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Development of Tools Enabling the Deployment and Management of a Multi-Energy Renewable Energy Community with Hybrid Storage

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Historically, electrical system networks have been designed to allow a small number of centralized electricity generating facilities to distribute electricity to many consumers. With the deployment of the means of production in renewable energies, necessary to reach the objectives of Paris Agreements, the means of energy production multiply and decentralize. This decentralization leads to an additional cost of electricity due to the need to strengthen the distribution and transport networks, as well as the exchange capacities at the borders. In addition, these means of producing renewable energy (whether wind turbines, photovoltaic panels, hydraulic central) have intermittences both daily and seasonal. Within the framework of the “Smart Energy Systems” ERA-Net (European Research Area Network), the recently funded “H2 CoopStorage” project responds to the challenges posed by the deployment of renewable energy production means, by improving local balancing, by reducing renewable intermittences and by intensifying the production of renewable energy. More specifically, the project aims to develop methodological tools and software allowing the deployment and management of a multi-energy (electric, heat, hydrogen) energy community integrating hybrid storage (electrochemical and fuel cell) to be able to respond to the storage of daily and seasonal energy needs. The tools will be developed on the real Mortsel pilot site (Belgium), responding in a global manner to the challenges posed by technological, societal and legal barriers. The project is also innovative in its approach because the actors of the energy community will participate in the development of tools through a co-construction process. This is fundamental to ensuring that the tools developed meet the needs of all stakeholders. This contribution aims at providing both a detailed description of the project activities ahead and the preliminary results already obtained.

1. Introduction

Electricity production is traditionally designed based on generation from large-scale, centralized, power stations providing bulk energy supplies. This is due to several factors (Martin, 2009), such as economies of scale, the search for high energy efficiency and reliability, effective electricity transmission, environmental constraints and regulation promoting larger generation facilities. In fact, in this configuration, electricity is generated, transported over long distances through the transmission network and medium distances through the distribution network to be finally used by a relatively high number of consumers.
However, due to the global concern on greenhouse gas emissions, of which the Paris agreement is an expression, the use of renewable energy in the electricity sector is increasing at a fast pace. Renewable electricity generation reverses the trend and promotes decentralization, which comes at an additional cost. In fact, the distribution and transport networks must be strengthened, for instance the capability of a bidirectional flow of electricity is required (Arantegui and Jäger-Waldau, 2018). In addition, fluctuating characteristics of renewables bring new technical and economic challenges to the energy system. System flexibility may be provided by increased supply side flexibility, new storage solutions or increased demand side management.

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The main challenges for large-scale implementation are, however, high costs and/or low technical maturity for many of these options (Chen et al. 2020).
For this reason, the project “H2 CoopStorage”, recently funded within the “Smart Energy Systems” ERA-Net (European Research Area Network), aims to develop methodological tools and software allowing the deployment and management of a multi-energy (electric, heat, hydrogen) energy community integrating hybrid storage (electrochemical and fuel cell) to be able to respond to the storage of daily and seasonal energy needs.

2. Smart Energy Systems framework

A European Research Area Network (ERA-NET) is a European funding instrument designed to support public-public partnerships in their: preparation, establishment of networking structures, design and implementation, and coordination of joint activities. ERA-NET is aimed at funding joint-calls for transnational research and innovation in selected areas. This aims to increase substantially the share of funding that Member States dedicate jointly to challenge driven research and innovation agendas (European Commission 2021).
One of the research areas addressed by the ERA-NETs is Smart Energy Systems (SES). SES is targeted towards a sustainable and service-oriented joint programming platform to finance transnational research, development and demonstration projects. Its focus is on technologies and solutions in thematic areas like smart power grids, regional and local energy systems, heating and cooling networks, digital energy and smart services, etc (Smart Energy Systems ERA-NET 2021). Table 1 summarizes the overarching innovation goals of the ERA-NET on SES.

Table 1: Overarching innovation goals of the European Research Area Network on Smart Energy Systems.

