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Heat Roadmap Europe
A low-carbon heating and cooling strategy

Cost-curve Guide for Lead-Users

Relating investments to delivered energy savings

Deliverable 4.4

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Introduction

In Europe, there is a clear long-term objective to decarbonise the energy system, but it is currently unclear how this will be achieved in the heating and cooling (H&C) sector. The Heat Roadmap Europe 4 (HRE4) project aims to enable new policies and prepare the ground for new investments by creating more certainty regarding the changes that are required. HRE4 is co-funded by the European Union, brings together twenty-four academic, industrial, governmental and civil society partners, and runs from 2016-2019.

The objective of Work Package (WP) 4 of the HRE4 project under which this guide was produced, is to calculate individual cost curves for reducing the H&C demand in buildings and industries for fourteen Member States in Europe[1]. Cost curves combine information on energy savings and their related costs. They have been widely used as a decision-support tool by showing the additional costs or investment needed for achieving a certain additional amount of energy- or CO_2-savings.

The cost curves developed in HRE4 focus on delivered-energy savings and the additional investment needed. The starting point for these cost curves is the HRE4 baseline scenario for the fourteen countries towards 2030 and 2050 for H&C demand developed within the FORECAST model (WP3)[2]. The demand cost curves of WP4 are input to the energy system analyses conducted with the EnergyPlan model (WP5) which is used by the HRE4 project to create comprehensive heating and cooling strategies for the entire energy system in the target years 2030 and 2050.

The purpose of this document is to facilitate lead-users (i.e. policy-makers, industry and researchers) to access and better comprehend how HRE4's WP4 results can benefit them. The document helps shed light on questions about at what additional investment costs, and with which measures, can a baseline path plausibly shift towards a path of maximum-savings potential.

Important points to be kept in mind include the following:

- WP4 focuses on energy *demand*, more specifically on so-called *delivered energy* (which will be generally referred to as "H&C demand"). Examples of *delivered energy* include 1) the heat produced by a domestic or industrial boiler; 2) the heat (and cooling)

[1] Though insights from HRE4 should be applicable to countries all across Europe, the HRE4 project itself concentrates on those fourteen countries with the highest heat demands in the EU28: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the UK.

[2] For an introduction to this WP, the reader is referred to D3.5 "FORECAST Guide for Lead-Users"

delivered by a heat pump; 3) the heat (and cooling) delivered by a substation of a district heating or cooling (DHC) network.

- One should not confuse *delivered*, *useful* and *final energy*, the latter being commonly provided in energy statistics and referring to the energy supplied to end-users. Though in the case of DHC, *delivered energy* actually is the same as *final energy*, for boilers and heat pumps, *final energy* is actually indicative of the gas or electricity provided for end-use, not the heat (or cooling) subsequently delivered to the end-users. The difference between *delivered energy* and *useful energy* are the losses in the internal distribution system of a building or industrial complex.
- WP4 primarily focuses on investment costs. This means that the financial benefits of H&C savings (i.e. leading to a lower energy bill) are *not* addressed in this WP, but rather form part of the energy system optimization in WP5. The investment costs shown here include the total investment costs of a technical measure and the costs for installing such a measure (all expressed in 2015 Euros). Planning, financing and other transaction costs are *not* included.
- A few key features of cost curves which are worth mentioning:
    - Based on detailed technology-specific, bottom-up modelling
    - Take the characteristics of production technologies and buildings into account, thereby considering technical limitations of energy-saving measures
    - Allow for capital age and inertia from the slow replacement and refurbishment of the building sector
    - Consider the individually-different starting points of EU countries and their individual framework conditions (e.g. climate, energy prices, etc.)
    - Show additional savings beyond what is (potentially) achievable with current policy measures – in other words, the savings shown in the cost curves are additional to the baseline.

Key messages drawn from the cost curves

1

While HRE4's baseline scenario already indicates a great share of heat savings, the WP4 cost curves reveal almost double the amount of savings, though with some important variations between the built environment and industry. By 2050, the assessed potentials allow a reduction of total delivered heat demand by about one third compared to 2015.

When looking at Europe's built environment (i.e. residential and tertiary sectors) and industry, the HRE4 baseline scenario from WP3 in Figure 1 (blue line) already shows substantial savings due to implemented policies and autonomous improvements, as compared to the so-called "frozen efficiency" scenario (red line), which excludes the blue baseline's heat savings measures in the period 2015-2030/2050. The "frozen efficiency" scenario is hypothetical, but even so provides useful insights into the amount of savings which are already embedded in WP3's baseline scenario.

Furthermore, the green bottom curve reveals the significant heat savings potential which could be applied on top of that baseline, and which is the aggregate result of WP4. This equals about 740 TWh of additional savings in 2050 compared to the baseline, which is more than today's heat demand in France.

