Large scale energy storage

Developing Cryogenic Energy Storage at Refrigerated Warehouses as an Interactive Hub to Integrate Renewable Energy in Industrial Food Refrigeration and to Enhance Power Grid Sustainability

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- On the project Portal
- On the CryoHub Intranet (http://cryohub.psutec.com/)

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1. Executive summary

WP10 of the CryoHub project considers energy policy and future integration with two objectives. The first; to develop a long-term policy framework that rewards business models in the context of a local grid system. The second; to position the CryoHub technology within a market that properly rewards balancing services, low-carbon and renewables usage. This report is the first step and assesses where and when the technology could be deployed to provide the greatest value.
In the report we analyse energy scenarios and existing refrigeration infrastructure at an EU, and a national level for five countries (UK, Belgium, Spain, Bulgaria and Germany) selected to represent the diversity across the EU. We find that with growing levels of electricity generation from variable renewable sources and a significant number of refrigerated warehouses the CryoHub technology has the potential to provide value in many areas of the EU through the 2020s. However, as LAES is still pre-commercial, and with the proportion of electricity from variable renewable sources still low in many countries it is likely that the technology will not be deployed widely under current market conditions. Countries which have the greatest need for additional energy system flexibility as well as having the most refrigerated warehouses are likely to gain the most value from the technology initially, with the UK and Spain the two countries that would particularly benefit.

2. Introduction

Almost every country in the world has signed up to the Paris Climate Agreement which commits the parties to keep the average global temperature rise by the end of this century to below 2ºC [1]. To do this will require a significant decarbonisation of many global energy systems which will in turn result in a substantial increase in energy generated from renewable energy sources (RES) both for electricity and heat, with global RES consumption expected to rise an average of 2.3%/year until 2040 [2]. Many RES are variable (e.g. wind, solar, tidal) and so the need for energy storage technologies to maintain flexibility within energy systems will increase.
The food sector is responsible for 30% of global energy consumption which is met largely by fossil fuels [3]. Processing and distribution, including refrigeration is the largest consumer, responsible for approximately 40% of this demand, followed by retail, preparation and cooking which consumes ~35%, and then agricultural production which consumes ~15%, with the remaining demand consumed by livestock and fisheries production [3]. Food waste due to a lack of refrigeration is estimated at 9% for developed countries (such as those in the EU), and 23% for developing countries [4]; refrigeration infrastructure is therefore an area where significant global growth is expected.
The need to increase flexibility within energy systems [5], alongside the need to lower the dependency of the food sector on fossil fuels [6], and the importance of refrigeration infrastructure presents an opportunity for LAES in refrigerated warehouses (the CryoHub technology). The extent of this opportunity in individual countries will depend on the future makeup of the energy system and food sector of specific countries.
This report aims to quantify the opportunity for the CryoHub technology by identifying when and where integration of LAES would be most valuable for business and at the energy system level in Europe. To do this, the report has been structured in the following way:

- The European Energy System; a broad analysis of the current EU energy system and its possible trends until 2050.

- The European Food Sector; an overview of the EU food sector, especially refrigeration, is provided. The possible growth in the EU demand for refrigeration is also considered.
- Energy Storage/LAES; a summary of the need for energy storage is given, followed by a discussion around the potential benefits of LAES integrated with refrigerated warehouses.
- Case Studies; an examination of five case study countries; the UK, Belgium, Spain, Bulgaria and Germany, focusing on their current and future energy systems and refrigeration demand is carried out.
- Discussion/Summary; a discussion on the implications of the case study findings for those specific countries and the EU is provided.
- Conclusion; a series of conclusions regarding the value of LAES integrated with refrigerated warehouses across the EU are made.

3. The European Energy System

The European Union (EU) has several climate change related targets, chief of which is a reduction in greenhouse gas emissions of 40% by 2030, and 85% by 2050 from 1990 levels. To help meet this target the EU aims to meet 27% of final energy consumption from RES by 2030, and to improve energy efficiency by 27% by 2030 [7].

Figure 1 shows the EU's (under its current composition) gross inland energy consumption by fuel type from 1990 to 2016 [8]. Carbon emitting fuels (solid fossil fuels, petroleum, natural gas and waste) are still the most consumed energy sources (73% of energy consumption in 2016) but this has been steadily decreasing from 1990 when they represented 83% of energy consumption. Energy consumption from RES has increased significantly over this period from 4.3% to 13.2%.

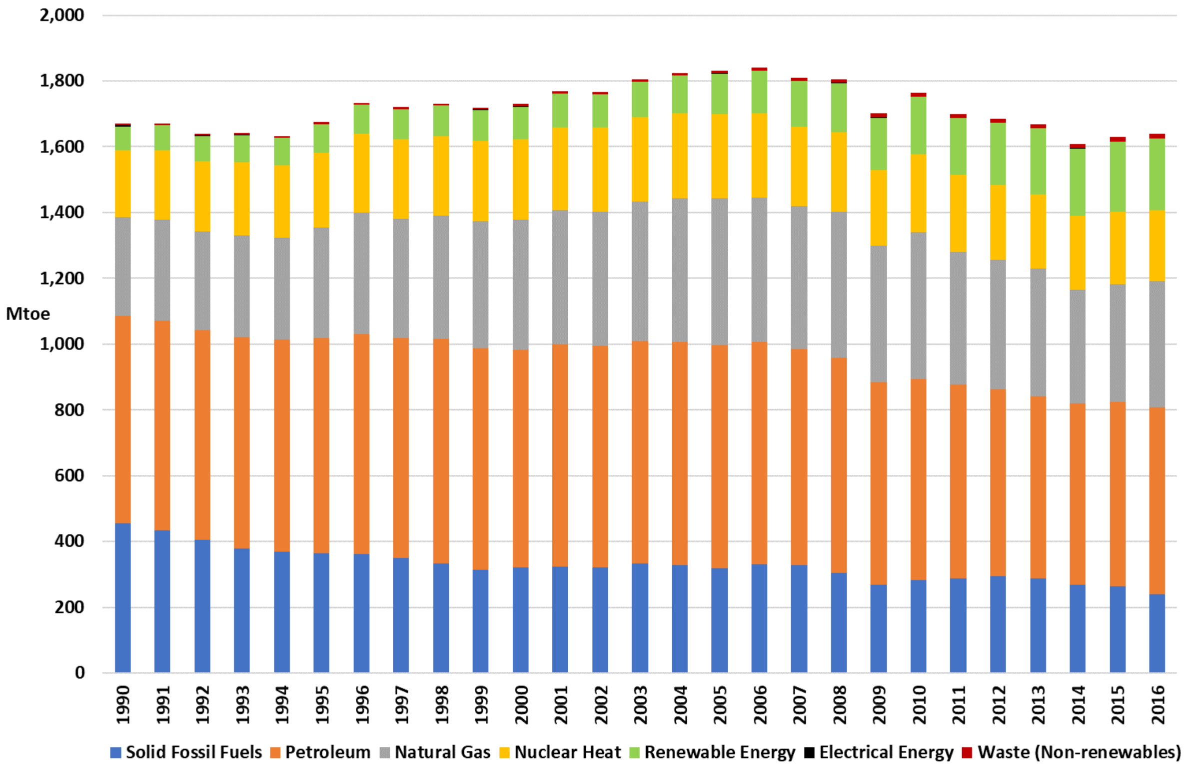


Figure 1 EU Gross Inland Energy Consumption by Source: 1990-2016

Figure 2 shows the EU's gross electricity generation by source from 1990-2016 [9]. The use of fossil fuels to generate electricity has decreased from 57% in 1990 to 44% in 2016. Over the same period electricity from RES has increased from 13% to 30%, (328TWh to 981TWh). Although the proportion of electricity from RES has been rising since 1990, it has been rising at its greatest rate since 2011. Figure 3 shows the generation from variable RES (wind and solar), baseload (nuclear) and flexible generation (all other sources) as a proportion of total electricity generation from 1990 to 2016 [9].

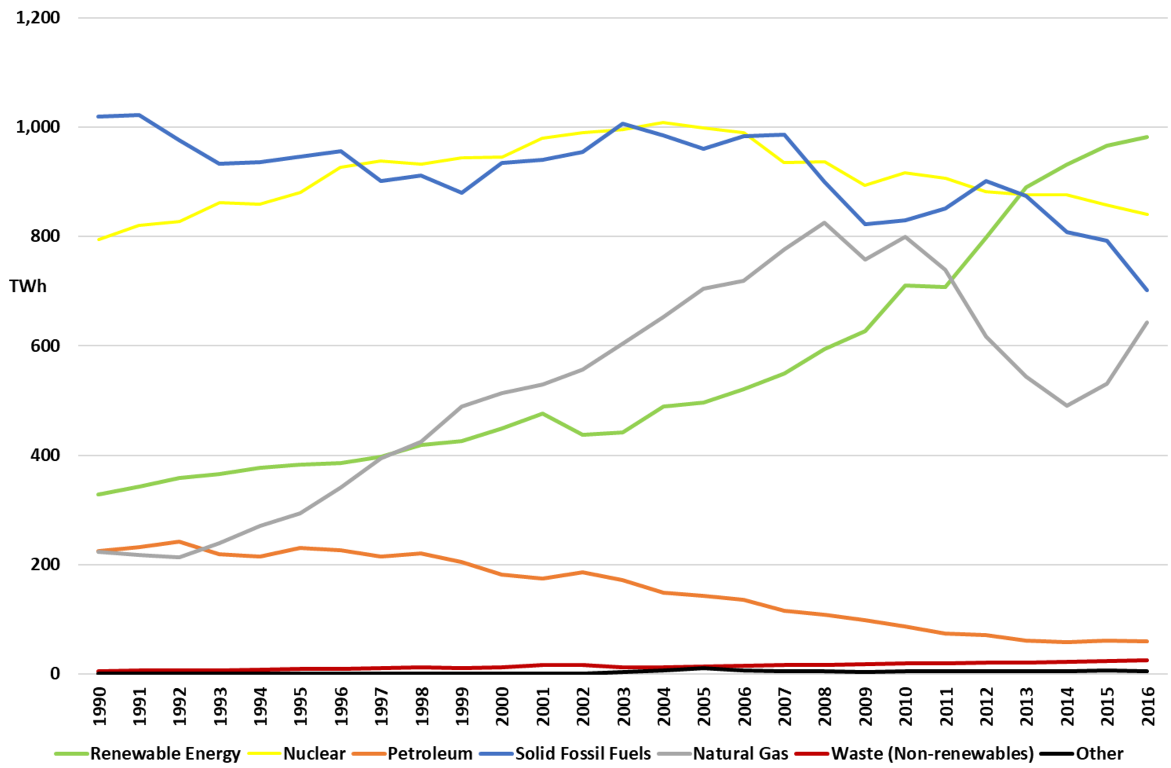


Figure 2 EU Gross Electricity Generation by Source: 1990-2016

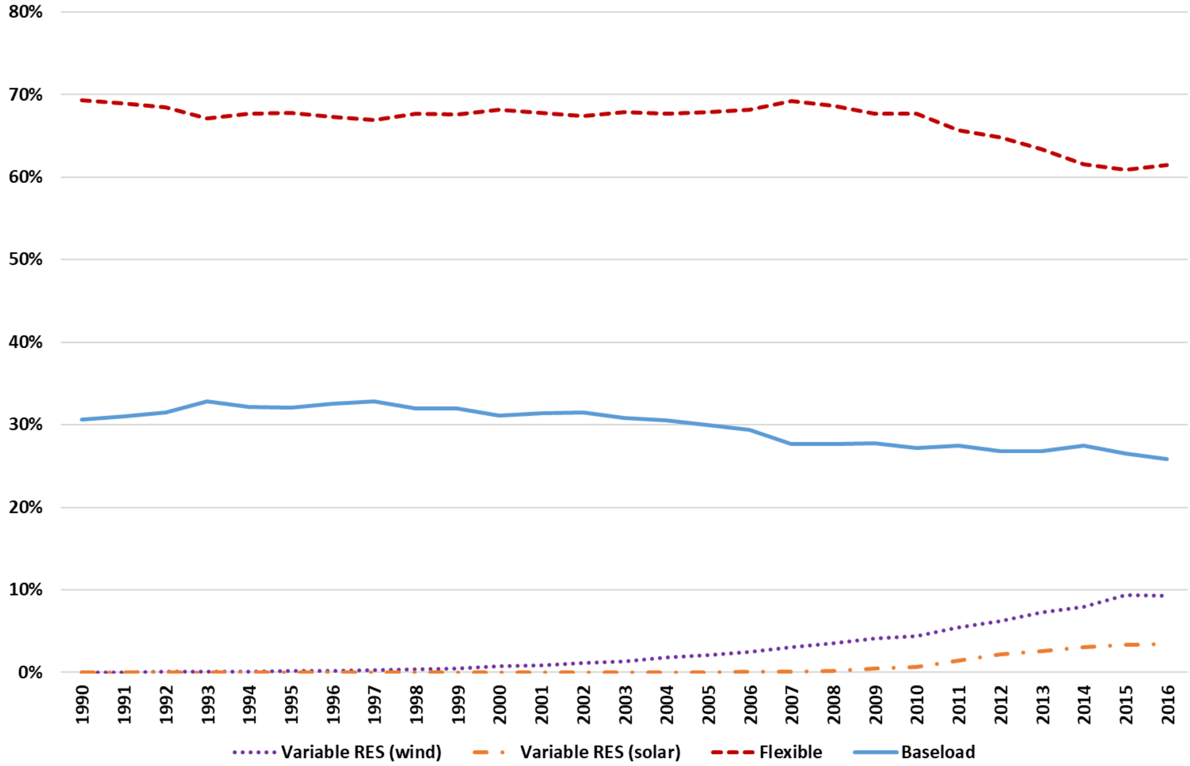


Figure 3 EU Electricity Generation as Variable, Flexible or Baseload: 1990-2016

Figure 3 shows that wind and solar generation accounted for over 12.5% (400TWh) of total generation by 2016 [9]: 303TWh and 105TWh respectively. Additionally, levels of dispatchable generation (e.g. natural gas or biomass-fuelled plants) have begun to decrease, which will further reduce the flexibility in the electricity system.