Overarching innovation goal	Description
Integration	Integrated local and regional energy systems shall be developed to improve accessibility of various infrastructures, integration of new technologies and players in end-use, system operation, generation and conversion, storage, mobility, smart services, etc.
Flexibility	Flexibility of the energy system shall be increased to fulfil the requirements for system operation as well as from different user-groups (end-users, retail, generation, local storage) with a particular focus on the optimised integration of energy from local renewable sources.
Optimization	Optimisation of Energy Systems shall be sought to minimize the consumption of non-renewable resources, high efficiency, optimal use of new and existing energy and ICT infrastructure.
Resilience	Resilience of the energy system shall be maintained and improved, considering safety, security and privacy aspects as integral to design parameters.
Smart Energy Services	Smart energy services shall be developed for the dynamic management of the energy systems and to empower end-users by increasing connectivity and data accessibility.
Communities and Regions	Communities and regions shall be enabled to be active players in taking responsibility for their sustainable energy supply, including solutions that allow for high shares of renewables up to and beyond 100% in the regional supply, and allow for participation in inter-regional exchange of energy as well as in sharing of responsibility to maintain the overall System.

3. H2 CoopStorage (H2CS) project

The H2 CoopStorage (H2CS) project was recently funded within the framework of the SES ERA-Net. Its consortium includes universities, institutes and companies from Belgium, Iceland and Norway.
H2CS is part of the context of the transformation of our electrical system by seeking to implement a hybrid solution of hydrogen, heat and electric storage within a citizen Energy Community (EC), in a context of collective self-consumption. These storage solutions foster the integration of renewable energies on the network and thus improve their deployment. The H2CS project responds to the challenges posed by the deployment of renewable energy production means, by improving local balancing and by reducing renewable intermittences. Concerning local balancing, a hybrid storage solution can be used to increase the resilience of electricity transmission and distribution networks in a context of increasing the injection of decentralized renewable production, by balancing within “energy cells” (geographic perimeter) and by strengthening the decentralization of storage structures (contribution to the network and to reliability services), this means

increasing collective self-consumption at the district level. Moreover, a hybrid solution storage can be used by the transmission system operator's or other network balancer as tertiary reserve. Concerning the intermittency of renewable energies, the electrochemical part would reduce the intermittency of production / consumption, while the hydrogen part would have a wider temporal scope allowing reduce intermittency to the seasonal level. Finally, the project will help to intensify the production of renewable energy. Operators must sometimes stop renewable production when the selling prices are negative. Instead of stopping the production because of the negative prices, it would be possible to continue to produce energy and to store it.
To deploy this type of hybrid storage solution, the consortium identified three main barriers:

- Technological: the lack of technical tools allowing the integration of a hybrid storage solution in a network of collective self-consumption. There is a need to create dimensioning tools to measure the technological, economic, environmental and societal consequences of a hybrid storage device. Moreover, there is need to create a tool for managing several energy flows (electric and hydrogen) dynamically, allowing to arbitrate the use of energy in a cooperative mode within the community (which is call the energy management system).
- Societal: the lack of integration of stakeholders (end-users such as citizen, tertiary sector; transmission system operator; distribution system operator; electricity and gas supplier; EC manager) in the dual process of self-production and self-consumption, in order to take into account local needs. In this context, it is necessary to ensure that the technical solutions are the most suited to meet the needs of each stakeholder, considering the end-user as actors and building tools community-adapted. The lack of innovative co-created business models for collective self-consumption projects. These co-created business models are allowing all stakeholders to participate in the energy transition, and not to leave some on the side-lines for lack of resources.
- Legal: the absence of regulatory standards (both at national and European level) framing the development of the hydrogen vector. There is a need to take ownership of the technology and begin to define the regulatory framework.

The consortium is aware that the challenges posed by these barriers must be tackled holistically, considering technical, but also economic, environmental, regulatory and social criteria. H2CS plans to develop its tools on a real pilot site, within a EC. Thus, the project aims to prove the feasibility of integrating a hybrid storage solution within a district, and therefore to reassure public and private investors for a wider deployment. Ultimately, this project will facilitate the deployment of renewable energies and will contribute to the following actions of the ETIP SNET R&I roadmap 2017-264 (Technofi et al., 2016):

- Develop performant renewable technologies integrated in the energy system;
- Create new technologies and services for consumer;
- Increase the resilience and security of the energy system.

3.1 Project objectives

H2CS aims to develop methodological and software tools enabling the deployment and management of a multi-energy EC integrating a hybrid storage (electric and hydrogen), in a collective self-consumption context.

1. Creation of methodological tools. The methodological tools aim to anticipate the environmental, economic, security and societal consequences. The results will participate in the use of the dimensioning tool and will reassure public and private funding during the replication of the project.
2. Creation of software tools. The software tools aim to set up and manage a multi-energy EC. In particular:
    a. The Sizing tool defines holistically the needs in terms of production, storage and flexibility. It makes it possible to define the economic aspects, and to adapt the business models according to the previous results.
    b. The Energy Management System (EMS) allows managing the means of production (multiple sources: solar, wind, geothermal, hydraulic), storage (hydrogen, electric, heat), flexible loads of the EC dynamically. This too will be based on Internet of Things (IoT) data and model predictive control approach (MPC).

