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# Energy mapping of large refrigerated warehouses co-located with renewable energy sources across Europe

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## ABSTRACT

Powering refrigerated warehouses by renewable energy sources (RES) turns from an extravagancy to a routine. RES intermittency requires suitable energy storage for both off-grid and on-grid applications. Cryogenic energy storage, integrated synergistically with RES and large refrigerated warehouses, is a promising environmentally friendly technology (addressed by the EU CryoHub project). Hence, studies were carried out to identify where large energy-intensive refrigerated warehouses are situated across Europe and how much power they consume. By employing diverse instruments and data sources, some 1049 warehouses were established, while 503 energy intensive ones were mapped and further co-located with 3200 solar PV and 11700 onshore wind parks to discover the best areas for RES integration across EU28. As compared with similar international surveys, the CryoHub statistics covers simultaneously warehouse capacity, geographical location and energy data, which permit a comprehensive analysis and strategic planning in both food refrigeration and energy sectors.

Keywords: Refrigeration, Food, Refrigerated Storage, Warehousing, Renewable Energy, Energy Storage, Mapping, European Union

## 1. INTRODUCTION

Low- or zero-carbon cold chain economy is only achievable by intensive utilisation of renewables and building associated energy storage infrastructure to compensate for their intermittent nature and to balance the electrical grids (Fikiin and Stankov, 2015). The EU CryoHub project investigates and develops the potential of large scale cryogenic energy storage (CES) at refrigerated food warehouses. The innovative CES technology is based on storing renewable energy as a cryogenic liquid (being liquid air in this project), which is then boiled at low temperatures to generate electricity for on-site or grid use. Unlike the stand-alone CES installations, CryoHub co-generates both power and refrigeration supply to the warehouse, with a number resulting benefits (Fikiin *et al.,* 2017).

The need for energy mapping, reported in this contribution, was a logical consequence of the three important prerequisites needed to implement CryoHub-like liquid air energy storage (LAES) Europe-wide: (i) existence of large refrigerated food warehouses; (ii) presence of RES, and (iii) reasonable geographical proximity between the warehouses and RES, possibilities for mutual integration, along with potential benefits from the technology uptake.

## 2. REFRIGERATED FACILITY MAPPING SURVEY

### 2.1. Data collection methodology

Studies were carried out by the CryoHub project consortium to identify where large scale refrigerated warehouses and food factories are situated across Europe (Figure 1). In addition, their estimated power usage has been mapped. The first step to achieve this goal was the development of an on-line energy mapping survey with a detailed questionnaire of 14 queries published in the English language (CryoHub, 2017a). Translated versions of the survey were also prepared and published in 5 EU national languages (German, French, Bulgarian, Spanish and Italian).