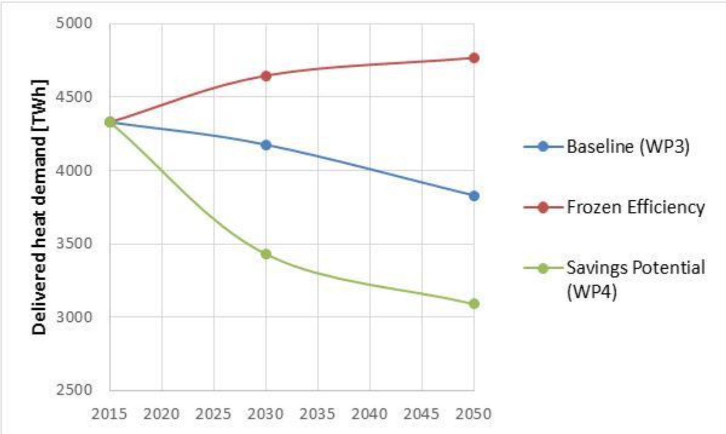

Figure 1 Total heat savings potential relative to the baseline for the built environment and industry in the fourteen HRE4 countries

Breaking down the aggregate scenarios along the built environment and industry (Figure 2) shows a declining trend in the baseline scenario (blue lines) for the built environment and a (slightly) increasing trend for industry. When comparing these to WP4 results (green lines), one sees that the greatest total potential for further reduction of the heat demand is still much higher in the built environment, though WP4's potential savings for industry appear to be relatively greater than those found in the WP3 baseline.

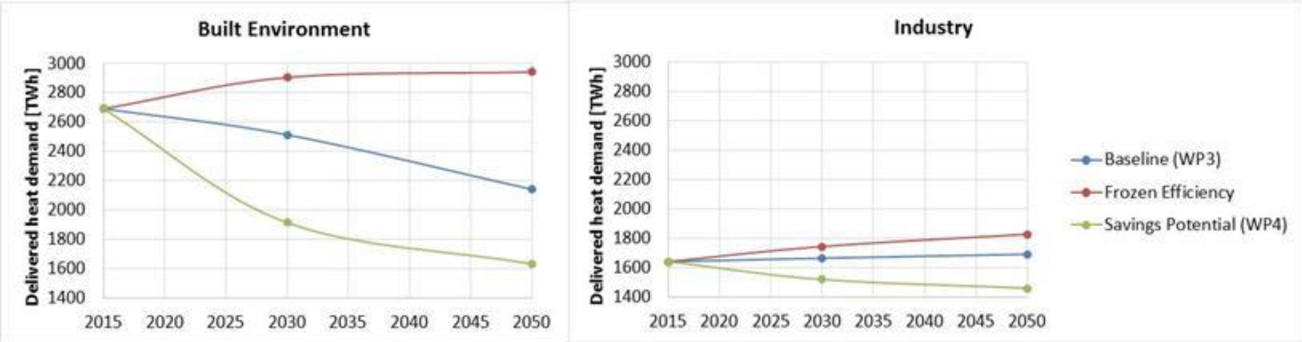

Figure 2 Heat savings potential relative to the baseline for the individual sectors

According to WP4 results, in order to close the overall savings gap for built environment and industry, a total of €4,100 billion needs to be invested for the period 2015-2050 of which €3,200 billion is already invested in the baseline scenario (Figure 3). If distributed appropriately across all sub-sectors of the built environment and industry, then their maximum potential would be achieved.

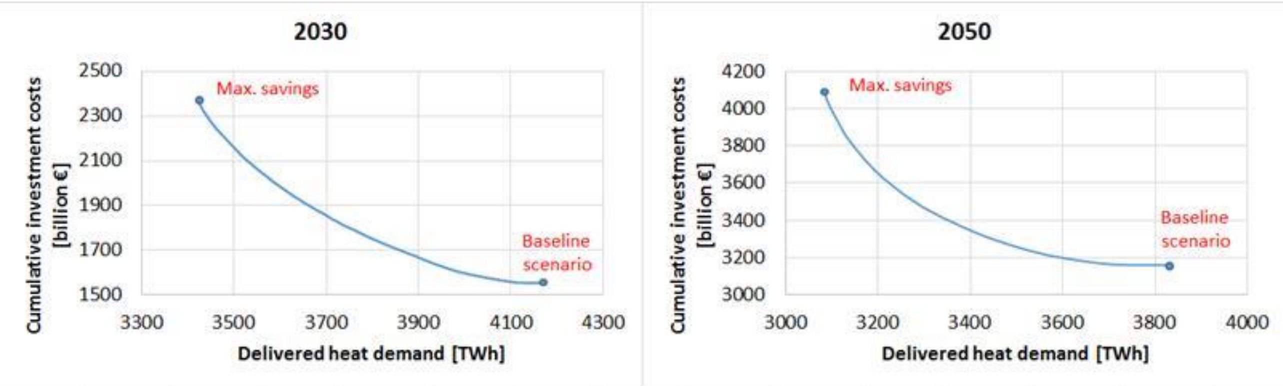

Figure 3 Cost curves for 2030 and 2050 for the built environment and industry in the fourteen HRE4 countries