The European Commission has carried out detailed energy modelling to produce several scenarios which consider how the EU energy system may develop out to 2050. This includes a Reference scenario which is based on factors that are assumed to follow expected trends, with the implementation of all energy and climate change policies out to 2020. Full details of the assumptions made in the scenario are given in the 'EU Reference Scenario 2016' report [10].

Figure 4 shows the EU's standard reference scenario for gross inland energy consumption out to 2050 [11]. Consumption of carbon emitting fuels continues to decrease out to 2050 where they represent 63% of gross energy consumption, although it should be noted that some of this will be captured through a Carbon Capture and Storage process (CCS). Energy consumption from RES continues to rise, reaching 25% of inland energy consumption by 2050, equivalent to 379Mtoe.

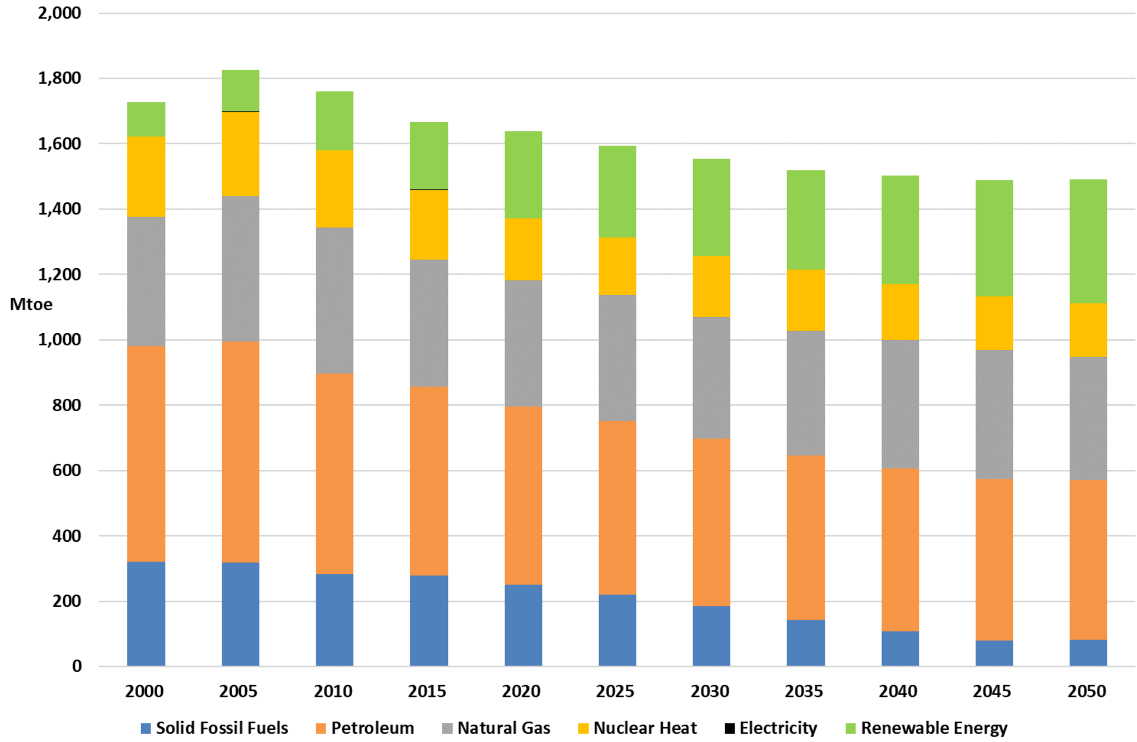


Figure 4 EU Reference Scenario; Gross Inland Energy Consumption by Source: 2000-2050

Figure 5 shows the reference scenario projections for gross electricity generation out to 2050 [11]. Generation from RES continues to rise significantly, and at a relatively constant rate, reaching over 55% of all electricity generation (over 2,200TWh) by 2050. Figure 6 shows the generation from variable RES, baseload and flexible generation as a proportion of total electricity generation out to 2050. Wind generation accounts for 17% (610TWh) of all electricity generation by 2030 and 24% (980TWh) by 2050, while solar produces 6.5% (230TWh) by 2030 and 11% (430TWh) by 2050. Under this scenario therefore, over a third of all electricity generation is from variable sources by 2050. In addition to this, flexible generation shows a decreasing trend from 61% (2,000TWh) in 2015 to 54% (1,900TWh) in 2030 and then 47% (1,900TWh) in 2050. These two factors will contribute to a substantial reduction in the flexibility of the EU energy system.

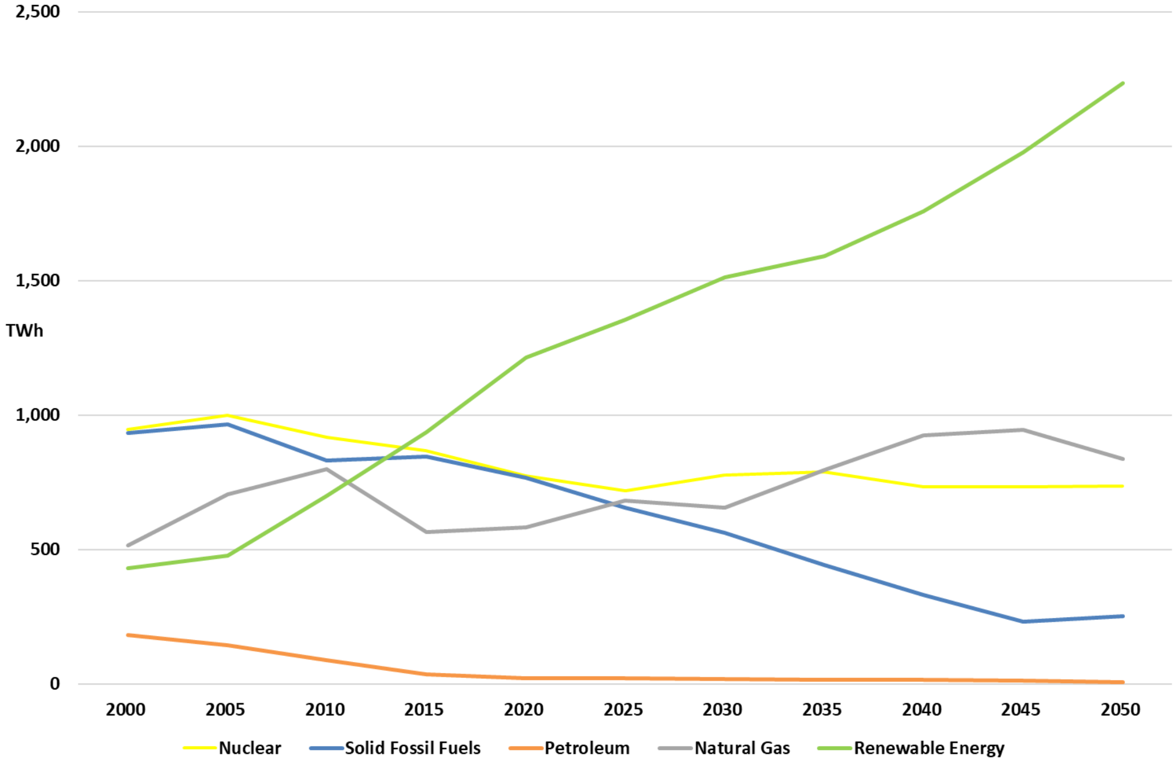


Figure 5 EU Reference Scenario; Gross Electricity Generation by Source: 2000-2050

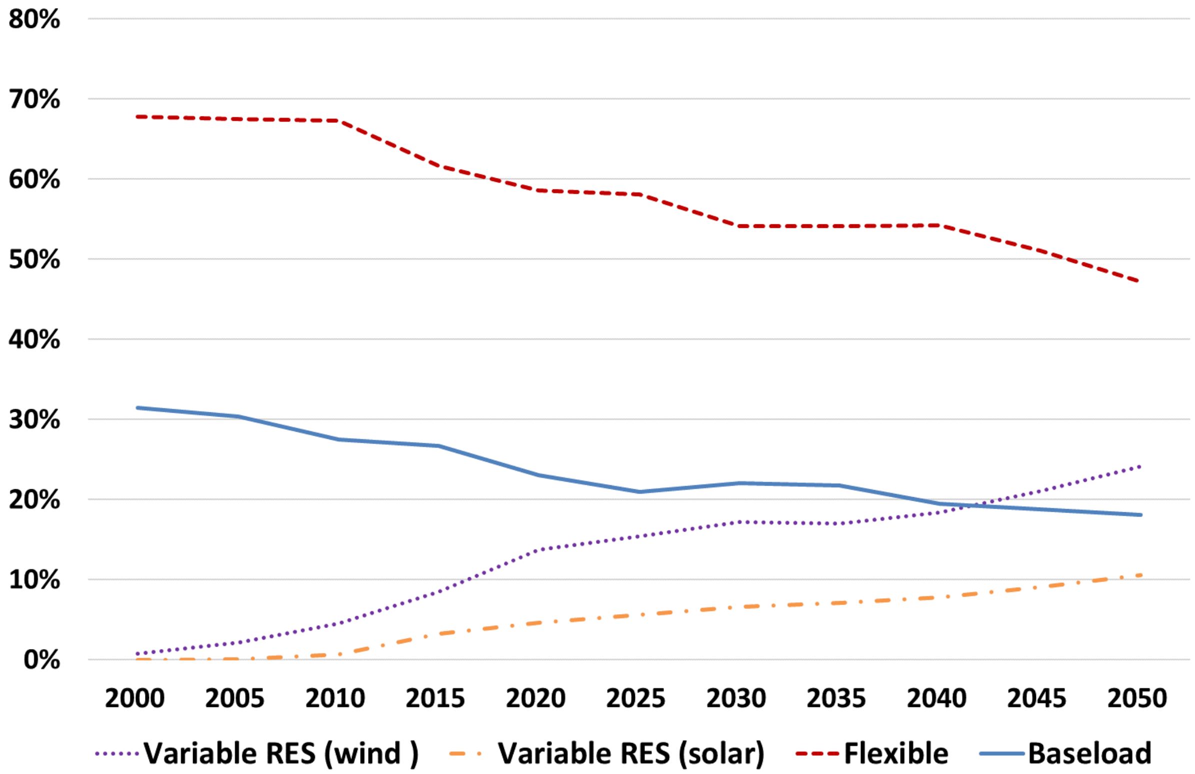


Figure 6 EU Reference Scenario; Electricity Generation as Variable, Flexible or Baseload: 2000-2050

4. The European Food Sector

The food sector is the largest manufacturing sector, a leading employer and contributed 1.7% of the EU's GVA in 2016 [12]. However the food sector is energy intensive; with approximately 26% of the EU's final energy consumption used to grow, process, pack and transport food to European tables [13], so to achieve the EU's carbon reduction targets it is important that the food sector contributes to decarbonisation.

Refrigeration is vital to food sectors and food security, with over 70% of foods chilled or frozen when produced [14], allowing food to be preserved and so reducing losses. However it consumes significant energy, with one study suggesting it accounted for approximately 35% of electrical consumption in the EU food sector [15]. Consequently, several studies have considered how energy demand from refrigerated warehouses may be reduced [16-19].

