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ESTABLISHMENT OF A BASELINE INTEGRATED ENERGY SYSTEM TO DECARBONISE GEOGRAPHICAL ISLANDS

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ABSTRACT

Achieving strict decarbonisation targets, while providing a safe, reliable, and affordable supply of energy on geographical islands is more complex than in mainland locations. Contrary to the mainland, where grid support and energy exchange with other regions are possible because of integration into large energy grids, the situation for geographical islands is different. Islands often have either no or limited connection to neighbouring ones or to the mainland resulting in a relatively costly energy supply and less opportunities for services such as balancing or backup to overcome the challenges that fluctuating renewables can cause. This can be tackled by development of highly flexible energy systems integrating various available renewable energy sources, multiple prime movers, and necessary energy storage and transportation infrastructure.

A currently ongoing ROBINSON project aims at contributing to decarbonise geographical islands by developing and installing a demonstrator of an integrated energy system on the island of Eigerøy at the south-west coast of Norway. As part of the ROBINSON project, this paper presents a brief overview of the project and its objectives, the baseline configuration of the integrated energy system and its energy fluxes that will be demonstrated on the island of Eigerøy in Norway. Even though the project is still in an early stage of implementation, this paper describes possible challenges and resulting requirements of different sub-systems including a gas turbine based combined heat and power unit within a highly integrated energy system.

Keywords: Decarbonisation, energy system integration, geographical islands

NOMENCLATURE

AD	anaerobic digestion
AD+BES	anaerobic digestion supported by a bio-electrochemical system
AEL	alkaline electrolyser
BES	bio-electrochemical system
BOD	biochemical oxygen demand
BOL	beginning of life
CHP	combined heat and power
COD	chemical oxygen demand
EMS	energy management system
EOL	end of life
EU	European Union
GHG	greenhouse gas
HHV	higher heating value
IRENA	International Renewable Energy Agency
LHV	lower heating value
LNG	liquified natural gas
MGT	micro gas turbine
NCV	net calorific value
Nm^3	normal cubic meter
PV	photovoltaic
RES	renewable energy source
SIDS	Small Island Developing States
TOC	total organic carbon
TPES	total primary energy supply
TRL	technology readiness level
TSS	total suspended solids
WP	work package

1. INTRODUCTION

To stabilise the greenhouse gas (GHG) concentrations in the atmosphere, hence reducing adverse impacts of climate change, many measures on different sectors have been implemented during the last couple of decades. Energy systems that are still predominantly based on fossil fuels are amongst those sectors. In EU27 countries, for example, energy supply has contributed with about 27% to the total GHG emissions [1]. In the same year, about 60% of the final energy consumption of the EU was based on fossil fuels, namely oil and petroleum products with 37%, natural gas with 21%, and solid fossil fuels with 2% [2].

To actively support and accelerate the transformation of the global energy system towards a low-carbon one, as also stipulated in several climate agreements, different areas have been targeted including geographical islands. This has been carried out via implementing several measures and launching different programs and initiatives. Small Island Developing States (SIDS) Lighthouses Initiative from the International Renewable Energy Agency (IRENA) [3], or Clean Energy for EU Islands Initiative [4, 5] are amongst relevant initiatives for geographical islands. In general, such locations are more vulnerable to climate change [6]. They are also notably facing various energy challenges due to geographic insularity that makes them special in the context of decarbonisation of the energy system. Two main energy challenges are:

- security of energy supply, in many cases reliance on imported fossil fuels, despite of having access to renewable energy sources (RES) [5], and
- high energy costs due to several reasons e.g., additional transport of fuel supply, limited or lack of connection to the main energy markets [7], as well as unable to profit from economies of scale because of small energy consumption profiles (in case of small islands) [8].

At the same time, islands pose a great potential to be involved as living labs for hosting pilot projects and for demonstration of sustainable development pathways [9, 10].

The mentioned challenges and the potential for energy system transition on islands have also attracted the research and development community in the recent years. In this regard, different researchers have investigated the energy systems of islands (mainly power systems) from different perspectives and using different methodologies. A few examples of available studies focusing on geographical islands are listed in Table 1. The available publications have mainly focused on scenarios assessment and theoretical studies considering increase in the share of RES for power generation in the energy systems. Within the list, there are only a few research studies that also considered the thermal energy as part of the studied energy systems. Knowing the list provided in Table 1 is not an exhaustive one, further development of integrated energy systems obviously requires more demonstration projects also considering sector coupling, multiple energy vectors, different energy storage options and transportation infrastructure.

To support islands' decarbonisation, a currently ongoing ROBINSON project has received funding from the European Union's Horizon 2020 programme with the aim to develop and install a demonstrator of an integrated energy system on the island of Eigerøy at the south-west coast of Norway [11]. As part of this EU project, this paper presents a brief overview of the project and its objectives, as well as the baseline configuration of the integrated energy system, and its energy fluxes that will be demonstrated on the island of Eigerøy in Norway.

It needs to be noted that optimization studies are outside the scope of the current paper and numbers presented (such as power ratings) are based on the determined sizes of different components of the system under the design conditions and specific capacity factors (number of operational hours). Detailed system optimization is currently ongoing.