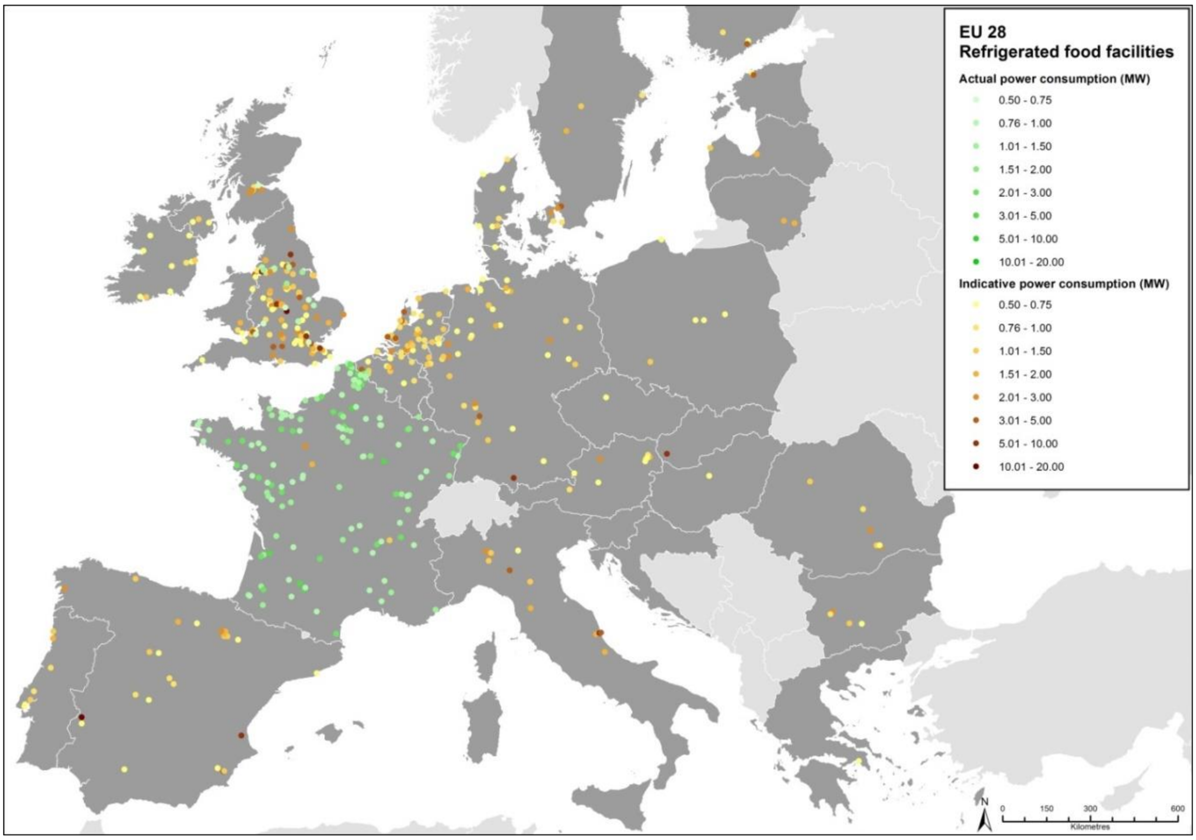



**Figure 1: Mapping large refrigerated food warehouses (over 0,5 MW) across EU28.**

To maximise the response to the CryoHub mapping survey, a special awarding system was designed. All organisations properly completing the survey obtained the status of *'Bronze CryoHub Champions'.* Those wishing and endorsed to host a case-study visit on site were named *'Silver CryoHub Champions'*. Finally, the warehousing company willing and approved to host the Demonstration plant was acknowledged as the *'Gold CryoHub Champion'*. Certificates of merit were designed to reward CryoHub Champions, while their company logos were published on the project website.

The CryoHub survey was then actively promoted via the established channels of governmental and non-governmental professional organisations, editorial boards and sectorial networks. For instance, the following stakeholders' organisations were approached and provided with information about the survey:

- ☑ ECSLA (*European Cold Storage and Logistics Association*) and relevant national associations, GCCA (*Global Cold Chain Alliance*), IAR (*International Academy of Refrigeration*), GCI (Green Cooling Initiative), IIAR (*International Institute of Ammonia Refrigeration*), ASHRAE (*American Society of Heating, Refrigerating and Air-Conditioning Engineers*), AFF (*Association Française du Froid*), EHPA (*European Heat Pump Association*), EPEE (*European Partnership for Energy and the Environment*), AREA (*Air Conditioning and Refrigeration European Association*), Euroheat & Power, Eurocommerce, Eurovent, Eurammon, etc.

- ☑ FoodDrink Europe, EFFoST (*European Federation of Food Science and Technology*), ETPs (*European Technology Platforms*) *'Food for Life',* and *'Renewable Heating and Cooling',* EHEDG (*European Hygienic Engineering & Design Group*).
- ☑ FSDS (*Food Storage and Distribution Federation*), FDF (*Food and Drink Federation*), CFA (*Chilled Food Association*), BFFF (*British Frozen Food Federation*), IOR (*Institute of Refrigeration*) in the UK.

As a result of the above-mentioned endeavours, survey-related articles and the relevant Call for CryoHub Champions were published worldwide by various international organisations and networks, specialised periodicals, professional magazines and mass media (CryoHub, 2017a). Furthermore, the energy mapping survey and Call for Champions were presented at several international fora (Fikiin, 2016a, 2016b), including many IIR's sponsored and co-sponsored conferences around the globe, alongside the IIR newsletters, web-publications, social media and e-mailings to IIR members of different categories – a network of over 6000 professional subscribers.