A previous report in the CryoHub project (Report D2.1: Report on refrigerated food facility mapping) assessed the location, number and energy consumption of refrigerated warehouses in the EU [20]. The report identified 1,049 refrigerated warehouses of which 503 were classed as 'large warehouses' having a power consumption exceeding 500kW. These large warehouses were estimated to have a total power capacity of over 500MW, indicating the average power rating of a large warehouse to be around 1MW although they ranged from 500kW to >10MW. Total power capacities for individual countries were also estimated and these have been explored in more detail in section 6. Figure 7 shows the location and power rating of these large warehouses.

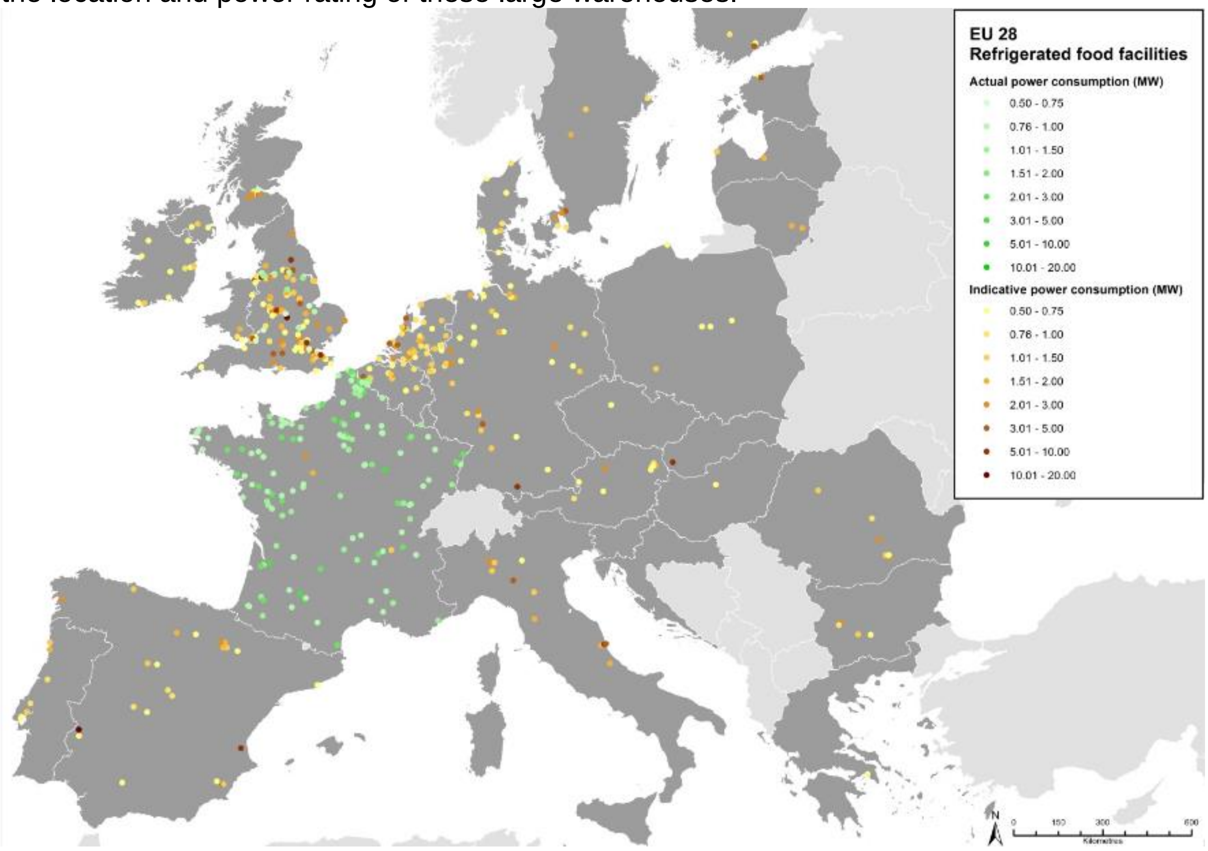


Figure 7 Map of Large Refrigerated Warehouses (>500kW) across the EU [20]

It can be seen from Figure 7 that large refrigeration warehouses are most concentrated around both sides of the English Channel (e.g. in Benelux, Southern England, Northern France and Northern Germany), which roughly corresponds with those areas in Europe with the greatest population density.

As the world population rises and the economies of developing nations grow there is expected to be significant global growth in refrigeration infrastructure for the food sector; the "cold chain" [14, 21]. However the EU's cold chain is already well developed and so growth is expected to be small; around 0.24%/year [22, 23]. This is in contrast to the EU's rapidly transforming energy system, therefore unlike in the case of the energy system, EU-scale future scenarios projecting the development of refrigeration in the food sector are not widely utilised.

5. Energy Storage/LAES

The CryoHub technology considered is a LAES plant integrated with a refrigerated warehouse. LAES is currently at pre-commercial stage with two systems in operation, both of which are in the UK. A pilot plant with a rated power capacity of 350kW and a total energy capacity of 2.5MWh is installed at the University of Birmingham [24], while a demonstration plant has been constructed near Manchester, with a rated power capacity of 5MW and a total energy capacity of 15MWh [25].
The UK is the global leader on LAES research with 18 of the 41 journal articles published between 2000 and 2017; Figure 8 shows the publication of journal articles regarding LAES, globally and from the UK.

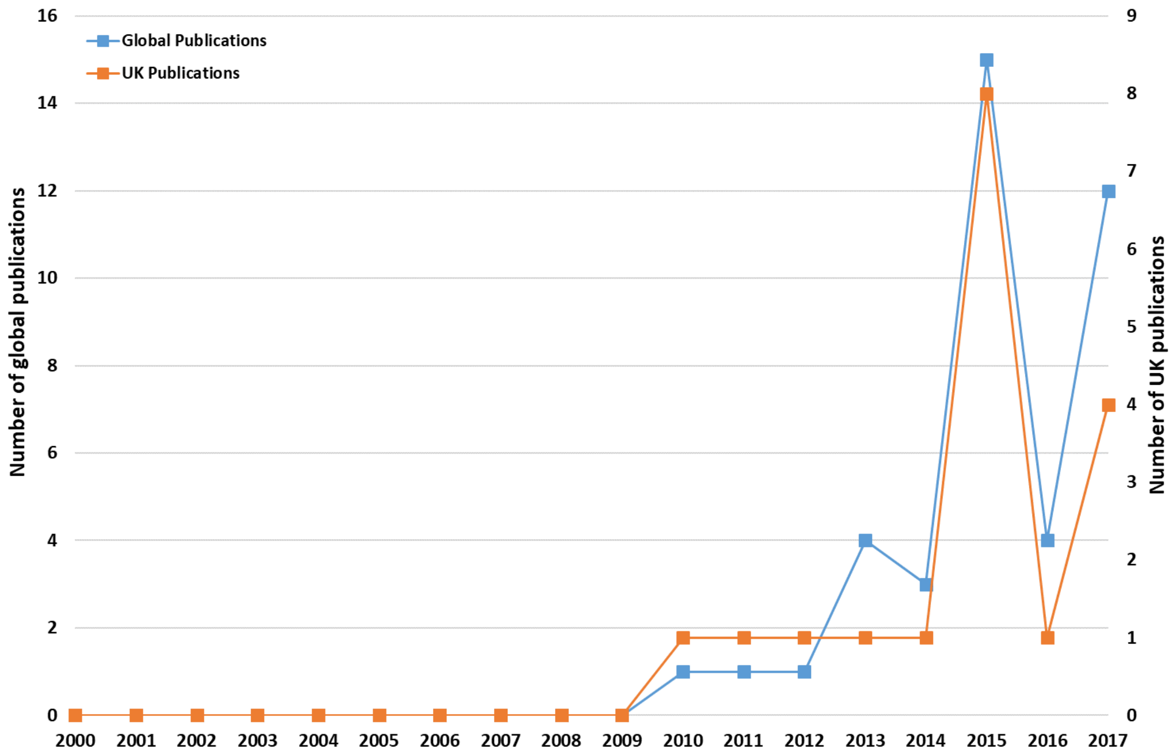


Figure 8 Global and UK Publication Trends of LAES Studies between 2000 and 2017 from the Web of Science Database [26]

Recycling available waste heat and cold energy can significantly increase the round-trip efficiency of LAES [27, 28]. If LAES is integrated with a refrigerated warehouse then cold energy which it is not economic to store and re-use in liquefaction can be used for cooling [13]. Other methods for increasing round trip efficiency include optimising the compression process, developing advanced devices and systems (such as air purification units) and researching novel thermodynamic cycles [24, 29, 30].

Generation from variable RES does not always coincide with demand so balancing measures are required; LAES is one such measure. Integrating LAES with a refrigerated warehouse would allow a greater proportion of electricity to be provided by on-site RES as it could be stored when generated for use when required. Alternatively the flexibility provided by the LAES would enable greater integration of RES into the network. This would provide savings to the warehouse operator by allowing electricity bought at times of low demand (and therefore low price) to be used (or sold back to the network) at times of high demand (high price).
Using LAES at refrigerated warehouses as a balancing measure to facilitate RES generation would also contribute to lowering CO_2 emissions with Initial estimates suggest an annual saving of 9Mt of CO_2 could be achieved across the EU by applying RES-powered CES to some 10% of 5000–6000 large refrigerated facilities EU-wide [13].
In addition to decarbonisation and RES integration other drivers for warehouse operators to adopt the CryoHub technology may include;

A reduction in energy bills; as already demonstrated above by, providing cooling, facilitating RES generation or allowing electricity to be bought at a lower price.

Additional revenue streams; by selling electricity back to the network and/or through providing energy storage flexibility services to the network such as Short Term Operating Reserve [27].

Wider societal benefits; for example the health benefits associated with replacing fossils fuels with RES [31].

6. Case Studies

Figure 9 shows the electrical energy consumption of the EU member states in 2016 [9], this was cross-referenced with Figure 7 to select five case study countries which would represent a range of energy demands, warehouse numbers and geographical locations. The case studies selected and their key characteristics are given below. While the case studies do not represent the entire diversity present in the EU they do provide a range of cases which are similar to many, if not all EU countries.
UK: High electricity demand and many refrigerated warehouses. Located in Western Europe.
Belgium: Average electricity demand and a medium number of refrigerated warehouses, including the CryoHub demonstration site. Located in Western Europe.
Spain: High/medium electricity demand and a relatively large number of refrigerated warehouses. Located in Southern Europe.
Bulgaria: Low electricity demand and a small number of refrigerated warehouses. Located in South-Eastern Europe.
Germany: Highest electricity demand and many refrigerated warehouses. Located in central Europe.
For the case studies electricity demand out to 2050 has been considered using the EU reference scenario. In addition another scenario; EUCO 2030, which was developed by the European Commission as part of their impact assessment work will also be used [32]. This scenario only extends to 2030 but, unlike the reference scenario which focusses on 2020 policies, it assumes all 2030 climate change and energy targets (including an energy efficiency target of 30%) are met, and so places a greater emphasis on decarbonisation which is likely to provide greater opportunities for the CryoHub technology [32].
It is important to note that energy scenarios are not predictions, however, they can provide useful insights into the consequences of a range of decisions for example in

terms of cost and carbon emissions and how the energy system could evolve to arrive at a given future outcome [33],[34].

Although the overall growth in the EU's demand for refrigeration is expected to be small (section 4) this will vary from country to country. However due to the small net growth, there is limited country specific data on future refrigeration demands, especially post-2030 out to 2050 where most available literature focuses on food security and food safety, or food emissions [35-38]. Therefore this report will focus on food refrigeration growth to 2030 only. With energy systems across Europe continuing to install additional RES out to 2050 and beyond it must be acknowledged that the potential for the CryoHub technology is likely to increase further by 2050. Additional research to assess the demand for refrigeration to 2050, to be in line with current energy scenarios would be beneficial.

A recent study commissioned by the European Commission; '*Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)*' forecasts the electrical demand from refrigeration, which it acknowledges is primarily used in the food industry, for each member state in 2030, relative to its demand in 2012 [39]. This report has been used to compare the expected growth in refrigeration demand for each case study country.

