Reduction of CO_2 emissions, impact on the power system:

Contribution of heating in buildings by 2035

SUMMARY

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DECEMBER 2020

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EXECUTIVE SUMMARY

In France, the building sector accounts for 75 million tonnes of direct CO_2 emissions a year from combustion (i.e. without counting the upstream fuel cycle or emissions from the production of the electricity and heat used). This represents 20% of the country's emissions. Approximately 53 million tonnes of this is generated by fuel-based heating, accounting for 15% of the country's emissions.

Decarbonising the building sector is therefore a prerequisite for achieving carbon neutrality, and is a priority for public policy.

The French government's National Low-Carbon Strategy (NLCS[1]) defines a trajectory to reduce the associated emissions. The measures for implementing the NLCS guidelines are specified in policies for the energy sector (Multi Annual Energy Plan, MAEP[2] in France) and the building sector (project to draft environmental regulations for new build (RE 2020), reform of the energy performance assessment regulations (EPCs[3]), etc.).

This strategy is based on three main principles:

1. A significant improvement in the performance of buildings – via more stringent standards for new buildings and a major programme of high-performance retrofitting of old residential and commercial buildings to bring the stock up to the level of low consumption buildings (BBC) on average by 2050.

2. Improving the efficiency of heating solutions – by choosing high-performance solutions such as heat pumps.

3. Replacement of fossil fuel heating plant by low-carbon solutions, such as high performance electric heating methods, heat networks using renewable sources and energy recovery, or the use of wood and biomass.

It is vital to combine these changes to avoid falling behind in the emission reduction trajectory, as has been pointed out in a recent report by the French High Council on Climate, published in November 2020.

Questions to be addressed by the study

The debate on the regulations to be introduced in the building sector to achieve carbon neutrality is particularly vigorous, especially since numerous policies must be coordinated for effective action to be taken on France's greenhouse gas emissions. The associated changes can only happen over the long term:

- By improving the energy and environmental performance of new buildings. However, these buildings only account for around 1% of the housing stock each year.
- By retrofitting existing buildings. Over the mid-to-long term, however, the rate and quality of retrofitting has not improved to the level expected for the past few years, despite the government's high ambitions and the mechanisms put in place, and the first carbon budget of the NLCS was exceeded during the period 2015-2018. Over the last few months, a change in the rate of retrofitting work has nevertheless been observed (energy efficiency certificate mechanism (CEE), and assistance with energy retrofitting), which must be continued in the future.

At the same time, part of the debate is focusing specifically on the benefit of using electric solutions

1. Known as the *Stratégie Nationale Bas-Carbone* (SNBC) in French
2. Known as the *Programmation Pluriannuelle de l'Energie* (PPE) in French
3. Known as the *Diagnostic de Performance Energétique* (DPE) in French, and as the *Energy Performance Certificates* (EPCs) at the European level

in heating, which is an opportunity to use energy-efficient electric solutions (heat pumps) countering the concern that less efficient solutions (resistive heaters) will be developed in poorly insulated buildings, with questions about the consequences in terms of consumption peaks and CO_2 emissions.

The work described in this report has been carried out by RTE and ADEME in order to answer some of these questions, based on refined modelling of the power system:

1. From a climate perspective, do the proposed guidelines in the field of energy policy and building actually **reduce emissions and make it possible to keep to the climate trajectory established by the NLCS?** Is this emission reduction trajectory, which includes partial electrification of heating, **still valid when the emissions due to electricity generation, in France and other European countries, are included?**

2. From the perspective of security of supply, does the target of increasing the electricity share defined in the NLCS, which is in the process of being transposed into the building sector, **create a risk for the security of supply?** Does it create a trend towards increasing electricity consumption or winter peaks?

3. From an economic perspective, does the reduction of emissions in buildings require significant investment: **could some configurations be more efficient** in economic terms?

For each of these questions, RTE and ADEME have endeavoured to analyse the relative influence of the various levers: efficiency of the heating methods, the aim of energy retrofitting and the change in the electricity mix. The study has also explored what complementarity conditions there may be between improving the performance of buildings and changing energy sources.

Methodology used in the study to address these questions

The RTE-ADEME study assesses the consequences of the long-term policy implemented in the building sector, up to 2035. This date is halfway to that by which France should achieve carbon neutrality and corresponds to the overall framework used since 2017 for the electricity mix (it is also the date on which the share of nuclear in the electricity generation mix should be 50%).

The methodology used consists of examining and comparing various trajectories:
- **The reference trajectory corresponds to the satisfactory implementation of all the government guidelines** given in the MAEP and the NLCS, currently being implemented in the regulations (RE 2020, reform of the EPC, support mechanisms, obligations on retrofitting, etc.). It is represented by two scenarios, which only differ in the share of electricity in new buildings.
- Trajectories in which some targets are not met: **these are stress tests; they can be used to assess the risks** (on security of supply, emissions or costs) associated with incomplete implementation of the NLCS.

In total, this work has focused on 6 main scenarios and 6 specific sensitivities. A threefold analysis of the effects of all these scenarios and sensitivities has been carried out:
- **On the power system** (average annual consumption, peaks).
- **On CO_2 emissions** (assessed within France and including those of the power system, and then including the resulting variations on the power system Europe-wide).
- **On costs** (including those of retrofitting, installation and maintenance of heating solutions, fuel costs and the costs of changing the power system).

In all the scenarios studied, the NLCS targets for the development of other low-carbon heating methods such as fuelwood, biogas or heat networks mainly supplied from renewable sources have been taken into account.

Main messages of the study

The conclusions of the study can be divided into two categories:

- Conclusions on the NLCS implementation scenarios
- Conclusions resulting from the analysis of the stress tests and examples of incomplete implementation of the trajectory

1. With regard to the overall objective: the study confirms that the retrofitting of buildings combined with the development of energy-efficient electric heating solutions is a relevant solution for reducing emissions in the line with the trajectory and the carbon budgets defined by the NLCS.

The results of the study confirm the benefit of electric solutions for reducing greenhouse gas emissions in the building sector, within the framework defined in the NLCS and the building policy, which incorporates significant development of energy efficiency, both in terms of buildings and heating solutions.

This result confirms and expands on the conclusions of recent publications and studies, including the recent report by the French High Council on Climate on energy retrofitting. The latter report highlights both the importance of improving the insulation of the building shell and that of switching to energy-efficient low-carbon heating solutions: electricity with heat pumps, heat networks and biomass boilers and heaters.

In the study carried out, the emission reduction targets can only be met by combining the three main parameters (performance of buildings, performance of heating solutions and switch to low-carbon solutions, one of which is electricity). Compliance with the carbon trajectory was confirmed as regards 1) the specific objectives for the building sector defined in the NLCS (for heating, **a reduction from 53 $MtCO_2$ today to approximately 25 $MtCO_2$ in 2035**), and 2) the objectives for the electricity sector in the application of the trajectory defined by the MAEP (reduction from approximately 20 $MtCO_2$ today to 11 $MtCO_2$ in 2035).

The downward effect on emissions is also confirmed once the spillover effects on the power system Europe-wide are taken into account. In other words incorporating the fact that, all other things being equal, the development of a new use for electricity in France results in less low-carbon electricity being exported (general case) or electricity with generally higher carbon levels, produced in neighbouring countries, being imported (uncommon case).

A public policy that keeps to the trajectories and levers of the NLCS, which do not have a major impact on the power system: **annual electricity consumption associated with heating would be stable or even decrease slightly by 2035** if the energy efficiency measures were applied correctly. Peak electricity consumption would not change significantly either, and would even be slightly lower.

These actions form a coherent whole that maximises their effectiveness:

- **None of these actions, taken individually, is enough to meet the emission reduction target** of the NLCS, and each of them raises specific issues (effectiveness of expenditure or impact on the management of the power system, see below).
- **Each one results in reduction of greenhouse gas emissions,** and none of them creates any risk of increasing emissions over the long term.

Optimum insulation of buildings also has other benefits, which go beyond the energy sector: increased comfort for residents, with positive effects on health, on the quality of the building and preservation of their heritage value, lower energy bills and thus less energy poverty, and a source of local non-relocatable jobs.

The above conclusions also apply in the scenario in which electricity (using heat pumps) has a greater share in the new building sector. The CO_2 balance even gradually becomes slightly better over time (by 2035, an additional reduction of 1 $MtCO_2$/year in France).

2. Concerning the issue of keeping to the climate trajectories: the study shows that failing to meet the target for just one of the aspects studied (building efficiency, performance of heating solutions, or switch to low-carbon heating, including electricity) would lead to delay with respect to the NLCS trajectory.

This effect has been assessed for each of the partial implementation scenarios of the NLCS trajectory. In relation to the NLCS scenario, by 2035 and incorporating the variations in emissions within France's power system, it leads to:

- A difference of +5 $MtCO_2$/year if high-performance building retrofitting is carried out and the heating systems are energy-efficient, with no switch to electric solutions.
- A difference of +6 $MtCO_2$/year if the heating equipment is electrified, but using low performance resistive heaters in houses in which the performance has not been improved.
- A difference of +11 $MtCO_2$/year if these effects are combined. There would then be a significant delay in the NLCS trajectory, with a mid-way balance in 2035 of 36 $MtCO_2$/year instead of 25 $MtCO_2$/year.

This underlines the importance of each of the three main actions described by the NLCS, which are in the process of being implemented in the building sector.

If the electric heating solutions are developed in line with the trajectory in the NLCS scenario, using energy-efficient solutions such as heat pumps, but with no significant change in the rate or performance level of the retrofitting of buildings in France, the difference remains +6 $MtCO_2$/year in relation to the target. However, in this case, the European balance is more favourable than if this electrification were carried out using electric heaters (mainly because France would export more low-carbon electricity, and in some cases because imports would be reduced).

