033	2027	2010
Service	GWh	3089	3108	3312	3420	3443	3418
Industry	GWh	2369	2297	2197	2195	2224	2339
Transport	GWh	281	587	1097	1474	2380	3306
Total	**GWh**	**7708**	**7954**	**8624**	**9123**	**10074**	**11072**
Peak	MW	1545	1632	1854	2043	2293	2697
Summer Peak	MW	971	1056	1174	1264	1408	1782
Lowest	MW	200	-5	-272	-603	-949	-1299

The following page contains the results of our new model.

4.1 Combined model results

The numbers in each scenario represent different combinations of transport demand and electrification strategies for heating, specifically district heating. Here's the breakdown:

First Number: Transport Demand

1 – Expected transport: This implies a scenario with low demand for transportation. Estonia follows the historical trend of adopting EVs in other European countries with some delay depending on the development of the EV sector in a specific country. In 2035, only zero-emission vehicles will be sold as new. The market for used cars follows the trend set by the sales of new cars.

2 – Progressive transport: This indicates a scenario with high transportation demand. stonia catches up with other leading European countries in the popularity of zero-emission vehicles quicker. By 2030, 80% of new vehicles sold are zero-emission vehicles and by 2035 only zero-emission vehicles are sold new. The market for used cars follows the trend set by the sales of new cars.

Second Number: Electrification Strategy for Heating

1 – Peak Load, Base Electrification: This strategy involves electrifying the heating system to manage peak load demands with basic or conventional electrification methods. It focuses on ensuring that the system can handle high demands during peak periods (like cold weather spikes) without advanced or rapid technological upgrades.

2 – Peak Load, Fast Electrification: This approach also targets peak load demands but with a faster pace of electrification, potentially involving advanced technologies, rapid infrastructure upgrades, and possibly integrating more renewable energy sources quickly to meet high demand periods.

3 – Base Load, Base Electrification: In this strategy, the focus is on electrifying the heating system to handle the base or regular load with standard electrification techniques.

4 – Base Load, Fast Electrification: Similar to the base load strategy, but with a quicker implementation pace. It involves rapidly upgrading and integrating technologies to ensure the heating system can manage the ongoing demand.

Each combination of these numbers describes a different energy scenario, with varying implications for infrastructure, technology, energy sources, and policy. The calues for each scenario is in the Annex.

- Scenario 11: Low Transport, Local Heating Electrification, District Heating Peak and Summer Load Base Electrification.

- Scenario 13: Low Transport, Local Heating Electrification, District Heating Base Load Base Electrification.

- Scenario 22: High Transport, Local Heating Electrification, District Heating Peak and Summer Load Fast Electrification.

- Scenario 23: High Transport, Local Heating Electrification, District Heating Base Load Base Electrification.

- Scenario 24: High Transport, Local Heating Electrification, District Heating Base Load Fast Electrification.

4.1.1 Consumption

Figure 4.1 compares the average climate year end consumer consumption with the old result. Scenarios 13, 22, and 23 outline an average electrification scenario. In contrast, Scenario 11 illustrates a low electrification scenario, and Scenario 24 depicts a high electrification scenario. The realization of Scenario 24 is highly unlikely, and it has been modeled to illustrate an extreme scenario, establishing an upper boundary for the possible growth of electricity consumption.

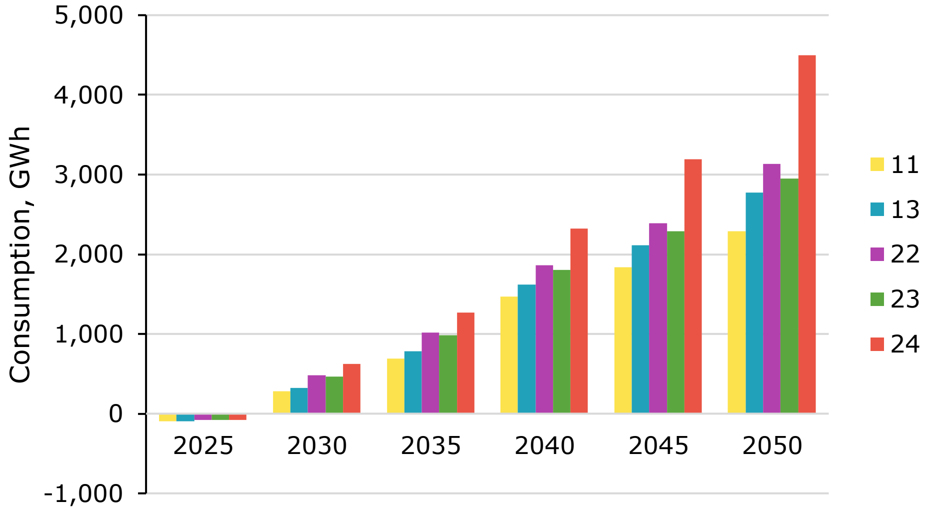


Figure 4.1. New model end consumer consumption difference by scenario

Figure 4.2 and Table 4.3 illustrates the projected average differences in end consumer consumption across various sectors from 2025 to 2050. The data reveals a consistent increase in heating electrification, which becomes the dominant energy demand by 2050. Transport sees a variable but overall upward trend.

