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Highly efficient innovative shallow-water based Sea Water Air Conditioning solution for the Channel Area

EUROSWAC

216-T4.3-UNE-201- EuroSWAC Exploitation Plan

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Executive Summary

This exploitation plan combines and summarises a number of the key outputs from Work Package 4 (WP4) of the Interreg funded EUROSWAC project, to create a logical legacy of documents and learning around how to conceive, undertake an outline design and evaluate Seawater Air-conditioning systems (SWAC). Seawater air-conditioning (SWAC) exploits the natural temperature difference between ocean water and the outside air, with the water in effect acting as a heat source or refrigerant. SWAC has rarely been considered for the Channel Area due to the uncertainty as to its efficiency and cost-effectiveness in sites where the water is relatively shallow, and the temperature gradient tends to be minimal and subject to seasonal fluctuations. The EUROSWAC project addresses this uncertainty by designing and validating cost-efficient SWAC solutions in the Channel Area.

The Exploitation Plan includes key exploitable outputs; a summary of two demonstrator projects (Brixham Lab and National Lobster Hatchery) and consideration of possible future SWAC replication sites. It also considers key target groups who might use SWAC along with the potential barriers and enablers for those wishing to install a SWAC system in England or France.

Results from the WP highlights that SWAC does offers a potential solution to the high energy costs and chemical usage required by traditional Air Conditioning (AC) systems, however, whilst the cost of the water is low, the installation costs of the abstraction and return pipework can be a limiting factor. Sites should therefore be selected a) where there is existing infrastructure, or (b) where the distance between the abstraction / return are close to where the cooling / heating is required c) where there in a wayleave that can be negotiated and secured for both the heat exchanger and the pipework. Critical factors associated with making the decisions to explore SWAC are provided in Figure 6, section 4.6.

There are other barriers and obstacles to SWAC roll-out which include: cost; a lack of awareness of the SWAC technology; seasonal fluctuations in the thermal needs of end users; environmental considerations and permitting requirements; restricted equipment lifespan in a challenging marine environment; and the insurance and investment barriers that come with a relatively untested novel technology.

However, in terms of the potential to roll-out SWAC across the channel area, an initial sample of 601 possible replication sites in 137 coastal locations in England and France was collated based on bathymetrical evaluation and criteria set out in the Project Plan, as well as other factors, including proximity to the shore, population size, the presence of key industries and prevailing HVAC technologies. Regions in the Channel Area with potential for year-round heating and cooling based on an analysis of sea and air temperatures were also identified.

One key enabler to SWAC installation was sites that could take a combined approach to water extraction and municipal heat exchange, for connection by a range of individual users. This offsets the installation costs and also potentially sidesteps some of the environmental and marine permissions, but adopting a single point of abstraction and return. Also modelling 60-year lifecycles of SWAC, also highlighted that whilst traditional installation would require replacement every 20 years, a more cost effective and more societally beneficial approach

could be to adopt the principles of circular economy and design the installation to be long-life cycle, with re-useable or re-manufacturable componentry.

Five coastal communities were identified that could benefit from district-scale SWAC installations, in which a single abstraction pipeline is shared by multiple sites: Brighton, Falmouth, Plymouth in England, and Calais in France. In terms of key sectors that might benefit from SWAC: tourism and leisure attractions, hotels, and retail were identified, and to a lesser extent ports and maritime transport, computer data centers, nuclear facilities, marine energy and aquaculture.

For longer-term scale up of SWAC in the Channel Area, communication and dissemination efforts should be targeted at these sectors. An initial conservative analysis indicates that between 50 and 200 new jobs could be created based on the number of potential new SWAC installation sites identified in the Channel Area.

Contents

Abbrevations

ACRIB	Air Conditioning and Refrigeration Industry Board (UK)
ADEME	Agence de l'environnement et de la maîtrise de l'énergie (France)
AREA	Air Conditioning & Refrigeration European Association
BEIS	Department for Business, Energy & Industrial Strategy (UK)
Capex	capital expenditure
CE	circular economy
CFD	computational fluid dynamics
DCA	Data Centre Alliance
DE	Doris Engineering (France)
Defra	Department for Environment Food and Rural Affairs (UK)
DM	Doris Marine (France)
DPI	Deprofundis (France)
EDF	Électricité de France
EIA	Environmental impact assessment
ENSTA	École Nationale Supérieure de Techniques Avancées (France)
FOWT	floating offshore wind turbines
GHNF	Green Heat Network Fund (UK)
HVAC	heating, ventilation and air conditioning
HVCA	Heating & Ventilating Contractors Association (UK)
IP	intellectual property
IPR	intellectual property right
JS	Joint Secretariat
LCA	lifecycle analysis
LCC	lifecycle costing
LEPs	Local Enterprise Partnerships (UK)
MMO	Marine Management Organisation (UK)
NLH	National Lobster Hatchery (UK)
NOC	National Oceanography Centre (UK)
OEE	Ocean Energy Europe
Ofgem	Office of Gas and Electricity Markets (UK)
Opex	Operational expenditure
OTEC	Ocean Thermal Energy Converters
PMBA	Pôle Mer Bretagne Atlantique (France)
PMM	Pôle Mer Méditérannée (France)
RHI	Renewable Heat Incentive (UK)
SACP	Sacrificial anode cathodic protection
sLCA	Social Lifecycle Analysis
SSSI	Site of Special Scientific Interest (UK)
SWAC	Seawater air conditioning
UKRI	UK Research & Innovation

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Introduction

1.1. The EUROSWAC project

As elsewhere, anthropogenic climate change is driving an increased demand for cooling in coastal communities around the Channel Area. This cooling is almost invariably delivered using chillers, which consume large amounts of electricity at considerable financial cost to the end-user. Furthermore, the energy used by conventional cooling is partially or wholly sourced from the combustion of fossil fuels, which results in the emission of greenhouse gases and hampers efforts by the UK, France, and other European governments to meet their urgent climate objectives.

