Large scale energy storage

CryoHub

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

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691761.

Deliverable D2.3

Report on potential opportunities for CryoHub in Europe

Deliverable Information

Dissemination : Public

Nature : Report

Contractual Delivery Date : 31 March 2017

Actual Delivery Date : 30 March 2017

Scientific Coordinator: Prof. J. Evans
London South Bank University, UK
e-mail : j.a.evans@lsbu.ac.uk

Document Information

Project	: CryoHub
Document	: D2.3
Filename	: D2.3 Potential opportunities for CryoHub in Europe S1.docx
Last saved on	: 30/03/2017 13:57 by Jacques BERTRAND/Kostadin FIKIIN

Authorship and Review

	Name (Organisation)	Approval Date
Written by	Alan Foster (LSBU)	
and	Kostadin Fikiin (TUS) Paola Mazzucchelli (EUREC) Ian Truckell (CRAN) Liz Varga (CRAN) Miriam Rodway (IOR)	
For review by	Jonathan Radcliffe (UB)	30/03/2017

Release Details

Release	Date	Comments
Draft 01	24/03/2017	First draft
Draft 02	28/03/2017	Second draft after assessment by Reviewer(s)
Release 01	30/03/2017	First release for approval by Coordinator
Submitted	30/03/2017	Submitted to the Commission

Distribution List

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

Table of Contents

1. Executive summary

The CryoHub concept employs Cryogenic Energy Storage (CES) to store energy from Renewable Energy Sources (RES) at times of low grid demand and releases the energy to refrigerated food warehouse at high grid demand. Further to the refrigerated warehouse' and RES mapping surveys, developed in this work package and reported as Deliverables 2.1 and 2.2, this task focuses on the financial benefits from the CryoHub technology examining the electrical load profiles of the refrigeration warehouse, the electrical generation profiles of the RES and tariff prices for import and export of electricity.

To assess the potential benefits and economic implications of the CryoHub technology, two feasibility studies were carried out - one located in Spain and another in Belgium. Both studies used electrical consumption data from the cold stores and RES from solar PV. The feasibility study was only carried out on one day (March 20th 2016).

For this day, there was no marginal economic benefit for the Spanish location, however, there was for the Belgian location. The reason for this was not due to differences in PV generation or cold store load at the different locations, but due to differences between import and export tariffs. The ratio of import and export tariffs (at the time of storage and generation) needs to be higher than the round trip efficiency of the CryoHub system. This was the case for the Belgium study, but not the Spanish study.

More work needs to be carried out investigating periods when there is a larger difference between tariffs as well as assessing the economic benefits taking into account capital costs, and considering operation over a whole year and extending the study to other countries.

2. Context

2.1. CryoHub overview

The CryoHub innovation project investigates and extends the potential of large-scale CES and applies the stored energy for both cooling and energy generation. By employing RES to liquefy and store cryogens, CryoHub balances the power grid, while helping to meet the cooling demand of a refrigerated food warehouse and recovering the waste heat from its equipment and components.

The intermittent supply is a major obstacle to the RES power market. RES may over-produce when demand is low and fail to meet requirements when demand peaks. Europe is about to generate 20% of its energy from RES by 2020, so the proper integration of RES poses continent-wide challenges.

The CES, and particularly the Liquid Air Energy Storage (LAES), is a promising technology enabling on-site storage of RES energy during periods of high generation and its use at peak grid demand. Thus, CES acts as Grid Energy Storage (GES), where cryogen is boiled to drive a turbine and to restore electricity to the grid. To date, CES applications have been rather limited by the poor round trip efficiency (ratio between energies spent for and retrieved from energy storage) due to unrecovered energy losses.

The CryoHub project is therefore designed to maximise the CES efficiency by recovering energy from cooling and heating in a perfect RES-driven cycle of cryogen liquefaction, storage, distribution, efficient use and power regeneration. Refrigerated warehouses for chilled and frozen food commodities are large electricity consumers, possess powerful installed capacities for cooling and heating and waste substantial amounts of heat. Such facilities provide an ideal industrial environment to advance and demonstrate the LAES benefits.

CryoHub could thus resolve most of the above-mentioned problems at one go, thereby paving the way for broader market prospects for CES-based technologies across Europe.