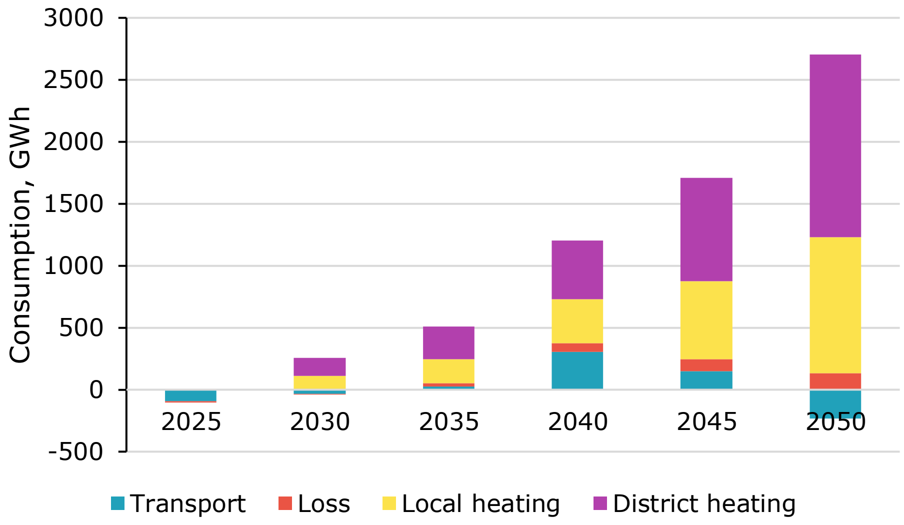


Figure 4.2. New model end consumer consumption average difference

Table 4.3. New model end consumer consumption average difference

Year	2025	2030	2035	2040	2045	2050
Heating	0	249	442	799	1410	2483
Local heating	*0*	*110*	*195*	*358*	*629*	*1097*
District heating	*0*	*148*	*262*	*468*	*831*	*1474*
Natural gas	0	0	0	0	0	0
Buildings	0	0	0	0	0	0
Transport	-94	-33	26	306	151	-231
Base Growth	0	0	0	0	0	0
S1 Loss	-7	0	25	69	96	135
Total	**-101**	**216**	**492**	**1173**	**1657**	**2388**
Local Generation	0	0	0	0	0	0
Veichle to Grid	0	0	0	1	-3	-1
S3	0	0	0	0	0	0
S3 Loss	0	0	0	2	-10	-1
Total	**-101**	**216**	**492**	**1176**	**1644**	**2386**

There is a high probability that the heating solutions will be electrified by 50% as planned since currently, 32% of them depend on fossil fuels, and a further 18% are due to be replaced from aging biofuel solutions predominantly in use in rural areas.

It is essential to cautiously interpret the data on local heating electrification. The complexities introduced by the intertwining factors of national economic growth and the inherent uncertainties in forecasting models necessitate a careful analysis. Disentangling the surge in electricity usage due solely to local heating electrification from the general rise in electricity demand presents a complex challenge. Thus, while these projections offer important perspectives, they must be viewed within a broader, fluid context that accommodates fluctuations and economic patterns.

Figure 4.3 presents the average climate year end consumer consumption for all scenarios. Notably, after 2040, there is a marked divergence where the newer scenarios show a significant increase in consumption compared to the old model. Newer model predicts a more substantial growth in energy consumption in the later years of the forecast period. When local heating is subtracted from the model, the difference is nearly halved.

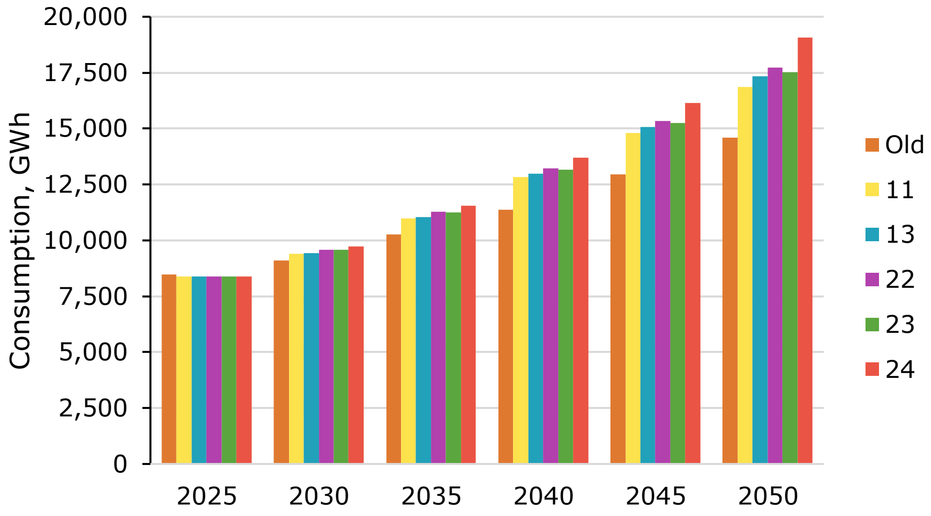


Figure 4.3. Average climate year end consumer consumption (level 1)

4.1.2 Peak consumption

Figure 4.4 compares the average climate year end consumer peak consumption with the old result. Scenario 24 depicts an extreme case, whereas Scenarios 13, 22, and 23 fall within a similar order of magnitude. Notably, even with the minimal rate of electrification, there's a projected rise in peak consumption of 1391 MW by the year 2050.