Seawater air conditioning (SWAC) exploits the natural temperature difference between ocean water and the outside air, with the water in effect acting as a refrigerant. There is a lower limit to the cooling SWAC can directly deliver, with a typical system able to achieve a target of perhaps 5°C, but in conjunction with other cooling technologies it can significantly reduce the overall energy required to achieve the very lowest temperatures. In recent decades SWAC has emerged as a promising low-cost, low-carbon alternative to conventional cooling, with the potential to significantly lower operational costs compared to a standard HVAC (heating, ventilation, and air conditioning) installation, due to a reduced need for electricity and chemical inputs. The SWAC principle can also be used to derive cooling from other naturally occurring water bodies, such as rivers and lakes; and in certain situations, SWAC can be used in reverse – i.e., heating a building when the temperature of the air falls significantly below that of a nearby water body.

Until now, SWAC installations have generally been restricted to tropical coastal locations close to deep water (c. 1,000 metres in depth), where a significant and constant air-seawater temperature differential is available year-round through accessing cold water from ocean depths. By contrast, the technology has rarely been considered for the Channel Area due to a lack of information as to its efficiency and cost-effectiveness in sites where the water is relatively shallow, and the temperature gradient tends to be minimal and subject to seasonal fluctuations. In the UK, and probably other parts of the Channel Area, the exploitation of seawater's thermal energy has to date centred on the provision of heat in winter, rather than summer cooling (e.g., in 2014 the National Trust installed the UK's first marine source heat pump at Plas Newydd House in Anglesey, Wales.)[1]

[1] https://www.kimpton.co.uk/marine-source-heat-pump-plas-newydd/

Co-financed by the European Regional Development Fund, the EUROSWAC project addresses this uncertainty by designing and validating cost-efficient SWAC solutions in the Channel Area. Benefiting from the expertise of 11 UK and France-based academic and industrial partners, EUROSWAC aims to provide a thorough analysis of the Channel's unique features, and to develop and test in real-life conditions a SWAC prototype at two UK demonstration sites: the Brixham Laboratory, Devon, and the National Lobster Hatchery (NLH) in Newlyn, Cornwall.[2] Empirical data gathered at these demonstrator sites informed the development and design of several key project outputs (listed in Section 2). Several feasibility studies have also been initiated in France (see Section 3.3).

1.2. Aims and objectives of the Exploitation Plan

This Exploitation Plan, developed following discussions with all the EUROSWAC project partners as well as via engagement with some key external organisations with expertise in renewable energy, forms part of the research output for the T4 work package of the EUROSWAC project. The Exploitation Plan details the activities required to disseminate the project's outputs to a wide range of stakeholders, enabling potential end-users to become aware of, and benefit from, the project outputs, and thus facilitating the upscaling of SWAC within the Channel Area. The Plan helps fulfil the objectives outlined within the initial Project Plan, strengthening the links between academia and industry within the value chain, enhancing the competitiveness within the Channel Area, facilitating new SWAC projects within the Channel Area, and disseminating outputs which could lead to progress against the UK and France's energy-climate objectives.

Specifically, the Exploitation Plan covers the following:

- Exploitable outputs: The key findings and other outputs emerging from the EUROSWAC project of benefit to future end-users.
- Demonstrator projects: A summary of the work undertaken at two sites (Brixham Lab and NLH) which has informed the production of several of EUROSWAC's project outputs.
- Future replication sites: Details of sites and market segments to be pursued in the future. These include at least 12 potential future short-term replication sites (with one in each region of the Channel Area) and three key long-term market segments.
- Target groups and exploitation activities: Outlining how, and to whom, the results of the EUROSWAC project should be disseminated. Past exploitation activities are also detailed.
- Knowledge ownership: Detailing how the intellectual property of the EUROSWAC project's outputs should be managed going forwards.
- Potential barriers: The potential barriers which should be considered when seeking to disseminate the EUROSWAC project's outputs or replicating within future sites – and how these might be overcome.

[2] NLH itself is headquartered in Padstow, Cornwall

- Sources of funding: Support for those wishing to install a SWAC system in England or France.

2. Exploitable outputs

2.1. Introduction

This section details the exploitable outputs from the EUROSWAC project. The varied nature of the outputs demonstrates the inter-disciplinary collaboration between industry and academia which has taken place during the project. Outputs reflect the environmental considerations of future SWAC installations, the technical components required for both the installation and the operation of a SWAC system, and the optimisation and potential business models required for future SWAC uptake. Taken together they form a valuable bank of knowledge to facilitate the installation of SWAC systems in the Channel Area.

2.2. Validation of SWAC performance in the Channel Area

The most important output from the EUROSWAC is the demonstration that a SWAC system can work in the relatively shallow, temperate seas of the Channel Area, and in similar waters beyond the Channel Area. The testing and monitoring phases have validated – in a real environment - the design and performance of the shallow-water based SWAC components, paving the way for its commercialization and replication by other end-users. The EUROSWAC project clearly demonstrates that SWAC can play an important role in the energy transition from fossil fuels, and that in the future it should be routinely considered as part of a potential low-carbon HVAC solution in coastal sites.