2	**A great share of Europe's heat savings potential can be associated with the built environment, but correspondingly a substantial investment of €3,600 billion is required here. This investment can potentially lower delivered heat demand by about 1000 TWh by 2050 - nearly 40% of today's heat demand in buildings.**

Within the built environment, WP4 finds that heat demand in the residential sector can potentially be 400 and 450 TWh lower than the baseline heat demand, with estimated extra investments on top of the baseline scenario of €600 million for the 2015-2030 period, and €700 million for the 2015-2050 period (Figure 4). Meanwhile, for the tertiary sector, heat demand can potentially be lowered by 100 TWh (2030) and 140 TWh (2050) by investing €100 million in addition to the investments in the baseline scenario for both the 2015-2030 and the 2015-2050 period (see also Figure 4). In order to better comprehend what these significant investments entail, it is worthwhile to focus on what HRE4 suggests about how the residential sector can be improved – many of the same findings are also valid for the tertiary sector. The majority of the extra savings revealed by WP4 for the residential sector should be first achieved by implementing more ambitious renovation measures than implemented in the WP3 baseline for buildings that undergo a renovation anyway. Further savings should then be achieved by increasing the refurbishment rate considered for the baseline scenario (i.e. doing renovations in buildings which are untouched in the baseline scenario or doing these renovations earlier than in the baseline scenario).

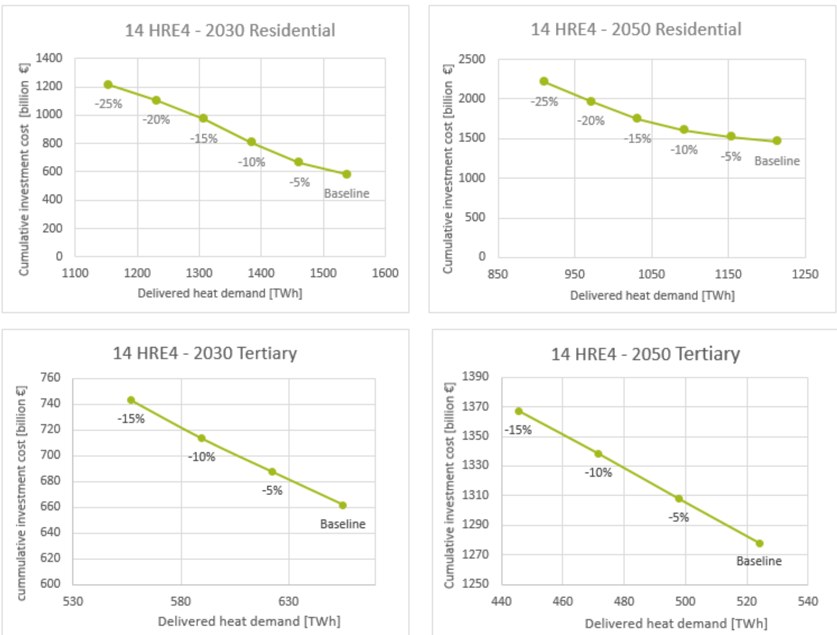

Figure 4 Investment cost curves for additional heat demand reduction in the built environment in the period 2015-2030 and 2015-2050

Since the graphs from all fourteen HRE4 countries look quite similar to each other, even though each country has a different starting point, it is possible to focus in on just one country as an illustrative example. Figure 5 shows, using WP4's 2050 results for Finland's residential sector, how the share of different levels of renovation, depending on buildings' ages, can contribute to varying target level scenarios of heat demand reductions. The grey bars ("non-energetic renovations"[3]) represent those buildings without any energy efficiency improvements implemented at all. The yellow bars ("Baseline packages"[4]) are those actually included as part of WP3's baseline scenario. Meanwhile, the remaining categories are those packages defined for WP4's "savings potential" scenarios, including full renovation packages (blue bars[5]) and partial renovations packages (green bars[6]).