## 2.2. Correlating capacity and energy data

As the on-line survey received a rather modest public response (because of the conservatism in the sector, reluctance of warehouse operators to share their energy data and the need for a much longer period of data collection), another approach was therefore employed, based on warehouse capacity data. This required determining the warehouse size (in $m^2$, $m^3$ or tonnes) and then using its specific energy consumption to estimate the energy spent. A special Excel spreadsheet for data collection was elaborated for that purpose, while the specific energy consumption was obtained by employing the methodology from a previous work by Evans *et al.* (2014).

When capacity information was not available, the warehouse volume was estimated by using Satellite Imaging and Google Maps to find the refrigerated facility and then using the Google measurement tool to ascertain the floor area. By means of a custom-made methodology, Google Streetview was then used to ascertain height by comparing the height of the store with items of known height, as described in CryoHub (2017a) and illustrated in Figure 2.

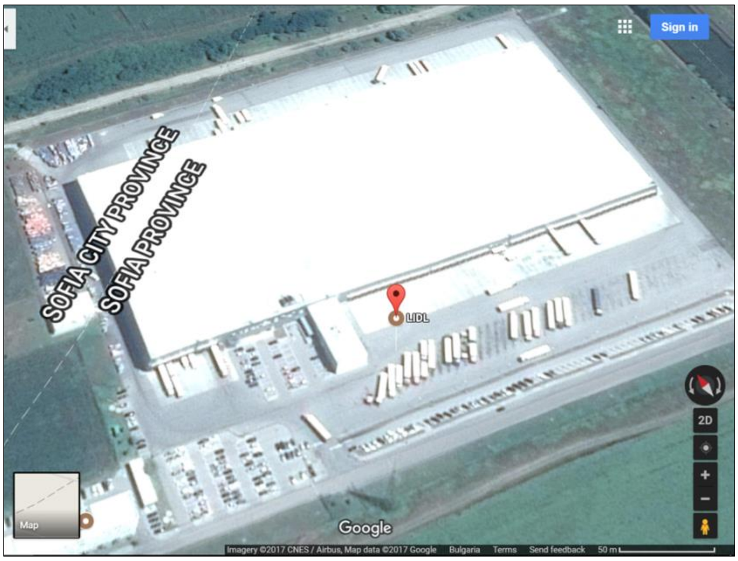



**Figure 2: Satellite imaging of large refrigerated food warehouses to correlate their capcity (in $m^2$, $m^3$ or tonnes) with the energy use.**

Different databases for warehouse locations and capacities (in terms of $m^2$, $m^3$, tonnes or pallet number) were employed, for example:

- Printed editions of the GCCA International Cold Chain Directory, GCCA Directory of Refrigerated Warehouse and Distribution Centres, ECSLA Directory of European Cold Stores, etc.
- On-line Global Cold Chain Directory of GCCA
- Euro-pages on the Internet (Business Directory).

- Data of UK Environment Agency (through the freedom of information act).
- Database of French Ministry of Environment (containing both capacity and energy consumption figures).
- DG SANTE website linked to the sites of national food safety authorities, providing information for refrigerated warehouses and food factories permitted to operate at an EU level.
- National cold chain associations.

## 2.3. Mapping results

While a total of 1049 refrigerated food warehouses throughout the EU were reported (consuming together some 933 MW), some 503 of them had an estimated average power consumption exceeding 500 kW and spend approx. 780 MW in total (CryoHub, 2017a). These highly energy intensive warehouses are widely distributed on the European map, but the highest concentration of such large refrigeration facilities exists in Benelux, Southern England, Northern France and Northern Germany, which coincides very logically with the highest population density in Europe approximately in the same regions (Figure 1). This study covered comprehensively EU28, with a little exception for Croatia, Malta, Luxemburg, where less attention was paid and no facilities were taken into account. While the first of these countries is the newest EU member, no indications were found for existence of large facilities in the second two states.

A number of EU countries' groups have been identified and classified (based on their geographical location; climatic similarities; traditions; economic, administrative and cultural interlinks), as follows: (i) Benelux (Belgium, the Netherlands and Luxemburg); (ii) Central and Eastern Europe (Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia and Slovenia); (iii) Germany and Austria; (iv) Mediterranean countries (Cyprus, France, Greece, Italy, Malta, Spain and Portugal); (v) Nordic and Baltic countries (Denmark, Estonia, Finland, Latvia, Lithuania and Sweden), and (vi) UK and Ireland. Energy consumption maps were elaborated for the large warehouses in each one of these groups of countries, where the situation was analysed in more details (CryoHub, 2017a). Along with the overall map of EU28, individual maps for each explored country were featured as well.