Previously, it was assumed that for SWAC to be effective, a constant, steep temperature gradient between air and water was needed. The mixing by various tides and currents of waters at different depths means that such an established thermal stratigraphy is often less readily available in the Channel compared to tropical sites (see Section 4.2). However, the EUROSWAC project has demonstrated that when used in combination with air- and ground-source heat pumps for both heating and cooling, the technology can significantly reduce the electricity usage of a site - and its carbon footprint. Heat maps produced for the project (see Section 2.3) show that while sea temperatures remain broadly similar all year round, in the winter, the waters are usually marginally warmer than the air, which enables SWAC to be used for heating with the addition of the heat pump; and in the summer the seawater temperatures are lower, allowing their use for cooling (with the heat pump used in reverse).

Furthermore, the lack of thermal stratification means that pipe lengths can be considerably shorter – i.e., seawater pumped from 50 metres depth, will not be much colder than at 10 metres. This potentially reduces the installation and maintenance costs of a 'temperate SWAC' compared to its tropical counterpart. The findings from the demonstrator sites at Brixham Lab and NLH (Section 3) suggests that small-scale SWAC installations for sites with relatively low power demands are also viable, and that flexibility can be incorporated into the design of these applications while maintaining a modularised approach. Moreover, the trials at Brixham Lab generated valuable real-world data for those designing future SWAC systems to complement the outputs from theoretical models.

2.3. Enhanced knowledge of the Channel waters

The EUROSWAC project disseminates a comprehensive mapping of Channel's coastline, enabling to better understand key physical factors which can affect a design and optimisation of a future SWAC system. This includes a detailed study of hydrology (e.g., tides, currents), morphology (e.g., bathymetry, geomorphology), sedimentology and seasonal changes. New outputs also include comprehensive heat maps for the Channel Area, showing areas with a significant difference between surface and water temperatures (Section 2.3). These maps, in combination with the market analysis (Section 2.11), helps to target the most appropriate end-users and lay the groundwork for rapid replication of the SWAC technology. Furthermore, the project disseminates analysis of biodiversity-related constraints and characteristics through studies on seawater quality measurements, sediment analysis, and the simulation sediment reorganization following marine works. The output from these data may be used in future offshore research activities.

2.4. Understanding of the impact of SWAC on marine environments

A range of outputs from the EUROSWAC project have improved understanding of the likely impacts on the natural environment when a SWAC system is installed and running. For instance, the University of Plymouth has conducted computational fluid dynamics (CFD) modelling of the impacts on the marine environment of discharging warm water from any system (including SWAC) that exploits the thermal energy of seawater for heating or cooling a building. The research shows how marine currents and waves affect the temperatures of water released, and demonstrates how this relationship varies with different designs of discharge pipe. In the future, those with an engineering background would be able to use these CFD models for testing the impacts of new SWAC designs. An important finding of this novel research is that the environmental impacts of discharging warm water from a SWAC system back to the sea appear negligible.

Further data on the impacts of wave action on the SWAC system has been gathered at the University of Plymouth's COAST facility. The latter provides physical model testing with combined waves, currents and wind, offered at scales appropriate for device testing, array testing, environmental modelling and coastal engineering.[3]

Working with NKE, specialists in water quality monitoring, the University of Plymouth researchers have also deployed two instrumented marine buoys as an environmental observation platform. The buoys are sited approximately 20 metres out in the water from

[3] https://www.plymouth.ac.uk/schools/school-of-engineering-computing-and-mathematics/coast-laboratory

Brixham Lab and their sensors provide baseline data on the water quality (including water temperature, turbidity, pH levels and oxygen reduction) from July 2022 to January 2023. The sensors, which have been used to confirm the theoretical models, are able to monitor the 'real world' impacts of an operational SWAC system. NKE and the University of Plymouth have also developed a new data interface allowing users to view and store data generated by this environmental observation platform.

The outputs also comprise a study, led by Doris Marine, on existing methods to mitigate biofouling which concludes that the use of chlorine is the cheapest approach, with more environmentally friendly alternatives adding to the cost of SWAC installations and maintenanceAll the work, made public, can be used by other projects to reduce environmental impacts in SWAC installations both under development and planned.

2.5. Permit applications and instructions

The University of Plymouth produced an analysis and guidance on the permitting requirements and regulations in the UK and France governing those seeking to install a SWAC system: 216-T1.5-UNP-001 Permitting Applications (public report). This output helps to address barriers associated with what can often be onerous permit application requirements.

2.6. Drawings, design and technical specifications of the components and overall system of the innovative SWAC solution.

This output consists of the overall design of the solution led by DPI. Such design includes the mechanical drawings of the overall system, logic diagrams, and operation notice (for the operation of the system) and relevant safety reports, and the definition and elaboration of a complete set of technical specifications for the SWAC components (for example, pumps, heat exchangers, filters, instrumentation and controls).

2.7. Design and specifications for onshore/offshore civil works needed for innovative SWAC systems

Led by Doris Marine, the project highlights the necessary specifications of the offshore installations (pipes layout, pumps structure, concrete-made shell structures for the pipes, fixing structure) and onshore installations (building, pipes) as well as the interfaces between the offshore and onshore parts.

2.8. R&I engineering studies to enhance the optimisation of a SWAC installation

The project shares outputs in relation to the development of three new technologies, which are presented in more detail below:

- A self-burying system for the SWAC water pipes,
- A flexible pipe concept for the SWAC water pipes;
- Research on slowing the corrosion potential of metallic structures in the ocean.

These innovations will contribute to the reduction of the cost of the SWAC system by reducing the material cost and the installation cost.