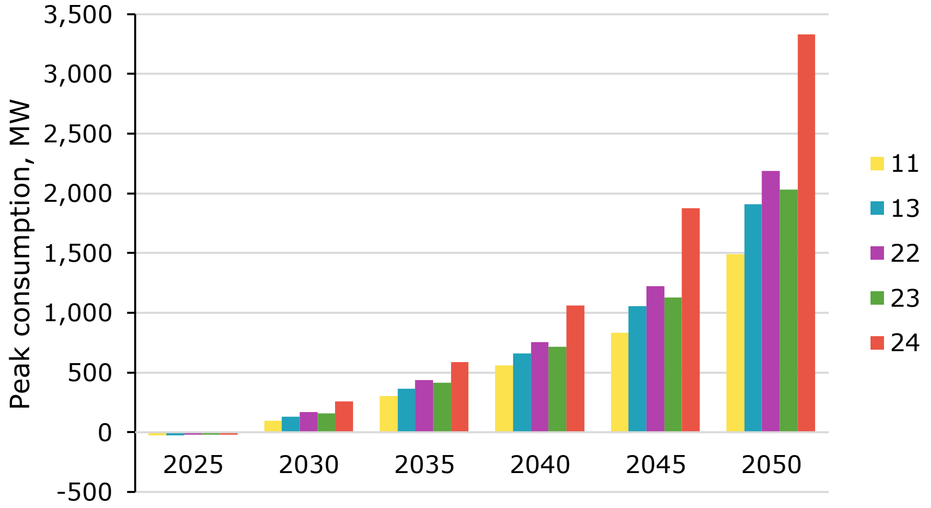


Figure 4.4. New model end consumer peak consumption difference

Figure 4.5 and Figure 4.6 provide histograms of peak consumption in megawatts (MW) for the years 2035 and 2050, respectively. The histograms display the number of hours that consumption falls within specified ranges. In 2035, the most frequent consumption range is 1000-1250 MW, while by

2050, this shifts to a higher range of 1000-2000 MW. By 2050, there is not only a noticeable shift towards a higher consumption bracket of over 2000 MW but also an increase in the frequency of hours with consumption below 0 MW. However, the period of peak loads continues to be brief, not exceeding 100 hours.

The increasing variation in power usage highlights the importance of implementing strong grid management and adaptable energy storage systems to effectively manage these dynamics in the future. It is very unlikely that controllable capacities based on renewable energy would be developed in the electricity grid to ensure peak loads that occur less than 1000 or even 100 hours. It is more likely that such loads will be regulated through demand-side management or mitigated with the adoption of storage solutions and cross-border energy interconnections.

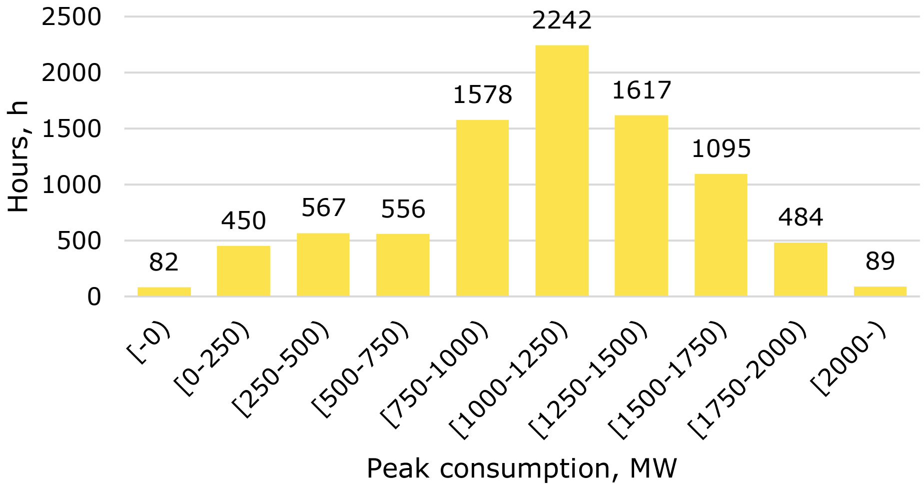


Figure 4.5. Histogram of peak consumption in 2035 (Scenario 23, Level 3)

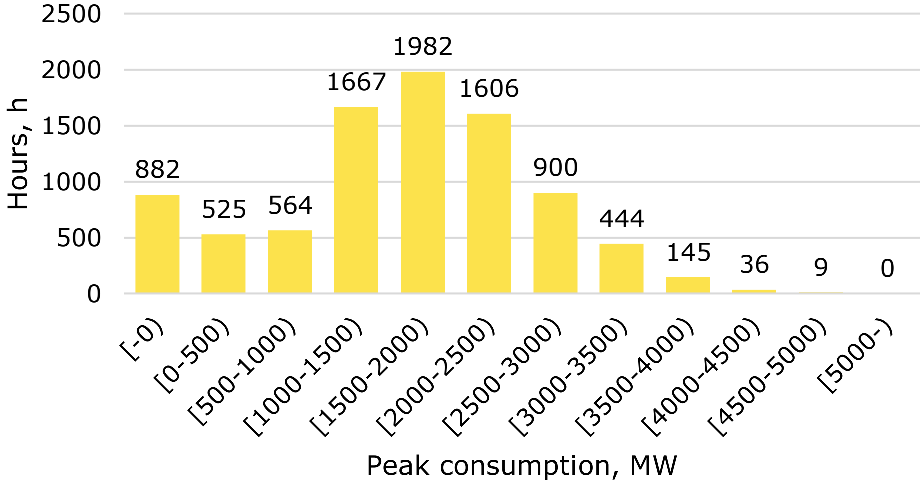


Figure 4.6. Histogram of peak consumption in 2050 (Scenario 23, Level 3)

Figure 4.7 presents the average climate year end consumer peak consumption for all scenarios. As previously noted, removing local heating from the model results in a reduction of the projected increase in electricity consumption by half. Consequently, by 2050, we might observe a surge in peak electricity demand ranging between 800-2000 MW.