3. With regard to the issue of security of supply: the study underlines how important it is that the 'building' regulations specifying electricity and other low-carbon methods also require good insulation of buildings and energy-efficient heating equipment. Otherwise, peak consumption would increase.

Existing buildings

Reduction of emissions is favoured if electrification of heating (replacing oil-fired and some fossil gas fired equipment) is accompanied by efforts on the number of retrofitting jobs and their performance level across the whole housing stock (not just on houses which have electric heating systems or are being converted to electric solutions when they are retrofitted).

Consumption and the electricity peak are reduced (-3 TWh of annual consumption and -3 GW on the peak in the reference scenario).

However, if the development of electric heating involved the widespread installation of low performance electric heaters in poorly insulated houses, the electricity peak would increase substantially (+6 GW in 15 years in the scenario which combines stress tests on retrofitting and efficiency of heating systems, as against an electricity peak of approximately 100 GW today). This would lead to strain on the security of supply. As the risk of the development towards mainly resistive heaters, which could seem credible to some given past trends, the regulations on new buildings that are currently being defined must aim to steer investment in electric solutions towards heat pumps so that these solutions also become the reference in existing buildings.

New buildings

The benefits mentioned with regard to retrofitting of course also apply to new buildings, in which measures to ensure the energy efficiency of buildings are much easier to implement. The house-building rate in France (400,000 a year, i.e. 1% of the housing stock) is not high enough to lead to significant effects for several decades, and fully justifies efforts to make changes through retrofitting, in particular that of old, poorly insulated housing.

4. From an economic viewpoint: the study concludes that it is important to focus on retrofitting houses that consume most energy (energy-intensive housing) and underlines the benefit of high-performance approaches to retrofitting

Policies to improve the energy efficiency of existing buildings, houses and offices, lead to ongoing investment for the community, which produces various types of benefit over and above combating climate change.

When assessed from the emissions aspect only, which does not consider the benefits of retrofitting, the transition costs (in particular building retrofitting costs) compared with the amounts invested (abatement costs) are higher than those of other emission reduction policies (for example the change to e-mobility). However, they are **compatible with the 2035 shadow price of carbon determined by the government (375 €/tCO_2):**

- Taking the rebound effect into account (i.e. incorporating the fact that energy retrofitting increases the comfort level): the abatement costs are between 310 and 430 €/tCO_2 (reference assumption) according to how much the retrofitting costs fall due to scale effects and the industrialisation of retrofitting.
- Not taking the rebound effect into account (unchanged comfort level): the abatement costs are between 160 and 240 €/tCO_2 (reference assumption).

The prospects for reducing the retrofitting cost (e.g. through industrialisation of the work in the context of a major national programme) and residents' decisions on how to make use of the energy savings resulting from building retrofitting and heating solutions (lower energy bills or improved comfort and less energy poverty) are therefore the main variables to be taken into account in the economic analysis of the scenarios.

The economic issue is particularly important as the work requires considerable initial financial investment to reduce energy consumption, which only pays for itself in the long term and therefore requires a significant amount of support to trigger the investment. This is where the main challenges lie, as well as in non-economic deciding factors (ease of carrying out the retrofitting, training of the workers, etc.).

4. If it is installed under technical conditions that ultimately enable the required performance level to be reached (with retrofitting which reduces the energy requirement by 50%, as opposed to less comprehensive retrofitting which only lead to a 30% reduction),

It should however be noted that the best insulation of buildings[4] provides other benefits beyond the energy sector: increased comfort for residents with positive effects on their health, lower demand on budgets for heating and therefore a decrease in energy poverty, and a source of local non-relocatable jobs. These external effects could help compensate for the problems mentioned, but they are mostly related to financial insecurity, and this may be a significant barrier to implementation in practice.

To maximise the effectiveness of the expenditure, it appears advisable to optimise and prioritise retrofitting: prioritising the replacement of oil-fired heating, which creates most emissions and is the most costly in terms of fuel, targeting poorly insulated homes and prioritising high-performance retrofitting. One sensitivity analysed in the study shows that it is possible to significantly increase the efficiency of the euros invested by targeting old houses that consume a great deal of energy. The abatement cost changes from 430 €/tCO_2 in the reference scenario to 290 €/tCO_2 where the retrofitting concentrates on energy-intensive housing, taking the rebound effect into account in both cases.

The study shows that, from the point of view of the community, targeting 'energy-intensive housing' and demanding high performance levels during retrofitting is an effective way of maximising the effectiveness of the expenditure and quickly achieving significant results on the climate front.

This analysis was carried out without prejudice to broader consideration of the constraints on the capacity of households to invest. It may therefore also be relevant to combine preferential treatment of energy-intensive housing with an increased number of retrofitting operations in order to maximise the ripple effect for the sector.

Finally, the scenario involving electrification using energy-efficient solutions such as heat pumps, but with no significant change to the insulation of the building, shows a high degree of efficiency from an economic viewpoint.

OVERVIEW OF THE STUDY

Why and how the study was conducted

To tackle a specific issue in the building sector

The building sector is responsible for almost 75 million tonnes of CO_2 emissions in France, accounting for around 20% of the national total. One of the aims of the NLCS is to achieve a substantial reduction in carbon emissions from heating systems through a variety of measures. Upstream, ensuring that buildings are properly insulated is considered an essential step in reducing the heating requirement. The plan downstream is to promote different energy carriers:

- Electricity, through heat pumps, which offer the added advantage of being extremely energy efficient
- Renewable heat, through biomass boilers and heat networks

The new RE2020 environmental regulations governing new builds come into force in France in 2021. These requirements aim to align the carbon neutral standards with the NLCS strategy trajectory and to translate the ambitions to halve total energy consumption in France over the next thirty years into concrete actions. They are designed to reduce a building's carbon footprint over its entire life cycle by increasing the use of low-carbon materials (particularly biosourced materials) for construction, imposing strict standards on building insulation and prioritising the installation of low-carbon heating solutions.

Measures proposed to target existing buildings, such as revisions to the EPC energy performance diagnosis, retrofit support programmes and schemes to cut energy consumption in commercial buildings (as laid down in new legislation for retrofitting commercial buildings), are currently the subject of ongoing discussions between the French government and industry stakeholders.

Electric heating is a hotly debated topic in France. Proponents see it as an effective means of tackling climate change, since electricity produced in France has already achieved a 93% reduction in carbon emissions. Opponents, however, believe that conventional resistive heating solutions are not energy efficient, arguing that their impact on electricity consumption peaks is likely to cause security of supply issues and that the carbon balance for electric heating would not be positive if France had to import electricity.

Whilst those on one side of the debate advocate that heating should be electrified as a matter of priority to be able to move away from fossil fuels, those on the other side believe that alternative solutions should be considered, with both camps brandishing different accounting methods to substantiate their arguments. Disagreements over the choice of carbon emission factor or primary energy factor (CEP or PEF) for the new environmental regulations governing new builds are proof of this ongoing debate.

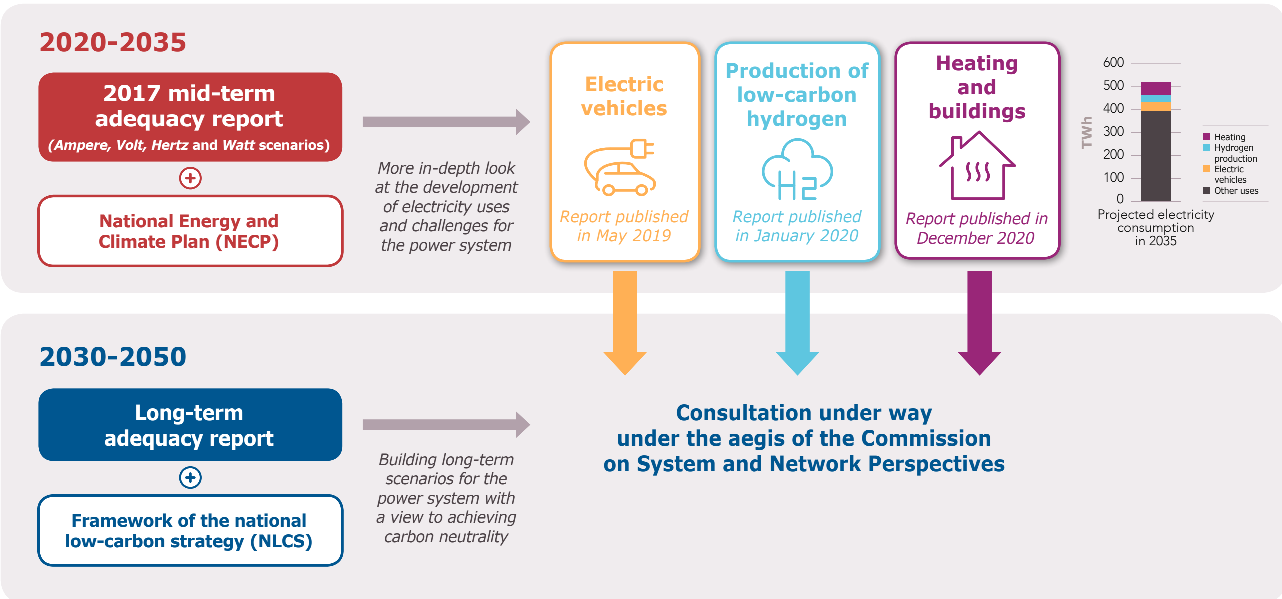
This is the backdrop against which the report was drawn up by RTE and the ADEME. The aim of this report is to assess the multiple parameters involved to demonstrate the impact of choices made by government and private individuals on building insulation, and on the choice and performance of heating solutions, in order to provide a quantitative response and bring a greater degree of objectivity to the debate.