2.8.1. Self-burying system for SWAC pipes

A large proportion of the cost incurred in marine installations, such as those used in the offshore energy installation, arises during the laying of pipes. In the case of SWAC systems, the input pipe needs to be buried close to the shore for several reasons:

- to thermally insulate the intake water (you don't want cold water from the depths of the sea being heated up by warmer water close to the surface);
- to avoid disturbance to fishing and other activities;
- to stabilise and protect the pipe from physical damage due to currents and waves

Typically, when burying a pipe at sea, underwater trenching machines are used which inject water into the seabed under the sections of pipe to be buried, liquefying the sediment and allowing the weight of the pipe to cause it to sink into the substrate. This is an expensive process. The self-burying pipe system, developed and tested by DPI and Doris Engineering, offers a way to avoid some of the costs. The system being tested has additional pipework underlying the pipe to be buried which injects the seawater into the seabed and avoids the need for underwater trenching machines. The output from the EUROSWAC project will be an initial prototype (216-T2.3-DEN-006 -Self Burying Rigid Pipe System Tests_Report).

2.8.2. Flexible pipe concept for SWAC pipes

The testing of the flexible pipes concept led by Doris Engineering, Océanide and DPI was ongoing at the time of writing, and due for completion by the end of March. As with self-burying pipe system, this disruptive solution offers a way to reduce high costs associated with using trenching machines, water-jetting machines and marine vessels to install sections of rigid steel or HDPE pipes on the seabed. The use of flexible pipes allows for an entire run of pipe to be rolled out in one go from a reel, and hung off the seabed on slings, reducing capex costs by as much as 50%. Rigid pipes are widely used in the oil and gas industry for the necessary robustness they offer when pumping these products. However, in SWAC given that only seawater being pumped flexible pipes are likely to be sufficient. Yet a flexible pipe may be more vulnerable to water currents and other disturbances causing it to buckle. The EUROSWAC partners studied the impacts of hydrodynamics on flexible pipes in the sea, developing a new modelling methodology. They also tested what effect would be if different types of flexible pipe were installed. These findings can be used to inform the design of future SWAC systems, and indeed any other marine installation using flexible pipes (216-T2.3-DEN-003 - SWAC-R&D - Model Calibration Report -rev01).

2.8.3. Corrosion potential for metallic SWAC structures

EUROSWAC partners, Doris Marine and NKE, have led research into the potential of sacrificial anode cathodic protection (SACP) to slow the corrosion of metallic subsea components of a SWAC system. Sacrificial anodes are highly active metals used to prevent a less active material surface from corroding.[4] The performance of two SACP systems installed at French Corrosion Institute in Brest was evaluated over a six-month period. Should SACP prove effective, this will reduce frequency of inspections needed for a shallow-water SWAC system, thus saving costs (216-T2.3-NKE-001 Report on corrosion potential).

2.9. Reporting from the onsite installation and deployment of the produced SWAC system (at component and system levels).

The Project has evaluated on the installation and deployment of all the components of the SWAC system and all the needed onshore and offshore works to be able to carry out the testing and monitoring of the solution.
Doris Marine and DPI have also been studying a French big industrial site, delivering a report on offshore and onsite design for this kind of SWAC installation (216-DMA-T2.1-001 Design and specifications for onshore/offshore civil works needed for innovative SWAC system).

2.10. Tools, methods and solutions to enhance SWAC replicability after the end of the project.

A key output from the EUROSWAC project, led by the University of Exeter, is a set of methodological approaches and tools for performing pre-assessment and pre-feasibility studies for identified sites in terms of their economic and physical suitability for SWAC. The tools highlight which background and enabling data needed to be collected produce an optimal design for a SWAC system at a given site. This enhances SWAC cost-effectiveness and helps build a business case for new investments, thus boosting replicability.

This output includes the following main elements, which are presented in more detail below:

- A SWAC design optimisation tool
- A business plan incorporating a scenario costing toolkit

2.10.1. SWAC design optimisation tool

The SWAC design optimisation tool uses genetic algorithms, a form of machine learning programme, coded and validated by the project, to identify the ideal dimensions and designs for SWAC components (e.g., pipe length, pipe diameter, heat-exchanger size, pump size, etc.) for a given replication site based on multiple technical variables, such as distance

[4] https://www.corrosionpedia.com/definition/1657/sacrificial-anode-cathodic-protection-sacp

from shore, seawater depth, thermal requirements of a site, the costs of a temperature control system, and so on (reference to Olas report). The optimisation tool projects financial and carbon impacts based on the technical design parameters, and allows those to be tuned for new SWAC installations, ensuring value for money, significantly improving cost-efficiency and performance. The optimisation tool enables a way to quickly discuss with an end-user the potential carbon benefits and likely costs of a SWAC system, given a few key parameters. As noted in Section 7.2, it is not just the high capital costs of installing the technology, but also uncertainty about the eventual costs, which in itself acts as an obstacle to replication.

2.10.2. Business plan and scenario costing toolkit

A business plan uses the optimisation tool to model and compare likely financial costs (capex and opex) for three scenarios, based on assumptions and empirical data collected at the NLH and Brixham Lab demonstrator sites.

- a *standard HVAC installation*;
- an *optimised 'linear' SWAC*;
- and a *circular economy (CE)-orientated SWAC*,

In the optimised SWAC scenario, thermal performance and short-term cost minimisation are the prime objectives in a 'linear' design with a single operating life for this system assumed to be 20 years, as typically the case with traditional engineering design. In the CE-orientated design, by contrast, the SWAC system is assumed to have a 60-year lifespan, with 50% of the components refurbished and 50% replaced after 20 years, and 25% refurbishment and 75% replacement at the 40-year mark. In an installation whose design is governed by 'circular' principles, components most likely to fail (e.g., due to corrosion) may be engineered with greater durability or made easier to refurbish or replace, instead of the entire system being scrapped. While a circular SWAC design may reduce material waste and embedded environmental impacts over the longer term, it is likely to have higher capex and opex costs than its optimised, linear counterpart.