2.2. Overview of Work Package 2

Work Package 2 "*Refrigerated Warehouse and Renewable Energy Mapping*" has three main objectives:

- ❄ To map locations of large refrigerated warehouses and food factories in Europe (over 0.5 MW average power input) and their power usage, looking also at possible waste heat generation and power consumption profiles over time.
- ❄ To map whether these stores have access to RES on site or locally (within 1 km). Potential for stores without access to RES to install RES.
- ❄ To determine the potential for CryoHub application with resulting benefits (to be further explored in WP3).

2.2.1. Purpose of deliverable

The present deliverable D2.3 assesses the practical and economic feasibility of the CryoHub technology and the potential benefit of CryoHub for cold store warehouses through a couple of case studies conducted in European regions with high concentration of refrigerated food facilities and RES (such as Benelux and the Mediterranean basin).

Hence, D2.3 forms an essential input to WP3 *"Current and future benefits of CryoHub",* WP 8 *"Market barriers and strategies"* and WP 10 *"Energy policy and future integration",* as well as to determining the most appropriate company to host the CryoHub Demo site (*Golden CryoHub Champion*), addressed by WP 11 *"CryoHub Demonstration".*

3. Recap of the CryoHub mapping surveys

3.1. Refrigerated food warehousing as a market driver for renewable technologies and cryogenic energy storage

The Renewable Energy Directive sets rules for the EU to achieve its 20% renewables target by 2020. One of the major obstacles to the wider adoption of renewable energy technologies is the ability to supply energy when needed. Supply of renewable energy is often variable and unable to match changes in demands of the grid, so methods of storing excess energy until it is needed are being developed.

CryoHub investigates the role that liquid air could play as an energy storage medium. An important effect of generating power from liquid air is the ability to absorb heat at low temperatures. This is what a cold store does and therefore there appears synergy between cold store warehouse facilities and cryogenic energy storage.

Pure atmospheric air can be liquefied by employing renewable energy and then stored and used to generate electricity (via a turbine or reciprocating engine) at periods of peak grid demand. At the same time, refrigerated facilities can be cooled and waste heat can eventually be recovered to improve the efficiency of the cryogenic expansion process. The CryoHub project explores the potential to maximise efficiencies by regenerating energy from the refrigeration plants of food storage warehouses.

3.1.1. *Matching the energy demand of large refrigerated food facilities and the availability of renewable energy sources across Europe*

Studies have been carried out by the CryoHub 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. This data was further overlaid with information about the availability of nearby renewable energy sources to pick out locations where renewable technologies might be applied. This information is a valuable starting point for the next stage of the research which will involve an analysis of the potential for the wider adoption of the CryoHub concept.