To tackle a specific issue in the energy sector

Developing electrical solutions for heating systems is part of a vast array of transformations at work in the energy sector to achieve carbon neutrality. The various strategies adopted by European countries or the European Commission (such as the NLCS in France) all seek to increase the role of electricity in the highest emitting sectors, namely transport, industry and construction. The special situation of the French electricity industry – already very low carbon – could enhance the overall benefit of the measures adopted.

To study these transformations and their impact on the power system, RTE has been developing a three-part plan for uses (dubbed 'trilogy' in French) since 2019, in some cases in conjunction with other institutions. This involves three special focus studies intended to provide a more in-depth analysis of the electrification of each specific use. These studies share the same methodology and consider the same time line (with 2035 being the mid-point on the carbon neutrality trajectory). The cumulative effect of these transformations is analysed in the mid-term adequacy report.

The 'Heating and Buildings' study conducted in partnership with the ADEME represents the final component of this three-part plan. It incorporates the specific issues associated with the temperature sensitivity of electricity consumption in France, given that existing heating systems are already partly electrified.



Study parameters

The RTE-ADEME study is based on four key parameters:

- **Building energy performance –** specifically the rate and quality of work to insulate existing housing and offices
- **The share of each of the different energy sources** and carriers used in heating – specifically the penetration of electric solutions
- **The efficiency of the heating solutions installed** – which, for electricity, involves making a distinction between heat pumps and resistive heating
- **The evolving electricity mix in France** – considering the challenges associated with the pace of development of renewable energies and the fixed trajectory for nuclear power.

Each of these parameters can vary independently of the others, which allows a wide variety of scenarios to be studied.

Other significant parameters also evaluated in the study include the following:

- The extent of the retrofit effort, where a distinction can be made between the residential and commercial sectors
- The cost assumptions for retrofit activities, which are extremely diverse and not yet fully scoped
- The unit performance of retrofit activities, specifically the average number of actions completed during retrofitting (ranging from an approach involving a series of successive actions to a full retrofit approach)
- The distribution of retrofit effort, which may be considered to be uniform (as in the reference scenario) or may involve prioritising certain kinds of housing, such as those with very poor energy efficiency ratings
- The duty cycles and satisfaction of the heating requirement before and after retrofitting, allowing the rebound effect to be taken into account
- The unit performance of heat pumps (specifically their coefficient of performance – or COP – on average and during a severe cold spell) and the potential need to supplement certain installations with electric heaters
- The types of heat pump deployed (air-to-air, air-to-water, gas/electric hybrid)
- The unit cost and servicing costs of heating solutions

To make it easier to understand the results, the findings are structured so that they can be read in two different ways.

Firstly, the main results are grouped around scenarios, which describe different development trajectories for the building sector and the associated heating solutions over a 15-year period.

Secondly, the results are cross-tabulated around a single theme to allow for comparison. This format is structured around what are now considered to be three standard pillars: power system operation, CO_2 emissions and economic analysis.

The scenarios

The results of the study focus on six main scenarios:

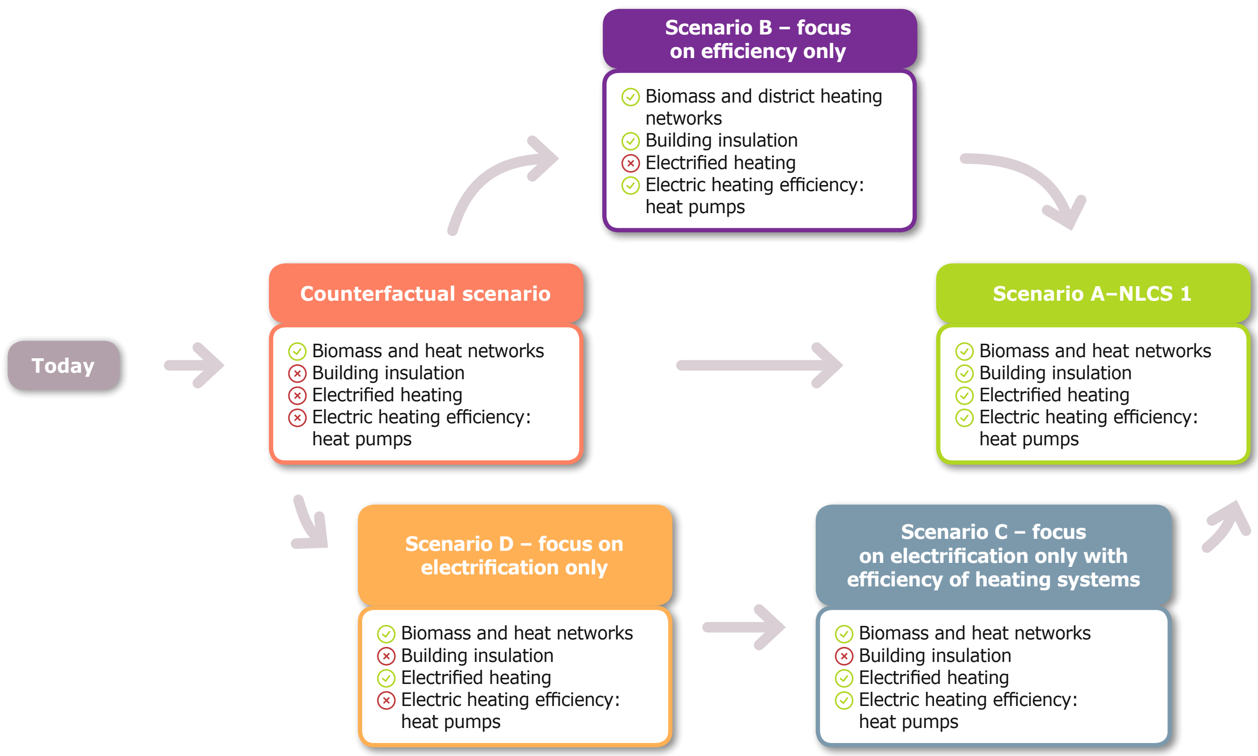
- A 'counterfactual' scenario, in which none of the efficiency targets (for buildings and heating solutions) or the improved electricity rebound effect are met.
- A scenario aligned with the NLCS roadmap: Scenario A-NLCS 1 represents the study's reference scenario. The efficiency targets (for buildings and heating solutions) and the improved electricity rebound effect (using heat pumps) are met.
- Scenario B, in which the efficiency targets are met, but not those relating to the growth in electric heating solutions.
- Scenario C, in which the efficiency targets are partially met (rise in heat pump solutions, but the rate of home energy retrofits does not increase), and the electric heating development targets are met.
- Scenario D, in which the efficiency targets are not met, but the electric heating development targets are.

All these scenarios have the following in common: the targets relating to growth in district heating, greater sector penetration of wood-fired heating solutions and the growth of biogas systems are all met. This allows the scenarios to be compared without the need for key assumptions regarding the development of these energy sources, which are outside the scope of the present study.

Another scenario in which the goals of the NLCS are achieved – A-NLCS 2 – was also studied. This was developed as part of a stress test, based on the same principles as scenario A-NLCS 1 but including the following specific adjustments for new builds: greatest market share attributed to electricity; little development of biomass and heat networks; gradual phasing out of gas.

The cost, peak demand and CO_2 emissions impacts on the power system are all analysed as standard based on the assumption that the NECP targets are met.

Depending on the level of consumption resulting from the different scenario sensitivities, some sensitivities with a less developed generating capacity were also tested (where the electricity fleet is then adapted by adjusting nuclear production or wind power capacity).



Scope of validity of the findings

The study presents a detailed analysis of multiple factors relating to the building sector, which have an impact on the power system. It does not, however, represent an attempt to optimise the overall energy mix. The goals of the NLCS strategy are therefore assumed to have been achieved for the other energy carriers (district heating, development of wood-fired and biomass heating), as are the National Energy and Climate Plan targets (development of biogas and wind energy, etc.).

The study explores the way in which the NLCS trajectory is followed in the building sector. It does not aim to demonstrate that the scenarios studied represent the only solution to achieving carbon neutrality[5].

The reference scenario corresponds to that of the National Energy and Climate Plan and its 2035 time line. It does not extend beyond this time frame[6].

The development of hydrogen and electric vehicles is included in the NLCS trajectory and RTE models in the mid-term adequacy report and special focus reports. The development scenarios for the European electricity generation fleet follow the reference assumption applied in the National Energy and Climate Plan.

As regards the environmental impacts, the study only covers greenhouse gas emissions (in France and neighbouring countries). Other environmental impacts, such as on the resources required to enable these changes in the building sector and the power system, have not been assessed within the scope of this study. The resilience of the building sector and the power generation systems in the face of climate change, which may vary quite significantly depending on the scenario, is also not considered in the study.

In terms of the retrofit trajectory to meet the target for low energy buildings across all building stock, the study does not examine the technical retrofit conditions necessary to achieve the required energy performance rating whilst ensuring the comfort and safety of occupants (all year round) and build quality.

Lastly, the study does not evaluate the macroeconomic effects of scenarios, nor their impact on household energy bills.