3.2 Tools for the multi-energy community

Several software packages for dimensioning and operating energy networks at the district level with energy storage are available. For instance, the Hybrid Optimization Model for Electrical Renewable (HOMER) software is a well-known micropower optimization model (Okedu and Uhunmwangho, 2014). However, the purpose of these software packages is barely to load the storage means as much as possible when the production exceeds consumption, and then unload them in case of production needs. These simplified models are not optimal for a complex multi-energy system composed by a hybrid storage. More recently, different tools for modelling and exploiting multi-energy communities with hybrid storage were developed (Mashayekh et al., 2017) (Acha et al., 2018) (Ceseña and Mancarella, 2019). Generally, these tools do not consider the demand management and the community aspect fades in front of the technical and economic features. Few projects such as the MeryGrid project (Cornelusse et al., 2017) as well as the E-Cloud project (Vangulick, 2017) try to understand the multi-user communities aspect. Nevertheless, these models are designed for small communities (less than ten users). In general, very few software packages focus on the development and management of EC, probably because the European directive is recent and there are not many existing ECs. Recently, van Summeren et al. (2020) published an article in which the criteria necessary for the tools to operate the EC are investigated. The article underlines that it is not enough to involve the community in the project, it is also necessary that the ICT-based control system works according a community logic. The architecture of software tools must be community driven.

3.3 Pilot sites

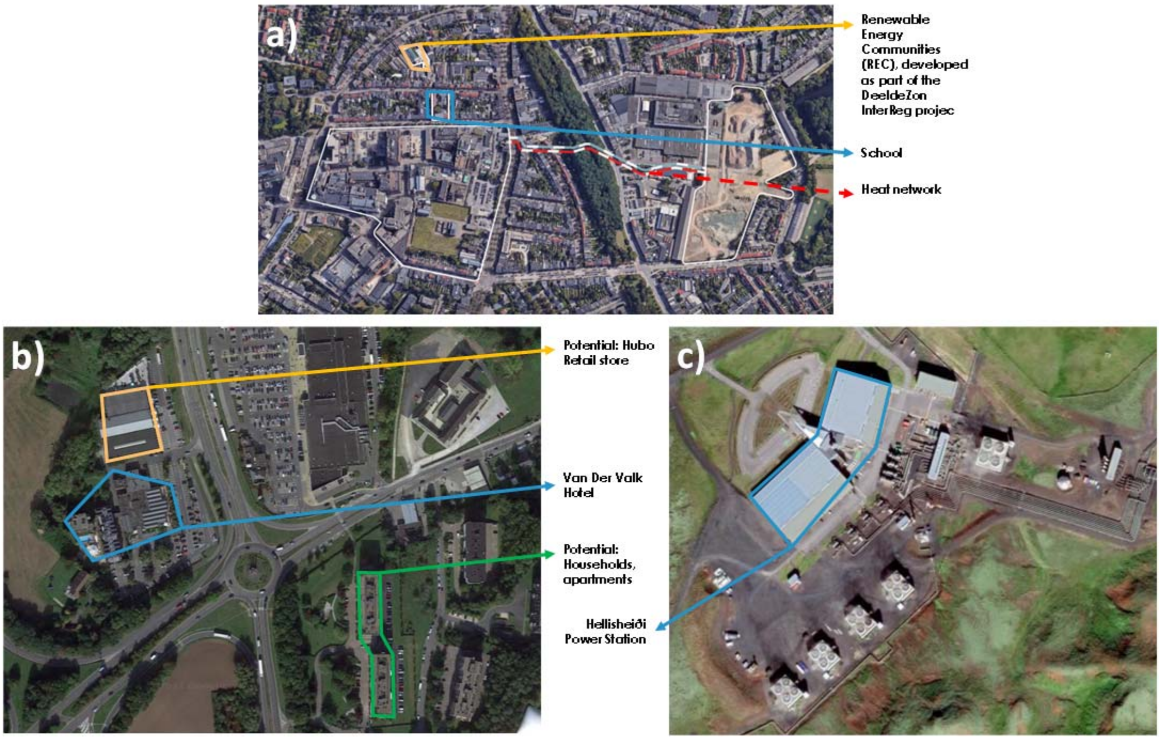

Figure 1: a) Mortsel pilot site; b) Nivelles pilot site; c) Hellisheiði Power Station pilot site. Adapted from (Google Earth 2021)