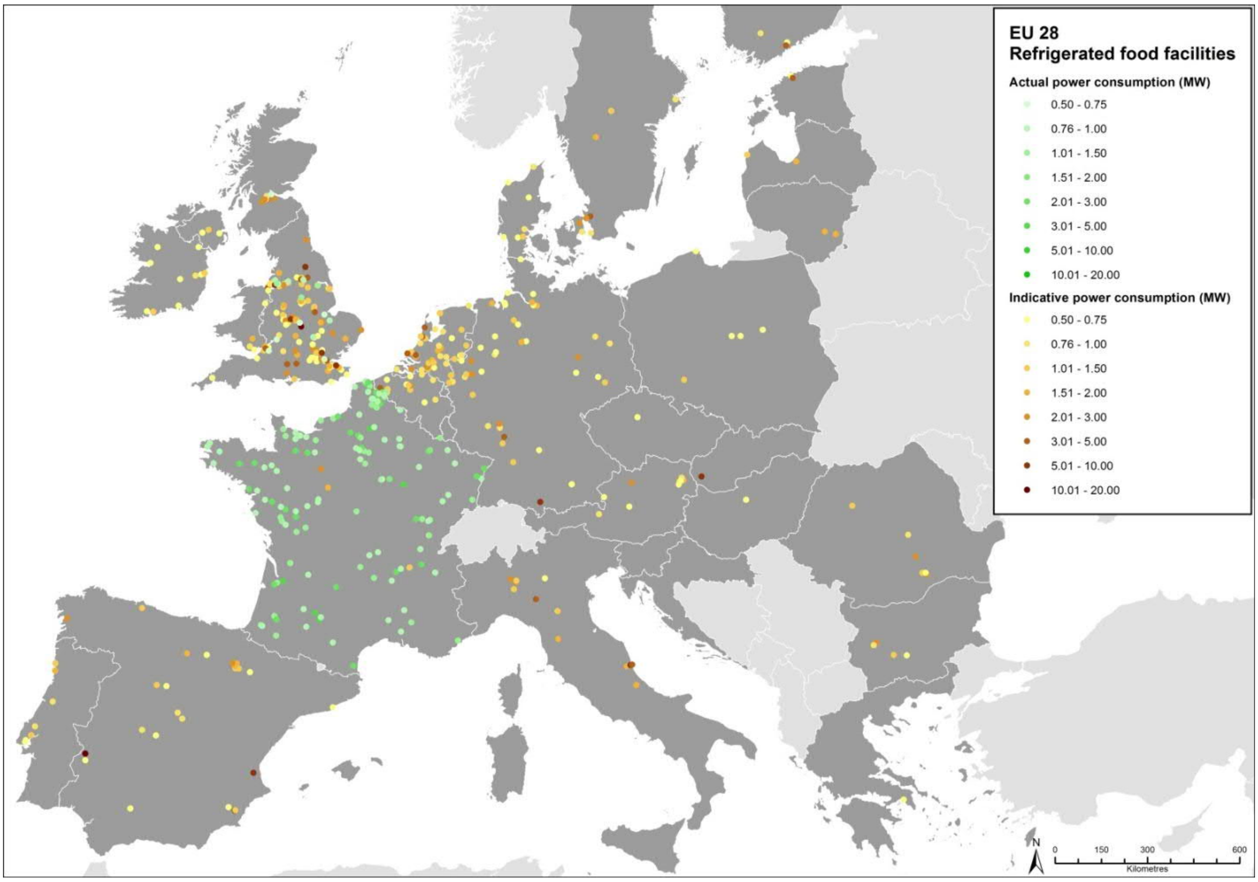

Figure 1. Mapping large refrigerated food warehouses (> 0,5 MW) across EU 28.

While a total of 1049 refrigerated food warehouses were explored throughout the EU, some 503 of them had an estimated average power consumption exceeding 500 kW. 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.

The new EU Members States (i.e. the countries from Central and Eastern Europe and Baltics, which joined the EU in 2004, 2007 and 2013), do not yet possess so many large warehouses. Likewise in Western Europe, the food cold chain sector in the region is rapidly growing and the market is very dynamic. Energy intensive warehouses (spending over 500 kW of electrical power on average) belong, in the most cases, to the logistics and distribution centres of multinational retailers and hypermarket operators.

The CryoHub survey is comparable with previous databases of such nature (e.g. the GCCA Global Cold Storage Capacity Report & Global Cold Chain Directory and the ICE-E energy survey) and even exceeds them with some features and EU coverage. In fact, CryoHub 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. However, unlike the GCCA global survey, CryoHub centres primarily on Europe, where some previously unreported warehouse volumes were recently discovered.

3.1.2. *Where is renewable energy readily available?*

Across the whole of Europe the overall share of renewable energies in the energy mix was estimated at 15% in 2013, increasing to 16% in 2014. The share of electricity generated from renewable energies was 25.4% in 2013 and grew to 27.5% in 2014. EU policy targets are for 20% of energy to be generated from renewable sources by 2020, increasing to 27% in 2030. It is, therefore, expected that the share of renewable energy generation will continue to increase. This suggests a readily available and growing supply of renewable energy in the future.

The European Commission published EU reference scenarios in its 2016 report on *"Energy, transport and GHG emissions – Trends to 2050"*, which provides data on projected renewable energy generation up to 2050 with an analysis of the main factors and policies influencing the mix of renewable energies. An energy mapping of refrigerated warehouses' capacity, energy consumption and availability of renewable energy sources across Europe is currently being analysed by the CryoHub project, but the EU report indicates right now that the share of wind and solar is projected to grow across Europe from 6% in 2010 to 36% in 2050.

The results of the mapping so far have identified 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 (Figure 2). 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.

The total power output of renewables' installations, considered by CryoHub, amounts to 154,758 GW, representing about 70% of the solar and wind energy installed capacity in EU28. 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 are 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 CryoHub application.