The EUROSWAC project has also created a dedicated SWAC scenario toolkit for conducting lifecycle costings (LCCs) alongside environmental lifecycle analyses (LCAs) and 'social' lifecycle analyses (sLCAs). The purpose of the tool – developed by the University of Exeter - is to enable users to balance the economic impacts of a potential SWAC installation (e.g., costs of installation and operation), against a range of social impacts (e.g., health and safety, local employment, promoting social responsibility) and environmental impacts (e.g., climate change impacts, ozone depletion, toxicity, land use). LCAs were developed based on empirical data collected from actual sites and expanded these to a hypothetical harbour and a large coastal site. The relative merits of standard HVAC designs, linear 'optimised' SWAC designs and circular SWAC designs were established across a range of economic, social and environmental categories. Full details are provided in 216-T4.3-UNE-101-EUROSWAC market and replication analysis report.[5]

[5] Only available in English.

The optimisation and scenario toolkits can be used together iteratively, with the outputs from one informing the input parameters for the other, to arrive at the best design for a given site in which social, economic and environmental factors.

2.11. Business model and market analysis for SWAC

The project has included a detailed market and replication analysis, led by the University of Exeter, identifying and quantifying the short-term and long-term market segments within and outside the Channel Area, relying on a comprehensive set of technical, climate-related, environmental and economic criteria, as well as 10 short-term replication sites (at least one in each Region of the Channel Area) in the Area (25 by 2026, to be launched by 2030). The market analysis is combined with the study of associated business models and the elaboration of exploitation plan to foster market uptake. This market study is a major contribution as it helps with communicating with potential new clients of SWAC.

2.12. Aquaculture potential

The project has also demonstrated, in work led by NLH, that the discharge water from a from a shallow-water SWAC system has potential to be used to improve the efficiency of aquaculture activities, since its higher temperature can accelerate the growth of species. The research shows that discharge water is suitable as a growing medium for hatchlings given its temperature, pH, carbon dioxide and dissolved nutrient levels. More details are available in 216-T1.4-NLH-001 - Potential of using SWAC's discharged water in aqua farms.[6]

3. Demonstrator projects and feasibility studies

3.1. Brixham Lab

Formerly owned by AstraZeneca, Brixham Lab was donated to the University of Plymouth in 2014, which now rents out its space and facilities to a variety of separate organisations. Across the site, heating is currently provided by conventional gas-fired boilers and cooling by conventional electrical chillers (using glycol). Brixham Lab is sited directly adjacent to the sea and had a system called a 'sustainability loop' installed in the 2008. The intention was to use seawater to cool the ground floor of a new building constructed that year. The seawater is brought into a pump house (at the front of Brixham Lab) via two abstraction pipelines in the Bay. Only one of the pipelines is used at any one time, and each pipeline has its own pump. Ambient air is brought into the building and seawater used via heat-exchanger to cool, or heat, that air to a target 16°C. This air at 16°C would then be distributed to different parts of the site, for further cooling or heating with additional HVAC equipment, depending on the required temperature.

The system did not however prove economically viable to operate because the seawater was sourced from very shallow water, and therefore the temperature differential between

[6] Only available in English.

the air and water was insufficient (i.e., the seawater was not cool enough in the summer). The energy in pumping seawater outweighed any energy savings offered, particularly as it was designed to cool just one floor of one building, rather than the entire site. This meant that the seawater sustainability loop was not cost effective to run compared to the conventional HVAC systems installed at the site. Moreover, there were concerns that seawater abstraction might disturb the operations of one of the Brixham Lab's tenants, a contract research organisation which uses seawater for environmental testing of pharmaceuticals and other compounds. The SWAC system was therefore left dormant for over a decade.

The EUROSWAC project's key contribution at Brixham Lab was the installation of a third abstraction pump which separates the abstraction line, enabling a SWAC system to be run without disturbing the tenant. The new configuration was trialled for heating purposes for several hours during cold spells in December 2022 and January 2023. In the latter trial (when the outside air temperature was 3°C), a 53% reduction in demand from the site's gas boilers to maintain an inside air temperature of 16°C was indicated due to the contribution from the seawater (being pumped into the building at 10°C). As with the NLH Newlyn site (Section 3.2), the introduction of a heat-pump to work alongside Brixham Lab's seawater loop would effectively boost the temperature allowing a greater differential and hence improving the system's overall efficiency. Other changes for the SWAC system at Brixham Lab were also explored and costed by DPI.

As part of the EUROSWAC project sensor-carrying buoys have been installed in the waters close to Brixham Lab's SWAC intake pipe to monitor baseline levels of a variety of physical and chemical parameters (e.g. water temperature, salinity, etc.), and changes should the SWAC system enter full-time operation (Section 2.4 has more detail on this).

3.2. NLH, Newlyn

In 2017 the National Lobster Hatchery (NLH) built an off-site hatching, growth and research facility consisting of two former shipping containers situated on the southern end of Newlyn harbour on the south Cornwall coast. The developing lobsters are housed in water-filled tanks within the shipping containers. The NLH Newlyn site is conceived of as a lobster hatching 'module' enabling the installation to be easily moved to new locations as needed. From the perspective of lobster hatchling rearing, Newlyn is considered a better site than NLH's main site at Padstow because the seawater at Newlyn is of better quality (i.e., less turbidity).