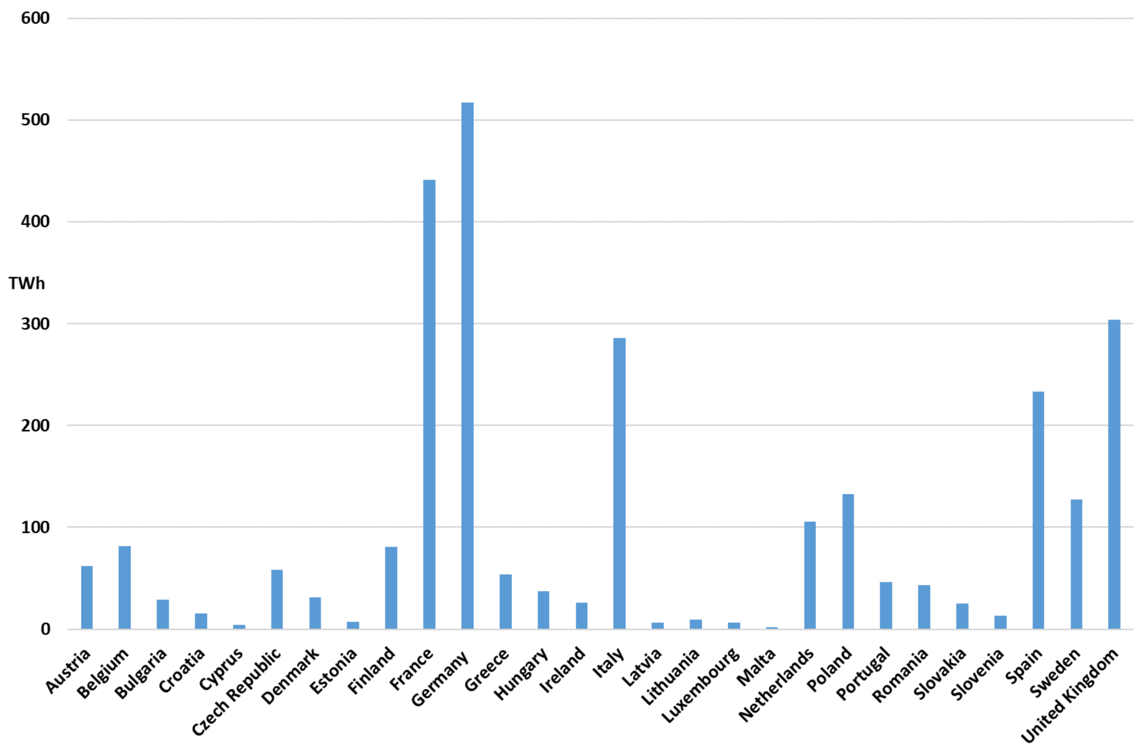


Figure 9 EU Member States Electricity Consumption: 2016

6.1. UK

6.1.1. Energy System

Figure 10 shows the gross electricity production in the UK by source from 1990 to 2016 [9]. Over this period the use of natural gas and RES has increased while petroleum and coal have decreased. Figure 11 shows the gross generation from variable RES, baseload and flexible generation as a proportion of total electricity generation, highlighting the impact these trends have had on the flexibility of the UK electricity system. The proportion of flexible generation in the system over this period has decreased by over 15% to be replaced by inflexible generation; variable RES and baseload generation.

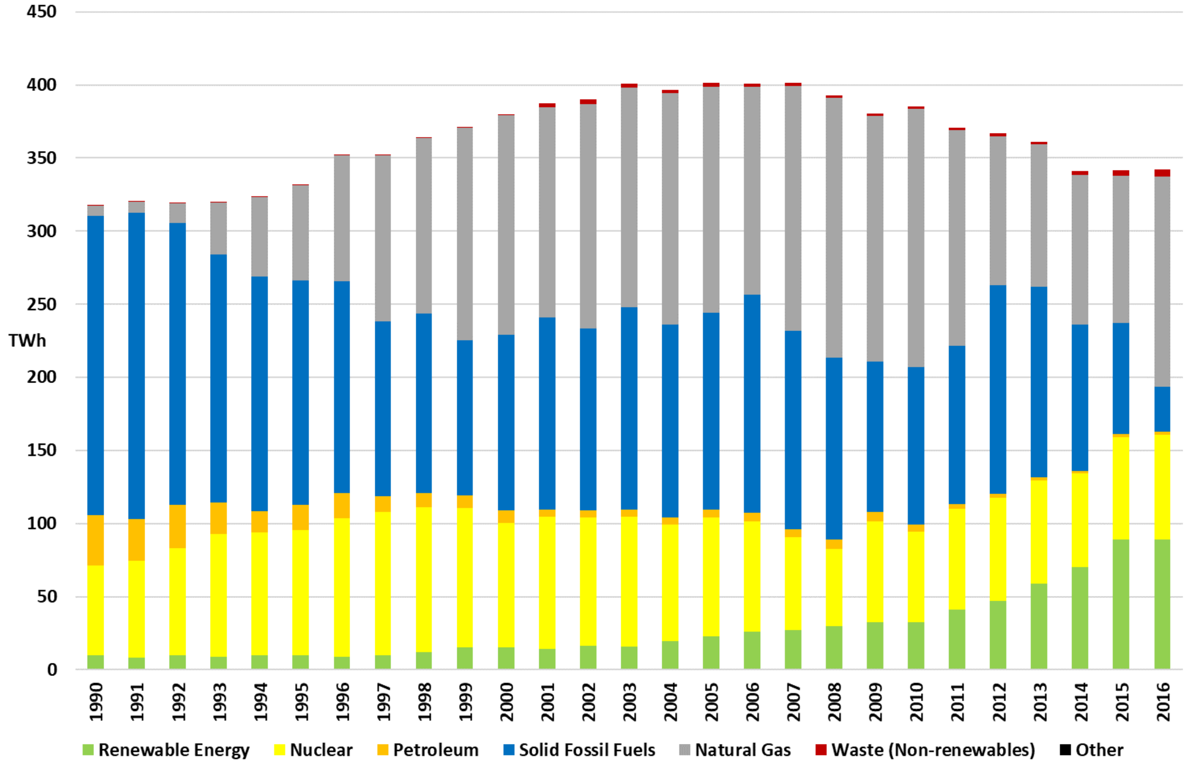


Figure 10 UK Gross Electricity Production: 1990-2016

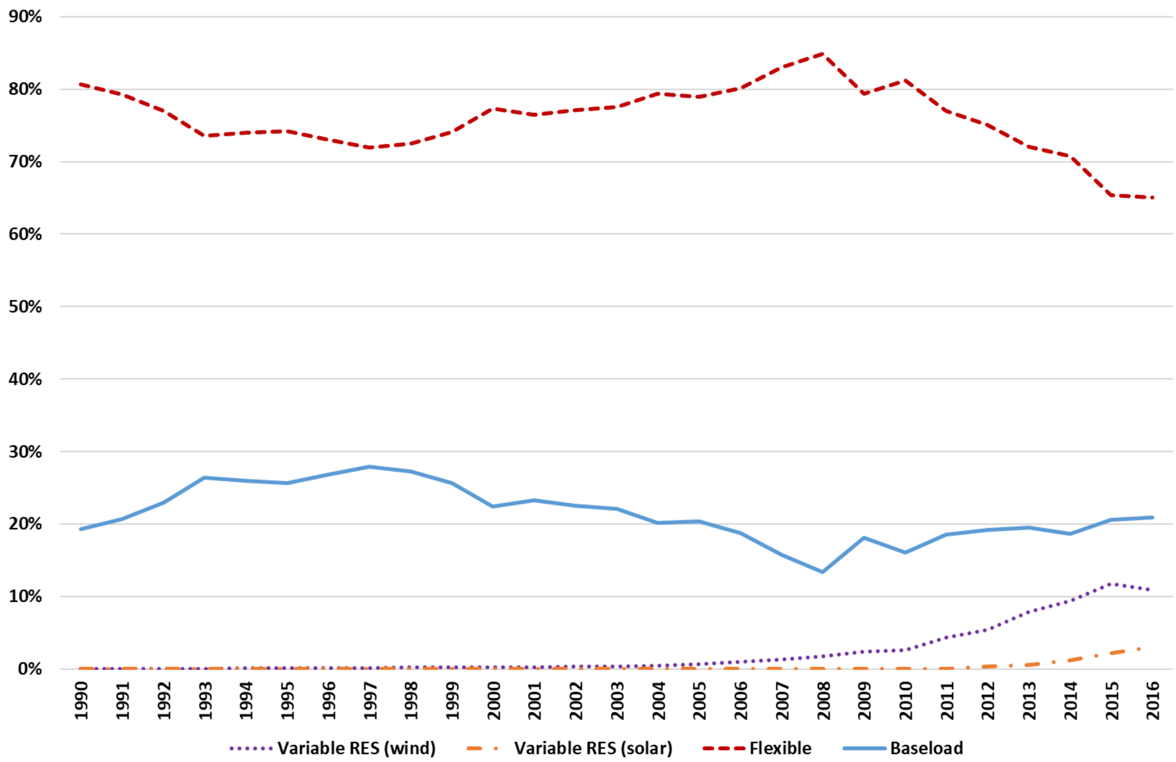


Figure 11 UK Electricity Generation as Variable, Flexible or Baseload: 1990-2016

Figure 12 shows variable, flexible and baseload electricity generation for the UK out to 2050 under the EU Reference and EUCO30 scenarios. For the reference scenario the proportion of flexible generation decreases to 47% by 2030 and 43% by 2050, to be replaced largely by wind, and to a lesser extent nuclear and solar generation. Under EUCO30 the trends are broadly the same although flexible generation decreases more sharply to 40% by 2030, while wind increases at a greater rate to 30%. Under both scenarios the bulk of the reduction in flexibility is expected to happen by 2030 and so additional flexibility measures such as energy storage are likely to be needed by 2030, particularly for the EUCO30 scenario.

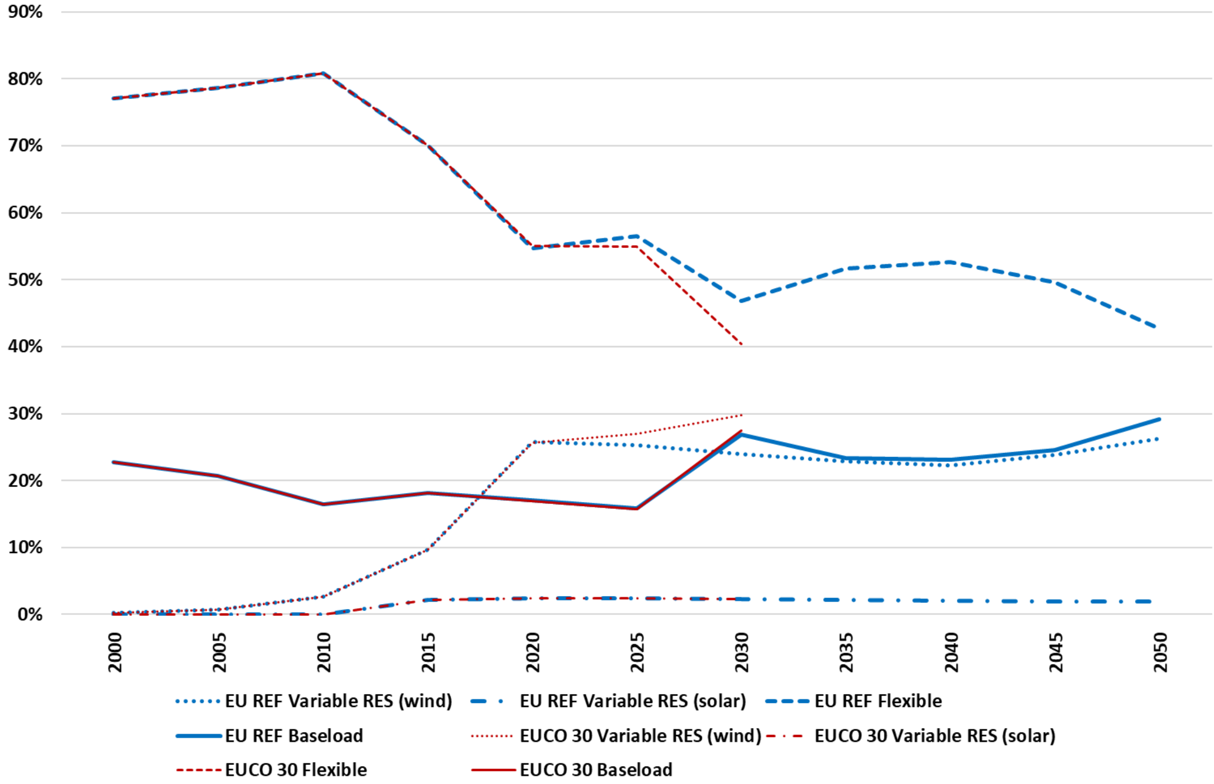


Figure 12 EU Reference and EUCO30 Scenarios; UK Electricity Generation as Variable, Flexible or Baseload: 2000-2050

6.1.2. Food Refrigeration Sector

The need for LAES coupled with refrigerated warehouses in specific countries will depend not only on the need for energy storage but also the number and electricity demand of refrigerated warehouses. As discussed in section 4, Report D2.1 assessed the number of large (>500kW) refrigerated warehouses in each of the member states, it found that the UK has 142 large refrigerated warehouses; second only to France. Report D2.1 also estimated the total power consumption of these warehouses to be 232MW (an average of 1.6MW/warehouse), the greatest of the member states.

