A sustainable energy future: the role of heat pumps in a fossil-free system

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Combined, renewable energy and energy efficiency measures have the potential to deliver 90 % of the reduction of greenhouse gas emissions needed by 2050. With the IRENA tool "REmap" it is possible to analyse for each country which technologies should be used for decarbonisation of the energy system, in order to find the potential of cost-effective low-carbon solutions in line with the Paris Agreement and a 2 °C scenario. It is clear that heat pumps could have an important role to play in this development, and the business case development seems positive.

Introduction

Today, countries around the world are more firmly committed than ever to accelerating renewable energy deployment. Technological innovation, enabling policies and the drive to address climate change have placed renewables at the centre of the global energy transformation. Yet alongside these developments, the chief driver of renewable energy is its strong business case, which offers increasingly exciting economic opportunities.

IRENA's "REmap" approach to analysing which technologies are required for an energy transition or a decarbonisation of the energy sector is an important tool to identify the most cost-effective technology solutions for different countries. The REmap technology option analysis is carried out at the sub-sector level for the world as a whole, with energy demand of each end-use sector disaggregated into the main energy-consuming applications. 1 The common goal is to explore technology deployment pathways in line with the goals of the Paris Agreement and to assess the implications of a 2 °C scenario (with a 66 % probability of meeting that target).

To achieve these goals, energy CO_2 emissions need to fall from 33 gigatonnes (Gt) in 2015 to below 10 Gt per year in 2050, then drop to zero by 2060 and stay at that level (emissions must drop below zero to limit the increase to 1.5 °C). The 2°C target requires energy-related CO_2 emissions to drop to 20-22 Gt per year by 2030. Such a reduction translates to a decrease in the average CO_2 emissions per unit of gross domestic product (GDP) (or the carbon intensity of the global energy supply) by more than 85 % between 2015 and 2050 (IRENA, 2016).

The REmap framework and analysis

The aim of REmap is to communicate results to a diverse audience. This includes policy makers to technology developers, academia and the general public. Therefore, REmap employs a unique methodology to assess the potential of low-carbon technologies. The identification of the additional low-carbon technology potential is the most important step of the process. The aim is not to apply complex models or sophisticated tools to assess the potential, but to facilitate an open framework with countries to aggregate the national energy plans, and subsequently identify technology options and is not meant as a target-setting exercise.

Given its nature, the REmap approach also has a number of limitations. For instance, REmap looks at discrete time steps, focusing on 2030 and 2050. For example, the analysis does not take into account interactions, developments and dynamics across technologies or feedbacks in energy prices due to demand and supply changes (e.g. rebound effects). Moreover, inter-temporal dynamics and inertia that determine deployment, system constraints, path dependencies, and competition for resources, etc. also are not explicitly taken into account (Saygin et al., 2015).

However, a comparison of the findings of REmap with the results of the IEA-ETSAP models at both national and global level has shown that for a number of countries and regions, the results are directly comparable to the REmap country results (Kempener et al., 2015). This is important, as it suggests that the sequence of technology options selected in REmap's cost-supply curves, despite lacking the dynamic temporal modelling in IEA-ETSAP models, still yields similar results to the technology options selected by the ETSAP models (as they increase the required share of renewables in their energy system).

The key role of renewable energy toward 2050

Accelerated deployment of renewable energy and energy efficiency measures are the key elements of the energy transition. By 2050, renewables and energy efficiency would meet the majority of emission reduction needs (90 %), with some 10 % achieved by fossil fuel switching and CCS. Crucially, sooner rather than later, the world must address emissions from the end-use sectors, an area where heat pumps will play a crucial role.

[1] For more details, see the suite of IRENA REmap publications, background documents and data available at http://irena.org/remap.

Energy and materials efficiency improvements can reduce emissions by about 4 Gt by 2030, about 30 % of the emissions reductions needed (Figure 1). Electrification cuts another 1.5 Gt, or 10 % of what is needed. Renewable energy options that were identified based on the bottom-up analysis of the G20 countries can reduce emissions by another 10 Gt. As a result of these measures, 2030 emissions would fall to 25.5 Gt in 2030, with the remaining fossil fuel combustion emitting about 22 Gt of CO_2 emissions per year.