At Newlyn, the key thermal challenge is that as the air in the shipping containers warms during the summer, this elevates the temperature of water within the holding tanks above 19°C, the optimum for lobster development. If too hot, hatchlings grow fast, but are less robust due to insufficient calcium absorption into the exoskeletons. Currently, conventional glycol chillers are used to cool the facility, but this consumes significant electrical energy at great cost. During the winter, meanwhile, temperatures dip significantly below the optimum, and warming is then provided via conventional electricity. The heating and cooling costs in the hatchery are therefore considerable.

A SWAC installation, in combination with a reversible heat-pump, could maintain the optimum temperature levels year-round at an operating cost far below that of the present HVAC arrangement. The Newlyn site has already elements of a potential SWAC system in that seawater can be manually pumped into the shipping containers from an intake pipe located further down the harbour wall. This seawater is used as a medium for the lobsters, and is pumped into the rearing tanks on the incoming tide (which is of a better quality than it is on the outgoing tide). The submerged section of the intake pipe is not particularly long, and indeed is exposed at low tide.

As part of the EUROSWAC project, a design to adapt the existing infrastructure for a shallow water-based SWAC system – without interfering with lobster development - was developed and costed. This would involve a valve being installed at the end of the intake pipe, allowing the seawater currently used for the lobster tanks to be instead directed into a new thermal loop via a small heat-exchanger connected to the ventilation system. The installation of a variable pump switch accessible in stormy weather, an air-source heat pump, solar photovoltaic cells and external insulation cladding, to be used in conjunction with the SWAC system, were also costed. With sufficient capital, this hybrid heat pump-SWAC system could be the first of its kind anywhere in the Channel Area to support aquaculture, representing major benefits in terms of reductions in both greenhouse gas emissions and costs compared with existing solutions. Moreover, an opportunity exists to scale up the installation should additional end-users located on or close to the Newlyn harbourside benefit from the same SWAC facility. These might include local businesses such as a fish market and harbour offices, as well as residential dwellings. This 'district cooling model', which may substantially increase the cost-effectiveness as well as environmental and social benefits of a single SWAC installation, is discussed in Section 4.4.3 for Falmouth, another Channel Area site with replication potential for the SWAC technology.

3.3. Feasibility studies

Several feasibility studies for the installation of temperate, shallow-water SWAC systems, have also been initiated and scoped by DPI in France during the course of the EUROSWAC project. These studies have been conducted at Océanopolis Maire d'Etel and on a big industrial site in Normandy. Further details are provided in Section 4.3.

4. Future replication sites

4.1. Introduction

This section assesses the potential for future short-term and long-term replication within the Channel Area. Revisiting environmental optimisation carried out within T4, this section first highlights, based on bathymetrical evaluation, which coastal communities have potential for SWAC usage, in the summer and winter, and during the whole year. A range of short-term replication sites are then presented based on these data, comprising large, individual end-users, or clusters of smaller sites that could benefit at a district scale.

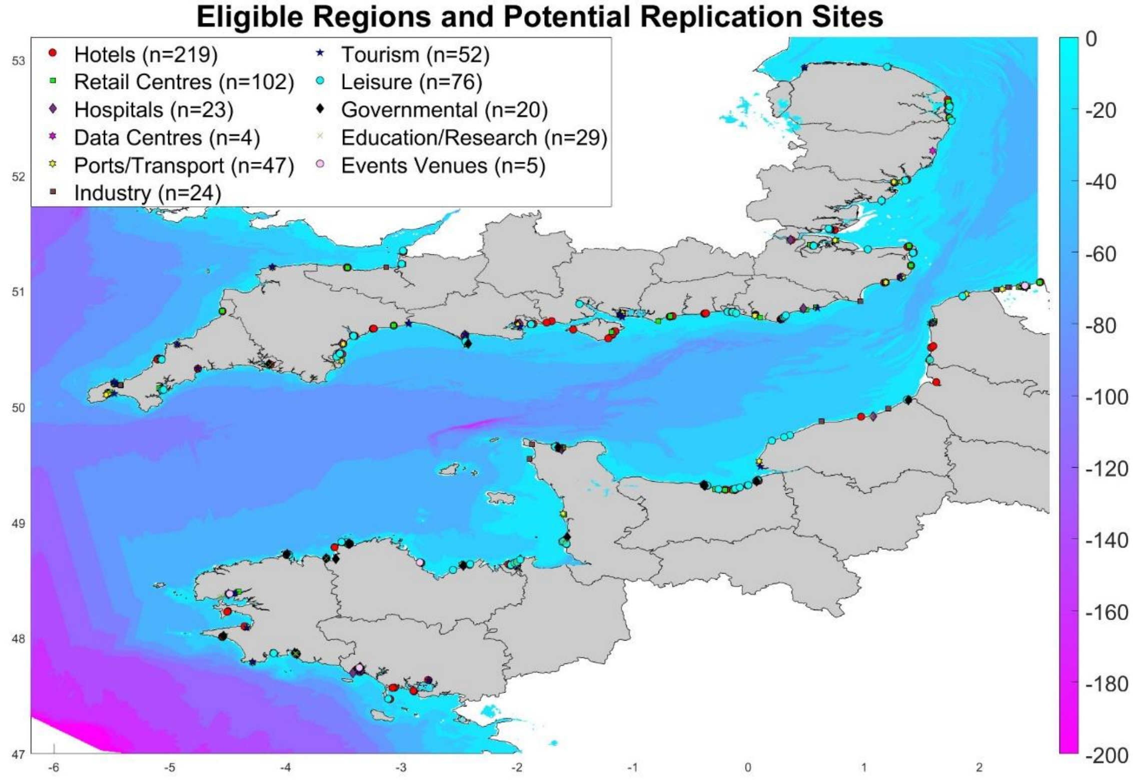
From these, the most prominent market sectors to be targeted by dissemination activities in the longer term, are also identified. The section closes with a simple decision tree that non-experts can use to determine whether potential for SWAC exists at a given site before commissioning a more detailed - and expensive - feasibility and other technical studies.