5. An ADEME study of prospective energy-resource scenarios in 2050 is currently under way and explores four different scenarios for achieving carbon neutrality
6. RTE is currently in consultation with stakeholders to build trajectories for the electricity mix and consumption levels over the time line to 2050. This work is due for completion by mid-2021

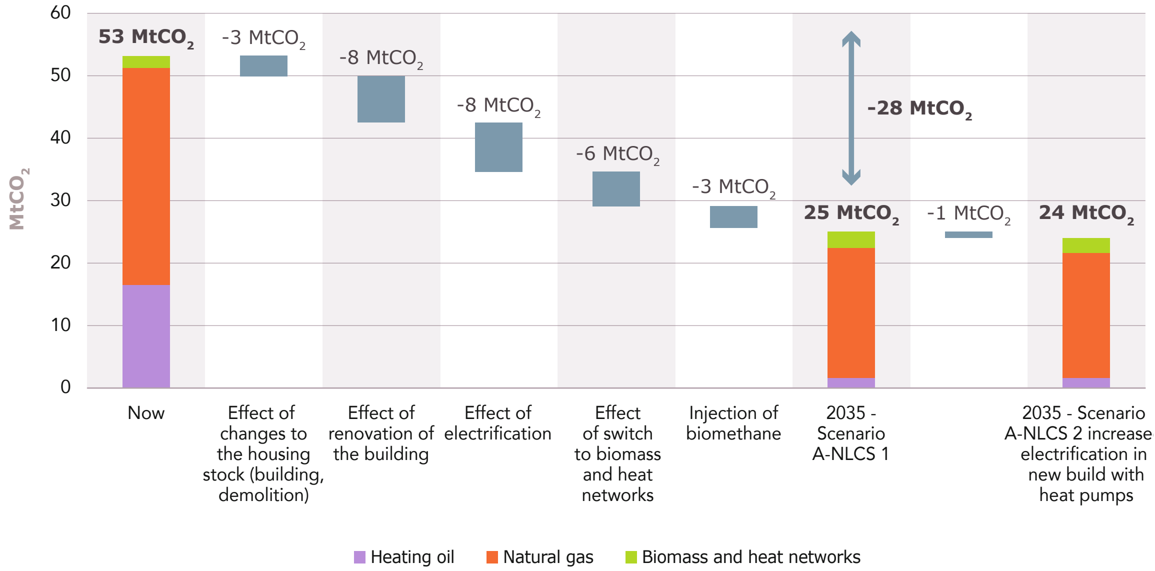
SUMMARY
OF THE MAIN RESULTS

1) A policy that combines retrofitting of existing buildings, use of the most efficient heating solutions and switching to low-carbon carriers, such as electricity, biomass[7] or heat networks mainly supplied from renewable sources, sets the 'building' sector's emissions on a trajectory that is in line with France's climate commitments.

1. Over 50% of France's heating requirements are currently being met using fossil fuels. This is responsible for 53 million tonnes of CO_2 emissions, i.e. approximately 15% of the country's emissions.

2. The central scenario of the RTE-ADEME study is based on the NLCS. It combines substantial work on the energy efficiency of the building's shell (through thermal retrofitting of existing housing and commercial buildings and high

Figure 1. Evolution of emissions from heating (excluding electricity) between now and 2035 in the NLCS's scenarios



7. Energy wood and biogas injected into the gas networks

performance of new buildings), the efficiency of the heating solutions (using mainly heat pumps rather than electric heaters), and switching to low-carbon energy carriers (electricity, biomass, heat networks mainly supplied from renewable sources and energy recovery). **It leads to a 28 million tonne reduction in emissions in 2035 compared to today.** Increased use of high-performance electric heating in new buildings reduces emissions from heating slightly more, to 24 million tonnes by 2035.

3. Within the French power system on its own, these two scenarios have little effect on CO_2 emissions, which are currently very low in comparison with France's total emissions and those from electricity generation elsewhere in Europe (approximately 20 million tonnes a year, the electricity produced in France being 93% low carbon). They are expected to be even lower in the future, stabilising at around 10 million tonnes a year for all uses of electricity (i.e. 95% low-carbon electricity).

4. The study confirms that the NLCS's scenario does not lead to the 'externalisation of emissions' by increasing those of neighbouring countries. By incorporating the growth of renewable energies in Europe and the reference trajectory of the National Energy and Climate Plan (NECP), the NLCS's scenario also leads to a reduction in emissions on a European scale.

2) Decisions made now will permeate very gradually through the building stock and heating solutions. In the NLCS scenario, the use of fossil fuels in residential and commercial buildings will still be the overriding standard in 2035, midway along the path to carbon neutrality.

5. The NLCS scenario policy involves a gradual increase in the rate and efficiency of home energy retrofits. By 2035, some 15 million homes (corresponding to 50% of all existing residential properties) will need to have been retrofitted to be able to meet the target for all building stock in France to be low energy buildings by the year 2050. This corresponds not only to a rapid increase in the number of homes retrofit each year (double the number in the scenario studied) but also to a higher energy performance rating for the retrofit activities considered (to achieve an increase in conventional energy gain from 30% to 50% on average between 2020 and 2035).

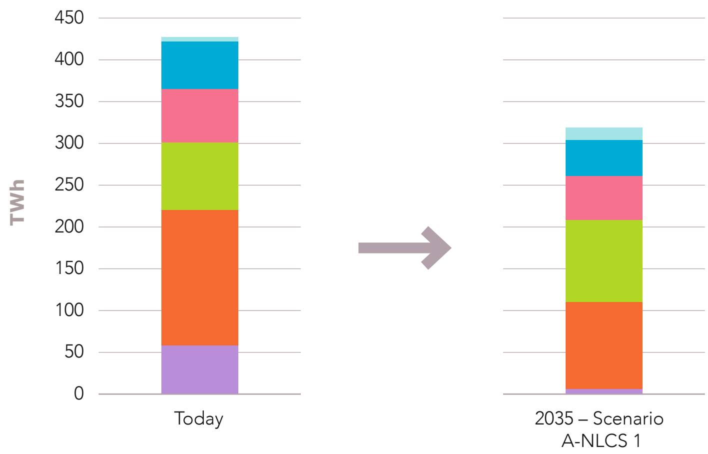
6. The measures proposed in the NLCS are a long way from France becoming 'all electric': By 2035, electricity will heat 50% of residential and commercial buildings, yet will only provide around 20% of France's final heating energy due to the predominance of heat pumps (the energy extracted from the environment by heat pumps is added to this total). Gas will still account for a third of residential and commercial properties and more than a third of the final heating energy.

7. In existing residential buildings, the initial measures announced will effectively end the use of oil as a heating fuel. More than 3 million homes still use oil for heating, which is the largest contributor to greenhouse gas emissions. This measure is the highest priority from an efficiency perspective.

8. For new builds, the French government announced the guidelines for the future RE2020 regulations in November 2020. Although these are still at the consultation stage, they could see a complete ban on using gas as the primary fuel in new-build houses (also known as single-dwelling units) by the middle of 2021 and in new apartment blocks (also known as multi-dwelling units) from 2024. This will mean that all new builds will have to be heated by electric solutions (heat pumps), low-carbon heat networks or biomass. Scenario A-NLCS 2 in the RTE-ADEME study allows the case for a high level of electrification in new builds to be tested. The results obtained are remarkably close to the reference scenario in the present study across all the variables studied, but with slightly better CO_2 performance levels.

Figure 2. Evolution of heating consumption and systems between now and 2035 in the NLCS scenario

Annual heating consumption (residential and commercial sectors)



Number of homes* (residential sector only)

* For the purposes of simplification, only residential properties are considered in the chart

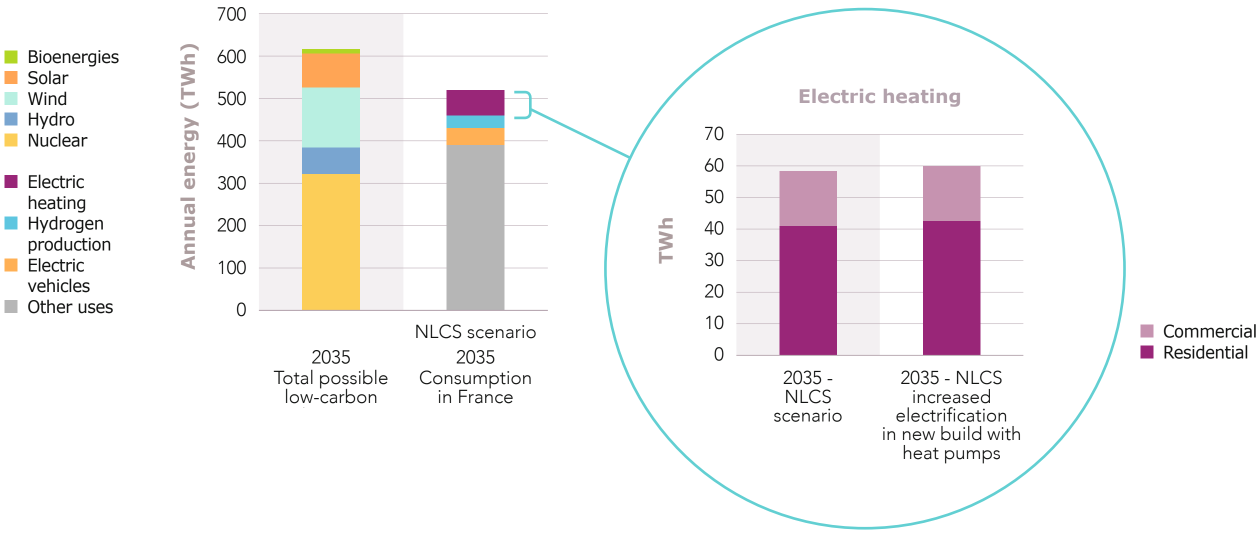
3) The reference framework established by the NLCS and the NECP combines ambitious targets for retrofitting and the development of renewable energies; it does not lead to any increase in electricity consumption for heating and has no impact on peak demand.