This level is sufficient to put the world on a 2 °C pathway in 2030. But to keep the world on this pathway, efforts need to be strengthened further between 2030 and 2050. This would require energy-related CO_2 emissions to drop to below 10 Gt by 2050, which would be 70 % lower than 2015 levels and 31 Gt less than in the Reference Case. About half of these reductions would come from renewable energy technologies. Energy efficiency improvements and electrification would account for the bulk of the other half. The remaining 10 % of reductions would come from additional measures in industry, notably CCS, material efficiency improvements and structural changes.

As a result, emissions from all sectors must be cut. The power generation and buildings sectors would see the largest percentage reduction in emissions by 2050 in the REmap case (Figure 2). The largest CO_2-emitting sectors are electricity generation and industry. They are responsible for about 65 % of all energy-related CO_2 emissions today. The remaining 35 % comes from transport, buildings and district heating. Buildings have a low share, but this increases if indirect emissions related to electricity use are included.

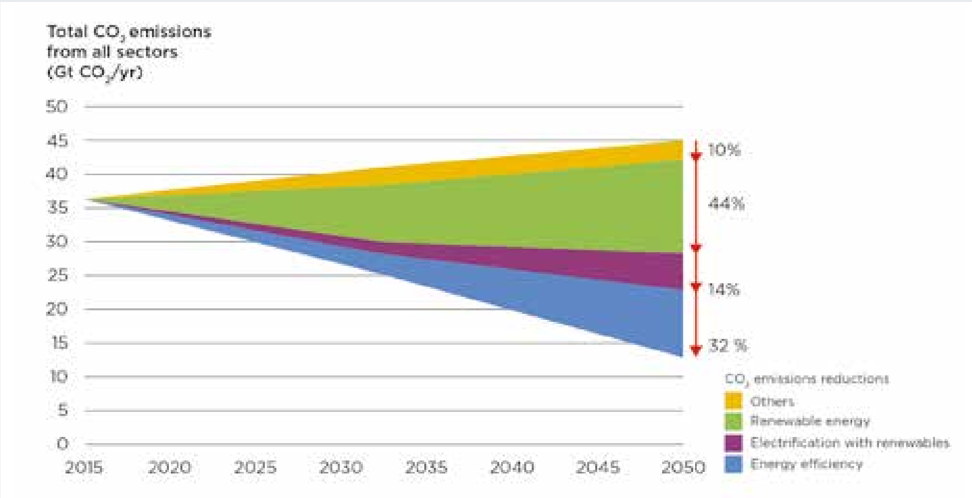

Figure 1: Primary CO_2 emission reduction potential by technology in the Reference Case and REmap, 2015-2050
Source: IRENA, 2017