The methodological tools will be developed and applied on three living labs. The first lab is located in Mortsel near Antwerp (Belgium) (Figure 1a). It already presents a basic Renewable Energy Communities (REC), developed as part of the DeeldeZon InterReg project (Interreg Vlaanderen-Nederland, 2018). The perimeter includes photovoltaic panels (13 kW), several consumption profiles (households, electric cars, cultural center) and an electrochemical battery (13 kW).

The second lab is sited in Nivelles (Belgium) (Figure 1b). The perimeter includes renewable photovoltaic (25 kW) and wind energy facilities (4 wind turbines of 2 MW), several consumer profiles (household, hotel, tertiary building, electric cars, a city gas low pressure pipeline, opportunity for hydrogen cars and for valorizing heat).

The last lab is the Hellisheiði Power Station, located about 30km East of Reykjavik (Iceland) (Figure 1c). The Hellisheiði Power Station uses geothermal heat from the Hengill Volcane to produce low carbon renewable electricity (300 MW) and thermal energy (133 MW). At this location electricity and thermal energy could be used for hydrogen production.

4. Preliminary results

Methodological tools for risk assessment, inspection and maintenance are among the first to be defined as they represent an enabler for hydrogen technologies.

A review of the available standards and recommended practices for inspection planning has been conducted to identify how metal-hydrogen interactions in hydrogen storage are currently considered in terms of degradation mechanisms. Focus is given to risk-based approaches, which include the assessment of potential accident scenarios as consequence of loss of integrity (LOI). In particular, the association of metal-hydrogen mechanisms with damage factors influencing the predicted LOI frequency is studied to both understand their impact on risk and the inspection typology.
The main available standards and recommended practices for risk-based inspection planning are listed in Table 2. The standards suggest inspection once the predicted risk of a piece of equipment reaches a predetermined risk value. The calculated risk can be decreased or confirmed by the inspection results. The evaluation of risk generally follows the procedure described in Figure 4 and can reflect the current system conditions by means of advanced dynamic models providing continuous updates of the risk picture (Bucelli et al. 2018).

Table 2: Risk-based inspection standards and recommended practices

Standard	Title	Year
API 580	Risk Based Inspection	2016
API 581	Risk Based Inspection methodology	2016
DNVGL-RP-G101	Risk based inspection of offshore topsides static mechanical equipment	2017
EN16991	Risk-based inspection framework	2018

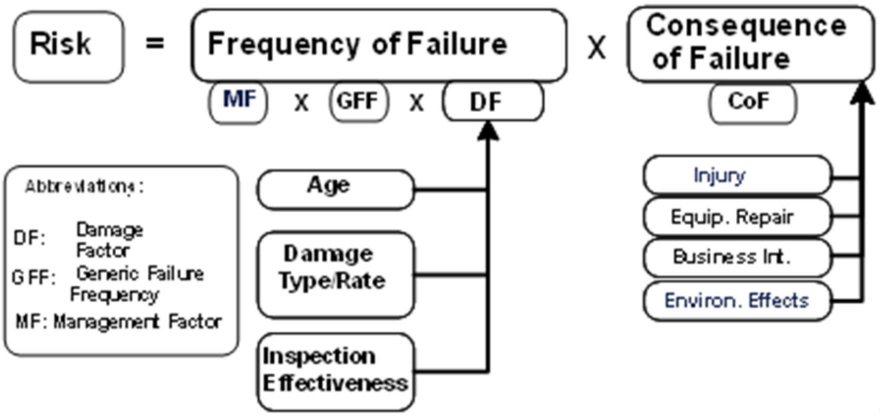

Figure 4: Risk evaluation approach

5. Conclusions

H2CS project is still at a preliminary start-up phase. For this reason, the only results produced are represented by a review of standard and recommended practices for risk assessment, inspection and maintenance of hydrogen storage equipment. However, such results is the demonstration of the solid basis of the wok, as priority is given to the conduction for safe and reliable activities, in respect with the agreements established with consulted communities. Such approach is also innovative in itself as the actors of the energy community are actively participating in the development of tools (such as innovative risk-based inspection planning techniques) through a co-construction process. This is paramount to providing results that meet the needs of all stakeholders.

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