2. THE EU ROBINSON PROJECT

Given the limitations listed for decarbonising geographical islands, the overall objective of the ROBINSON project is to develop and demonstrate an innovative, flexible, and cost-effective energy system to contribute decarbonise islands. This will be done by utilisation of locally available RES, and reducing the dependency on fossil fuels, without adversely affecting the energy supply security and costs through the following items:

- Better integration and optimised utilisation of local RES, power and heat networks, and storage infrastructure.
- Biomass/biowaste and wastewater valorisation, and industrial symbiosis.
- Optimisation and validation of innovative technologies.
- Development of an innovative, adaptable, and modular energy management system (EMS) integrating different energy vectors, both existing and newly developed energy and storage technologies (for electricity, heat, and gas).

The energy system will be demonstrated on the island of Eigerøy at the south-west coast of Norway, while some simulation-based replication studies will be conducted for the island of Crete (Greece) and the Western Isles (Scotland). The consortium brings together 18 key stakeholders from 10 different European countries starting from 2020. The project is divided into the following six technical work packages (WP) [11]:

WP1: "Islands requirements, barriers, and system specifications" to define the boundary conditions at the demonstration island and at the follower islands.

WP2: "Technologies adaptation and development" to adapt, manufacture and test different technologies.

WP3: "EMS for European islands" to develop, validate, and optimise the energy management system for the project's islands.

WP4: "ROBINSON system demonstration" to prepare the necessary documentation for the pilot installation on Eigerøy.

WP5: "Sustainability assessment" to evaluate the sustainability of options for decarbonising the energy systems of geographical islands (addressing economic, environmental, and social concerns).

WP6: "Replication and business planning for local communities" to facilitate replicability of ROBINSON concept, identify its marketability and assist business models' transfer to other locations.

3. EIGERØY

Eigerøy is an island in the municipality of Eigersund in the southwest coast of Norway. The climate of the island is influenced by the coast, i.e., relatively high temperatures in winters and low temperatures during summers, as well as relatively high wind speeds.

This small island (~ 20 km^2) has about 2,500 inhabitants in about 800 households. Apart from the houses, the island has several traditional cabins (used for recreation) during weekends and vacation time.

TABLE 1: EXAMPLES OF RELEVANT RESEARCH ACTIVITIES IN THE CONTEXT OF DECARBONISATION OF GEOGRAPHICAL ISLANDS' ENERGY SYSTEMS

Reference	Focus areas	Methodology	Geographical scope
Duić et al. [8]	Scenario analysis for emission reduction via use of clean development mechanism of Kyoto Protocol	Estimated increase in RES share in power production	The island of Santiago (Cape Verde)
Duić et al. [12]	Scenario analysis for energy and resource planning	Establishment of a new energy planning method (RenewIslands)	Few Islands in the Adriatic Sea (Croatia)
Yue et al. [13]	Potential assessment for 100% local RES – electricity	Simulation of optimal RES integration using EnergyPLAN	Wang-An island (Taiwan)
Thomas et al. [14]	Potential assessment for isolated microgrids using different share of local RES – electricity	Techno-economic analysis using HOMER	Agios Efstratios island (Greece)
Gils and Simon [15]	Scenario analysis for 100% local RES – electricity, electric vehicles, electric heating, and hydrogen use	Model coupling between a long-term energy system balancing tool (Mesap-PlaNet) and a deterministic high resolution energy system optimisation model (REMix)	The Canary Islands, Spain
Hall and Swingler [16]	Scenario analysis for 100% local RES – electricity	Time-series simulations and modelling of power generation, consumption, and storage with and without curtailment for variable RES	Prince Edward Island (Canada)
Maïzi et al. [17]	Scenario analysis for 100% local RES – electricity	TIMES model and introduction of power system's reliability and robustness indicators	Reunion Island (France)
Selosse et al. [18]	Scenario analysis for 100% local RES – electricity	TIMES model	Reunion Island (France)
Pfeifer et al. [19]	Scenario analysis for 100% local RES – electricity, transport such as vehicle-to-grid (also including marine transportation), also thermal energy	Energy planning method using EnergyPLAN and embedded MultiNode tool	Few islands in the Adriatic Sea (Croatia)
Dorotić et al. [20]	Scenario analysis for 100% local RES – electricity, transport such as vehicle-to-grid (also including marine transportation), also thermal energy	Energy planning method using EnergyPLAN	Korčula (Croatia)
Ma and Javed [21]	Dimensioning of integrated hybrid PV-wind-battery energy system (electricity only)	Techno-economic and reliability modelling	Jiuduansha (China)
Marczinkowski and Østergaard [22]	Scenario analysis for increased local RES – energy system (also thermal energy)	Different energy planning approaches using EnergyPLAN	Samsø island (Denmark) and Orkney Island (Scotland)
Pfeifer et al. [7]	Scenario analysis for zero emission marine transportation (ferry lines)	Energy planning method using EnergyPLAN	Few islands in the Adriatic Sea (Croatia)
Calise et al. [23]	Scenario analysis for energy and resource planning – energy system	Energy planning model using EnergyPLAN	Sardinia (Italy)

The island has fish processing industry and some other industries. The fish industry in the harbour handles a considerable part of the turnover of all industrial fish processing in Norway. In the coming years, new industries are to be established on the island, specifically around the harbour area of Kaupanes.