Looking ahead to 2030, the UK annual refrigeration demand is expected to increase 9%, from 1.72TWh in 2012 to 1.88TWh by 2030, which is the third highest demand behind Germany and France [39]. It has been estimated that emissions from the whole UK cooling sector, the fourth highest in the EU, could be as high as 30.4Mt by 2030 if mitigation measures are not employed; providing a further opportunity for the CryoHub technology to provide value [40].

6.2. Belgium

6.2.1. Energy System

Figure 13 shows the gross electricity production in Belgium by source from 1990 to 2016 [9]. Again, the use of petroleum and solid fuels have decreased, while gas and RES have increased. Throughout the period Belgium has a strong reliance on nuclear generation which will reduce the 'built-in' flexibility in the system even before the growth of variable RES is taken into account. Figure 14 shows the gross generation from variable RES, baseload and flexible generation as a proportion of total electricity generation. Flexible generation is, as expected, lower than the UK's due to the reliance on nuclear (baseload) generation, although levels of flexible generation have stayed relatively constant over the period.

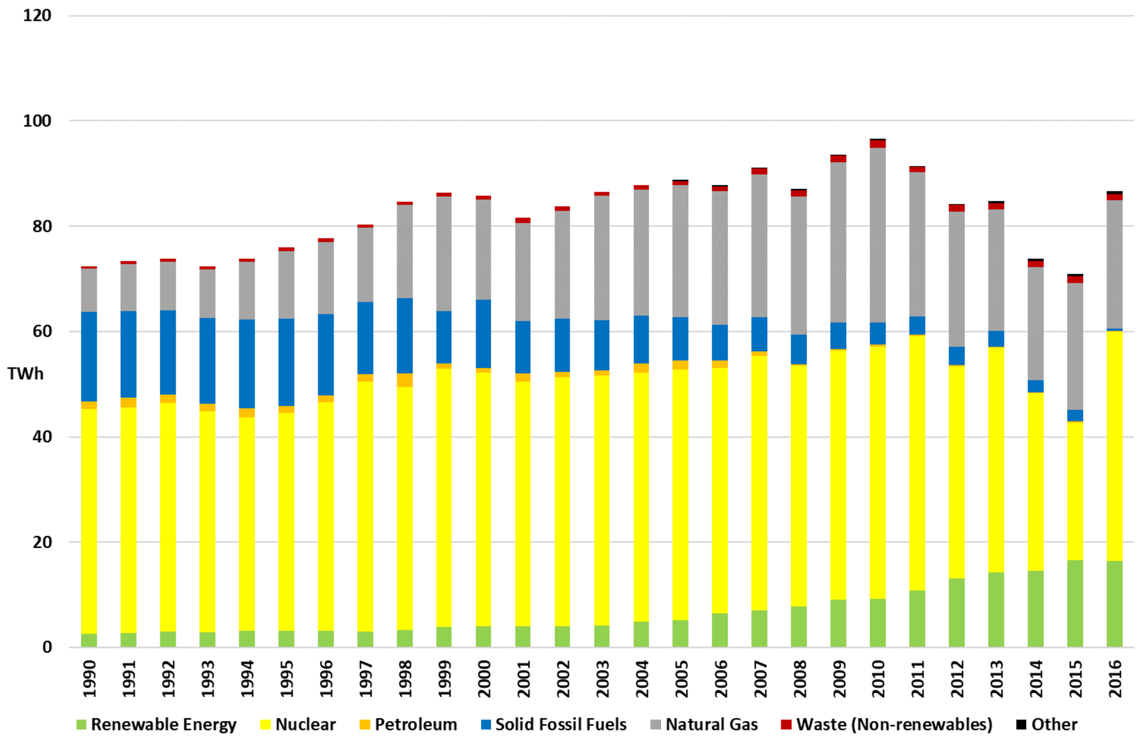


Figure 13 Belgium Gross Electricity Production: 1990-2016

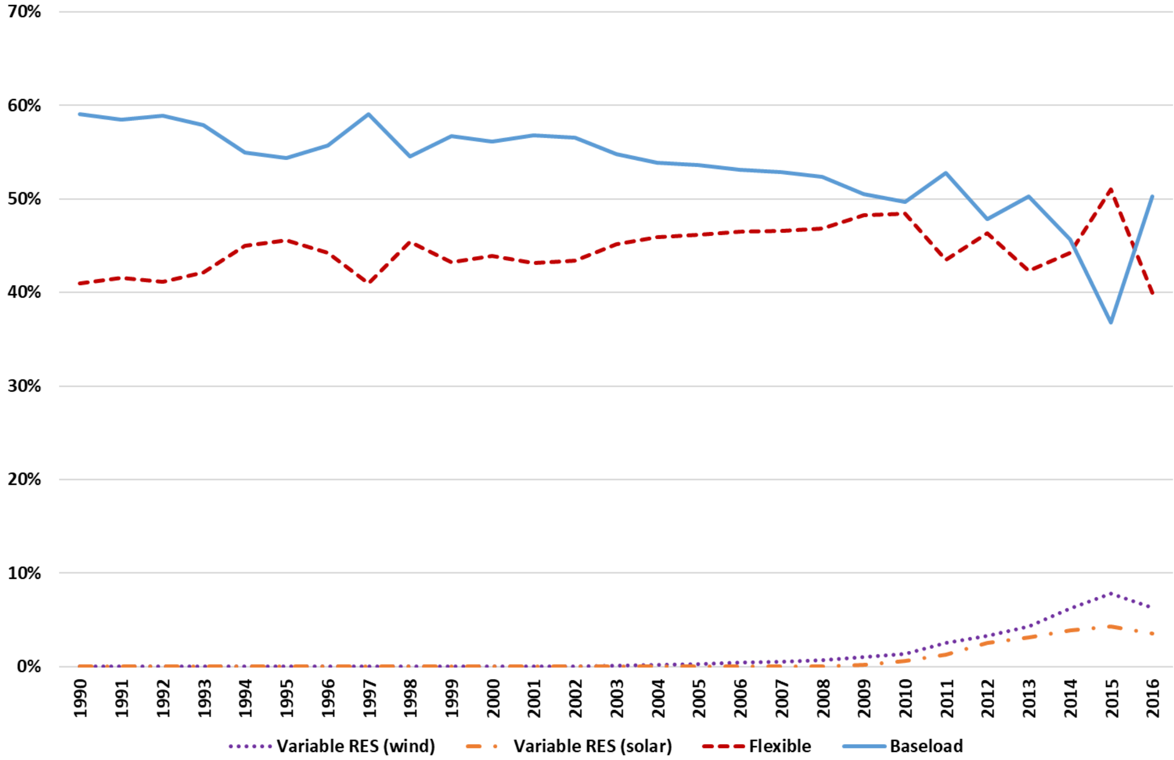


Figure 14 Belgium Electricity Generation as Variable, Flexible or Baseload: 1990-2016

Figure 15 shows how flexible generation is projected to change until 2050 under the EU reference and EUCO30 scenarios [32]. Under both scenarios the dominance of baseload generation is expected to decrease rapidly through the 2020's until it has ceased completely by 2030 due to nuclear plant closures, which were in part implemented due to the Fukushima accident. Although some of this generation need will be met by variable RES it is flexible generation which is expected to dominate under the reference scenario where it provides approximately 67% of generation in both 2030 and 2050. Whilst the trend is initially the same for EUCO30, flexible generation plateaus at 60% by 2025, with variable RES rising to 40% by 2030. This suggests that the need for energy storage, at least to provide flexibility will be limited unless variable RES generation replaces substantially more of the baseload generation than expected under the reference scenario.

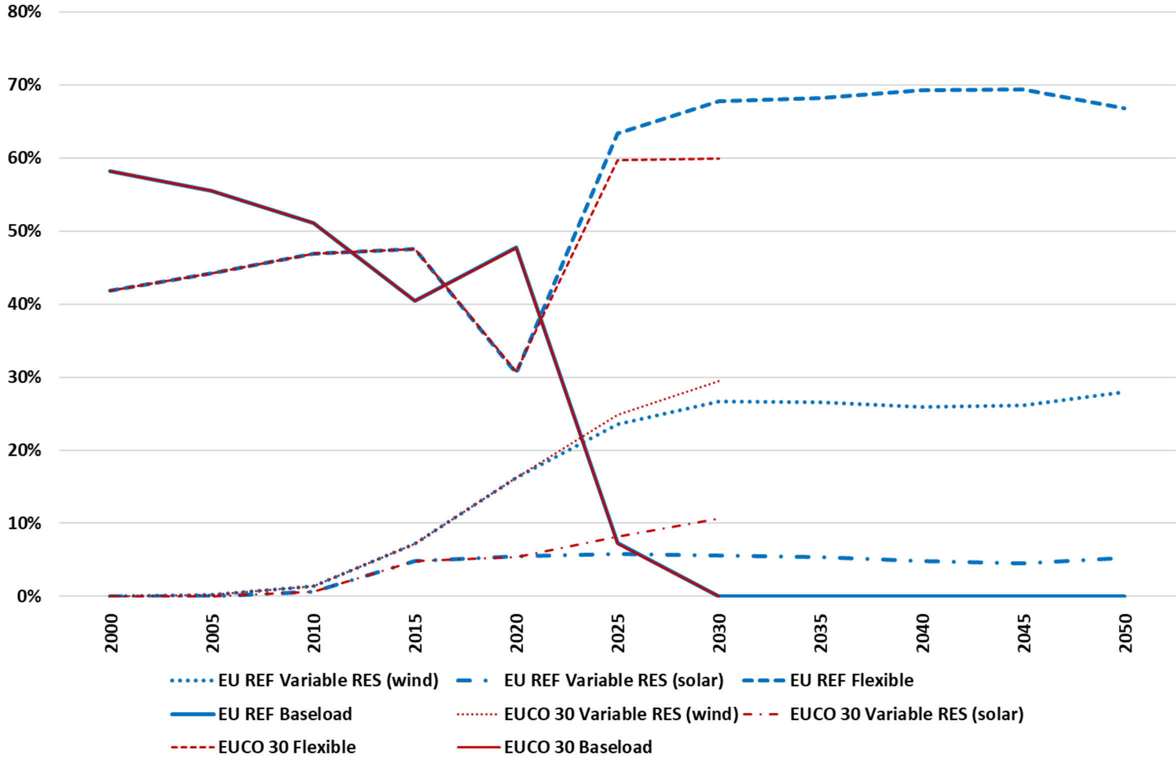


Figure 15 EU Reference and EUCO30 Scenarios; Belgium Electricity Generation as Variable, Flexible or Baseload: 2000-2050

6.2.2. Food Refrigeration Sector

Report D2.1 identified 14 large refrigerated warehouses in Belgium, the 6th greatest of the member states, with an estimated total power consumption of 15.72MW (average of 1.12MW/warehouse). The annual refrigeration demand is projected to increase 12% to 1.05TWh by 2030, which is the 8th highest demand of the member states [39].
By 2030 emissions from the Belgian cooling sector are expected to be around 4.41Mt; which is the 14th largest in the EU but significantly below the EU mean emission level of 12.4Mt [40]. Consequently, focusing on reducing emissions from refrigeration and cooling as a whole, while beneficial to Belgium, may be less valuable to the EU as a whole than it would be in the case of other countries.

6.3. Spain

6.3.1. Energy System

Figure 16 shows the gross electricity production in Spain by source from 1990 to 2016 [9]. Although there has again been a decrease in the use of solid fossil fuels it has been much less pronounced, although the use of petroleum has been decreasing since 2006 it is still above 1990 levels. Generation from gas is still considerably above 1990 levels although it has also been declining since 2006. Nuclear generation has stayed relatively constant across the period whilst RES has increased more than four-fold since 1990, this is particularly notable as of all the case study countries Spain had the greatest levels of RES generation in 1990. Figure 17 shows the gross generation from variable RES, baseload and flexible generation as a proportion of total electricity generation. Although Spain had a proportion of RES generation from 1990 it was not from variable sources which did not begin to be deployed until 1998, but in fact from hydro and bioenergy. Spain's flexible generation has been decreasing since 2007 and in 2016 represented

56% of generation. Variable RES has been increasing since 1998 and made up over 22% of all generation in 2016.