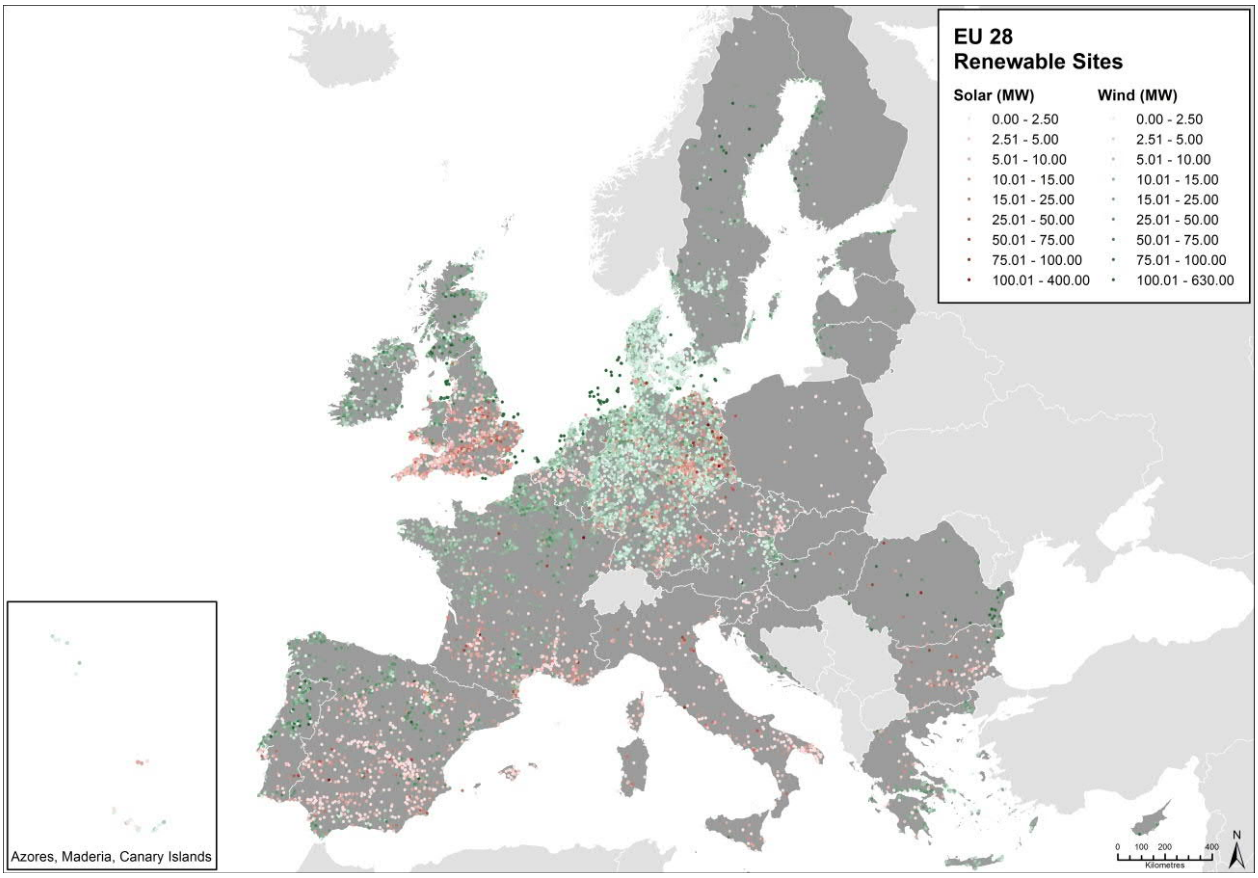

Figure 2. Mapping RES (both wind and PV) across EU28.

3.1.3. *How renewable technologies could be used?*

Some of the mapping surveys' 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.

The potential for the use of CryoHub at refrigerated food facilities depends on the overall technology level and 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), also have a major influence. This could have wider impacts on economies and sustainability.

3.1.4. *The significance of mapping studies*

Mapping of energy use 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.

As described in more details in the previous CryoHub reports (Deliverables D2.1 and D2.2), Figure 3 indicates the sites of large refrigerated food facilities across EU28, which are located in close proximity (within 1 km) to reliable renewable energy sources.

Figure 3. Mapping refrigerated food warehouses (> 500 kW) located closely (within 1 km) to wind energy parks (*left*) and solar PV installations (*right*).

The mapping studies are the first stages in understanding how the technology will work in practice.