9. Electricity consumption has been stable overall for several years, as has peak demand. At the same time, the potential for flexibility during peak periods has increased. The impact of the policies for buildings on the evolution of this consumption is one of the subjects studied in the report: no less than twelve sensitivities are considered to obtain a robust assessment.

10. In general, a significant part of the progress made in terms of energy efficiency associated with retrofitting, whether this is through insulation or changing the heating system, leads to an increase in thermal comfort for the occupants of the houses concerned (in practice, an increase in the heating temperature) and moderates the decrease in their consumption. **The RTE-ADEME study considers this 'rebound effect': retrofitting of the building or replacement by energy efficient heating systems have a moderate downward effect on electricity consumption.**

11. Prioritising the use of electricity in new buildings has a minor upward effect on electricity consumption, as current building standards are becoming more stringent. Electrification in housing and commercial buildings results in a rise in electricity consumption but only to a limited extent if it is based mainly on the use of heat pumps as specified in the NLCS.

Figure 3. French production mix and consumption in the NECP-NLCS scenario, by 2035



12. These effects are minor and in opposite directions when taken individually, but should only result in small variations in electricity consumption when combined. On average (adjusted for climatic variations), electricity consumption specifically for heating in housing and commercial buildings would be stable or even slightly lower (58 TWh in 2035 in the central scenario A-NLCS 1, and 60 TWh in scenario A-NLCS 2 which involves very robust development of electricity in new builds, as against 61 TWh today).

13. This central result is also found on the evolution of peak demand. In the NLCS scenario, the 'one in ten' peak would even be slightly lower (-3 GW) than in the counterfactual scenario. In numerous sensitivities, the scenarios studied in the building sector do not lead to an increase in peak demand.

14. In such circumstances, the NLCS scenario does not pose any problems in terms of security of supply:

- The development trajectory of the low-carbon electricity generation facilities defined by the NECP is more than adequate to cover the additional requirements arising from the transfers of use needed to decarbonise the economy (e-mobility for transport, low-carbon hydrogen for industry and heavy-duty vehicles, and electric heating for buildings).
- Security of supply would be assured within the framework of the NECP (as defined in the regulatory standard).

4) Within the scope of the scenarios studied, the development of electric solutions is essential to cut emissions, yet this alone is not enough to meet the NLCS targets if it is not accompanied by a drive to improve the efficiency of the solutions deployed and an energy performance requirement for buildings.

15. **All the scenarios studied involving the widespread use of electric heating solutions demonstrate a reduction in emissions in France compared with today's levels.** Compared with the less ambitious counterfactual scenario, the increased use of electric heating accounts for an annual saving of between 5 and more than 10 $MtCO_2$ by 2035. Electric heating involves an intermittent reliance on gas-fired or even oil-fired power stations in France, but in proportions that are far too small to negate the benefit of dispensing with fossil fuels for heating purposes for the rest of the year.

16. This finding is maintained in a European energy balance, which includes emissions from power systems in neighbouring countries. All the scenarios studied involving greater use of electric heating in France result in an overall reduction in emissions in Europe compared with the counterfactual scenario (up to 14 $MtCO_2$ per year), with just one exception (where the balance is almost zero).

17. This exception corresponds to a particularly challenging scenario involving (i) a 15-year extension of past trends in building retrofits in France; (ii) a delay in the development of renewable energies; and (iii) rapid development of electric heating predominantly through electric heaters rather than heat pumps. In this configuration, CO_2 emissions would fall in France but would be displaced to the rest of Europe, thus resulting in a zero balance compared with the counterfactual scenario.

18. Development of electric solutions that are not accompanied by an efficiency drive (scenario D) would not be sufficient to meet the targets. This is due to the absence of retrofits to buildings heated by gas (which still accounts for a third of all heating energy by the year 2035) causing a surplus of emissions from buildings in France. It is also due to the absence of retrofits to electrically heated homes causing, all things being equal, fewer low-carbon electricity exports and thus a smaller reduction in emissions on a European scale.

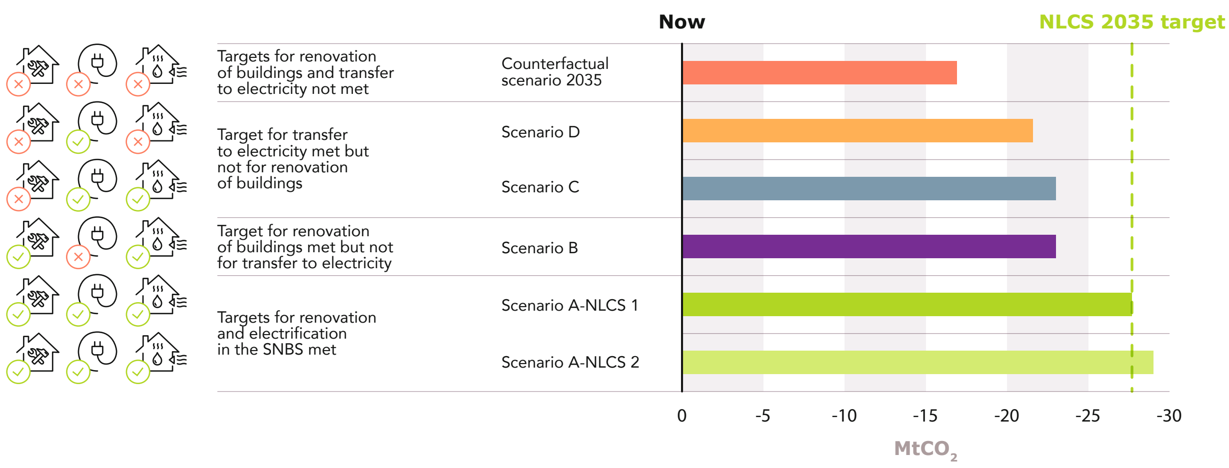
5) Within the scope of the scenarios studied, the policies for retrofitting buildings and improving thermal efficiency are essential for reducing emissions, but they are not adequate to meet the NLCS's targets if they are not accompanied by the development of electrical solutions.

19. Over the next 15 years, the use of fossil fuels for heating will remain the standard for a great many residential and commercial buildings in France, even in the scenario in which the NLCS's guidelines are implemented correctly leading to electricity, wood-biomass and heat networks gaining market shares. The consequence of the retrofitting programmes would be lower use of fossil fuels for these houses and commercial buildings: this would therefore result in reducing the country's emissions.

20. For the same number of houses and commercial buildings heated using electricity, the scenario involving the replacement of electric heaters with heat pumps and improving the performance of existing buildings (scenario B) avoids CO_2 emissions in France and above all on a European scale (in comparison with the counterfactual scenario). It leads to a decrease in electricity consumption and, all other things being equal, results in more low-carbon electricity generated in France being exported to neighbouring countries. By 2035, this effect still has a considerable influence on European emissions, as many countries would still be making substantial use of gas or coal-fired power plants in Europe. Electricity exports from France also exert considerable leverage on emissions.

21. However, this scenario is not adequate to meet the NLCS's targets. The main energy source would still be fossil fuels (gas and heating oil) in 2035, resulting in deviation from the trajectory needed to achieve carbon neutrality.

Figure 4. Evolution of emissions from heating in France between now and 2035 according to whether or not public policy targets are met (excluding electricity)



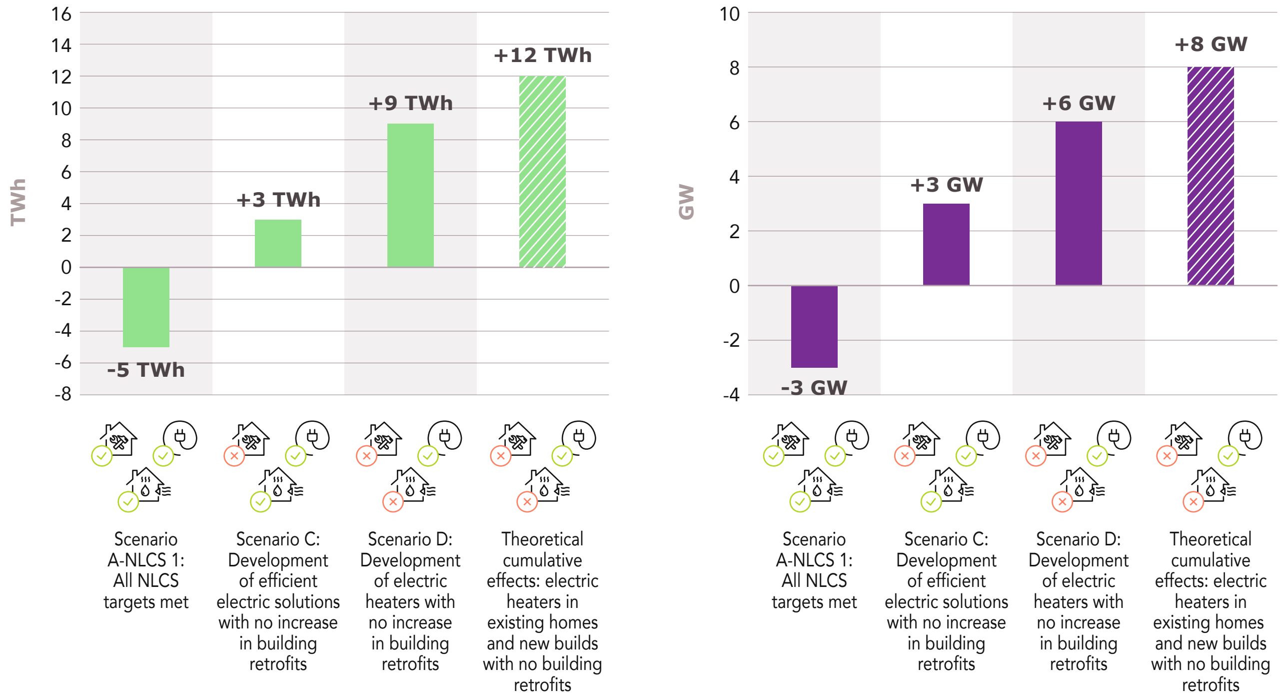
6) Scenarios involving an increased use of electric heating that are not supported by a drive to improve the efficiency of solutions deployed and a building energy performance requirement, lead to higher electricity consumption peaks and greater strain on the security of supply.