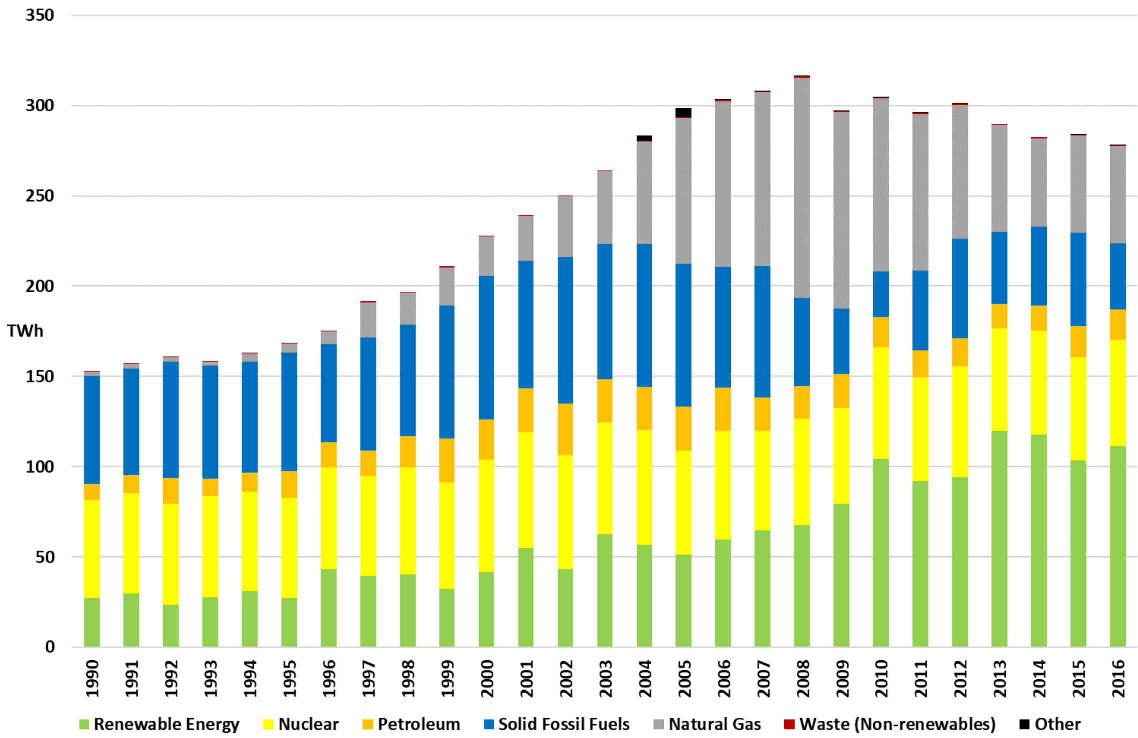


Figure 16 Spain Gross Electricity Production: 1990-2016

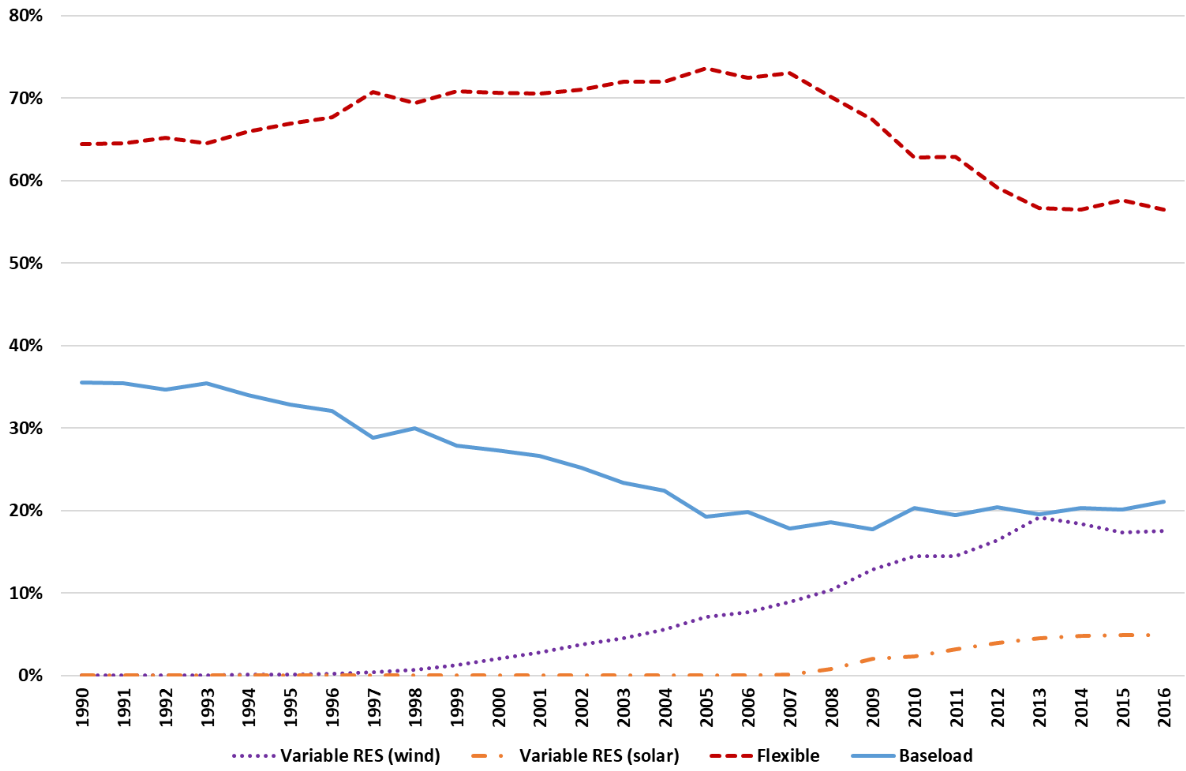


Figure 17 Spain Electricity Generation as Variable, Flexible or Baseload: 1990-2016

As shown by Figure 18 this trend of decreased flexibility is expected to continue through 2030 (38%) and onto 2050 (29%), according to the EU reference scenario [10]. This

reduction in flexible generation will be met by an increase in variable RES generation, with wind and solar generation producing 39% and 33% of generation by 2050. This will increase the need for system flexibility and therefore energy storage. Under the EUCO30 scenario this trend is more pronounced, with flexible generation falling to 25% by 2030 and wind and solar generation increasing to 31% and 23% respectively.
However it should be noted that, unlike the other case studies, a substantial proportion of the solar generation is solar thermal rather than solar PV which typically has molten salt storage built into the system and so is not applicable for the application of LAES as being investigated by CryoHub. The EU reference and EUCO30 scenarios do not break solar generation down into photovoltaic and thermal generation, however in 2016 41% of solar generation was from concentrated solar power (CSP) [9]. Nevertheless, with high levels of wind generation, and at least 50% of solar generation likely to be from photovoltaics it is probable that there will be a role for the CryoHub technology under both scenarios.

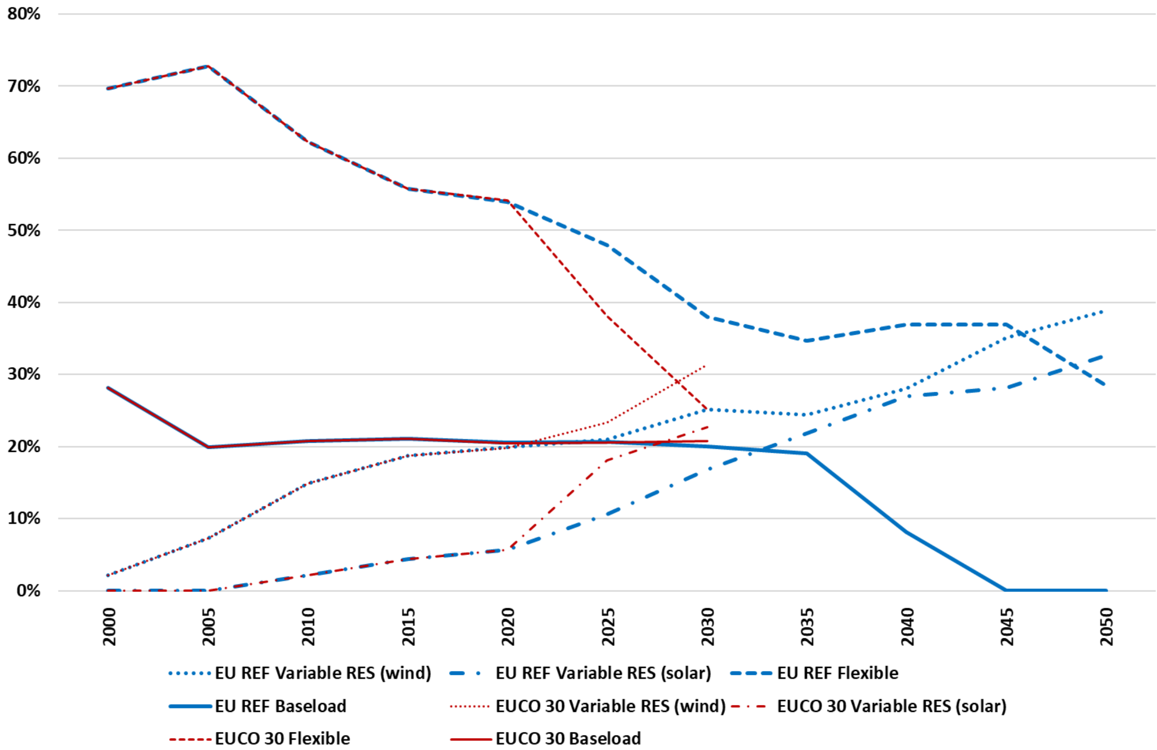


Figure 18 EU Reference and EUCO30 Scenarios; Spain Electricity Generation as Variable, Flexible or Baseload: 2000-2050

6.3.2. Food Refrigeration Sector

Report D2.1 identified 24 large refrigerated warehouses in Spain, the 5th greatest of the member states, with an estimated total power consumption of 56.33MW (average of 2.35MW/warehouse). The annual refrigeration demand is projected to decrease by 2% to 1.44TWh by 2030, which is the 5th highest demand of the member states.
By 2030 emissions from the Spanish cooling sector are expected to be up to 41.3Mt; the 3rd largest in the EU representing 12% of total EU cooling emissions [40]. Therefore, using the CryoHub technology to assist in reducing refrigeration emissions could provide significant benefit to the EU.

6.4. Bulgaria

6.4.1. Energy System

Figure 19 shows the gross electricity production in Bulgaria by source from 1990 to 2016 [9]. Unlike the other case study countries, the use of solid fossil fuels has stayed roughly constant across the period, as has natural gas and nuclear generation, although petroleum has declined from a small base to negligible levels. RES generation has increased 3-fold over the period. Figure 20 confirms what is shown in Figure 19, flexible generation has generally fluctuated slightly over the period, but in 2016 has decreased to 60% from 66% in 1990. Baseload generation peaked in 2006 but is now back at 1990 levels, flexible RES began to increase in 2009 but is still at relatively low levels, contributing 10% of generation in 2016.