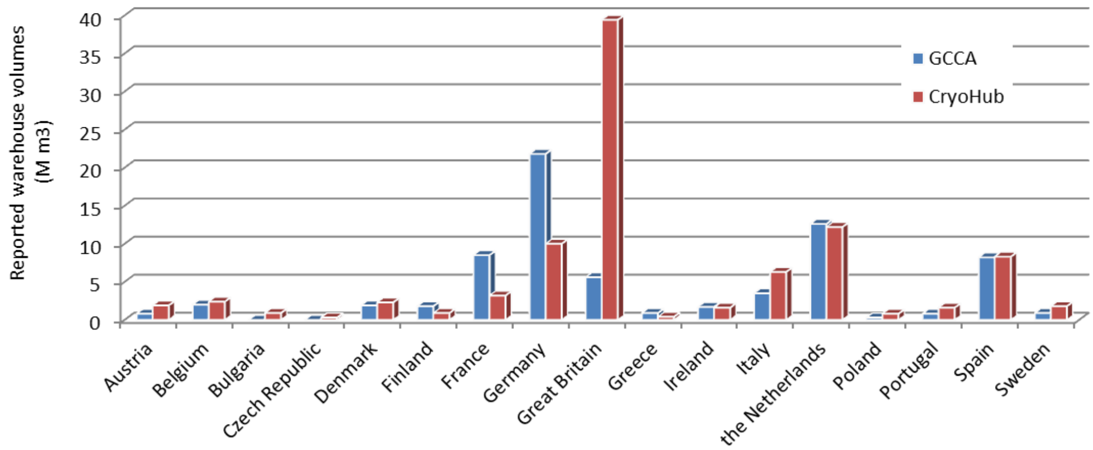



**Figure 3: Refrigerated storage warehouse space (in millions of cubic meters) for 17 representative EU countries – comparison between the CryoHub and GCCA surveys.**

## 2.4. Comparison with other warehouse surveys

To ascertain whether the CryoHub mapping survey adequately represents the amount of cold storage capacities and resulting energy expenditure in Europe, a comparison was made of the CryoHub results with those of the 2010 IARW Global Cold Storage Capacity Report (by Victoria Salin, Texas A&M University), using information collected from international offices of GCCA (Global Cold Chain Alliance). Newer versions named 2016/2018 GCCA Global Cold Storage Capacity Report are also available, along with the associated web-based GCCA Global Cold Chain Directory (CryoHub, 2017a). CryoHub found out more warehouse space than GCCA for 12 out of 17 representative countries (Figure 3), with a total difference of approx. 23 M $m^3$. For two of these countries CryoHub afforded data for the first time.

The CryoHub database can further be improved by paying more attention to key countries, such as France and Germany, which are expected to have more cold storage capacities than were actually identified by the CryoHub data gathering exercise. Another important data survey, which can serve as a reference source to compare with, is ICE-E (2012). The main features and capabilities of the three datasets considered are summarised in brief in Table 1.

**Table 1. Functionality of different international surveys of refrigerated warehouses.**

| Survey | Capacity Data | Location Data | Energy data | Mapping |
|---|---|---|---|---|
| **GCCA** | YES | YES | NO | NO |
| **ICE-E** | YES | PARTLY | YES (mostly actual) | NO |
| **CryoHub** | YES | YES | YES (mostly indicative) | YES |

Obviously, CryoHub represents a substantial advancement, as compared with GCCA and ICE-E, because this is the only international survey of refrigerated food warehouses which brings together capacity, geographical and energy information, including Europe-wide mapping suitable for further analysis and strategy planning in the food refrigeration sector. Let us remind, however, that GCCA affords a global survey, which does not focus specifically on Europe.