Electric energy on the island is currently generated to a very low extend on the local level. There are only six residential buildings equipped with solar photovoltaic (PV) panels. This low number of installed panels is mainly because of relatively low electricity costs in Norway and feed-in tariffs, which match the electricity market prices [24]. While most of the generated power locally is used within the corresponding buildings, only a very small share is fed into the grid. Some cabins, which are used during vacation or at weekends are also equipped with solar panels, but they are not connected to the local power grid. Close to 100% of the electricity of the island is provided through sea cables (with a peak capacity of 20 MW) from the mainland. The power produced in the mainland was mainly from hydropower (92% or 141.6 TWh), but also from onshore wind (6% or 9.9 TWh) and thermal power (2% or 2.7 TWh) in 2020 [25, 26].

FIGURE 1: AN OVERVIEW OF THE TRANSMISSION LINES AND ELECTRICITY NETWORK IN EIGERØY

Figure 1 indicates the connections to the mainland. The transmission lines are operated at 50 kV. One transformer station represents the connection to the distribution grid, which is operated at 15 kV. The current average electric energy demand amounts to about 8 MWh/h with peaks of up to 18.5 MWh/h. In 2020, about 88% of the electricity was consumed by the local industry, mainly by appliances on the 400V level [27].

The new industries, as well as additional local electrification (e.g., for transport on land and sea) will significantly increase the island's power demand (estimated to be increased by up to two times). The situation is similar for thermal energy. This requires an upgrade of the existing energy infrastructure and grids.

In households, thermal energy is covered mainly by electricity (79%), while wood, coal, and coke (16%), as well as liquid fossil fuel (5%) are also used for this purpose [28]. In the industrial sector at Eigerøy, both electricity and fossil fuel are used for thermal energy. Detailed data for the energy split is missing, as electric energy for machines, appliances and heating in industries is not separately measured. Fossil fuel-based heating were about 6,950 MWh/year of liquid fuels (based on available 2017 data), and about 26,500 MWh/year based on LNG.

4. METHODOLOGY

This work covers the description of the ROBINSON energy system that is going to be demonstrated on the island of Eigerøy, Norway. The energy system has several sub-systems (both future and existing installations), including:

- Air-blown wood gasifier.
- Anaerobic digestion supported by a bio-electrochemical system (AD+BES).
- Electrolysis unit consisting of two alkaline type A90 modules from Green Hydrogen Systems [29].
- V-Twin 100 wind turbine with nominal power of 100 kW.
- Combined heat and power (CHP) unit consisting of a 400-kW gas turbine based on Aurelia Turbine [30].
- Gas mixing system to ensure a flexible and reliable operation of the CHP unit.
- Steam boiler with a Weishaupt WKG80/3-A ZM-NR burner [31] that is an existing installation.

The expected performance parameters, characteristics and important considerations related to different sub-systems are provided in the next sub-sections. An emphasis in this regard has been given to the micro gas turbine (MGT)-based CHP unit, as this unit is an important component for the overall ROBINSON energy system. It is worth noting that thermodynamic modelling or a complete performance analysis of the entire energy system was not within the scope of the current study. The study tries to establish the foundation of the reference ROBINSON energy system; hence, providing a baseline for further detailed studies. However, a preliminary system integration scenario considering a steady-state operation of all sub-systems is provided.

Please note that the presented energy system does not replace all the fossil fuels that are currently used as a) the feasibility of the energy system should be demonstrated given the budget limitations, while not putting existing production processes at danger, and b) the existing system should be kept as a backup solution to maintain the industry's production profile.

5. ROBINSON BASELINE ENERGY SYSTEM

The ROBINSON project has its demonstration on one of the industries (a fish food production plant converting fish waste into protein) located in Eigerøy that has been in operation since January 2019.

In addition to electricity, the production process in the plant requires a considerable amount of high-temperature steam that is currently supplied by an LNG-fired boiler. The process also generates low-temperature waste heat, which other local industries could use for heating, and that is currently wasted.

The energy demand of the industrial plant is dependent on the availability of feedstock for protein/fish food production and varies with the availability of fish and fish residues. An example of the heat and electricity demand profiles (relative to the maximum values that is corresponding to the maximum protein production) are shown in Figure 2, and Figure 3, respectively.

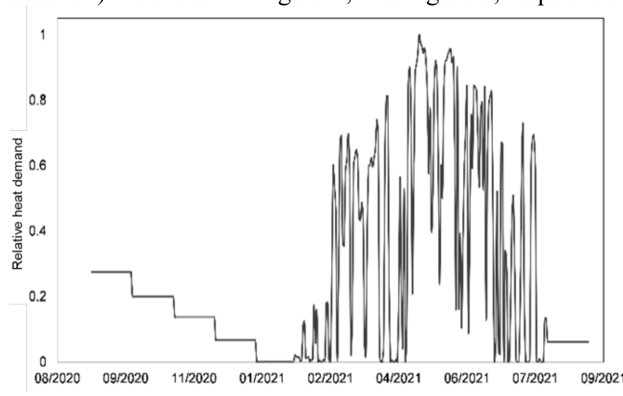

Figure 2: Variations in the relative heat demand of the local industry (Data from 2021 are actual data and those from 2020 are estimated)

Both figures indicate the heat and electricity demands relative to the maximum consumptions. It needs to be noted that the profiles vary throughout the years (and seasons) depending on the availability of feedstock. The energy demand of the industry, despite the large fluctuations, is plannable. The industry has a relatively large thermal inertia, as ramping up from stand-by operation (in average about 15% boiler load) to 75% load can take up to 7 hours.