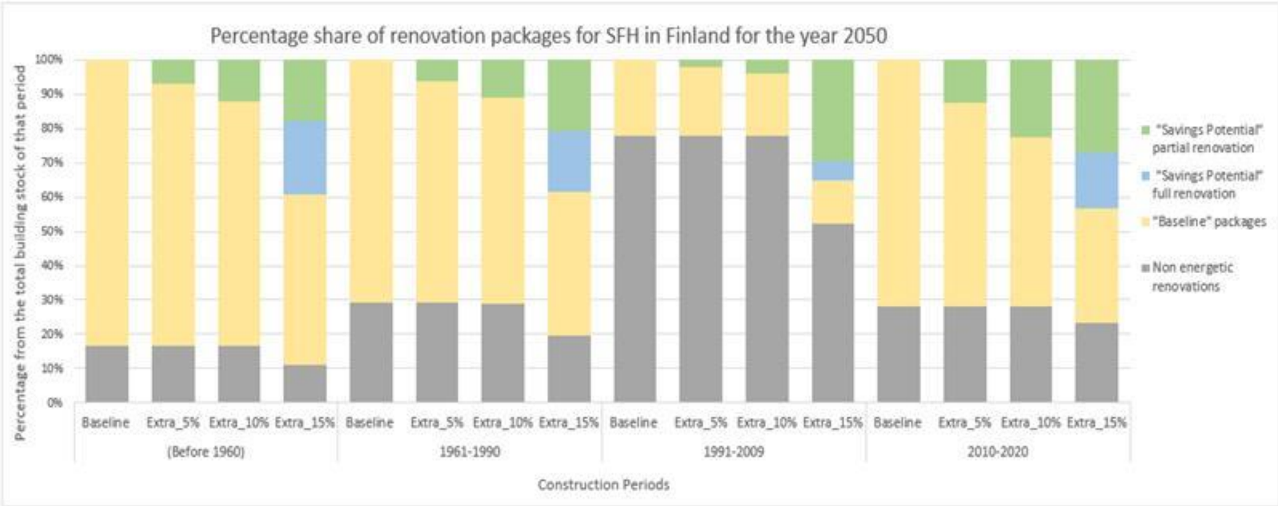

Figure 5 Comparison of how different renovation packages for single family houses (SFH) can contribute to reducing heat demand, and their dependence on buildings' construction periods for feasibility of implementation: Example for Finland

Additionally, as can be seen in the Finnish example of Figure 5 for 2050, a considerable amount of missed opportunities still exist for additional savings since non-energetic renovations are still in place even until 2050.

[3] Referred to as renovation packages P0a and P0b in HRE4 deliverable 4.2.
[4] Renovation packages P1 to P4 in D4.2.
[5] Renovation packages P5 to P7 in D4.2.
[6] Renovation packages P8 to P15 in D4.2.

3	**Heat savings in industry require less investment than in buildings.**

Heat savings in industry tend to be much more limited by industrial structures within the fourteen HRE4 countries, with a large share of heat needed for energy-intensive processes, especially with in the iron/steel, cement, glass, paper/pulp and chemical industries. Lowering the demand of high-temperature industrial processes tends to be more difficult than reducing low-temperature heat demand within the residential or tertiary sectors, partly because energy-intensive industrial processes have already been substantially optimised in the past and partly because different from the built environment, temperature levels of the industrial processes cannot easily be lowered. In order to further decarbonise industrial sub-sectors, it is therefore crucial to also look at additional mitigation options, including low-carbon fuels to adequately substitute fossil fuels, innovative new products and processes, carbon capture and storage, material efficiency, etc.

Since industries often benefit from economies of scale (e.g. larger equipment with greater demands and/or higher annual full-load hours than are available to the residential or tertiary sector), this translates to (mostly) smaller investment costs for industrial heat savings (at least on the scale of 15% or less) than the same relative reductions within the built environment. According to WP4 results, an estimated €350 billion investment is needed between 2015 and 2030 (of which €300 billion already invested in the baseline scenario), and €450 billion for the 2015-2050 period (of which €400 billion already invested in the baseline scenario), for maximising industrial heat savings in the fourteen HRE4 countries. In fact, WP4 results show that reducing process heat demand requires lower investment per MWh of heat saved than for space heat demand. By looking into more detail among industrial sub-sectors (Figure 6), one can see that a reduction of process heat demand in the iron/steel, paper/pulp and non-metallic minerals (cement and glass) industries account for 53% of the total industrial heat savings potential in the fourteen HRE4 countries by 2030, and for 67% by 2050.