## 3. MAPPING OF RENEWABLE ENERGY RESOURCES

This task focused on finding information about existing installations of wind and solar PV in EU28. Additional installations have been also identified in non-EU countries, such as Switzerland, Norway and Turkey. After some search, data from La Tene Maps (latenemaps.com) with proven reliability were acquired, being previously collected in cooperation with the major European renewable energy associations. In particular, datasets containing the following information (available in June 2016) were used:

- **Major Solar PV installations:** location of 3200 built Solar PV installations in Europe over 1 MW.
- **Major Onshore wind farms installations:** location of 11700 onshore installations in Europe. Offshore wind farms installations were not considered relevant for our analysis since they are not located close to refrigerated warehouses and food factories.

By using ArcGis software, characteristic maps of wind and PV installations were produced for EUE28 (Figure 4) and for the same groups of countries, formerly addressed by the warehouse study (see Section 2.3). The results of the mapping revealed a concentration of renewable energy (PV and wind) sites in Germany, Benelux, Ireland and UK, as well as in the Mediterranean areas, in particular, Spain. Solar PV installations tend to be more concentrated in Spain, Germany, South of France, Italy, Bulgaria, Greece, and the UK. Simultaneously, wind installations are more geographically concentrated in Germany, Benelux, Spain, Portugal, UK, Ireland, France and Sweden (CryoHub 2017b).

The total power output of renewable energy installations, considered by the RES mapping exercise, amounts to 154,758 GW, representing about 70% of the solar and wind energy installed capacity in EU28 (CryoHub 2017b). This is a good approximation of the existing installed capacity for wind and solar in EU28, given that only installations with a power output over 1 MW were included. A number of suitable wind and solar PV installations were found across EU, which are located in close proximity of, or directly in the territory of refrigerated warehouses, thereby permitting an easier renewable integration and CES application.

Data on the PV and wind penetration in the EU28 were also gathered (as detailed in CryoHub, 2017b), e.g.:

☑ **The PV and wind share in the electricity mix**, as a proxy of countries where the introduction of cryogenic storage to balance the transmission grid could be more promising, given the high penetration of PV and wind.

☑ **Wind and PV share in the renewable electricity mix** to give an order of magnitude of the importance of wind and PV, respectively, in the electricity mix, as a proxy to check the completeness of the available data on installations.