22. Scenarios involving a rapid pace of electrification but in which efficiency targets are not met result in higher electricity consumption for heating (+9 to +12 TWh over a 15-year period compared with the counterfactual scenario). All things being equal, this increased electricity consumption is far lower than the amount of electricity required for electric vehicles and hydrogen production and does not pose any specific energy issues if the NECP electricity mix development targets are met.

23. These scenarios also lead to higher winter demand peaks by 2035 (+6 to +8 GW in the cumulative effects scenario). However, in scenario C, in which electrification is achieved through heat pumps but the retrofit target is not met, there is a moderate rise in consumption peaks (3 GW over 15 years).

24. In the most challenging scenarios, maintaining a high level of security of supply involves a particularly advanced development of flexibility potential, which is achievable in

Figure 5. Variation in the electricity consumption and winter peaks compared with the counterfactual scenario



theory yet comes with a number of associated technical, industrial and societal conditions.

25. These increases in peak consumption would materialise over the long term. They have no short-term impact on the balance of supply and demand in the power system, which was placed under severe strain this winter with the pandemic. They will be monitored over the next two winters amid concerns about the pressure on production capacity (with coal power phased out in France, numerous planned outages of nuclear power plants, and the delay in commissioning of certain production methods for renewables, gas or nuclear).

7) The development of production and consumption flexibility is an appropriate policy to accompany the transition.

26. Heating is a temperature-sensitive use:

- It is not responsible for the 'evening peak' observed at around 7 p.m. every weekday during the winter. This peak is mainly due to residential uses (lighting and cooking), while consumption in offices and for transportation has not yet decreased. Heating contributes very little to this peak.
- Yet it is the main factor explaining the average consumption level during a given day in the winter (this average level can vary by several tens of gigawatts between a hot day and a cold day), and levels can be high for several consecutive days during a cold spell.

27. The various simulations carried out in the study have shown that the indicators on the 'one in ten' demand peak, projected by 2035, would range between two effects:

1) A downward effect (-3 GW in the NLCS scenario),
2) An upward effect (+6 GW in the scenario in which electric solutions are used but with no acceleration of retrofitting work and using electric solutions such as resistive heaters rather than heat pumps). This uncertainty argues in favour for the fact that policies to develop levers for flexibility on uses should be continued. In the most challenging scenario (D), implementation of this flexibility is a prerequisite for ensuring security of supply.

28. The study lists several ways of supporting the growth of temperature-sensitive uses, beyond the assumptions already considered by the NECP (6.5 GW of demand reduction in 2028, which includes 5 GW of demand reduction capacity in industry and the service sector):

- Smart charging of electric vehicles, which could provide up to 8 GW of additional flexibility (for 15 million electric vehicles, in line with the NLCS, i.e. almost half of the total number of electric vehicles by 2035) provided that it is carried out on a massive scale and includes bidirectional vehicle-to-grid charging.
- Control of electric heating, either through short periods of rolling 'cascade cycle' demand reduction on installed equipment – but its aggregate effect is limited – or by long periods of demand reduction. If the carry-over effects are incorporated, the positive effect on the margins would be approximately 2 GW, only in the residential sector.

29. However, the study does not intend to analyse the combined effects of rolling out new uses, such as electric heating, e-mobility and hydrogen production. These actions could be combined more or less favourably for the management of the power system. This type of analysis is carried out in RTE's Mid-term adequacy report, the next edition of which (March 2021) will look at the period up to 2030.

30. Encouraging flexibility of consumption when uses of electricity are growing fast is a no-regret policy, which makes the power system more able to withstand unforeseen events and thus helps to achieve climate targets. The costs of managing peak demand periods, for example by reducing consumption or the widespread use of smart charging for electric vehicles, appear to be of second order than the investment required in the building sector. The success of this type of policy is dependent on it being taken on board by consumers. The obstacles to be removed seem to be mainly practical ones: making it simple to control the charging of electric cars (like controlling domestic hot water in the 1980s), proposing control offers from the outset when renewing heating plant, etc.

31. The study also considers the possibility of installing hybrid gas/electricity heat pumps in place of heat pumps or gas boilers. A hybrid heat pump combines a low power heat pump with a gas boiler: it runs on electricity most of the time, except in cold conditions when the gas boiler takes over. Installing hybrid boilers instead of conventional heat pumps would reduce peak demand by 1.4 GW per million installations. The potential for savings using these technologies has yet to be clarified (see above).

8) Decarbonising the building sector requires significant investment in building retrofits and heating systems.

32. The gradual transformation of France's building stock to meet the targets for reduced consumption (where the aim is for the majority of building stock to be rated as low energy buildings by the year 2050) and decarbonisation of heating solutions requires heavy investment. This investment covers building retrofits and the replacement of existing heating systems with efficient low-carbon solutions and is largely funded by private stakeholders (individuals and corporate) supported by a series of government grants and incentive schemes.

33. In the NLCS scenario, public investment (by all French stakeholders, including the government) needs to increase by some 12 billion euros a year compared with the counterfactual scenario. This rise corresponds largely to an increase in the retrofit rate on existing buildings needed to achieve the targets. In terms of heating system retrofits – which account, in absolute terms, for a significant proportion of overall expenditure – the evolution of costs between scenarios is less pronounced; this essentially involves redirecting some of the recurring and essentially non-reducible business and household expenditure to low-carbon solutions, which often requires a substantial initial investment.

34. Investments in building retrofits and efficient electric solutions are only partly offset by a reduction in energy supply (gas, oil, electricity, etc.). Variable costs (gas, oil, wood, electricity) are cut by 2.2 billion euros a year compared with the counterfactual scenario.

35. The sums involved represent an investment in the climate required to meet the emissions reduction targets. Compared with other contributory factors (renewable heat, electric vehicles, hydrogen production by electrolysis, etc.), the volume of emissions avoided compared to the amount of finance committed (abatement cost) appears relatively high and depends largely on the retrofit cost assumptions considered. These can vary considerably given the wide variety of situations encountered and the projected potential savings associated with implementing retrofits on an industrial scale. By 2035, in the A-NLCS 1 scenario, abatement costs fall somewhere between 430 euros per tonne of CO_2 in the reference assumption on retrofit costs and 310 euros per tonne of CO_2 in the low assumption, corresponding to a significant cut in retrofit costs associated with scale effects and an industrialised approach to retrofitting. **This level is very similar to the shadow price of carbon determined by the government for this time line (375 euros per tonne of CO_2 avoided).**

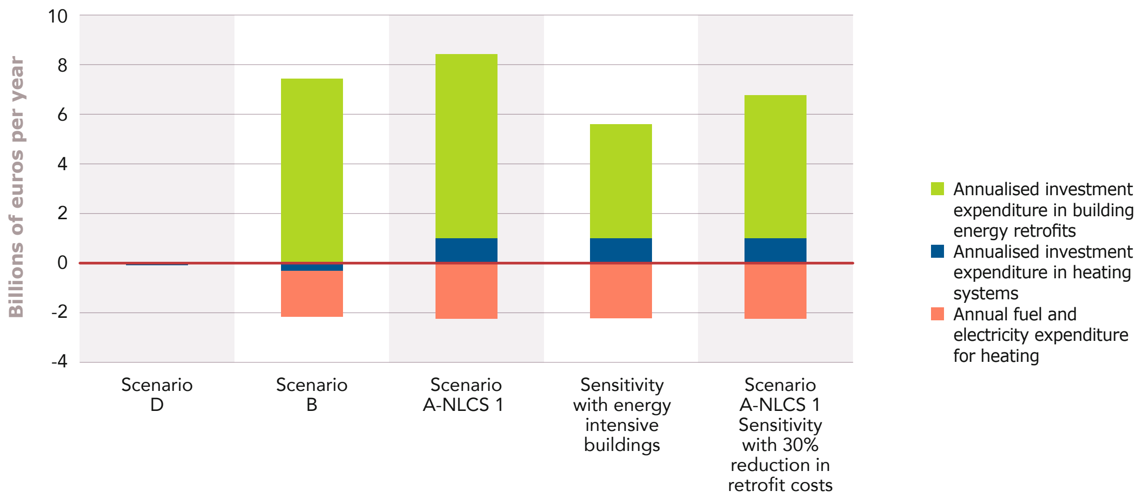
36. This initial gross margin on the abatement cost is largely attributable to the 'rebound effect' on energy consumption observed in homes with more energy efficient building fabric and heating solutions. This rebound effect corresponds to an improved quality of life for occupants, helps combat fuel poverty and has a positive effect on health: the monetary value of this kind of benefit cannot be estimated against a purely climate-based logic. **At the same level of comfort (i.e. without any rebound effect), the estimated abatement cost of a tonne of CO_2 avoided in the NLCS scenario would lie somewhere between 160 and 240 euros per tonne of CO_2 (depending on the retrofit costs), a value which is significantly lower than the value for climate action for 2035.**

37. Of all the various decarbonisation levers, the measures aimed at increasing the share of electricity appear to present the lowest economic cost. However, they do not allow the CO_2 emissions reduction targets to be met when taken in isolation.