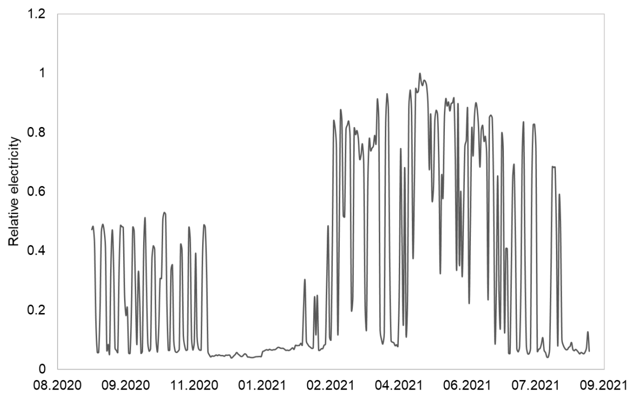

Figure 3: Variation of relative electricity demand of the industrial plant (data from 2021 are actual data and those from 2020 are estimated)

This plant is the main LNG consumer on the island. That is why all equipment and components of the ROBINSON project contributing to replace LNG will be located preferably close to the site of this plant. This ensures short connections for gas and heat transport pipes, as well as reducing transport related losses. Furthermore, the placement of equipment in an industrial area reduces possible hurdles, such as applying for permits to place such equipment close to residential areas that can be time consuming.

The coming sub-sections present the main characteristics of different sub-systems of the ROBINSON energy system. The block flow diagram of this system is shown in Figure 4.

5.1. Feedstocks and fuels

As also indicated in Figure 4, the energy system uses different primary feedstocks, including:

- LNG to the boiler,
- Wood chips to the gasifier (waste wood),
- Wastewater to the anaerobic digester, and
- Water to the electrolysis unit.

The properties of the mentioned feedstocks are listed in Table 2. In addition to them, the combined micro gas turbine (MGT)-based CHP unit is fuelled by three different fuels that are resulted from various conversion units, including:

- syngas from the gasifier,
- hydrogen from the electrolysis unit, and
- biomethane from the AD+BES unit.

Every fuel has different characteristics and availability that affects the design of a gas mixing system, as well as the combustor design of the CHP. In this regard, boundary conditions for the electrolysis and gasification units are better known compared to that of the AD+BES system. This is because the latter technology is of lower technology readiness level (TRL), while the first two are components that are already available in the market.

5.2. Gasification block

The gasification unit, which is planned to supply the main fuel source (syngas), will most probably be of fixed bed gasification technology. The gasifier, due to its design, has a high thermal inertia in comparison with the CHP unit. A hot start-up of the gasification system can take about 20-30 minutes, while a cold start-up can take up to three or even more hours.

The operational flexibility of the gasifier is limited due to its large volume. Due to the feeding process, the gasification unit is operating at close to ambient pressure, thus requiring a fuel (syngas) gas compressor to achieve a fuel pressure matching the need of the CHP unit.

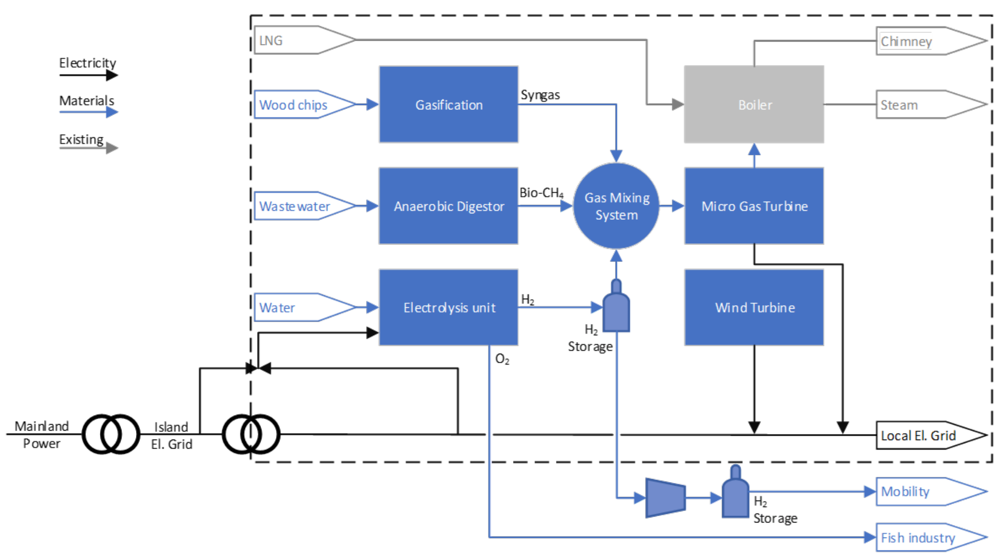

Figure 4: The block flow diagram of the integrated ROBINSON energy concept

The evaluation of a possible gasifier is currently ongoing. A system like for example a product from SYNCRAFT with the nominal energy input of 1,800 kW might be selected [32]. In terms of operation, a continuous operation of the gasifier in 90% of a year is considered.