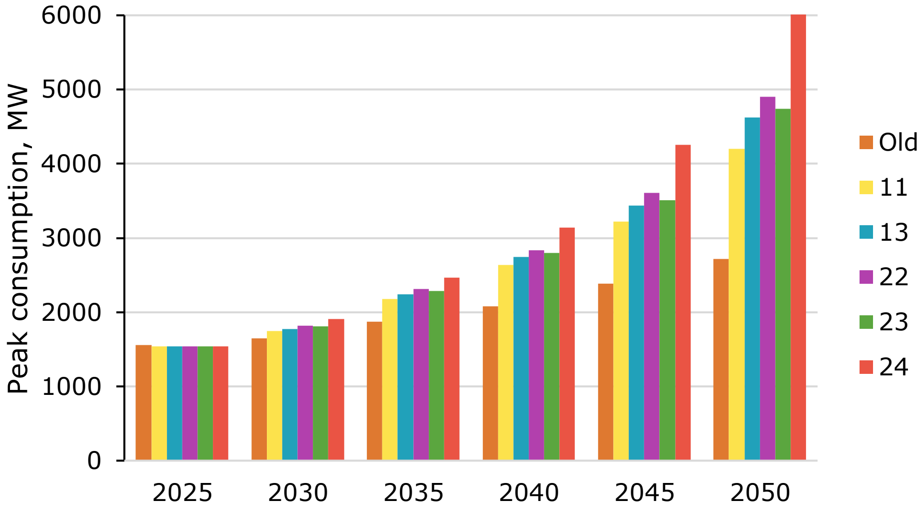


Figure 4.7. Average climate year end consumer peak consumption (level 1)

4.1.3 Converged results

Different scenarios yield an expected (Scenario 11), ambitious (Scenario 13, 22, 23) and extreme (Scenario 24) electrification outcomes as some scenarios have marginal differences and fall within the same magnitude.

The expected scenario envisions a gradual adoption of electric vehicles in Estonia, aligning with historical trends observed in other European countries, culminating in the exclusive sale of zero-emission vehicles by 2035. The ambitious scenario, however, anticipates a swift transition, with Estonia quickly matching the EV uptake of leading European nations, aiming for 80% of new vehicle sales to be zero-emission by 2030 and reaching 100% by 2035. Essentially, the scenario represents a more accelerated path towards electrification of transport compared to the expected scenario.

Expected scenario envisions that half of the thermal energy demand for local and district heating is projected to be met through electrification by 2050 but district heating is using electricity for peak and summer loads only. Ambitious scenario expects district heating to electrify the base loads. Extreme scenario involves rapidly integrating electricity to ensure the whole heating system to handle both the base and peak loads.

The expected scenario, according to the authors, is one that proceeds with today's policies, whereas the ambitious scenario assumes that the country will seriously commit to climate neutrality policies and significantly reduce the consumption of fossil fuels. Extreme scenario is to establish an upper boundary for the possible growth of electricity consumption on average climatic year.

Table 4.8 and Figure 4.8 illustrates detailed view of ambitious electrification scenario across various fields of electrification.

Table 4.4. New end user demand without local generation (level 1)

Parameter	unit	2025	2030	2035	2040	2045	2050
Expected	GWh	8 381	9 387	10 967	12 829	14 793	16 864
Ambitious	GWh	8 392	9 534	11 201	13 123	15 219	17 532
Extreme	GWh	8 397	9 736	11 545	13 685	16 144	19 079
Expected	MW	1 535	1 743	2 178	2 637	3 218	4 204
Ambitious	MW	1 533	1 796	2 272	2 775	3 524	4 809
Extreme	MW	1 540	1 906	2 465	3 140	4 259	6 043

Table 4.5. End user demand difference to old model

Parameter	unit	2025	2030	2035	2040	2045	2050
Expected	GWh	-91	278	693	1 470	1 839	2 285
Ambitious	GWh	-80	425	927	1 764	2 265	2 953
Extreme	GWh	-75	627	1 271	2 326	3 190	4 500
Expected	MW	-26	94	303	557	834	1 491
Ambitious	MW	-22	153	404	707	1 170	2 101
Extreme	MW	-21	257	590	1 060	1 875	3 330

Table 4.6. New transmission network demand (level 3)

Parameter	unit	2025	2030	2035	2040	2045	2050
Expected	GWh	7 616	8 232	9 319	10 598	11 919	13 362
Ambitious	GWh	7 627	8 379	9 553	10 893	12 346	14 031
Extreme	GWh	7 633	8 581	9 897	11 455	13 271	15 578
Expected	MW	1 519	1 727	2 155	2 591	3 220	4 366
Ambitious	MW	1 085	1 465	2 056	2 653	3 444	4 520
Extreme	MW	1 524	1 890	2 440	3 139	4 275	6 133

Table 4.7. Transmission network deman difference to old model

Parameter	unit	2025	2030	2035	2040	2045	2050
Expected	GWh	-92	278	695	1 475	1 845	2 290
Ambitious	GWh	-81	425	929	1 770	2 272	2 959
Extreme	GWh	-75	627	1 273	2 332	3 197	4 506
Expected	MW	-26	95	301	548	927	1 669
Ambitious	MW	-39	181	455	801	1 127	1 633
Extreme	MW	-21	258	586	1 096	1 982	3 436

Table 4.8. Detailed view of ambitious electrification scenario

Year	2025	2030	2035	2040	2045	2050
Heating	0	258	457	827	1460	2571
Local heating	0	110	195	358	629	1097
District heating	0	148	262	468	831	1474
Natural gas	0	49	424	776	1046	1285
Buildings	9	-36	-80	-60	17	127
Transport	98	432	953	1570	2238	2685
Base Growth	8244	8561	8879	9196	9513	9830
S1 Loss	20	60	133	224	338	470
Total	8371	9325	10766	12532	14611	16967
Local Generation	-609	-1018	-1540	-2163	-2852	-3542
Veichle to Grid	0	0	1	3	0	14
S3	-168	-168	-168	-168	-168	-168
S3 Loss	12	30	57	94	127	186
Total	7607	8170	9117	10299	11718	13458