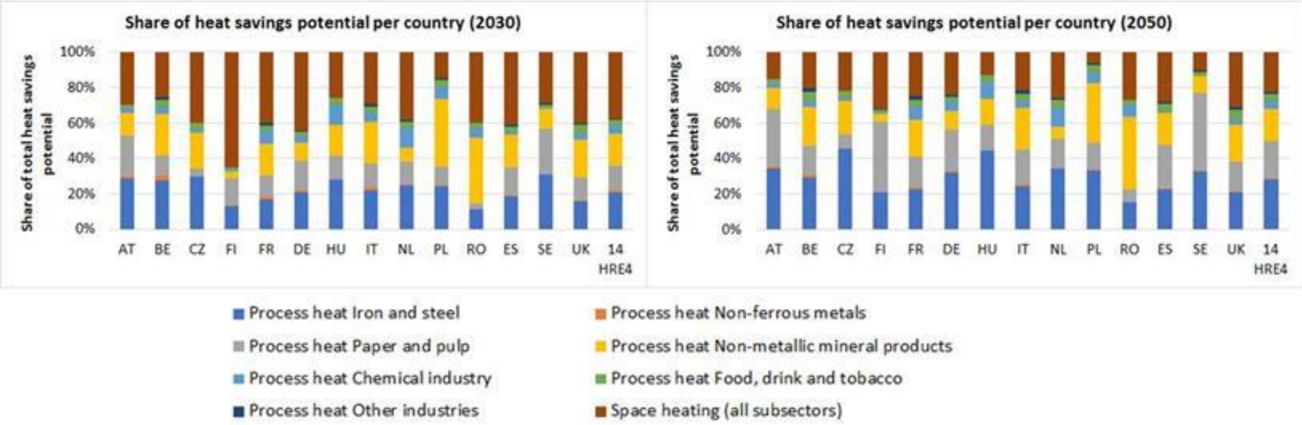

Figure 6 Share of heat savings potential per country among the fourteen HRE4 countries

Since the share of space heating in HRE4's fourteen countries' total industrial heat demand by 2050 is just 15% and fuel prices for industry are much lower than for in the built environment, it follows that incentives for reducing industrial space heat demand remain somewhat limited, especially in cases of locally-available/inexpensive excess heat. Nonetheless, it should be highlighted that space heating still remains, both in absolute and relative terms, quite important in the Food, Drink & Tobacco industry and in "other" industries, such as Machinery & Transport. Such circumstances contribute to the WP4 results highlighting that a reduction of space heat demand still accounts for 37% of the industrial heat savings potential in the fourteen HRE4 countries by 2030, and 23% by 2050. Even so, it should still be noted that much less is known about industrial buildings than about residential and tertiary buildings, and so tapping into available space heat-savings potentials first requires a better understanding of industrial building characteristics (e.g. renovation rates or heating patterns).

As can be seen by the results listed above, there are substantial variations between industrial sub-sectors, which would then clearly necessitate differing solutions. Achieving the full extent of heat savings for industries in the fourteen HRE4 countries will require a broad range of diverse technologies in the different sub-sectors, which makes them more difficult to tackle through standards than can be done quite effectively for the built environment if enforced.

4	**Reducing cooling demand is especially important for the tertiary sector, especially in an absolute sense, but cooling demand in industry should certainly not be overlooked.**

Though the consideration of cooling remains relatively neglected in many respects in favour of considering heating demands, implications, savings, etc., this should not be the case, especially in light of a clearly growing demand for cooling across Europe. As seen in Figure 7, the cooling demand in the WP3 baseline (blue line) shows an increasing trend for both the tertiary sector (+41%) and industry (+18%) in the period 2015-2050[7].

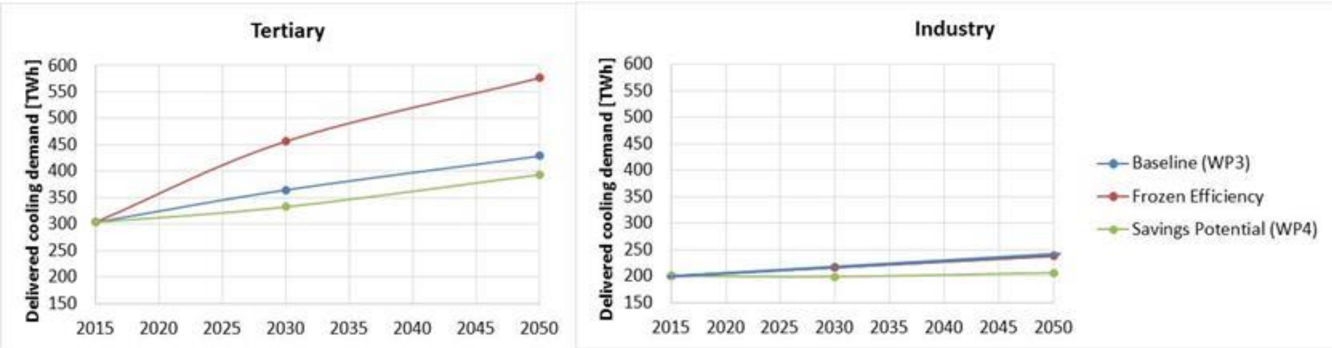

Figure 7 Cooling-savings potentials for the tertiary and industry sectors up to the year 2050

Beyond such an absolute increase, in a relative sense, cooling is expected to increase its share from 31% of total H&C demand among tertiary sector buildings in 2015 to 48% in 2050. Meanwhile, the share of industrial cooling within its entire H&C demand may only increase from 11% in 2015 to 12% in 2050. Looking more at Figure 7 shows that the WP3 baseline already includes a significant decrease of cooling demand by the tertiary sector (comparing the blue and red lines), whereas for industry the potential for cooling-savings has hardly been exploited in the WP3 baseline at all which can be explained by a focus on process heat savings in the scenario development. Nonetheless, the WP4 results show substantial potential for lowering cooling demands for both the tertiary and industry sectors even beyond the baseline scenario.