38. From a consumer perspective, the most efficient long-term solutions (heat pumps or home energy retrofits) are those that require the highest initial investment. This is likely to create difficulties in terms of securing retrofitting investment from householders (and particularly property owners) to adopt these solutions, such that specific support measures would be justified.

39. The overall result in terms of the economic benefit of home energy retrofits may be the subject of further analyses to identify the main priorities (in terms of housing type, geographical area, or most efficient retrofit activities) to support the government's decision. The study contains the initial focus areas for analysis in terms of the benefit of targeting the most energy intensive buildings.

Figure 6. Estimated total annualised costs of the different scenarios (difference in relation to the counterfactual scenario, excluding CO_2 recovery)



9) Targeting energy-intensive housing (dubbed 'thermal sieves' in France) and increasing the required level of efficiency of retrofitting work will maximise climate gains within a given financial framework.

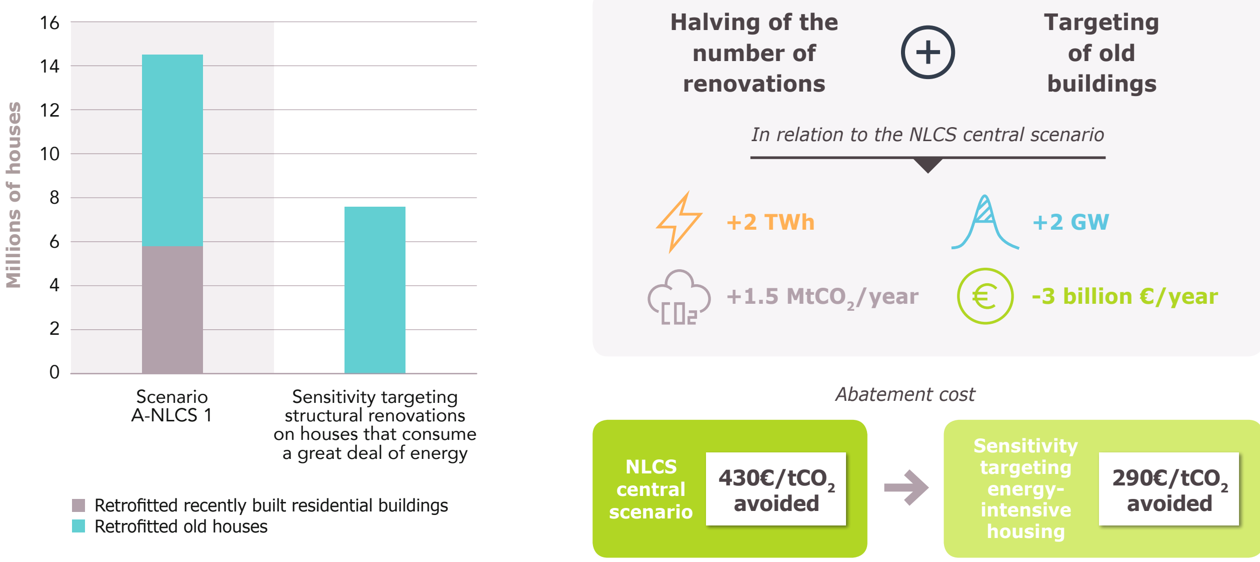
40. Existing buildings have very diverse characteristics. Some of them, qualified as energy-intensive housing (in particular buildings rated G and F in France) are very poorly insulated. They are also sometimes characterised by heating solutions which perform poorly (old electric heaters) or are incompatible with the building sector's low-carbon trajectory (for example, oil-fired boilers).

41. The RTE-ADEME study confirms that it appropriate, in terms of effective climate improvement actions, to carry out better quality retrofitting, targeting those houses that consume most energy.

42. In particular, the possibility of carrying out targeted retrofitting on buildings constructed before 1975 (mainly detached houses), i.e. before the oil crisis and the first thermal building standards, has been examined in a specific sensitivity. Here, buildings are retrofitted at a similar rate to previously, but more efficiently and strictly targeting the buildings concerned rather than spread uniformly across the existing building stock. This sensitivity gives interesting results:

- Electricity consumption indicators (annual average and peaks) which are stable in comparison with today, and slightly higher than the NLCS central scenario (+2 TWh,

Figure 7. Effect of prioritising retrofitting of energy-intensive housing



+2 GW), without causing any risk to security of supply

- CO_2 emission levels similar to the NLCS central scenario (additional emissions of 1.5 $MtCO_2$/year by 2035), therefore better than those of scenarios B and D
- A substantially lower cost (a saving of 3 billion euros a year) as 50% fewer houses would be retrofitted.

43. **The targeted retrofitting of energy-intensive housing therefore seems to be one of the actions providing the highest climate improvement efficiency and is of considerable economic interest.** Even taking the rebound effect into account, its abatement cost is 290 €/tCO_2. If the rebound effect is not taken into account, it would be less than 100 €/tCO_2.

44. Targeting retrofitting on those houses that consume most energy therefore appears to be a cost-effective decision from the point of view of the community, while it reduces energy poverty and has other positive external effects. Although public support for this type of work has improved, the main challenge of implementing this public policy is encouraging people to carry out this work, especially owners who cannot afford it or have difficulty accessing credit.

45. A policy to prioritise some houses can also be devised in the context of increasing the amount of retrofitting carried out each year, broadened to cover all types of building, but with an emphasis on those houses and commercial buildings that consume most energy and/or have the worst climate performance levels (including the type of heating solution). The 'targeting' scenario leads to some of the old, non-insulated houses being retrofitted, but does not deal with all the houses that consume most energy and/or have high emissions.

46. This type of study could be extended to identify the best combinations for maximising the effectiveness of collective action in the building sector, and the threshold effects concerned (in particular the building ratings above which the marginal effect of improving the building shell decreases).

10) Hybrid heat pumps may prove beneficial to the climate policy if they replace fossil fuel-fired boilers or to the security of supply of electricity if they replace electric heat pumps.

47. Hybrid heat pumps, not currently widely used, comprise a low power electric heat pump to meet the base requirement and use gas at times of peak demand; they can play a role in reducing electricity consumption peaks if they replace electric heating solutions. This finding is presented in more detail in point 31.

48. If hybrid heat pumps are used in place of fossil fuel-fired boilers, the combined use of electricity and gas avoids additional electricity consumption peaks, thereby contributing to a reduction in emissions. The improved carbon balance can be estimated, in this case, at around 3.5 million tonnes of CO_2 for more than 2 million hybrid heat pumps deployed as gas boiler replacements.

49. The deployment of hybrid heat pumps as a replacement for electric heat pumps also allows consumption peaks to be reduced, yet has no effect on emissions (no resulting rise or fall). The additional emissions associated with the use of gas in certain situations and the emissions avoided in the electricity industry to manage demand peaks essentially offset each other.

50. From a consumer point of view, the hybrid heat pump solution may prove to be a less expensive investment than a conventional heat pump, but further analysis would be necessary to establish the precise economic impact of this scenario from a collective viewpoint. There is a wide variety of potential situations. The hybrid heat pump seems to be of particular interest in certain situations (e.g. for single-dwelling units which prove difficult to insulate and which have a gas supply, enabling the full potential of a hybrid heat pump to be realised), but not in others (e.g. in existing housing which is not connected to a gas supply or does not have a hot water loop, with limited space to accommodate a dual heating system).

11) In new builds, the predominant use of electricity results in a similar energy performance to that of the NLCS reference scenario, with a slightly better CO_2 emissions performance.

51. Work began on the RTE-ADEME study in 2019 with the inclusion of the aim to prioritise energy efficient low-carbon solutions in low energy housing. The RE2020 guidelines had not yet been determined.

52. One of the government's announcements in November 2020 concerned the total phase-out of gas only heating systems in new builds (by 2021 for single dwelling units and 2024 for multi-dwelling units). However, this does not automatically mean that electric solutions will be installed, indeed renewable heat (wood, geothermal energy, solar energy) and connection to heat networks powered by renewable energies also figure in the solutions favoured in the NLCS. The possibility that the majority of new builds will be heated by electricity has to be studied nevertheless. The A-NLCS 2 scenario in the RTE-ADEME study allows the consequences of a 90% share for electricity in the new single dwelling units market and a 70% share in the multi-dwelling units market to be assessed, with the assumption of rapid growth in heat pumps.