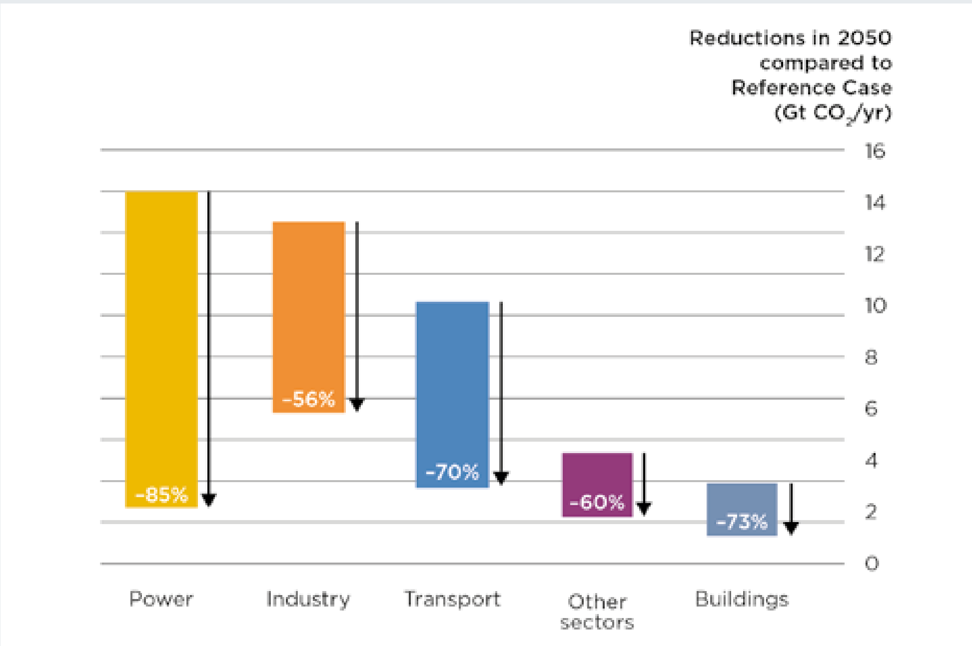

Figure 2: CO_2 emissions by sector in REmap relative to the Reference Case, 2015-2050
Source: IRENA, 2017

The building sector is growing quickly with today's 150 billion square meters of residential and commercial floor area projected to increase to 270 billion m^2 by 2050. Most of the growth will be in urban areas. Over the next two decades, two billion more people will live in cities, requiring the equivalent of 2 000 new cities of one million inhabitants. This is an unprecedented challenge.

Heating and cooling represents 80 % of the building sector's total energy demand. Space heating alone accounts for the largest share of all thermal energy needed in a building, at about 60 % of the total. The share for cooling is small today but demand for cooling is expected to increase to more than that of space heating by 2050. It will be critical that new cities (and in fact, all new buildings in all locations) are built according to the highest energy efficiency standards to minimise energy demand. Using modern building shell insulation technology, heating and cooling demand can drop by one order of magnitude compared to conventional buildings. This will allow highly efficient heat pumps to provide cost-effective heating and cooling services, complemented by other renewable solutions such as solar thermal and bioenergy. In developed countries, accelerated renovation and refurbishment offers great potential to improve energy efficiency and reduce emissions. More attention will need to be paid to retrofit or replace existing inefficient buildings and upgrade their heating and cooling systems to utilize renewable energy.

With the decarbonization of the electricity sector gathering pace, the opportunities to electrify larger parts of end-use energy service demand arises as an important solution to the goal of overall energy sector decarbonization. Heat pumps are thus an important part of the mix of technologies to provide cost-effective decarbonization, but could also play an increasing role in helping manage the growing share of variability renewable electricity (VRE) generation technologies in the electricity system. Heat pumps, when aggregated, can provide some of the ancillary services that the electricity sector will increasingly call on as the share of VRE technologies grows (e.g., frequency response, voltage control, etc.), while heat pumps with low-cost thermal energy storage can take VRE electricity when abundant and draw down the heat as required. Overall, the role of heat pumps for space and water heating will grow rapidly in the REmap case to meet the target, with heating-focused heat pumps growing from an estimated 4 million units in 2015 to 232 million units by 2050.

It is not just in buildings, however, where heat pumps will play a role. Electricity-based process heating technologies, such as heat pumps, can help industry raise its electricity share, enabling a higher penetration of renewables. These technologies are limited by the level of temperature of process heat (up to 250 °C), but the REmap case anticipates that globally, large-scale heat pumps in industry could grow from around 200 000 in 2015 to 80 million by 2050, with sectors such as the food industry being an important market due to the simultaneous need for heating and cooling in many cases.