4.2. Bathymetrical evaluation

4.2.1. Identifying locations and sites

The full methodology deployed to explore the optimum sea temperatures for SWAC deployment is detailed within Deliverable T4.2 (EUROSWAC Replicability Analysis). In brief, however, an initial sample of 601 possible replication sites in 137 locations (i.e., coastal communities)[7] was identified (Figure 1).

Figure 1: Eligible regions and potential replication sites



[7] 322 sites at 69 locations in England and 298 sites at 68 locations in France.

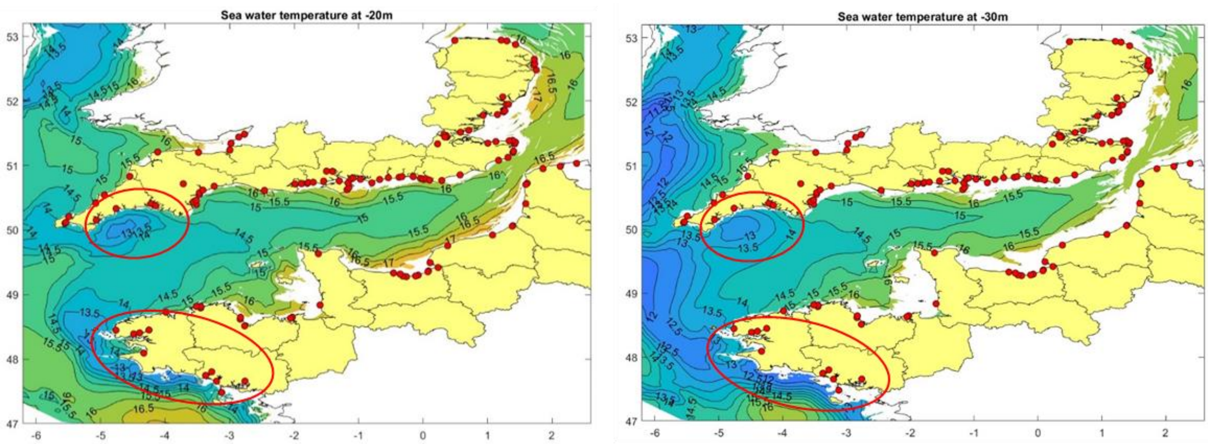
Each location was selected on the basis of various factors, including proximity to the shore, population size, the presence of key industries (e.g., museum, hotels, recreation, hospitals, supermarkets, etc.), prevailing HVAC technologies and a likely demand for specific year-round temperature control.

These 137 locations were analysed according to their year-round sea and air temperatures, to ascertain the potential for SWAC cooling during the summer months, along with those regions ideal for cooling and heating during the winter months. The output from these maps then provided an overlap between the summer and winter months, identifying regions which have the potential for year-round heating and cooling.

4.2.2. Locations with summer cooling potential

Analysis from the maps shows a lack of established thermal stratigraphy within the Channel, with the temperatures of waters at different depths being mixed by various tides and currents. As Figure 2 shows, there is little difference between sea temperature (at a depth of 0 metres) and air temperature, the latter averaging between 18 and 22°C in the summer.

Figure 2: Summer sea temperatures at depths of 20 and 30 metres

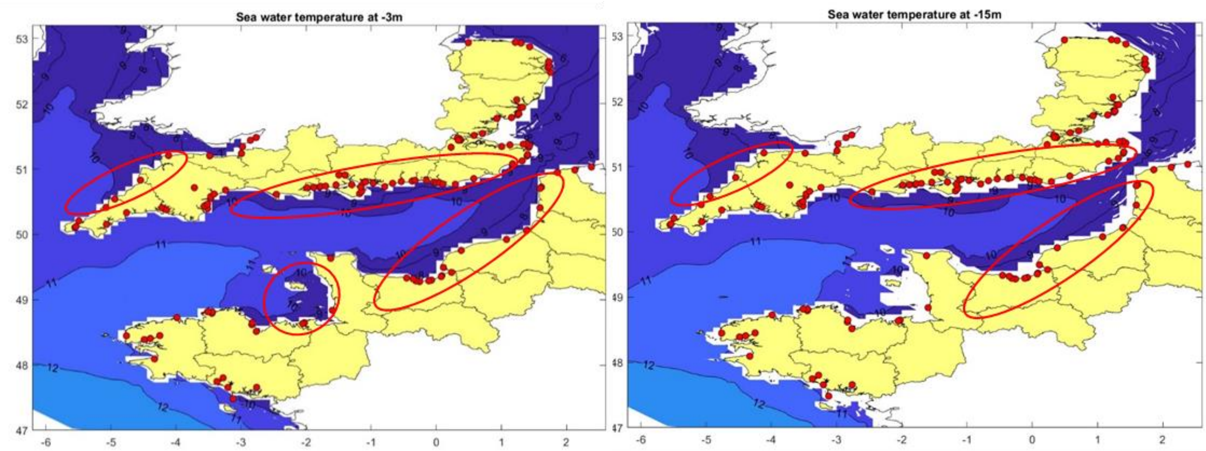


Parts of the Devon and Cornwall coastline in the UK, and the Atlantic coastline of Brittany demonstrate a potential for cooling during the summer months. Water temperatures in these two areas can vary between 13 and 14°C at a depth of 20 metres, and 12 and 13°C at a depth of 30 metres. These cooler temperatures theoretically facilitate SWAC cooling in and around Falmouth, Plymouth and Brest.