3.2. Assessing the practical and economic feasibility of the CryoHub technology

To assess the feasibility, potential benefits and economic implications of the CryoHub technology, two feasibility studies were carried out. The aim of the studies was to assess whether the CryoHub energy storage technology could provide a financial benefit to the cold store warehouse by moving electrical consumption of the warehouse away from peak demand and avoid exporting energy to the grid during low demand.

Electrical energy consumption profiles of two cold store warehouses in different European regions were obtained as well as corresponding RES generation profiles. These profiles consider electrical energy consumption/generation over the course of a year at quarter, half or hourly intervals. Electrical energy consumption and generation tariffs have also been obtained for different periods. On the basis of this information, two case studies have been performed with a view to understanding the factors that would have an impact on the successful adoption of the CryoHub technology in Europe.

3.2.1. *Feasibility case study of a refrigerated warehouse in the Mediterranean region*

A cold store warehouse in Spain whose location is close to a solar PV installation has been selected. Data from the *"NASA Surface meteorology and Solar Energy"* data set was used to generate the solar generation at this location, however, the cold store consumption was real. It was assumed that the solar PV installation was designed such that its average electrical generation was equal to the average electrical generation on the Spring equinox (20^{th} March).

The import tariff was determined by using the medium tension tariff (1 to 36 kV and >450 kW). In this tariff set, there are 6 tariff periods. We did not have information about export tariffs for the cold store warehouse as they did not have any renewable energy; however, it is likely to be based on the market price.

The import tariff was also determined from the wholesale price. The export tariff was considered as the import tariff minus the service costs. The import tariff was calculated as 32% higher than the export tariff. This was based on the average service costs during the period of March 2016.

Electrical generation and consumption and their respective tariff price were compared on the 20^{th} March to investigate the potential financial benefit of using CryoHub to shift electrical consumption away from peak periods.

3.2.2. *Feasibility case study of a refrigerated warehouse in Benelux*

A similar study was carried out for a refrigerated warehouse in Belgium. This store had its own RES generation on site. Instead of using predicted PV generation, the actual PV generation was considered.

The import tariff and export tariff were both provided by the cold store warehouse and therefore were the actual tariffs that the warehouse paid.

4. Results and discussion

4.1. Outcome of the cost assessment

4.1.1. *Mediterranean region*

Electrical consumption of the cold store did not follow any patterns e.g. seasonal or daily and therefore was considered for this analysis as a constant base load with a large degree of random fluctuation. This is an important consideration in the adoption of CryoHub, as the cold store load will need to be matched with the renewable energy.

The solar generation obviously followed both seasonal and daily patterns as it is proportional to the sunlight at any given time.

It was assumed for the sake of this analysis that the solar site matched the average consumption of the warehouse on a particular day. The day chosen was 20^{th} March 2016 (Spring equinox). This would mean that the solar site would be in deficit in the winter and producing more energy than required in the summer.

Figure 4 shows the electrical consumption of the warehouse and the generation from the solar installation. The energy consumption and generation have been normalised to an average of 1. The reduction in energy consumption between 6 and 10 hours is due to the random fluctuation as described earlier and therefore only particular to that day. On average we can assume that the consumption is constant. The solar generation follows the amount of sunlight as expected. From this result we can see a deficit of energy during the early morning and late night where energy will need to be imported and a surplus of energy during the day when energy would be exported. If the export tariff was higher than the import, which you would expect in a wholesale market (as the network needs to cover its costs), then it would be beneficial to store the excess energy during the day and use it in the evening, therefore meaning that no energy would be imported. However, two extra things need to be considered, firstly, the energy storage mechanism is not 100% efficient therefore not all energy stored will be transferred and secondly the price of energy varies during the day.

The same Figure 4 also shows the import and export tariffs during the day. The wholesale import and export tariff follow each other, as they are only separated by a service cost. The contract tariffs for the warehouse approximately follow the wholesale price. The price of electricity is cheapest during the early morning and is most expensive in the evening for both types of tariff. The most sensible use for CryoHub appears to be to store energy between 08:00 and 15:00 when the tariff is low and to use the stored energy between approximately 19:00 and 21:00 when the tariff is highest.

If we consider the contract tariff and assume that the cost of export is the same as the cost of import, then the ratio in tariffs between the two periods is 1.23. For it to be cost effective would require a storage efficiency (round trip efficiency) of 81%. These efficiencies assume that the cold energy generated in the cryogen evaporation process is usefully used in the cold store warehouse and liquefaction plant.