Table 2: Technical specification of feedstocks

Parameter	Amount	Unit/Remark
LNG[1]		
CH_4	92.095/85.416	[mol%] / [mass%]
C_2H_6	6.643/11.549	[mol%] / [mass%]
C_3H_8	0.762/1.943	[mol%] / [mass%]
i-C_4H_{10}	0.048/0.163	[mol%] / [mass%]
n-C_4H_{10}	0.081/0.273	[mol%] / [mass%]
i-C_5H_{12}	0.011/0.044	[mol%] / [mass%]
n-C_5H_{12}	0.010/0.043	[mol%] / [mass%]
n-C_6H_{14}	0.001/0.004	[mol%] / [mass%]
N_2	0.348/0.564	[mol%] / [mass%]
CO_2	0.000/0.000	[mol%] / [mass%]
Density (@-159.4°C)	443.8	[kg/m^3]
Density	0.774	[kg/Nm^3]
NCV	10.612/38.203	[kWh/Nm^3] / [MJ/ Nm^3]
Wobbe index	13.717/49.380	[kWh/Nm^3] / [MJ/ Nm^3]
Wood chips[2]		
Water content	<30-40	[wt%], W35-W40 [33]
Estimated demand	10	[tonne/d]
Size	G50/G100	According to [33] classification.
Type	A1	Used untreated white wood (Waste wood) without paints.
Heating value	3.5-4.0	[kWh/kg]
Wastewater source 1[3]		
TSS	90-240	[mg/l]
Total phosphorus	4.0-7.0	[mg/l]
Total nitrogen	28-230	[mg/l]
TOC	85-520	[mg/l]
BOD – 5 days	150-1,400	[mg/l]
Wastewater source 2[4]		
TSS	2,400	[mg/l]
Total phosphorus	60	[mg/l]
Total nitrogen	190	[mg/l]
TOC	1,300	[mg/l]
BOD – 5 days	3,000	[mg/l]
COD	7,000	[mg/l]
Magnesium	32	[mg/l]
Sodium	160	[mg/l]
Conductivity (@ 25°C)	132	[mS/m]
Water requirement[5]		
Water quality	<5	[µS/cm]
Water intake	0.9	[l/Nm^3]

Note 1: Typical values are reported for LNG.
Note 2: This section lists the most realistic type of wood chips that can be delivered to the plant.
Note 3: This refers to the wastewater after the primary treatment (including a rotating drum and a flotation tank).
Note 4: This refers to the raw wastewater prior the primary treatment.
Note 5: it refers to the quality of water for the electrolysis unit.

5.3. AD+BES unit

As mentioned earlier, the anaerobic digestion supported by a bio-electrochemical system unit (i.e., the AD+BES) is still in a low TRL level (TRL 4), and subject to ongoing development and adaptation activities. This development will add an uncertainty to the fuel supply system, which needs to be considered.

Anaerobic digestion (AD) itself is a process that is preferably operated in a close to steady-state operation due to the process (based on microorganisms' activities) and its volume. Within the ROBINSON project, this unit is highly influenced by the production process of the local fish industry, as it uses the organic contents of the plant's wastewater (refer to Table 2). Feedstock to the AD+BES unit is, therefore, only available when the plant is in operation.

The bio-electrochemical (BES) system is designed not to affect the operation of the AD part. In consequence, the process can be operated with and without the BES part ensuring fuel production even in case of a malfunction of the BES process. The fuel composition would then differ, being closer to biomethane (more than 90 vol% methane) or raw biogas (60-70 vol% methane) when the BES is in operation or not, respectively. Like the gasifier, the AD+BES system will also operate at close to atmospheric pressure, so that a fuel gas compressor is required to achieve the fuel gas pressure level required by the CHP unit. The prototype for the demonstration project has a volume of approximately 1 m^3 that can produce 900 l/day of biomethane (or 3.3 MWh biomethane per year considering a continuous operation in 90% of a year). The AD+BES process is currently in the development and testing phase (in LEITAT, Spain), using available samples of the wastewater from the plant on Eigerøy.

Table 3: Expected specification of the AD+BES unit

Parameter	Amount	Unit
Production capacity	0.12-0.22	[Nm^3/d]
Delivery temperature	37	[°C]
Delivery pressure	0.02	[barg]
AC power demand	3.5	[kW]
DC voltage of BES stack	~1	[v]
Wastewater demand	100	[l/d]
Wastewater temperature	5-40	[°C]

5.4. Electrolysis unit

The plan is to install two A90 process modules of alkaline electrolysis (AEL) supplied by Green Hydrogen Systems, Denmark [29]. Both modules will be installed in a standardised configuration, in a 40-ft container. Technical parameters of the electrolysis module are listed in Table 4, below.

The average need of hydrogen for the micro-CHP unit is estimated to be around 90-100 kg/d with the maximum demand of 220 kg/d or 2,448 Nm^3/d (1 kg H_2 is equal to 11.126 Nm^3).