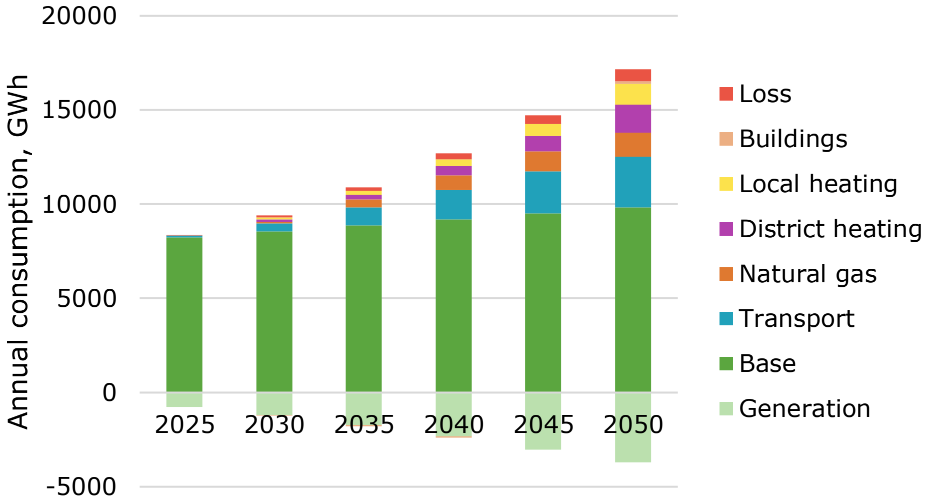
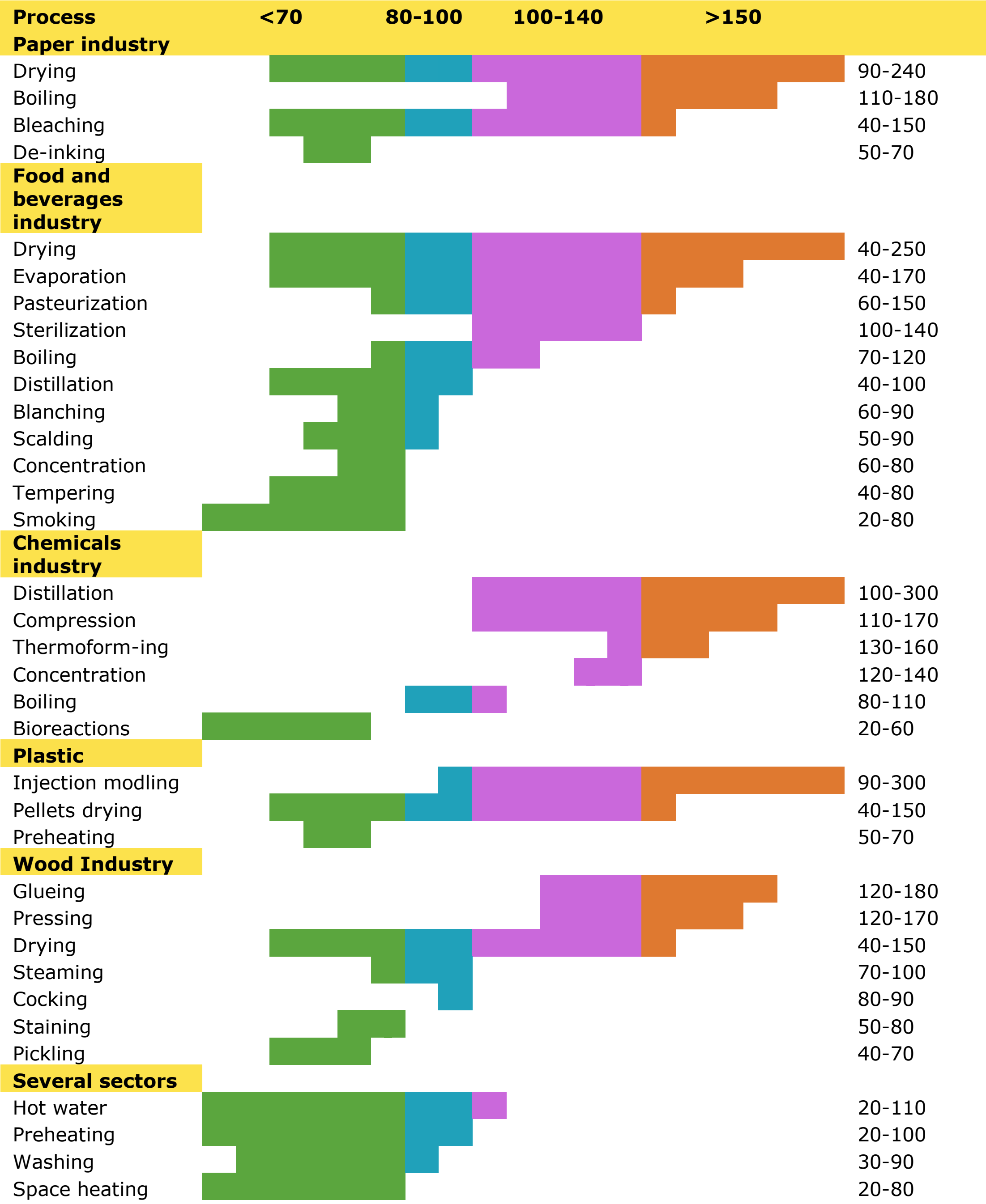


Figure 4.8. Average Climatic Year Consumption Under the Ambitious Electrification Scenario

Annex

Table A.0.1 Temperatures and heat pump technology readiness levels [17]