IRENA's analysis of the potential for renewables in the European Union(EU) (IRENA, 2018) goes into more detail. The largest markets for heat pumps in Europe (in terms of renewable heat captured) are Italy, France, Sweden and Germany (Eurostat, 2017). The REmap analysis reveals significant potential to accelerate the deployment of heat pumps – which could account for about 9 % of heating needs by 2030 in industry and buildings. The potential for heat pumps in industry is particularly economic (Figure 3),

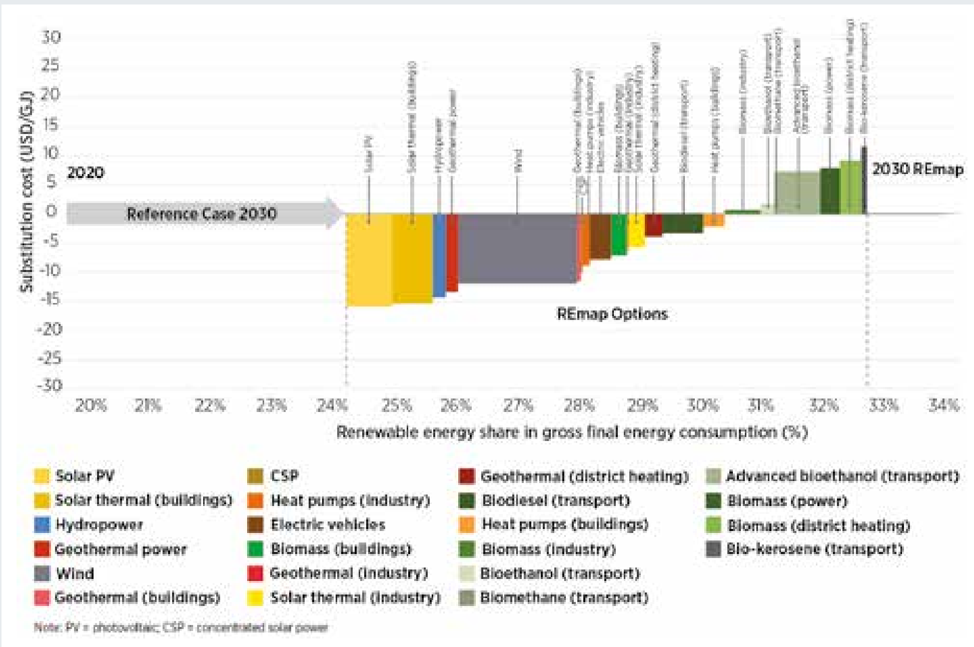

Figure 3: Cost-supply curve of renewable energy options for the EU to go beyond the 27 % target for 2030
Source: EU and IRENA, 2018

while there is significant cost-effective potential for heat pumps to provide decarbonized heat in buildings as well.

However, there are challenges to achieving these figures. About half of the EU-28 building stock was built before 1970, with limited energy efficiency considerations and no renewable energy requirements. These buildings will either need to be renewed and/or some of their equipment retrofitted over time. Another consideration is that renewables are easier to introduce in newly constructed buildings and for heat pumps, using low-temperature heating systems make the use of heat pumps much more efficient. Heat pumps additional barriers to implementation, including higher initial investments, sometimes difficult to access finance, landlord-tenant issues and insufficient knowledge of the advantages of the technology. As a result, it is imperative – if heat pumps are to deliver on their potential to help the EU decarbonise its energy system – that energy efficiency and renewable energy policies be co-ordinated to recognise the complementarity of heat pumps and support them by mitigating existing barriers to deployment.

Demonstrating the business case for heat pumps

IRENA has, since 2012, invested significant resources into collecting comprehensive, transparent and up-to-date data on renewable energy costs and performance to ensure that policy makers have the latest data on which to make decisions about the role of renewables in the energy sector. Given the, sometimes very, rapid improvements in the costs of renewable energy technologies (notably for solar electricity and wind power) this data plays a vital role in ensuring that policy makers make decisions based on real-world costs, that energy and climate modelers don't underestimate the potential contribution of renewables and that industry stakeholders discuss issues based on facts, not assertions.

In 2017, IRENA started working with the European Heat Pump Association to start collecting cost and performance data for heat pumps, as well as promoting the potential role of heat pumps in providing additional flexibility to the electricity system as the share of VRE rises.