At nominal production capacity, the unit (consisting of two modules) is expected to consume 6,846 MWh of electricity and producing 4,258 MWh of hydrogen (LHV basis) per year, assuming 90% availability (operational hours of the unit in a year).

Table 4: Technical specification of each electrolysis module [34]

Parameter	Amount	Unit
Nominal H_2 production capacity (vol. / mass)	90/8.1	[Nm^3/h] / [kg/h]
Max. H_2 delivery pressure	35	[barg]
H_2 purity	>99.998	[%]
O_2 purity	>99	[%]
Maximum stack power consumption BOL / EO	390/450	[kW]
Max. stack voltage (DC)	250	[V]
Stack current at 100% load	1800	[A]
Stack efficiency /power consumption at 100% load BOL	81.8/4.33	[%HHV] / [kWh/Nm^3]
Stack efficiency / power consumption at 50% load BOL	85.2/4.15	[%HHV] / [kWh/Nm^3]
Total system efficiency at 100% load BOL container	73.5/62.2	[%HHV] / [%LHV]
Total system power consumption at 100% load BOL container	53.6	[kWh/kg H_2]

As indicated by Table 4, the delivery pressure level is exceeding the required fuel pressure of the CHP unit (that is about 7-8 bara). While the response rate during operation seems to be matching the requirements of the CHP unit, the slow start-up of the AEL requires storage of H_2 as buffer to secure the continuous operation of the CHP unit during the start-up phase. The size of such a tank can be optimised based on different considerations. For example, this can be done based on the size of electrolysis unit in case of a load reject from the MGT to store the produced H_2 until the electrolyser is shut down. This optimisation task can be based on a storage capacity that is needed for a few hours up to one day operation of the CHP unit. For one day operation of the CHP unit, the total volume of H_2 storage could be up to 2,448 Nm^3. Commercial suppliers can provide such a stationary H_2 storage tank with up to about 30-40 bars and 40 m^3 [35]. As each one of such tanks has a hydrogen capacity of ~1,200 Nm^3, two of these tanks are required for sufficient storage of hydrogen at the site to cover the need for one day operation of the CHP unit. These tanks are considered upstream of the buffer tank (that also receives other gases e.g., syngas from the gasifier and biomethane from AD+BES) is considered (refer to Figure 4).

The additional capacity of the electrolysis unit exceeding what is needed in the CHP unit is directed towards a compression unit up to 350 bar (or 700 bar) and a pressurised H_2 storage tank(s) above the ground level targeting the planned H_2 use for transport. This part, in addition to O_2 and waste heat use for other industries, is outside the boundary of the ROBINSON project but still is shown in Figure 4. As per project plans, the electrolysis unit is expected to be operated under close to steady state conditions with grid connection. However, it will receive excess electricity from the Robinson energy system to contribute to balancing the low load change rates of the gasification unit according to the production requirements of the fish industry to for example avoid flaring of syngas (that is still produced from the gasification unit, but the need for electric/heating energy is reduced due to reduced production).

5.5. Wind turbine

The novel wind turbine (the V-Twin 100) with a nominal power output of 100 kW (maximum net delivered power of 90 kW), consisting of two turbines with 50 kW each, will be installed on the island to optimally use wind as an energy source. The turbine has been developed by a start-up company within the ROBINSON consortium, i.e., Renewable Energy Systems & Technology UG (RES-T). This wind turbine does not require a gearbox resulting in a reduced complexity and need for consumables (such as oil). Further, the wind turbine is designed in a flexible way since the blades can be unfolded to be situated near to the ground to ease the maintenance operation.

The preliminary estimations shows that the maximum power can be reached at wind speeds between 12-19.5 m/s (at hub height) and a cut-off is applied when wind speeds are higher than 19.5 m/s [36].

5.6. Combined heat and power unit

As mentioned earlier, the CHP unit will be based on an Aurelia gas turbine (Aurelia® A400), an intercooled and recuperated twin shaft gas turbine, with an electrical power output of 400 kW, and a thermal output of 500 kW. This micro gas turbine is currently under development to handle a wide range of fuels with various compositions. It will, together with a wind turbine feed electricity into the local industry's grid, with the possibility to feed the island's distribution network.

The heat in the exhaust gas of the gas turbine is used as heat input to the process steam generator. This will be performed via preheating the fresh air entering the boiler that produces process steam. Preheating the air will reduce the required LNG consumption by up to 375 kW (preheating the inlet air from 20 °C to about 68 °C).

The CHP unit will serve as central element within the energy system providing a reliable energy supply to the local industry. Within the local/island energy system and due to its dispatchability, the CHP also serves as a balancing unit, compensating the fluctuation and seasonal availability of other local renewable sources. The contribution of the CHP unit to stabilise the local grid will also be evaluated to pave the way for a full-scale installation at Eigerøy and the follower sites.

The gas turbine package is being developed to fulfil all the requirements of generators connected to the distribution network to support dynamic electrical conditions fluctuations.

The development of the combustor used in the gas turbine will allow the use of the wide range of fuels (with up to 30 vol% of H_2) in the project without stopping the gas turbine or changing internal components. It is anticipated that this combustor will enable the combination of multiple smaller scale fuel sources to supply a single generator prime mover, that until now required separate generators with separated combustion systems. This will have the effect of dramatically reducing the number of generators required and improving the financial proposition of follow-on projects.