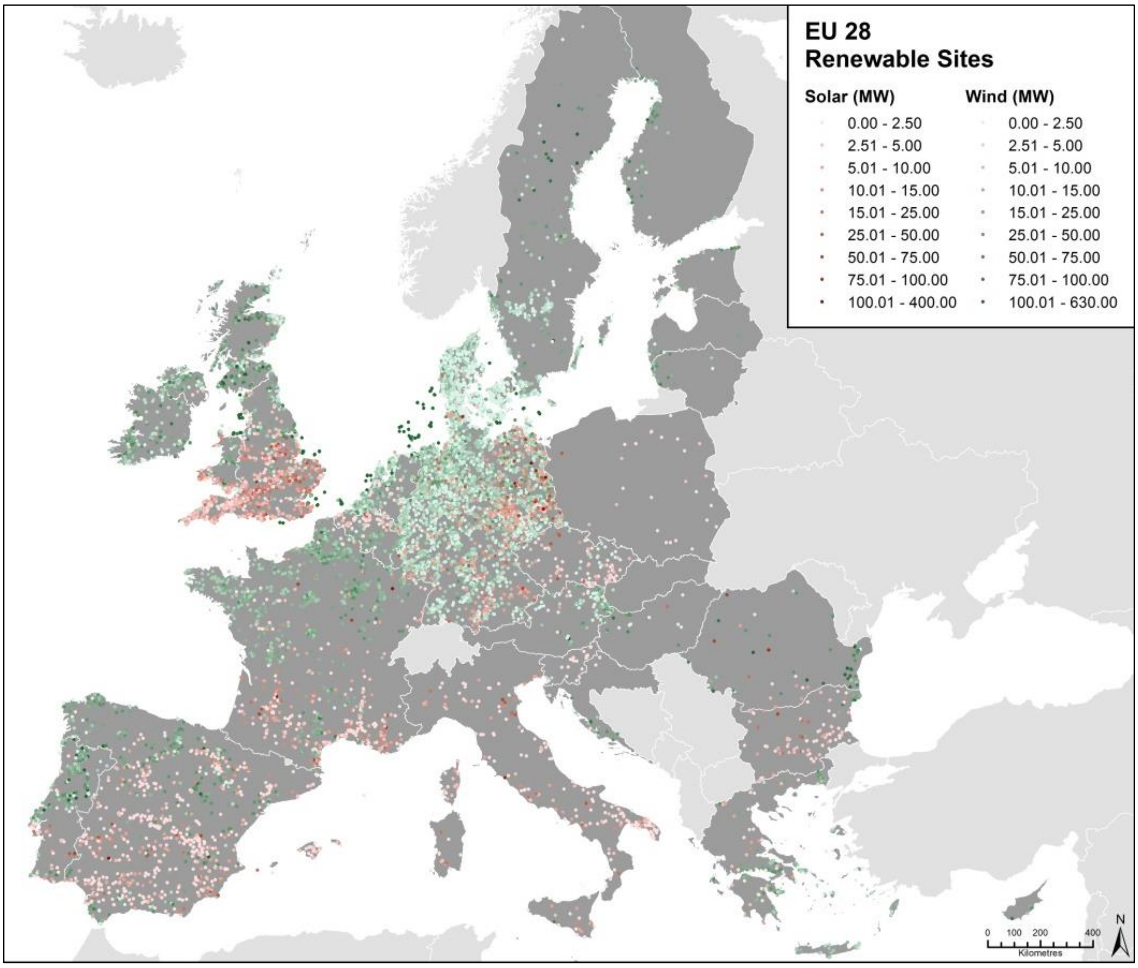



**Figure 4: Mapping RES (both wind and PV) across EU28.**

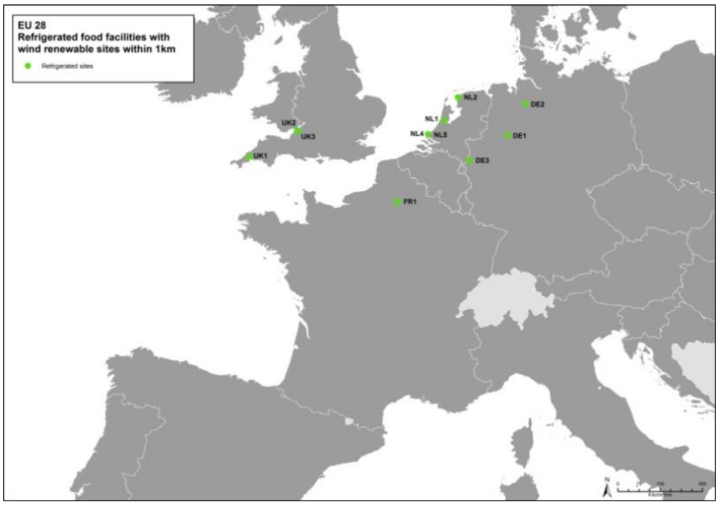
It was found out that renewable energy installations are widely spread across the EU28. Solar PV installations are spread all over Europe, but with an important presence in Spain, Germany, South of France, Italy, Bulgaria, Greece, and the UK. Wind installations are more concentrated in Germany, Benelux, Spain, Portugal, UK, Ireland, France, and Sweden. Countries with an important share (over 50%) of variable renewable energies, where the CES and LAES can potentially find place, are Belgium, Denmark, Germany, Greece, Ireland, Spain and the UK (CryoHub, 2017b). Small countries, such as Malta and Cyprus, even if they have a substantial share of variable renewable energy, does not possess sufficient RES and warehouse capacities to benefit from large scale energy storage. The share of wind and solar energy in the electricity generation is projected to grow from 6% in 2010 to 36% in 2050. This opens up promising opportunities for the introduction of energy storage technologies to ensure that variable renewable energies can be used at any time. A number of other countries thus become interesting as potential hosts of the novel technology, given their quickly increasing share of variable renewable energy (e.g. Estonia, Lithuania, the Netherlands, etc.).

## 4. LOCATIONS SUITABLE FOR CES-BASED TECHNOLOGIES

Mapping of energy used by refrigerated warehouse sites and comparing this to renewable energy availability permits to identify the EU regions and areas which are most promising for renewable energy projects in industrial food refrigeration. However, in some countries the smaller size of food storage installations might limit the suitability of such applications. The results of this work provide an on-going tool for determining the potential of CryoHub as an emerging sustainability-enhancing technology in both energy and food preservation sectors.