Figure 4 presents the cost data that has been collected for small-scale German heat pump systems installed to provide space and/or water heating in 2013 and 2016. In this market, there has been a significant shift toward technologies that provide higher performance, this has seen the total installed costs rise from USD 1747/kW in 2013 to USD 1925/kW in 2016. The 10% increase in total installed costs between 2013 and 2016 has, however, purchased an 18% increase in the weighted average seasonal performance factor of systems installed.

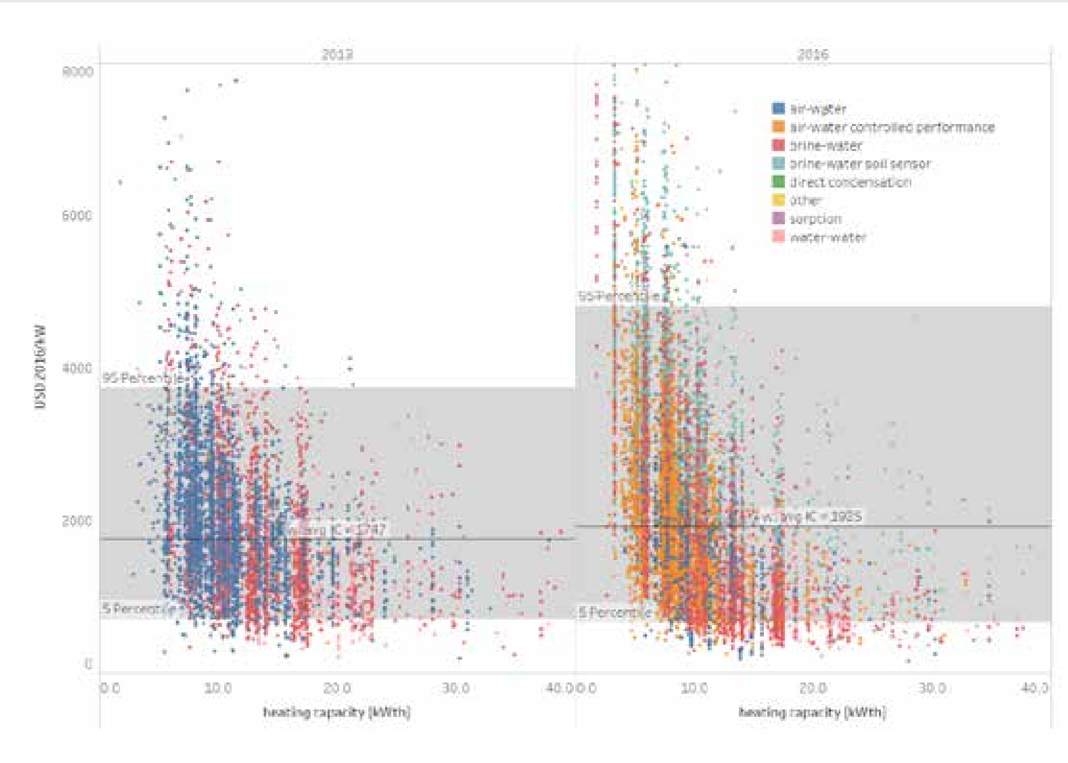

Figure 4: Heat pump total installed costs in the residential and commercial sectors in Germany, 2013 and 2016
Source: IRENA, based on Bundesamt für Wirtschaft und Ausfuhrkontrolle (BAFA)

[2] Data provision to IRENA is covered by the Confidentiality Protocol of the IRENA Renewable Costing Alliance, see www.irena.org/costs for more details.

Data for large-scale heat pumps are not as readily accessible as for small-scale units, while the data available is typically for the equipment costs only and exclude installation costs. However, the data available for 2013-2015 in Europe suggests that weighted average costs are coming down, as system sizes increase (Figure 5). The data collected so far represents a start, but more data is required to develop a comprehensive overview of heat pump costs and performance and IRENA would welcome new partners who could share, confidentially, real-world project data[2] to help convey the compelling message about the business case for heat pumps as part of the suite of solutions to our energy and environmental policy challenges.