[7] In the residential sector, the cooling demand is small compared to the tertiary sector and the expected demand growth is limited. Therefore, the cooling demand for residential sector is not considered in the cost curve analysis.

5	**In order to exploit all the additional H&C savings, stronger policy instruments are required, which address missed opportunities in current policy and financial frameworks. Supporting deeper thermal renovation of buildings that anyway undergo a renovation is the most important missed opportunity.**

It has already been adequately shown above that there is a massive potential for lowering H&C demand all across Europe. While the major policies currently in place in Europe are included in the WP3 baseline and result in substantial heat savings, much remains to be done. When addressing the extra reductions revealed by WP4, new policy instruments are necessary. At the least a tightening of existing policies, like the Energy Performance of Buildings Directive (EPBD) or the EcoDesign Directive, could significantly help decarbonise the H&C sector. As much of the low-hanging fruit for energy efficiency investment has already been gathered and the remaining potentials, with higher investment costs, need to be made attractive for the end-users, a stronger price signal is needed, which can be supported by energy obligation schemes or taxes. In addition to a price signal, information (e.g. smart meters), communication (e.g. homepage and nudging) as well as education of craftsmen, citizens and children is needed. Such policy changes will need to address missed opportunities in the buildings sector like the overly-high share of buildings which have been (or will be) renovated without any/sufficient energetic improvement being implemented. They also must stimulate an increase in renovation actions which cover the entire stock of existing buildings in Europe, as well as the systems and processes within them.

In particular for industry, it will be crucial to offer proper financial incentives for process heat savings, such as even stipulating a higher CO_2-price than currently is seen in the EU Trading System for ETS-credits to become a viable driver. Industry also requires a broad approach, taking into consideration its remarkable variation among sub-sectors and the technologies they use/require, as well as working towards a circular economy approach, with a larger share of heat savings resulting from recycling of resources, both materials and energy.

What are the main WP4 outputs and why are they important?

The main outputs of WP4 are cost curves for H&C demand savings in the built environment and industry. These cost curves provide information on the potential reduction of H&C demand and the investment costs which are needed to make such reductions actually happen. The following cost curves have been developed for 2030 and 2050, for each of the fourteen core HRE4 countries:

- Residential space heat demand
- Tertiary space heat demand
- Tertiary cooling demand
- Industrial space and process heat
- Industrial space and process cooling demand

Insight into the demand savings potentials and related investment costs are crucial to identify the most sustainable, efficient and economically-feasible pathways to decarbonise H&C until 2050.

How do cost curves work?

For the purpose of explaining cost curves even more, Figure 8 below portrays WP4's combined 2050 heat savings cost curve for all fourteen HRE4 countries' industrial sectors. The curve should be read from the right to the left, with the starting point being the *delivered heat* in 2050, from the HRE4 baseline scenario from WP3. The cumulative investment costs in 2050 (represented by the blue coloured vertical dotted line below the curve) include all heat-related investments in the baseline period (2015-2050), which entails all investments in heat savings and volume growth (e.g. newly constructed buildings or more industrial production capacity). Therefore, the cost curve represents all savings measures which can be implemented on top of the baseline scenario and allows one to identify the investment costs (Y-axis) needed to achieve a certain heat demand reduction (X-axis), or vice versa, meaning which heat demand could potentially be achieved, given a certain amount of investments costs.

Figure 8 2050 industrial heat savings cost curve for all fourteen HRE4 core countries

The underlying data of all of WP4's cost curves are to be entered into the EnergyPlan model (WP5) which is then to be used by the HRE4 project to calculate a cost-optimised energy system for both 2030 and 2050. To find such a cost-optimised energy system, the demand savings measures identified in WP4 compete with efficient and low-carbon supply options identified in WP6. As long as demand savings lead to further reductions of total energy system costs, deeper demand savings can be shown as an appropriate aim for Europe. In case the next unit of demand savings actually leads to higher total energy system costs, then any remaining demand should be fulfilled with efficient and low-carbon supply options.

For illustrative purpose, Figure 9 shows the 2050 cost curves for industry for a small selection of all fourteen HRE4 core countries. Since the size of heat demand can differ substantially between countries, the axes of the figure have been adjusted in order to allow comparison of the four example countries. The horizontal axis now shows the remaining percentage of heat demand, rather than the heat demand itself (as in Figure 8), whereas the vertical axis shows the so-called "proxy specific costs"[8] instead of the cumulative investment costs of Figure 8.