5.7. Gas mixing system

As mentioned earlier, every fuel for the CHP unit (syngas, biomethane and H_2) has different characteristics and availability. This highlights the need to develop a gas (fuel) mixing system to achieve the required fuel flexibility and reliable operation of the CHP unit. Such a mixing system acts as a buffer tank and provides a fuel mixture of the mentioned gases according to the specification that is determined by the CHP.

This system allows the gases to be blended and utilised when available, and includes fuel conditioning processes such as compression, flow control, heating, and condensate removal, as well as short term fuel storage to maintain fuel composition changes within a specified range for the gas turbine.

5.8. Steam boiler

As mentioned earlier, the local industry currently uses LNG to generate steam for their industrial processes. The properties of the steam boiler that uses a Weishaupt WKG80/3-A ZM-NR burner are listed in Table 5. It should be noted that part of the LNG use will be replaced by the heat from the ROBINSON energy concept, due to preheating the air before entering the burner. The local industry has a plan to eventually replace the remaining part by renewable-based heat to reduce environmental impacts.

6. RESULTS AND DISCUSSION

Figure 5 shows the schematic of a system integration scenario. All the sub-systems are considered to have a steady-state operation in this scenario. For electrolysis operation, electricity from the grid is considered. H_2 is stored in a H_2 storage tank. A part of that is mixed with the syngas from the gasifier and the other part goes for transport applications. To control the H_2 concentration in the fuel to the CHP unit (by up to 30 vol.%), 34% of the produced H_2 from the electrolysis unit with the energy content of 1,448 MWh/year is fed to the CHP unit.

The yearly production of bio-CH_4 is up to 3 MWh, which compared to the other fuels (i.e., H_2 and syngas) is small, but can be extended later when the system reached higher technology readiness. The biomethane will be mixed with the syngas before injection to the CHP.

Table 5: Technical specification of the steam boiler [31]

Parameter	Amount	Unit
Steam temperature	180	[°C]
Feedwater temperature	105	[°C]
Steam rate	20	[tonne/h]
Firing rate	13.3	[MW]
Max. water capacity	30	[tonne/h]
Design pressure	13	[bar]
Operational pressure	10	[bar]
Min. thermal output	2.2	[MW]
Max. thermal output	22	[MW]
Efficiency	98	[%]
Combustion air temperature	<40	[°C]

The electrical efficiency of the micro gas turbine is considered to be 40.2%, i.e., the thermal input is around 1 MWth. Steady-state operation of the CHP system is considered with the operation of 7,880 hours/year. The system produces around 3,152 MWh/year of electricity and 3,940 MWh/year of heat.

The wind profiles on the earth surface depend on the geographical location, as well as on the local weather conditions. So, for different locations and years, different capacity factors are obtained. The calculation of the capacity factor is based on [37] and using the web tool that is provided by [38], as shown in Figure 6. Wind conditions on Eigerøy are well suited, with relatively high average wind speeds, which are even higher if the wind turbines will be placed on top of the hill.

Using the capacity factor profile, the electricity production from the wind turbine is calculated as shown in Figure 7. For this calculation, 5% of loss between the converter and the point of connection to the grid/customer is considered. The power generated for one year is expected to amount to 384 MWh.

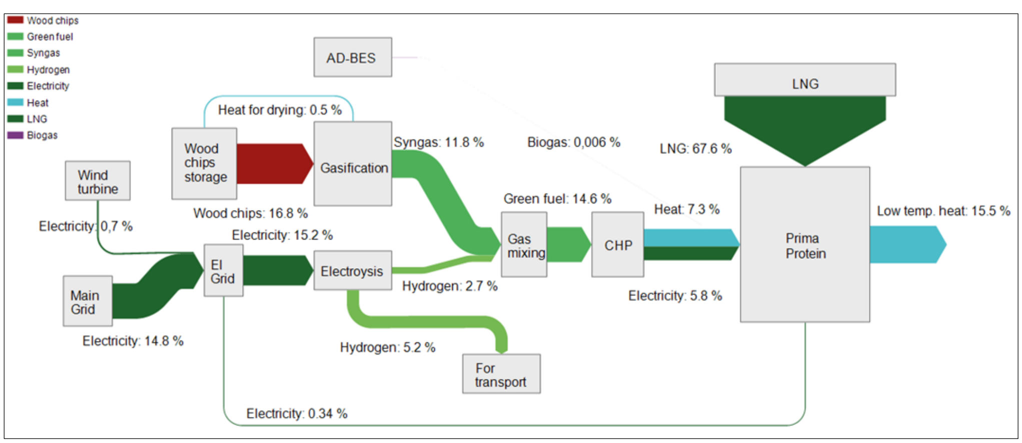

Figure 5: Sankey diagram for the demo site in Eigerøy (percentages are related to the total energy input to the site)