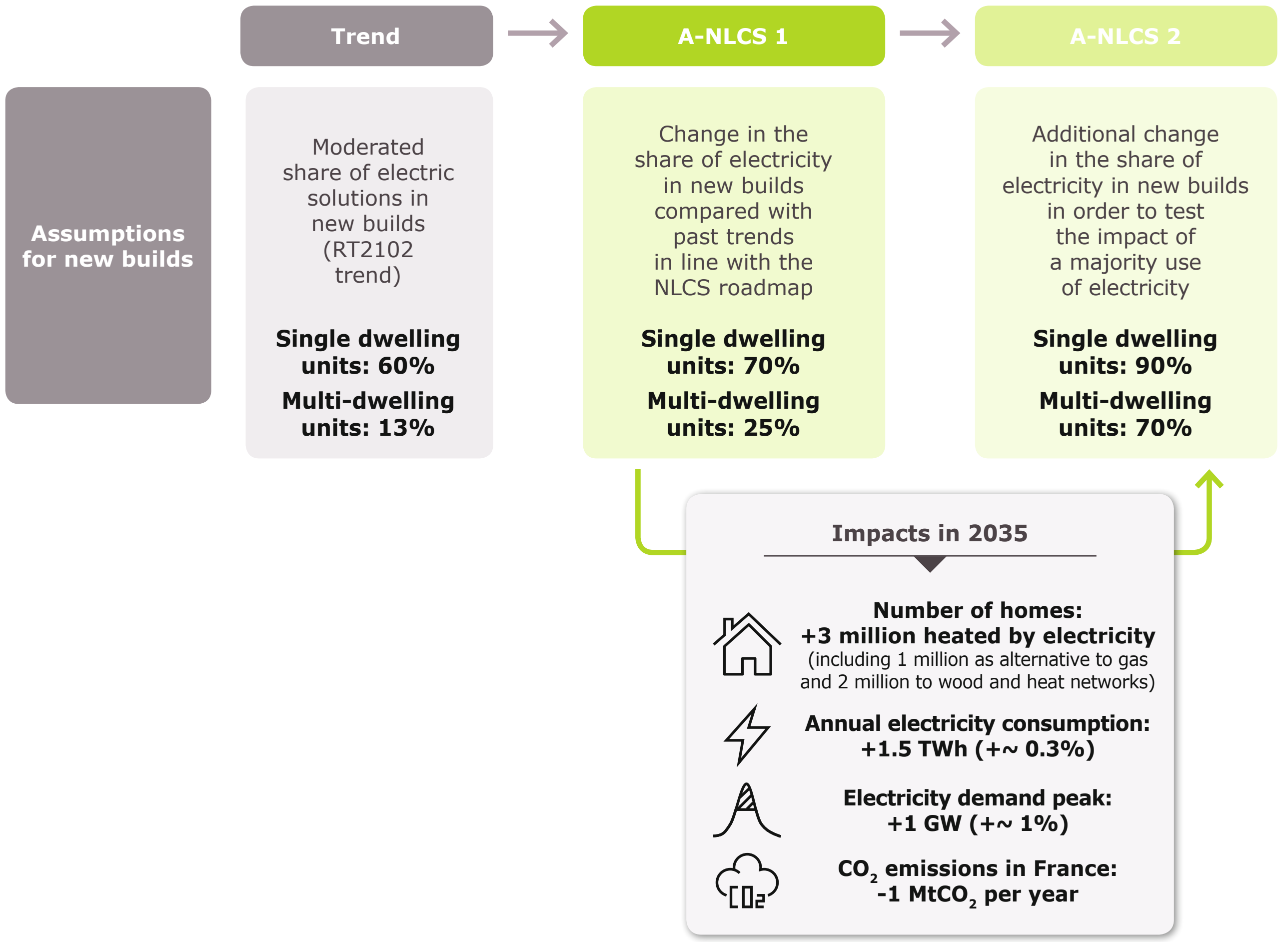
53. By 2035, this scenario is slightly better performing than the NLCS reference scenario in terms of emissions, since it allows a reduction of one million tonnes nationally[8]. This level of performance is achieved when an electric heat pump solution is used, in buildings where actual performance meets expected performance. The differentiating effect of measures prescribing the mandatory use of low-carbon carriers in new builds increases gradually over time and must be analysed to include the wider picture of carbon neutrality by 2050.

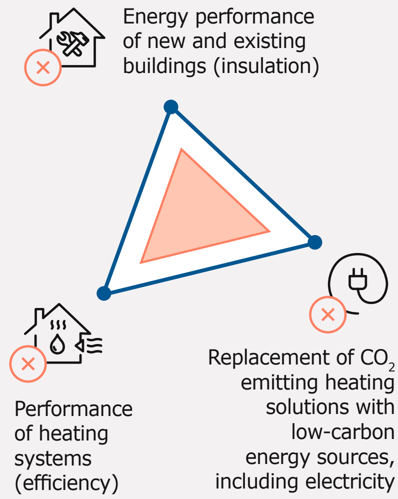
54. Compared with the NLCS reference scenario, the power system indicators are very similar (+1.5 TWh per year on average, +1 GW at the peak). **Although this scenario is challenging for new builds, it does not pose any risk to security of supply.**

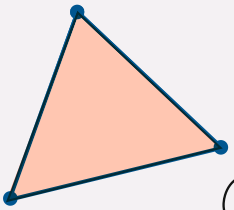
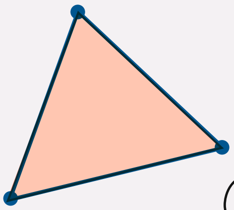
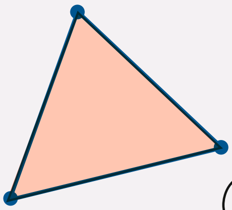
55. The impacts on the retrofit market (which is likely to follow that of new builds due to scale effects on the cost of technologies and competencies developed by tradespeople) may be the subject of further analyses. The RTE-ADEME study shows that the main challenge for the power system and emissions in the medium term lies with existing housing. On the one hand, building stock is not renewed annually, thus rate is of secondary importance in terms of the results of the analysis. On the other, new builds have a much better energy performance rating than older buildings and therefore do not present the same challenges.

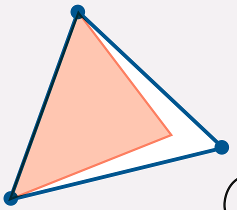
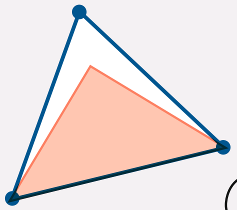
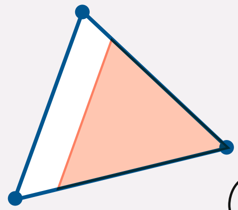
8. The effect of the transition from RT2012 to RE2020 regulations being greater due to the fact that scenario A-SNBC 1 in the RTE-ADEME study already incorporated a reduction from gas emissions in new builds

Figure 8. Effect of electrification of new builds on national CO_2 emissions and peak demand with and without retrofitting and performance targets for heating solutions being met



		Initial overview		*Absolute values*
		2018 Situation		**2035 Counterfactual scenario: NLCS targets partially met, ongoing electrification and energy efficiency trend**
Assumptions	General scope	**29 million** main residences	Effect of demographics + living apart →	**34 million** main residences
	Electric heating	**~10 million** households heated by electricity		
	Energy efficiency	Insulation: 400,000 building envelope retrofits per year with 30% saving on conventional requirement Resistive heating/heat pump share: 90%/10%		
	Electricity mix	**Current electricity mix** (390 TWh nuclear, 115 TWh renewables, 40 TWh fossil fuels)		
Results	Societal issues	**Thermal comfort** /		**Thermal comfort** /
	Technical impacts	**61 TWh** electric heating per year **99 GW** one in ten peak **~330 TWh** per year of fuel-fired heating (oil, gas, wood)		**63 TWh** electric heating per year **101 GW** one in ten peak **303 TWh** per year of fuel-fired heating (oil, gas, wood)
	CO_2 emissions	**50 $MtCO_2$** (fuel-fired heating in residential and commercial buildings) + **20 $MtCO_2$** (French power system)		**~35 $MtCO_2$** (fuel-fired heating in residential and commercial buildings) + **~11 $MtCO_2$** (French power system)
	Economic issues			**~19 billion euros per year** (Investment in heating installations and insulation work)

	2035 Scenario A-NLCS 1	2035 Scenario A-NLCS 2 – Sensitivity with greater electrification in new builds	2035 Sensitivity targeting energy intensive buildings
General scope	**34 million main residences**		
Assumptions about heating	Energy performance of new and existing buildings (insulation)  Performance of heating systems (efficiency) Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity	Energy performance of new and existing buildings (insulation)  Performance of heating systems (efficiency) Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity	Energy performance of new and existing buildings (insulation) Ciblé  Performance of heating systems (efficiency) Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity
Compared with the counterfactual scenario			
Societal issues	**Thermal comfort ++**	**Thermal comfort ++**	**Thermal comfort ++**
Technical impacts	**-5 TWh** electric heating per year **-3 GW** one in ten peak	**-3,5 TWh** electric heating per year **-2 GW** one in ten peak	**-3 TWh** electric heating per year **-1 GW** one in ten peak
CO_2 emissions	**-11 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-14 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)	**-12 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-14 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)	**-11 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-12 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)
Economic issues	**+ 12 billion euros per year** (Investment in heating installations and insulation work)	**+ 12 billion euros per year** (Investment in heating installations and insulation work)	**+6.5 billion euros per year** (Investment in heating installations and insulation work)

	2035 Scenario B – Focus on efficiency only	2035 Scenario C - Focus on electrification only with efficient heating systems	2035 Scenario D – Focus on electrification only
General scope	**34 million main residences**		
Assumptions about heating	✓ Energy performance of new and existing buildings (insulation)  ✓ Performance of heating systems (efficiency) ✗ Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity	✗ Energy performance of new and existing buildings (insulation)  ✓ Performance of heating systems (efficiency) ✓ Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity	✗ Energy performance of new and existing buildings (insulation)  ✗ Performance of heating systems (efficiency) ✓ Replacement of CO_2 emitting heating solutions with low-carbon energy sources, including electricity

Compared with the counterfactual scenario

	Scenario B	Scenario C	Scenario D
Societal issues	**Thermal comfort ++**	**Thermal comfort +**	**Thermal comfort /**
Technical impacts	**-10 TWh** electric heating per year **-4 GW** one in ten peak	**+3 TWh** electric heating per year **+2,5 GW** one in ten peak	**+10 TWh** electric heating per year **+6 GW** one in ten peak
CO_2 emissions	**-6 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-10 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)	**-5 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-5,5 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)	**-5 $MtCO_2$** (Scope: fuel-fired heating in France and French power system) **-3 $MtCO_2$** (Scope: fuel-fired heating in France and western European power system incl. France)
Economic issues	**+11 billion euros per year** (Investment in heating installations and insulation work)	**+1 billion euros per year** (Investment in heating installations and insulation work)	**+0 billion euros per year (very similar to scenario C)** (Investment in heating installations and insulation work)

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