If we consider the wholesale price, the maximum ratio between wholesale import and export is 1.11, requiring a storage efficiency of 90%.

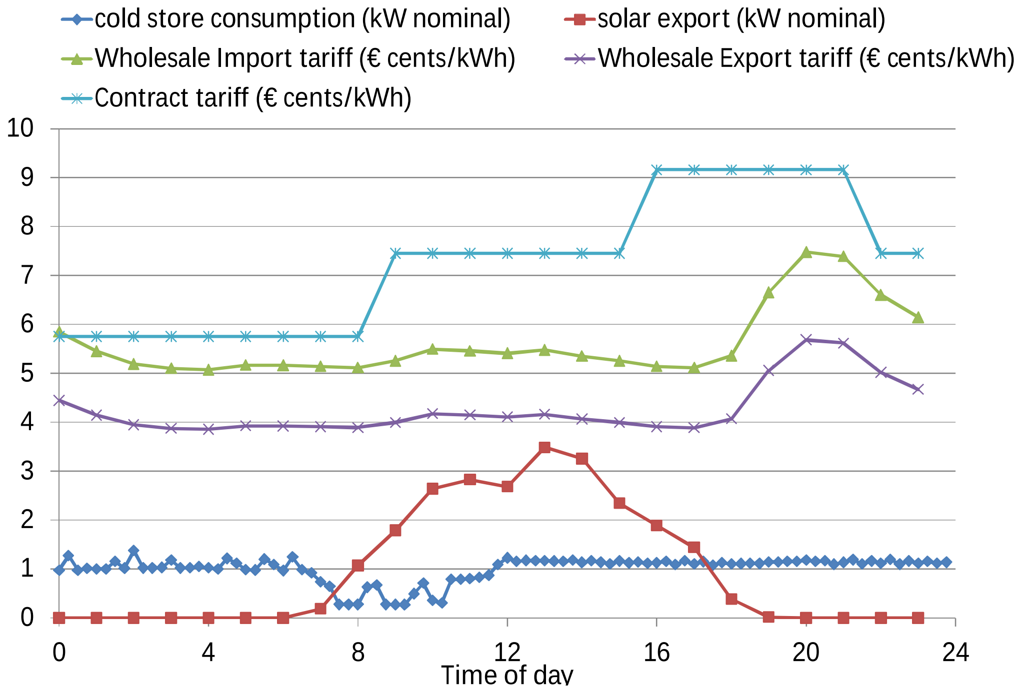

Figure 4. Electricity consumption, PV generation and tariffs at Spanish cold store.

The round trip efficiency of the type of CryoHub system planned for the project has been predicted as 46.5%. A best possible efficiency of 79.5% with 800ºC of waste heat has been predicted.

4.1.1. Benelux

As for the Spanish food cold store, the electrical consumption of the store did not follow any patterns, e.g. seasonal or daily and therefore was considered for this analysis as a constant base load with a degree of random fluctuation.

Figure 5 shows the electrical consumption of the warehouse and the generation from the solar installation. The solar generation follows the amount of sunlight as expected. It appears that the day chosen was under cloud cover for part of the day as the generation rises and falls unexpectedly.

For a period of 15 minutes in the middle of the day when the cloud cover lifted there was a surplus of energy from the PV installation and therefore the facility was exporting to the grid. This can be seen where the net import becomes negative at 12:00. If another day which was not cloudy was chosen, there would likely be a surplus of energy (export) for a longer period.

Normally, the energy in this period would be sold at the export tariff of €3.195 Cents per kWh. However, if the energy was stored using CryoHub technology and released at a later time in peak period it would save importing electricity at the rate of €10.735 Cents per kWh. This assumes the CryoHub system is able to absorb the entire capacity of cold energy.

In this scenario (excluding capital costs) as long as the CryoHub storage was more than 30% efficient, then the storage would potentially be financially viable.