Process	**<70**	**80-100**	**100-140**	**>150**	
Paper industry					
Drying	🟩	🟦	🟪	🟧	90-240
Boiling			🟪	🟧	110-180
Bleaching	🟩	🟦	🟪	🟧	40-150
De-inking	🟩				50-70
Food and beverages industry					
Drying	🟩	🟦	🟪	🟧	40-250
Evaporation	🟩	🟦	🟪	🟧	40-170
Pasteurization	🟩	🟦	🟪	🟧	60-150
Sterilization			🟪		100-140
Boiling	🟩	🟦	🟪		70-120
Distillation	🟩	🟦			40-100
Blanching	🟩	🟦			60-90
Scalding	🟩	🟦			50-90
Concentration	🟩				60-80
Tempering	🟩				40-80
Smoking	🟩				20-80
Chemicals industry					
Distillation			🟪	🟧	100-300
Compression			🟪	🟧	110-170
Thermoform-ing			🟪	🟧	130-160
Concentration			🟪		120-140
Boiling		🟦	🟪		80-110
Bioreactions	🟩				20-60
Plastic					
Injection modling		🟦	🟪	🟧	90-300
Pellets drying	🟩	🟦	🟪	🟧	40-150
Preheating	🟩				50-70
Wood Industry					
Glueing			🟪	🟧	120-180
Pressing			🟪	🟧	120-170
Drying	🟩	🟦	🟪	🟧	40-150
Steaming	🟩	🟦			70-100
Cocking		🟦			80-90
Staining	🟩				50-80
Pickling	🟩				40-70
Several sectors					
Hot water	🟩	🟦	🟪		20-110
Preheating	🟩	🟦			20-100
Washing	🟩	🟦			30-90
Space heating	🟩				20-80

🟩 Conventional heat pumps <80°C

🟦 Commercially available high-temperature heatpumps 80 – 100 °C

🟪 Prototype status, technology development, high temperatuure heat pump 100 – 140 °C

🟧 Laboratory scale reasearch, proof of concept heat pumps >140 °C

Annex 2

Scenario 11

Scenarios combined: Low transport scenario, Local heating electrification, District heating peak load base scenario electrification.

Table A.0.2. Average climate year end consumer consumption (level 1 of scenario 11)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	2 191	2 383	2 661	2 975	3 359	3 849
Service	GWh	3 398	3 685	4 197	4 710	5 291	6 060
Industry	GWh	2 602	2 647	2 678	2 860	3 096	3 436
Transport	GWh	190	672	1 431	2 284	3 047	3 519
Total	**GWh**	**8 381**	**9 387**	**10 967**	**12 829**	**14 793**	**16 864**
Peak	MW	1535	1743	2178	2637	3218	4204
Summer Peak	MW	973	1091	1256	1426	1599	1784
Lowest	MW	524	600	715	842	992	1127

Table A.0.3. Difference compare to original model result (level 1 of scenario 11)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	65	114	203	362	643
Service	GWh	0	115	222	398	708	1 262
Industry	GWh	0	12	21	54	88	130
Transport	GWh	-91	86	336	815	681	250
Total	**GWh**	**-91**	**278**	**693**	**1 470**	**1 839**	**2 285**
Peak	MW	-26	94	303	557	834	1 491
Summer Peak	MW	-19	13	55	123	126	126
Lowest	MW	-3	8	28	60	65	40

Table A.0.4. Average climate year end consumer consumption (level 3 of scenario 11)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	1968	2026	2131	2235	2386	2647
Service	GWh	3089	3221	3529	3808	4134	4643
Industry	GWh	2369	2312	2225	2261	2333	2511
Transport	GWh	190	672	1434	2294	3067	3561
Total	**GWh**	**7616**	**8232**	**9319**	**10598**	**11919**	**13362**
Peak	MW	1519	1727	2155	2591	3220	4366
Summer Peak	MW	951	1069	1225	1372	1604	1885
Lowest	MW	196	6	-243	-541	-888	-1258

Table A.0.5. Difference compare to original model result (level 3 of scenario 11)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	63	113	202	359	637
Service	GWh	0	113	217	388	691	1 225
Industry	GWh	0	15	28	66	109	172
Transport	GWh	-91	85	337	820	687	255
Total	**GWh**	**-92**	**278**	**695**	**1 475**	**1 845**	**2 290**
Peak	MW	-26	95	301	548	927	1 669
Summer Peak	MW	-20	13	51	108	196	103
Lowest	MW	-4	11	29	62	61	41

Scenario 13

Scenarios combined: Low transport scenario, Local heating electrification, District heating base load base electrification scenario.

Table A.0.6. Average climate year end consumer consumption (level 1 of scenario 13)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	2 191	2 427	2 740	3 115	3 606	4 290
Service	GWh	3 398	3 689	4 205	4 724	5 317	6 105
Industry	GWh	2 602	2 647	2 678	2 860	3 096	3 436
Transport	GWh	190	672	1 431	2 284	3 047	3 519
Total	**GWh**	**8 381**	**9 435**	**11 054**	**12 983**	**15 066**	**17 350**
Peak	MW	1535	1776	2237	2742	3440	4624
Summer Peak	MW	973	1091	1256	1431	1609	1813
Lowest	MW	524	600	715	842	992	1127

Table A.0.7. Difference compare to original model result (level 1 of scenario 13)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	0	109	193	343	609	1 084
Service	GWh	0	119	230	412	734	1 307
Industry	GWh	0	12	21	54	88	130
Transport	GWh	-91	86	336	815	681	250
Total	**GWh**	**-91**	**326**	**780**	**1 624**	**2 112**	**2 771**
Peak	MW	-26	127	362	662	1 056	1 911
Summer Peak	MW	-19	13	55	128	136	155
Lowest	MW	-3	8	28	60	65	40

Table A.0.8. Average climate year end consumer consumption (level 3 of scenario 13)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	1 968	2 068	2 205	2 366	2 618	3 061
Service	GWh	3 089	3 226	3 539	3 827	4 168	4 704
Industry	GWh	2 369	2 313	2 227	2 264	2 340	2 522
Transport	GWh	190	672	1 434	2 294	3 067	3 561
Total	**GWh**	**7 616**	**8 280**	**9 405**	**10 751**	**12 193**	**13 848**
Peak	MW	1519	1760	2214	2696	3455	4785
Summer Peak	MW	951	1069	1225	1376	1620	1913
Lowest	MW	196	6	-243	-541	-888	-1258

Table A.0.9. Difference compare to original model result (level 3 of scenario 13)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	0	105	187	333	591	1 051
Service	GWh	0	118	227	407	725	1 286
Industry	GWh	0	16	30	69	116	183
Transport	GWh	-91	85	337	820	687	255
Total	**GWh**	**-92**	**326**	**781**	**1 628**	**2 119**	**2 776**
Peak	MW	-26	128	360	653	1 162	2 088
Summer Peak	MW	-20	13	51	112	212	131
Lowest	MW	-4	11	29	62	61	41

Scenario 22

Scenarios combined: High transport scenario, Local heating electrification, District heating peak load fast electrification scenario.