[8] Proxy specific costs represent the annualized investment costs of a particular savings option, divided by its own heat savings. The lower fuel costs are neglected.

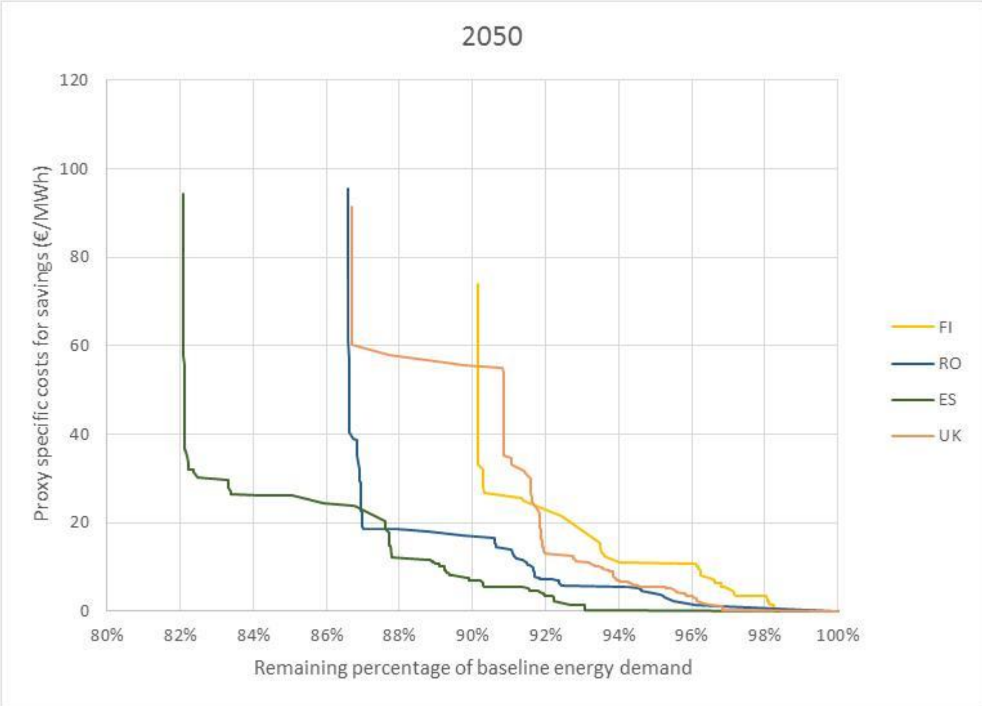

Figure 9 Example cost curves for industry

From the four countries used for illustration, Spain (ES, green line) is the one with the highest heat savings potential by 2050, whereas the savings potential for Finland (FI, yellow) is smallest. The basic shapes of the four countries' curves are essentially similar to each other – their divergence from one another can largely be explained by differences in their industrial structures (e.g. if a country's industry is dominated by industries that have relatively large savings potentials, its total potential will be greater) and the starting point of each country (e.g. if an industry in a country is already quite efficient in the baseline scenario, there is less to be gained). From the four countries shown, the curve of the UK (brown line) stands out because of a relatively huge savings potential against high proxy specific costs (55-60€/MWh heat saved) – this large potential relates to the UK's significant space heating savings potential, but which would end up coming at much higher costs compared to many other countries.

Who should use these cost curves?

The H&C demand cost curves from WP4 are most immediately applicable for relevant policy-makers, planners and other similar authorities in the fourteen HRE4 countries. It's quite likely that further beneficial insights for other countries beyond HRE4's core countries can still be drawn from WP4 results – for example that the cost curves of both the built environment and industry may be found to parallel savings potentials and related investment needs for those countries in a similar climate zone and with similar building traditions, or with similar industrial structures. In any case, the cost curves may prove useful for whichever lead-users are working to transform European H&C sectors, whether of individual nations or of the EU at large.

Regardless of the specific country context, it is nonetheless still important that decision-makers and other lead-users keep in mind the following caveats when working with these cost curves:

- The cost curves are intimately connected to the FORECAST baseline from WP3. The calculations in FORECAST have been done based on EU-wide datasets, which allows for the generation of a consistent set of results for valid country comparisons. However, this also means that the data used in FORECAST might deviate from other/country-specific sources, which may or may not be more accurate than the EU datasets actually used by WP3.
- The degree of certainty in FORECAST's 2015 profiles varies between segments. For example, whereas values for the use of natural gas, coal and oil for heating are relatively robust, data disaggregating service sub-sectors, the end-use of (specific) renewable sources for H&C, the use of electricity for H&C purposes and general data on space cooling each remain somewhat uncertain.
- The lifetime of cost curves is limited. If the policies required for yielding the savings potential are delayed or ill-designed, the reduction potential identified for 2030 and 2050 may just turn into nothing more than a *fata morgana* mirage. Also, the development of a new baseline scenario with new drivers (e.g. economic and demographic projections, new policies, etc.) implies that new cost curves would need to be developed.