Figure 5 depicts the sites of large refrigerated food facilities across EU28, which are located in close proximity (within 1 km) to reliable renewable energy sources, as described in more details in CryoHub (2017b, 2017c), The mapping studies were the first stages in assessing how the technology can be adopted in industry. Some of the mapping survey findings can be outlined as follows:

- ***Lack of very substantial variance of energy use across seasonal differences*** - even though energy use is generally higher in the summer and lower in the winter, there are significant peaks between November and January, possibly due to additional demand of Christmas and New Year shopping;
- ***Clear correlation between warehouse capacity, renewable energy availability and population of site locations***. Such localities of large refrigerated warehouses (consuming on average over 500 kW of power) are closely related to the need to process and preserve perishable food commodities.
- ***Climate*** is influential with higher need for refrigeration capacities in the warmer regions, while the largest refrigerated facilities are still located in Northern Europe.



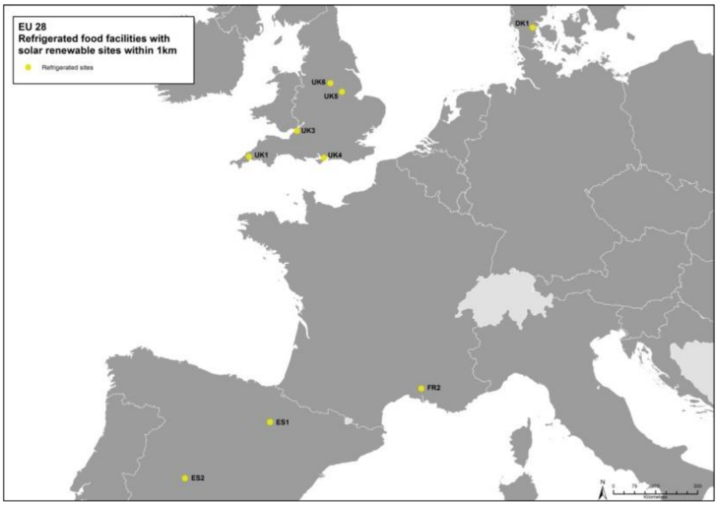



**Figure 5: Mapping refrigerated food warehouses (over 500 kW) located closely (within 1 km) to wind energy parks (*left*) and solar PV installations (*right*).**

As a result of the CryoHub mapping survey, the refrigerated warehouse of Frigologix in the city of Lomel (Belgium) was selected as a *"Gold CryoHub Champion"* to host the CryoHub Demonstrator (currently under construction). A detailed business case was developed to estimate the potential benefits from exploiting the project results.

## 5. CONCLUDING REMARKS

The information gathered by this survey ensures a science-based approach to the RES integration in refrigerated warehousing. The-first-of-its-kind Europe-wide mapping of the energy expenditure by the sector, co-located with the RES availability, permits to identify the EU regions and areas which are most promising for renewable energy projects in the area of industrial food refrigeration.

The concentration of large refrigerated warehouses in Europe clearly depends on the population density and the production capacities for perishable food commodities. Although the importance of climate, the potential for using CES and particularly LAES at refrigerated food facilities depends on the overall technology level and the economic development in a country or region, rather than just on the demand for food storage. Factors, such as population growth, migration and urbanisation processes, dietary habits (e.g. increase use of ready-to-eat and chilled foods), etc., also have a strong impact on economies and sustainability, thereby warranting further investigations.

It appears that, to date the reported CryoHub exercise is the only international survey of refrigerated food warehouses which brings together capacity, geographical and energy information, made readily available for strategic planning in the food refrigeration sector.

## ACKNOWLEDGEMENTS

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## ACRONYMS

| | | | |
|---|---|---|---|
| CES | Cryogenic Energy Storage | IARW | International Association of Refrigerated Warehouses |
| DG SANTE | Directorate-General for Health and Food Safety | LAES | Liquid Air Energy Storage |
| EU | European Union | PV | PhotoVoltaic |
| IIR | International Institute of Refrigeration | RES | Renewable Energy Source |

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