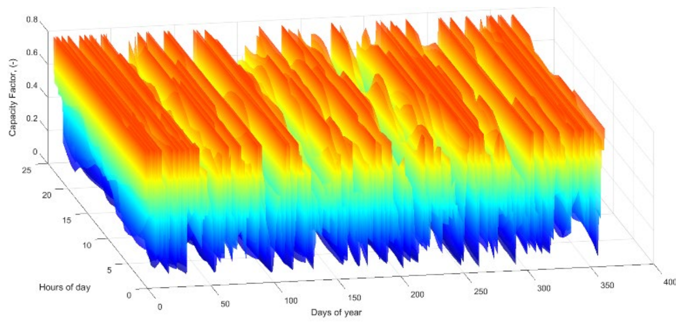

Figure 6: Capacity factor profile of the wind system in 2019 for the site in Eigerøy, Norway

The electricity demand profile of the local industry and the produced electricity from the CHP unit and the wind turbine are shown in Figure 8. Note that for confidentiality issues, the numerical indicators in the figure are not shown. In this figure, the red line shows the electricity production from the wind turbine and the yellow line the sum of CHP and wind electricity. According to this figure, there is excess of electricity specifically from December to February that can be sold to the grid. Alternatively, the load of the gasifier and consequently the CHP unit can be reduced in these periods. There is more demand for electricity from March to August, which needs be purchased from the grid.

7. CONCLUSION

The ROBINSON project with the goal to contribute to decarbonise geographical islands is in its early stage of implementation. As part of this project, this paper covers a brief overview of the project and its objectives, as well as the baseline configuration of an integrated energy system that is going to be developed and demonstrated on the island of Eigerøy, Norway. In addition to description of sub-systems of the baseline configuration, their expected performance parameters and characteristics, energy fluxes of the system are also preliminarily addressed.

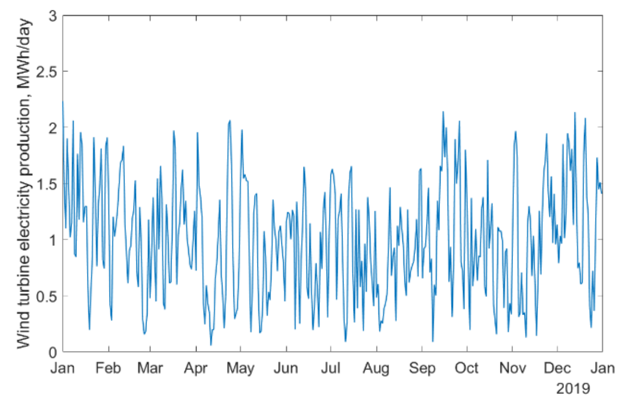

Figure 7: Wind turbines electricity production profile (2019) for the site in Eigerøy, Norway

The paper highlights the importance of the interactions of all components within a tightly integrated energy system. The CHP unit, in this context, has a central role to safely cover part of the energy demand of the plant. Accordingly, it must balance the available primary energy sources (wind, sun, biomass), and different characteristics and dynamics of the fuel production units with the determined demand.

An advantage of the selected pilot is the matching between the demand profiles of electricity and heat (as also shown in Figure 2 and Figure 3), thus not requiring specific flexibility in this respect. Nevertheless, proper sizing of storage devices needs to be carried out to match the needs of operation to avoid burning excess fuel in case fuel generation continues, while the demand of the plant is reduced to zero.

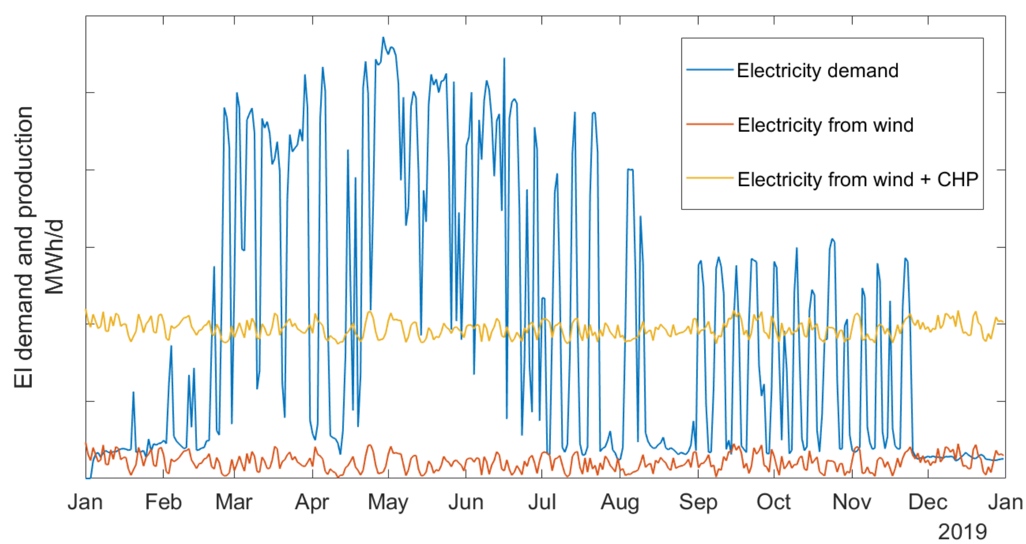

Figure 8: Electricity demand profile of the plant in 2021 (blue), electricity production from the 100 kW Twin wind turbine (red), and the total electricity from 400 kWel CHP and 100 kW wind turbine (yellow)

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