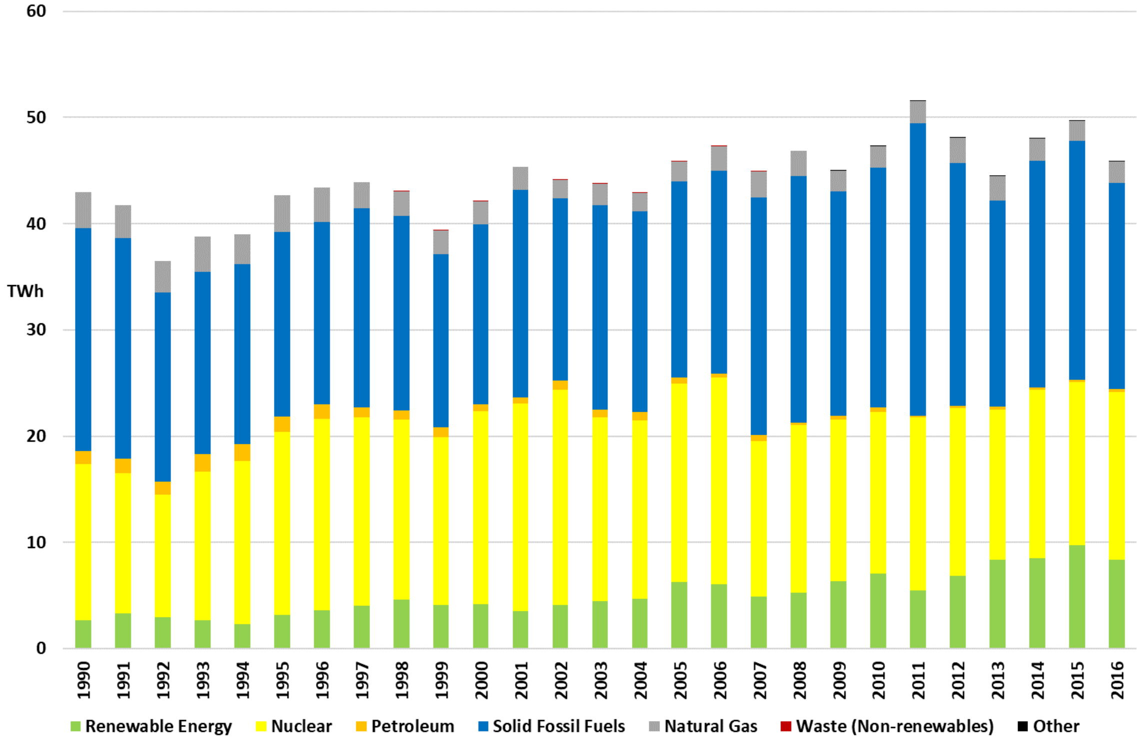


Figure 19 Bulgaria Gross Electricity Production: 1990-2016

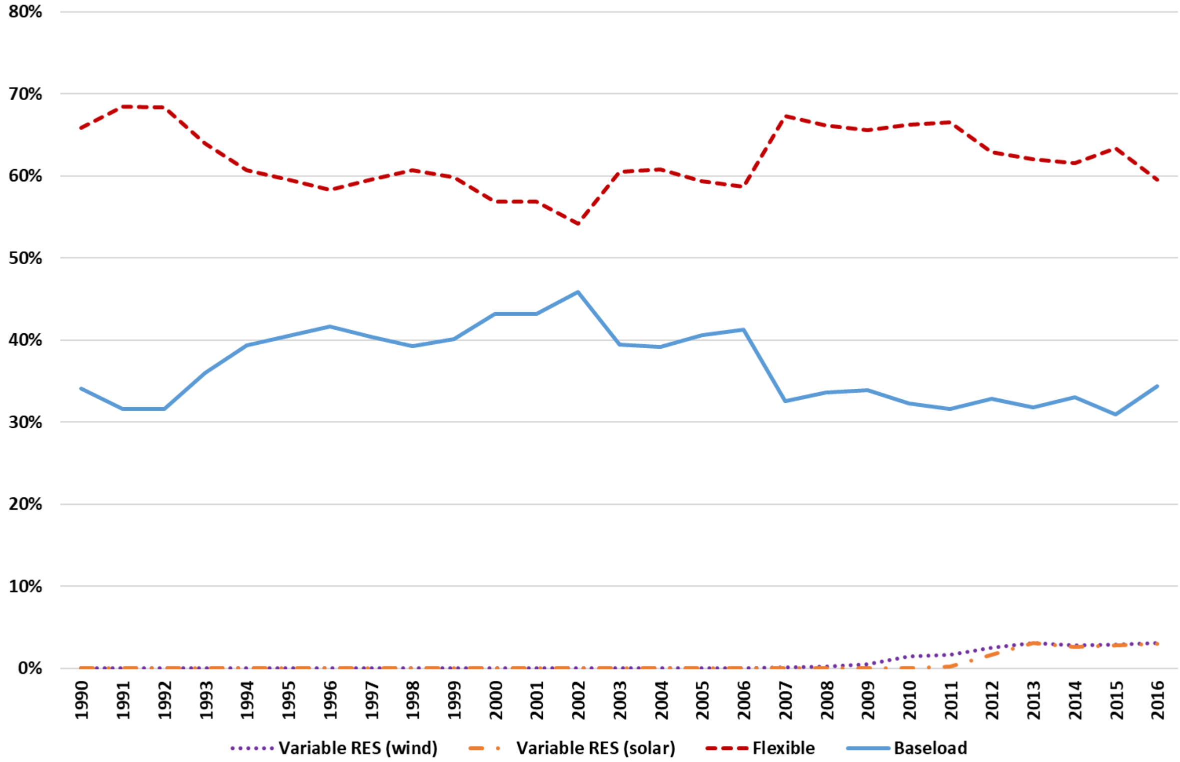


Figure 20 Bulgaria Electricity Generation as Variable, Flexible or Baseload: 1990-2016

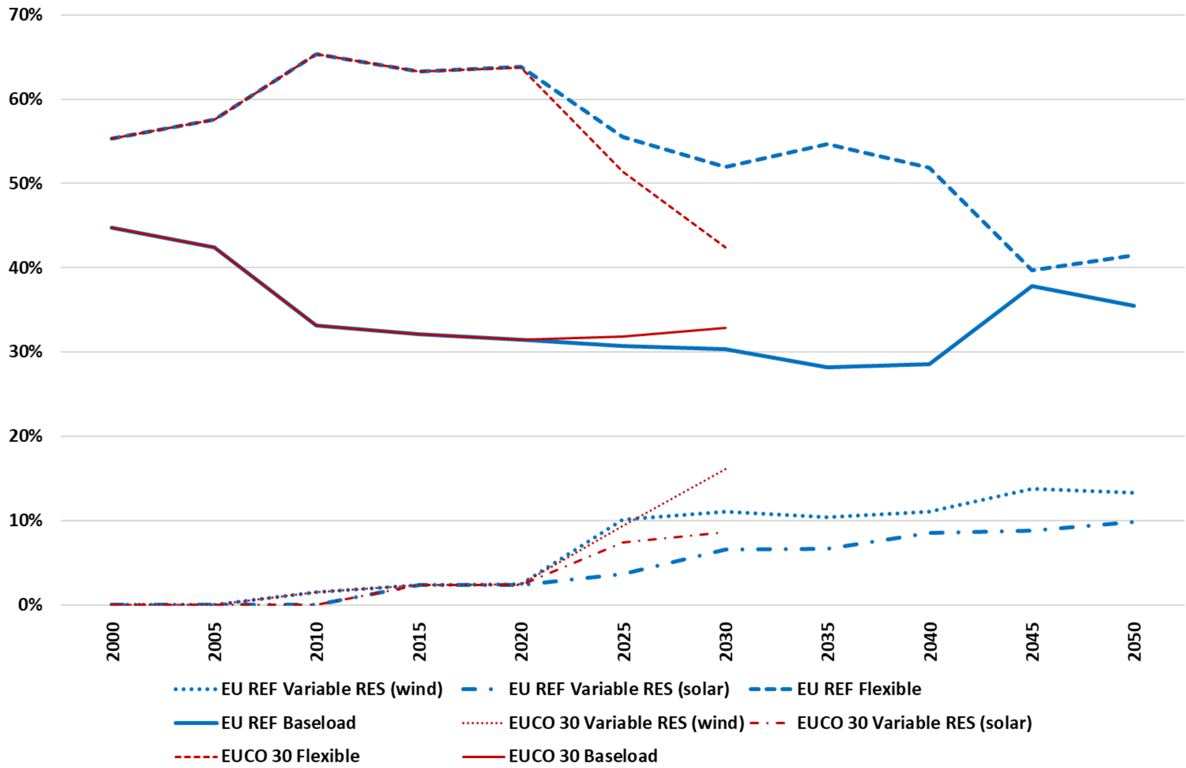


Figure 21 EU Reference and EUCO30 Scenarios; Bulgaria Electricity Generation as Variable, Flexible or Baseload: 2000-2050

Figure 21 shows that under the EU Reference scenario flexible generation is expected to decline to 52% in 2030 and 41% in 2050 [10]. This is replaced with wind and solar generation out to 2035 when there is an increase in baseload generation from 28.2% to 35.5% by 2050. Under the EUCO30 scenario flexible generation again falls and variable RES rises at an increased rate, while baseload generation begins to increase from 2025 rather than 2035 as in the reference scenario. Both baseload generation and variable RES will reduce system flexibility and increase the need for storage, however LAES with refrigerated warehouses tends to be better suited to variable RES as this can be co-located.

6.4.2. Food Refrigeration Sector

Report D2.1 identified 4 large refrigerated warehouses in Bulgaria, the 15th greatest of the member states, with an estimated total power consumption of 4.70MW (average of 1.18MW/warehouse). The annual refrigeration demand is projected to increase by 2% to 0.17TWh by 2030, which is the 20th highest demand of the member states.
By 2030 emissions from the Bulgarian cooling sector are expected to be around 7.13Mt; which is the 12th largest in the EU but significantly below the EU mean emission level of 12.4Mt [40]. Therefore, as in the case of Belgium, focusing on reducing emissions from refrigeration and cooling may be less of a driver for the CryoHub technology than would be the case in other EU countries.

6.5. Germany

6.5.1. Energy System

Figure 22 shows the gross electricity production in Germany by source from 1990 to 2016. Solid fossil fuel generation declined until 2009, and although it has increased slightly since then it is still below 1990 levels. Nuclear generation has been declining since 2011 following the Fukushima accident when it was decided all nuclear generation would be phased out. Natural gas generation has nearly doubled over the period while RES generation has increased substantially, by a factor of eight. The impact of these trends on flexibility is shown by Figure 23. Although variable RES has increased by 18% over the period, flexible generation has only decreased by 3%, as it has been required to replace the decrease in nuclear generation.