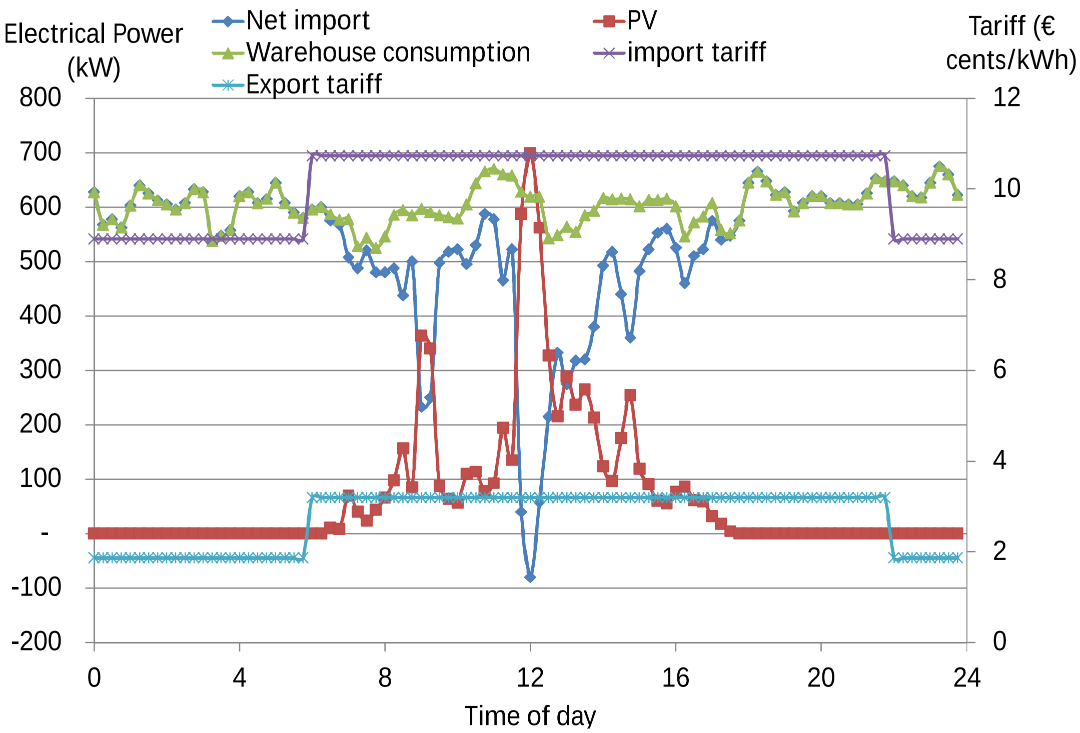

Figure 5. Electricity consumption, PV generation and tariffs at Belgium cold store.

5. Conclusions and future work

For the Spanish warehouse no short-term economic benefit in using the CryoHub system was found, even if we had a supply of high quality waste heat. There may be other economic reasons for energy storage, e.g. to reduce peak load, to reduce load at some periods or to supply when the grid is experiencing a deficit in capacity. This should be investigated further.

It is possible that there are other periods and other locations where there is a benefit and this should also be investigated.

Hence, the following directions for further work can be outlined for the Mediterranean region:

- ☑ To study other economic reasons beyond the difference in import and export price in storing energy. For example, peak shaving and capacity market.
- ☑ To investigate periods when there is a larger difference between tariffs.

For Belgium warehouse there is a potential short-term economic benefit in using the CryoHub system, even if we did not have a supply of high quality waste heat. However further analysis needs to be carried out for identifying different opportunities, e.g.:

- ☑ The quantity of heat stored, frequency of operation and, therefore, money saved in a period (e.g. a whole year) needs to be considered. This needs to be compared with the capital expenditure for the CryoHub storage system to investigate payback period.
- ☑ The warehouse installation currently has a Bio-CHP plant. The benefits of CryoHub to store energy from this plant might also be explored.
- ☑ As the warehouse installation has plans to upgrade the PV system and cold store warehouse, benefits of CryoHub to the upgraded facility should be investigated.
- ☑ Other income generation should be considered, e.g. peak shaving and capacity market.

Although WP2 focuses primarily on energy mapping, the feasibility case studies performed within Task 2.3 and included in this report, go a step forward and provide a starting point for further assessing the CryoHub potential and capabilities. A broader and more in-depth analysis of various operation scenarios should be carried out for refrigerated food warehoused at diverse locations throughout Europe to assess the technology's perspectives in a more comprehensive way. The capital costs of the technology are likely to be high, which the revenue will also need to cover, having a consequential impact on the efficiency needed for the system to be economically viable. Such research is further foreseen as part of several CryoHub work packages (e.g. WP3 *"Current and future benefits of CryoHub",* WP 8 *"Market barriers and strategies"*, WP 10 *"Energy policy and future integration"* and WP 11 *"CryoHub Demonstration*).