What are the main benefits of the cost curves?

The cost curves show what is possible in terms of demand reduction on top of the baseline scenario and, therefore, are a valuable starting point for developing legitimate national scenarios that aim to yield a maximum in demand savings potential.

Furthermore, the stringent use of the same methodology across all countries makes the cost curves inherently consistent. Such consistency means that the cost curves of different countries can be directly compared to each other, which means that it may be used to more readily identify suitable policy-making and other solutions from third countries which may have a realistic potential for replication/adaptation.

Should the cost curves be used in combination with other HRE4 outputs?

In effect, what WP4 offers are a few pieces of the much larger HRE4 puzzle. Figure 10 shows how WP4 is positioned against other HRE4 WPs. The starting point for WP4 is the baseline developed in WP3. The links between the baseline and the demand cost curves is that the cost curves show the savings potential on top of that which is already assumed as part of the baseline, not to mention also revealing the investment needs for realizing that potential. The demand cost curves of WP4 directly feed into EnergyPlan (WP5) for carrying out an energy system cost optimisation. While WP3 and WP4 respectively deliver the demand baseline and cost curves for demand savings for both the built environment and industry, all other energy system components are delivered by the JRC-EU-TIMES model (WP6). Dotted lines in Figure 10 refer to cross comparisons between the different WPs and are part of the validation of the project results.

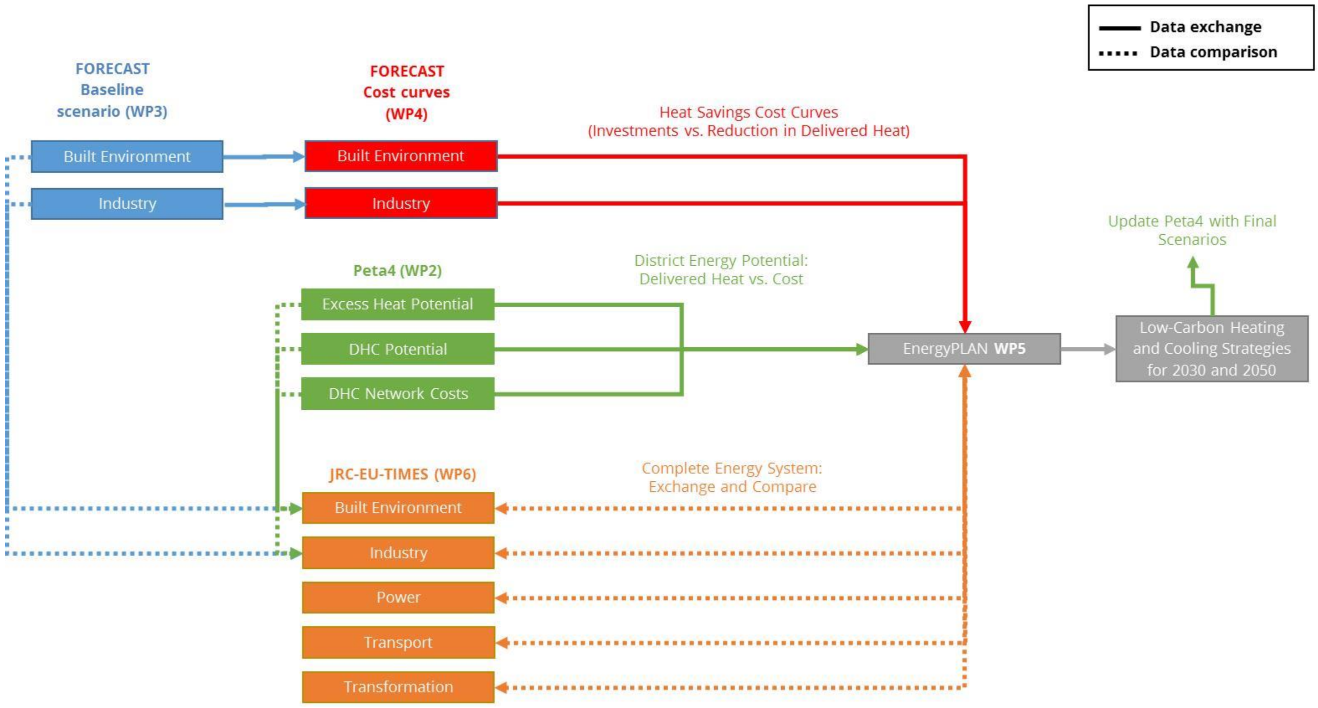

Figure 10 Interlinkages between WP4 and other HRE4 outputs