Conclusions

Major changes are needed to reach the 2.0-scenario needed according to the Paris agreement. One way to find a set of actions for each country is to use the IRENA tool REmap. It has also shown to give comparable results with the IEA-ETSAP models at both national and global level. This suggests that the sequence of technology options selected in REmap's cost-supply curves yields similar results, despite lacking the dynamic temporal modelling in IEA-ETSAP models. According to REmap, the power generation and buildings sectors would see the largest percentage reduction in emissions by 2050, and the role of heat pumps for space and water heating would grow rapidly. The REmap case actually anticipates that globally, large-scale heat pumps in industry could grow from around 200 000 in 2015 to 80 million by 2050. The REmap analysis reveals significant potential to accelerate the deployment of heat pumps – which could account for about 9 % of heating needs by 2030 in industry and buildings.

Sources

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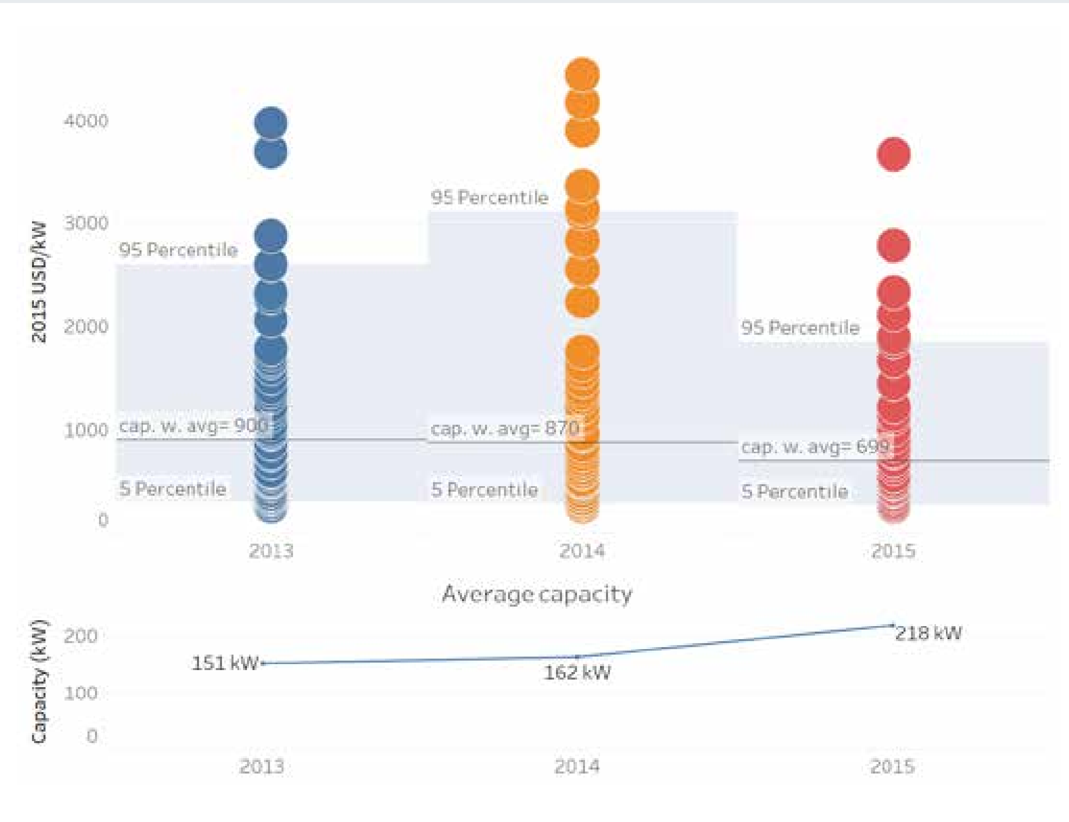

Figure 5: Large-scale heat pump equipment costs in Europe/mena, 2013-2015
Source: IRENA and the IRENA Renewable Costing Alliance