Table A.0.10. Average climate year end consumer consumption (level 1 of scenario 22)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	2 191	2 456	2 792	3 208	3 773	4 586
Service	GWh	3 398	3 689	4 205	4 724	5 317	6 105
Industry	GWh	2 602	2 647	2 678	2 860	3 096	3 436
Transport	GWh	207	799	1 615	2 430	3 161	3 586
Total	**GWh**	**8 397**	**9 592**	**11 290**	**13 222**	**15 346**	**17 713**
Peak	MW	1540	1820	2312	2833	3605	4899
Summer Peak	MW	976	1117	1288	1453	1630	1845
Lowest	MW	525	608	724	852	1002	1129

Table A.0.11. Difference compare to original model result (level 1 of scenario 22)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	138	245	436	776	1 380
Service	GWh	0	119	230	412	734	1 307
Industry	GWh	0	12	21	54	88	130
Transport	GWh	-74	213	520	961	795	317
Total	**GWh**	**-75**	**483**	**1 016**	**1 863**	**2 392**	**3 134**
Peak	MW	-21	171	437	753	1 221	2 186
Summer Peak	MW	-16	39	87	150	157	187
Lowest	MW	-2	16	37	70	75	42

Table A.0.12. Average climate year end consumer consumption (level 3 of scenario 22)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	1 968	2 096	2 255	2 454	2 775	3 339
Service	GWh	3 089	3 227	3 541	3 830	4 174	4 715
Industry	GWh	2 369	2 314	2 228	2 266	2 343	2 528
Transport	GWh	207	800	1 619	2 441	3 181	3 630
Total	**GWh**	**7 633**	**8 437**	**9 642**	**10 992**	**12 474**	**14 213**
Peak	MW	1524	1803	2287	2784	3630	5066
Summer Peak	MW	954	1094	1256	1396	1656	1951
Lowest	MW	196	13	-233	-535	-884	-1254

Table A.0.13. Difference compare to original model result (level 3 of scenario 22)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	133	237	421	748	1 329
Service	GWh	0	119	229	410	731	1 297
Industry	GWh	0	17	31	71	119	189
Transport	GWh	-74	213	522	967	801	324
Total	**GWh**	**-75**	**483**	**1 018**	**1 869**	**2 400**	**3 141**
Peak	MW	-21	171	433	741	1 337	2 369
Summer Peak	MW	-17	38	82	132	248	169
Lowest	MW	-4	18	39	68	65	45

Scenario 23

Scenarios combined: High transport scenario, Local heating electrification, District heating base load base electrification scenario.

Table A.0.14. Average climate year end consumer consumption (level 1 of scenario 23)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	2 191	2 427	2 740	3 115	3 606	4 290
Service	GWh	3 398	3 700	4 225	4 760	5 382	6 220
Industry	GWh	2 602	2 647	2 678	2 860	3 096	3 436
Transport	GWh	207	799	1 615	2 430	3 161	3 586
Total	**GWh**	**8 397**	**9 574**	**11 258**	**13 165**	**15 244**	**17 532**
Peak	MW	1540	1807	2290	2794	3510	4743
Summer Peak	MW	976	1117	1288	1451	1627	1834
Lowest	MW	525	608	724	852	1002	1129

Table A.0.15. Difference compare to original model result (level 1 of scenario 23)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	0	109	193	343	609	1 084
Service	GWh	0	130	250	448	799	1 422
Industry	GWh	0	12	21	54	88	130
Transport	GWh	-74	213	520	961	795	317
Total	**GWh**	**-75**	**465**	**984**	**1 806**	**2 290**	**2 953**
Peak	MW	-21	158	415	714	1 126	2 030
Summer Peak	MW	-16	39	87	148	154	176
Lowest	MW	-2	16	37	70	75	42

Table A.0.16. Average climate year end consumer consumption (level 3 of scenario 23)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	1 968	2 069	2 206	2 367	2 620	3 064
Service	GWh	3 089	3 237	3 558	3 862	4 229	4 813
Industry	GWh	2 369	2 314	2 227	2 265	2 341	2 524
Transport	GWh	207	800	1 619	2 441	3 181	3 630
Total	**GWh**	**7 633**	**8 419**	**9 610**	**10 935**	**12 372**	**14 032**
Peak	MW	1524	1791	2265	2745	3542	4910
Summer Peak	MW	954	1094	1256	1394	1650	1940
Lowest	MW	196	13	-233	-535	-884	-1254

Table A.0.17. Difference compare to original model result (level 3 of scenario 23)

Parameter	unit	2025	2030	2035	2040	2045	2050
Household	GWh	0	106	188	334	593	1 054
Service	GWh	0	129	246	442	786	1 395
Industry	GWh	0	17	30	70	117	185
Transport	GWh	-74	213	522	967	801	324
Total	**GWh**	**-75**	**465**	**986**	**1 812**	**2 298**	**2 960**
Peak	MW	-21	159	411	702	1 249	2 213
Summer Peak	MW	-17	38	82	130	242	158
Lowest	MW	-4	18	39	68	65	45

Scenario 24

Scenarios combined: High transport scenario, Local heating electrification, District heating base load fast electrification scenario.