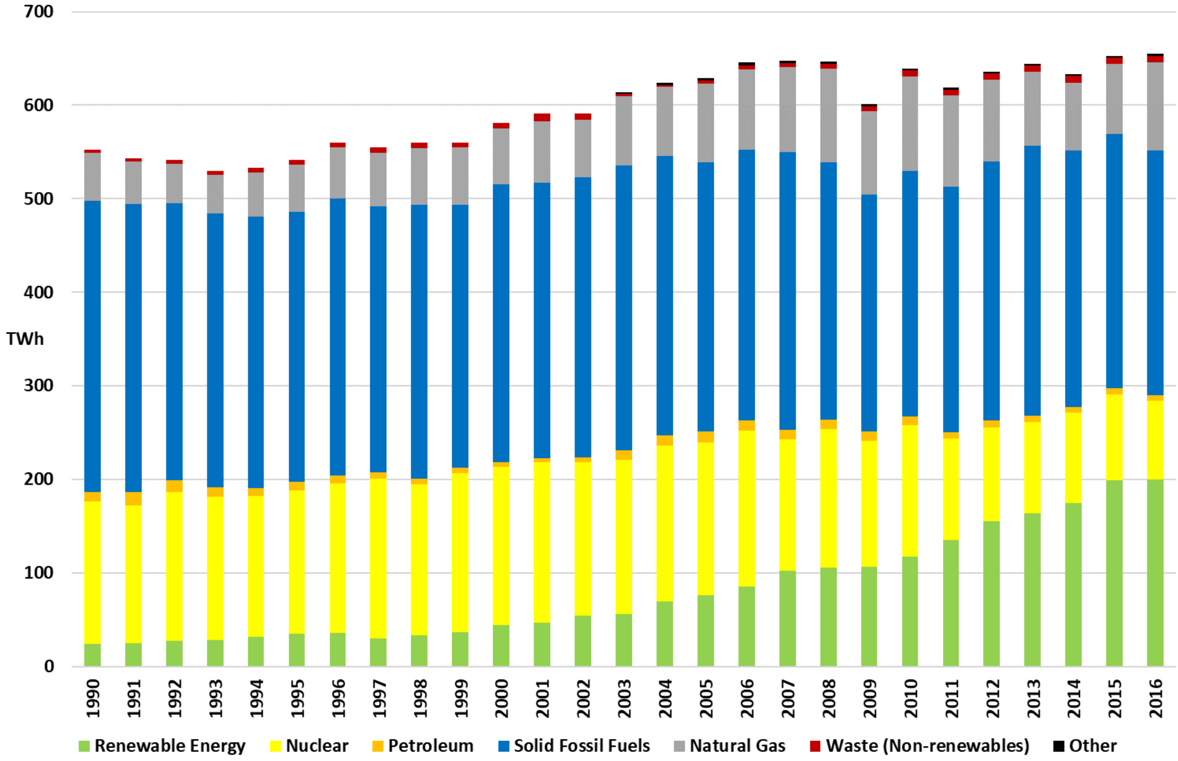


Figure 22 German Gross Electricity Production: 1990-2016

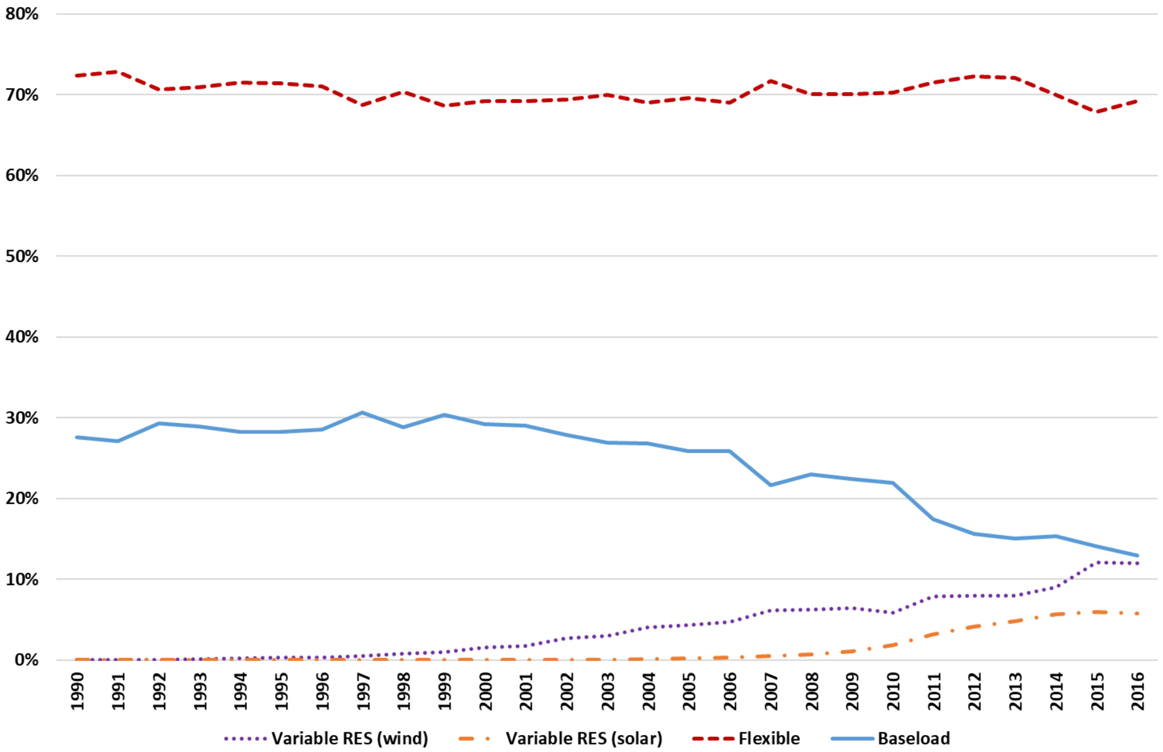
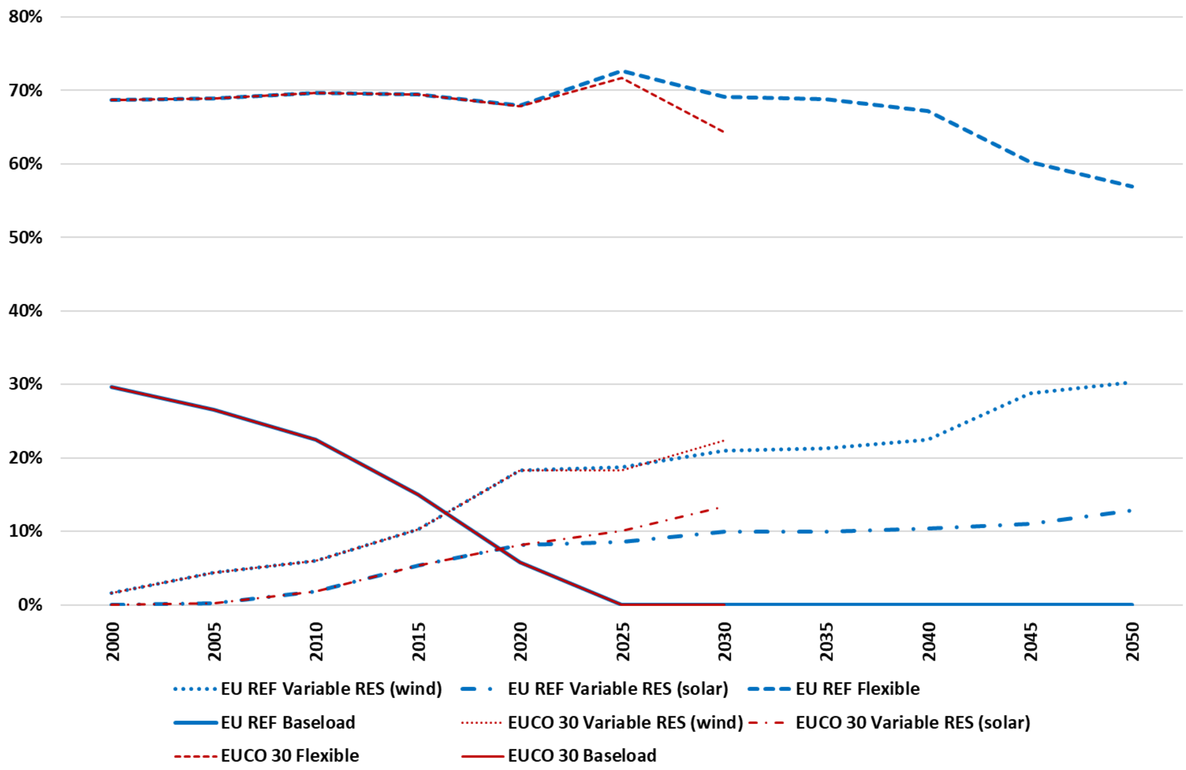


Figure 23 German Electricity Generation as Variable, Flexible or Baseload: 1990-2016

Figure 24 shows that this trend is expected to increase out to 2025 as nuclear generation declines to zero. Under the EU reference scenario levels of flexible generation begin to decrease from 2025, slowly at first, decreasing 3% to 2030, but then a further 11% to

57% by 2050. Wind and solar generation continue to increase to 19% and 9% in 2030 and then 30% and 13% in 2050. The EUCO30 scenario appears to follow a similar trend, with baseload generation being phased out by 2025 and flexible generation decreasing from 72% in 2025 to 64% in 2030. Wind and solar generation again appear to rise at a faster rate than under the reference scenario, providing 22% and 13% by 2030. These scenarios suggest that whilst there may be an opportunity for the CryoHub technology in Germany, it is likely to be over a longer timescale than in some other countries such as the UK and Spain, unless the current policy on nuclear generation changes. Although a more aggressive approach to decarbonisation as in the EUCO30 scenario may also bring this opportunity forward.



6.5.2. Food Refrigeration Sector

Report D2.1 identified 44 large refrigerated warehouses in Germany, the 3rd greatest of the member states, with an estimated total power consumption of 53.76MW (average of 1.22MW/warehouse). The annual refrigeration demand is projected to increase by 2% to 3.98TWh by 2030, which is the highest demand of the member states.
German cooling sector emissions are expected to be up to 47.8Mt; the 2nd largest in the EU representing 14% of total EU cooling emissions [40]. Therefore, using the CryoHub technology to assist in reducing refrigeration emissions in Germany could provide significant value to the EU more broadly.

7. Discussion/Summary

Across all the case study countries it is clear that the proportion of variable RES generation will increase until 2050, and it is likely that this trend extends to most if not all of the EU member states. Furthermore, four of the five case studies were forecast to see an increase in refrigeration demand, at least to 2030. This suggests that CryoHub's

LAES technology may provide benefit throughout the case study countries and the EU more broadly. However, the rate at which variable RES and refrigeration demand will increase varies from country to country, whilst other factors including the levels of flexible and baseload generation as well as the total cooling emissions will also impact the wider value of the CryoHub technology to specific EU countries. Consequently, the technology would be deployed in different countries over different timescales to maximise the value it provides.

The UK and Spain are expected to see a significant increase in their variable RES generation by 2030; both have a large number of refrigerated warehouses, especially the UK, and both have cooling sectors which contribute substantially to total EU cooling emissions. The UK's electricity demand for refrigeration is expected to rise by 9% by 2030 while the bulk of its increase in variable RES generation is also expected before 2030. These factors, alongside the fact that the UK has the only currently operational LAES plants make it an ideal candidate to be an early adopter of the CryoHub technology.

Spain is also likely to benefit considerably from the technology, despite a small decrease in electricity demand for refrigeration by 2030. However, variable RES continues to grow substantially past 2030 and on to 2050 when Spain has the greatest proportion of variable RES of all the case studies and so a longer roll-out than in the UK, continuing on past 2030 may be possible.

Germany has a large number of refrigerated warehouses with electricity demand for refrigeration expected to grow, a substantial and increasing proportion of variable RES generation, and is a major contributor to European cooling emissions. Despite this, the CryoHub technology is unlikely to provide significant value in Germany in the short to medium term as flexible generation is increasing in the German energy system to replace nuclear generation. However, post 2030, as variable RES begins to replace flexible generation the technology is likely to provide substantial value.

Belgium's energy system is currently heavily reliant on nuclear generation which, as in Germany is being phased out. Although variable RES is expected to meet some of the deficit, it is flexible generation which is likely to provide the bulk of electricity generation, even out to 2050. Whilst Belgium has a reasonable number of warehouses and an expected growth in electricity demand for 2030, the need for energy storage, and therefore the key value of the CryoHub technology, is likely to be limited by the flexibility already in the energy system.

Although the Bulgarian energy system currently has relatively low levels of variable RES generation, this is expected to increase steadily out to 2050 with flexible generation decreasing slightly, suggesting there will be a need for energy storage in general. However Bulgaria has few warehouses with only small growth in the electricity demand for refrigeration expected out to 2030, while its cooling sector only produces a small contribution of the EU's emissions from cooling. Therefore, it is unlikely that the CryoHub technology is this report is an energy storage option that will, at least through the 2020's provide the greatest value to Bulgaria as a whole, although there may still be value provided in some instances.

This report also found that if decarbonisation and consequently variable RES generation is progressed more aggressively as in the EUCO30 scenario, then the value of the technology across all case study countries, and likely the EU as a whole, will be greater and occur sooner.

Considering the EU as a whole the case studies suggest that areas of Western and Southern Europe will receive the greatest value over the shortest period of time from the CryoHub technology. This is because they generally have the most refrigerated warehouses, in part due to having the greatest population density, and the highest proportion of variable RES. Despite this general trend, the value which can be obtained from the technology is dependent on a number of factors which are country specific, therefore any country with a high proportion of electricity generated from variable sources and a significant number of large refrigerated warehouses is likely to benefit by employing the technology. An exception to this rule can occur if like in Germany and Belgium, nuclear generation is phased out quickly. Under this situation although both countries are increasing their levels of variable RES generation, the rapid drop in nuclear generation is being replaced principally by flexible generation which increases energy system flexibility and so lowers the need for energy storage.

An additional consideration is the power rating of individual refrigerated warehouses. The average size of a large refrigerated warehouse in the EU is approximately 1MW, while warehouses less than 500kW were not even considered. LAES plants are more economically viable at larger scales [28, 41], so if smaller refrigerated warehouses were consolidated into fewer larger sites this may also increase the demand for the CryoHub technology. For the case studies this may be of most relevance to Belgium whose large refrigerated warehouses had the smallest average power consumption of 1.12MW. The growth in electricity demand for refrigeration considered for each case study was for all refrigeration sites, however further work which examined the potential to consolidate smaller warehouses into fewer larger sites would be beneficial.

8. Conclusion

With a growing adoption of variable RES generation throughout Europe, and significant emissions resulting from food refrigeration there is value for warehouses operators and energy systems to be gained from integrating LAES with refrigerated warehouses (the CryoHub technology). This value gained will not be equal for each country and will depend on a number of factors, which in broad terms can be considered as the need for greater energy system flexibility, and the demand for refrigerated warehouses.

Although the value of the CryoHub technology should be assessed on an individual country basis, deployment of the technology would have most value in countries which have a large number of refrigerated warehouses and the highest levels of variable RES generation. Of the selected case studies, the UK and Spain, which have high and growing levels of variable RES together with a significant number of refrigerated warehouses, would be the best candidates for deployment through the 2020s.

As levels of variable RES rise across the EU the CryoHub technology is likely to provide value in many other countries. Currently all data on future growth of refrigerated warehouses is limited with no data available as far forward as 2050, further research in this area would be of benefit and bring the food sector in line with the energy sector. In summary this report has found that the CryoHub technology may provide benefit across the EU. Some Western and Southern European countries are likely to receive the greatest value initially, spreading to many areas of the EU, with a growing need for energy system flexibility and refrigerated warehousing through the 2020s.

On the basis of this analysis, we will assess the policy and regulatory barriers that could prevent the technology from being deployed (at EU and national level) drawing on this work. We will also consider how the technology, if deployed at scale, could impact other energy/food policy decisions.

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