Table A.0.18. Average climate year end consumer consumption (level 1 of scenario 24)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	2 191	2 545	2 949	3 487	4 268	5 467
Service	GWh	3 398	3 720	4 262	4 825	5 497	6 426
Industry	GWh	2 602	2 672	2 719	2 943	3 217	3 599
Transport	GWh	207	799	1 615	2 430	3 161	3 586
Total	**GWh**	**8 397**	**9 736**	**11 545**	**13 685**	**16 144**	**19 079**
Peak	MW	1540	1906	2465	3140	4259	6043
Summer Peak	MW	976	1119	1293	1474	1670	1935
Lowest	MW	525	610	729	861	1015	1145

Table A.0.19. Difference compare to original model result (level 1 of scenario 24)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	227	402	715	1 271	2 261
Service	GWh	0	150	287	513	914	1 628
Industry	GWh	0	37	62	137	209	293
Transport	GWh	-74	213	520	961	795	317
Total	**GWh**	**-75**	**627**	**1 271**	**2 326**	**3 190**	**4 500**
Peak	MW	-21	257	590	1 060	1 875	3 330
Summer Peak	MW	-16	41	92	171	197	277
Lowest	MW	-2	18	42	79	88	58

Table A.0.20. Average climate year end consumer consumption (level 3 of scenario 24)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	1 968	2 181	2 405	2 721	3 250	4 186
Service	GWh	3 089	3 260	3 602	3 940	4 368	5 057
Industry	GWh	2 369	2 340	2 271	2 352	2 472	2 705
Transport	GWh	207	800	1 619	2 441	3 181	3 630
Total	**GWh**	**7 633**	**8 581**	**9 897**	**11 455**	**13 271**	**15 578**
Peak	MW	1524	1890	2440	3139	4275	6133
Summer Peak	MW	954	1097	1260	1418	1710	2040
Lowest	MW	196	16	-228	-526	-871	-1237

Table A.0.21. Difference compare to original model result (level 3 of scenario 24)

Parameter	**unit**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Household	GWh	0	218	387	688	1 223	2 176
Service	GWh	0	152	290	520	925	1 639
Industry	GWh	0	43	74	157	248	366
Transport	GWh	-74	213	522	967	801	324
Total	**GWh**	**-75**	**627**	**1 273**	**2 332**	**3 197**	**4 506**
Peak	MW	-21	258	586	1 096	1 982	3 436
Summer Peak	MW	-17	41	86	154	302	258
Lowest	MW	-4	21	44	77	78	62

Annex 3

Table A.0.22 Cars and vans projections

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
All cars and vans registrations	60 386	44 905	56 003	56 533	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655	54 655
All new cars and vans registrations	28 845	20 695	25 128	23 734	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360	25 360
All used cars and vans registrations	31 541	24 210	30 875	32 799	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295	29 295
All cars and vans deregistrations					-36 347	-38 083	-39 573	-40 836	-42 057	-43 134	-43 824	-44 310	-44 755	-45 146	-45 506	-45 923	-46 407
New EV registrations	86	368	533	716	1 535	2 941	4 648	5 626	7 819	10 012	12 204	14 397	16 590	18 782	20 975	23 167	25 360
New EV registrations (progressive)	86	368	533	716	1 535	4 126	6 112	6 824	10 190	13 556	16 922	20 288	21 302	22 317	23 331	24 346	25 360
Used EV registrations					1 025	2 016	3 273	4 069	5 809	7 641	9 571	11 604	13 743	15 995	18 366	20 860	23 486
Used EV registrations (progressive)					1 025	2 829	4 303	4 935	7 570	10 346	13 271	16 352	17 647	19 006	20 429	21 922	23 486
EV deregistrations (expected)					-110	-199	-372	-641	-930	-1 322	-1 819	-2 406	-3 071	-3 831	-4 696	-5 678	-6 795
EV deregistrations (progressive)					-110	-199	-448	-811	-1 160	-1 666	-2 356	-3 192	-4 149	-5 093	-6 042	-7 030	-8 101

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Share of EVs in new cars and vans	0,3%	1,8%	2,1%	3,0%	6,1%	11,6%	18,3%	22,2%	30,8%	39,5%	48,1%	56,8%	65,4%	74,1%	82,7%	91,4%	100%
Share of EVs in new cars and vans (progressive)	0,3%	1,8%	2,1%	3,0%	6,1%	16,3%	24,1%	26,9%	40,2%	53,5%	66,7%	80,0%	84,0%	88,0%	92,0%	96,0%	100%
Share of EVs in used cars and vans					3,5%	6,9%	11,2%	13,9%	19,8%	26,1%	32,7%	39,6%	46,9%	54,6%	62,7%	71,2%	80,2%
Share of EVs in used cars and vans (progressive)					3,5%	9,7%	14,7%	16,8%	25,8%	35,3%	45,3%	55,8%	60,2%	64,9%	69,7%	74,8%	80,2%
Cumulatively EVs	1 354	1 744	2 418	3 415	5 864	10 617	18 165	27 219	39 917	56 248	76 204	99 799	127 061	158 007	192 650	230 997	273 049
Cumulatively EVs (progressive)	1 354	1 744	2 418	3 415	5 864	12 614	22 581	33 531	50 131	72 365	100 201	133 649	168 449	204 678	242 396	281 634	322 380
Share of EVs in fleet (expected)	0,2%	0,2%	0,3%	0,5%	0,8%	1,4%	2,3%	3,5%	5,0%	7,0%	9,3%	12,1%	15,3%	18,8%	22,7%	27,1%	31,8%
Share of EVs in fleet (progressive)	0,2%	0,2%	0,3%	0,5%	0,8%	1,7%	2,9%	4,3%	6,3%	9,0%	12,3%	16,2%	20,2%	24,4%	28,6%	33,0%	37,5%

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