4.2.3. Locations with winter cooling and heating potential

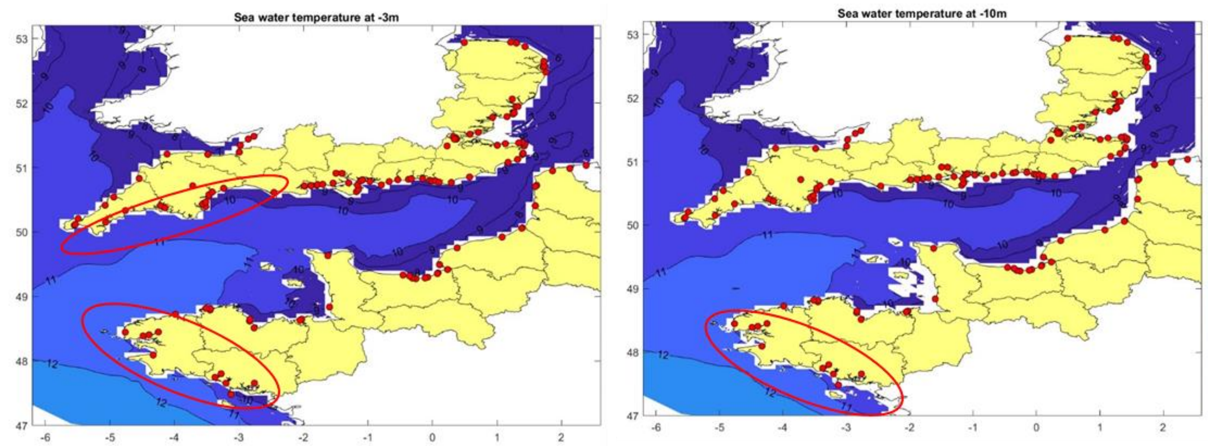
As with the summer months, during the winter there is little difference between the water and air temperatures within the Channel Area (both averaging between 7 and 10°C), with no established thermal stratigraphy. Colder waters are found on the eastern coasts of the Channel Area due to currents flowing in from the North Sea. Figure 3 shows that during the winter shallow seas offer sufficiently cool waters for the north Devon coast, the South East coast, and the Anglian coast of the UK, in addition to the North Eastern coast of France. Depths of up to 15 metres in these areas see seawater cool to a temperature of between 9 and 10°C.

Figure 3: Winter sea temperatures at depths of 3m and 15m.



Some industries (particularly those within the tourism and leisure sector) also require heating during the winter months. Figure 4 illustrates how the southern coasts of Devon and Cornwall, in addition to the Atlantic coast of Brittany, demonstrate a potential for heating during the winter, with sea temperatures measuring up to 12°C depending on depth (up to 10 metres deep).

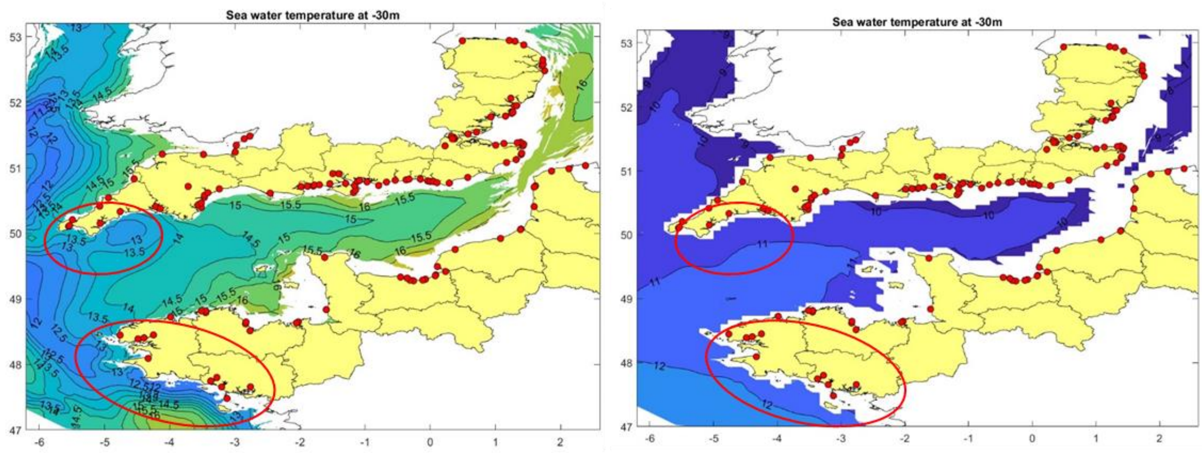
Figure 4: Winter sea temperatures at depths of 3m and 10m



4.2.4. Locations with year-round cooling and heating potential

Figure 5, created by overlapping the earlier maps of cooling and heating potential, indicates that the southern areas of Cornwall and Devon in the UK, along with the Atlantic coast of Brittany, can benefit from year-round SWAC usage. In these zones, a temperature difference between land and sea of at least 4 or 5°C is maintained during the summer (with the sea cooler), and SWAC can therefore be used for cooling; during the winter, the same areas again have at least a 4 or 5°C temperature difference (with the sea warmer), supporting the role of SWAC in heating.

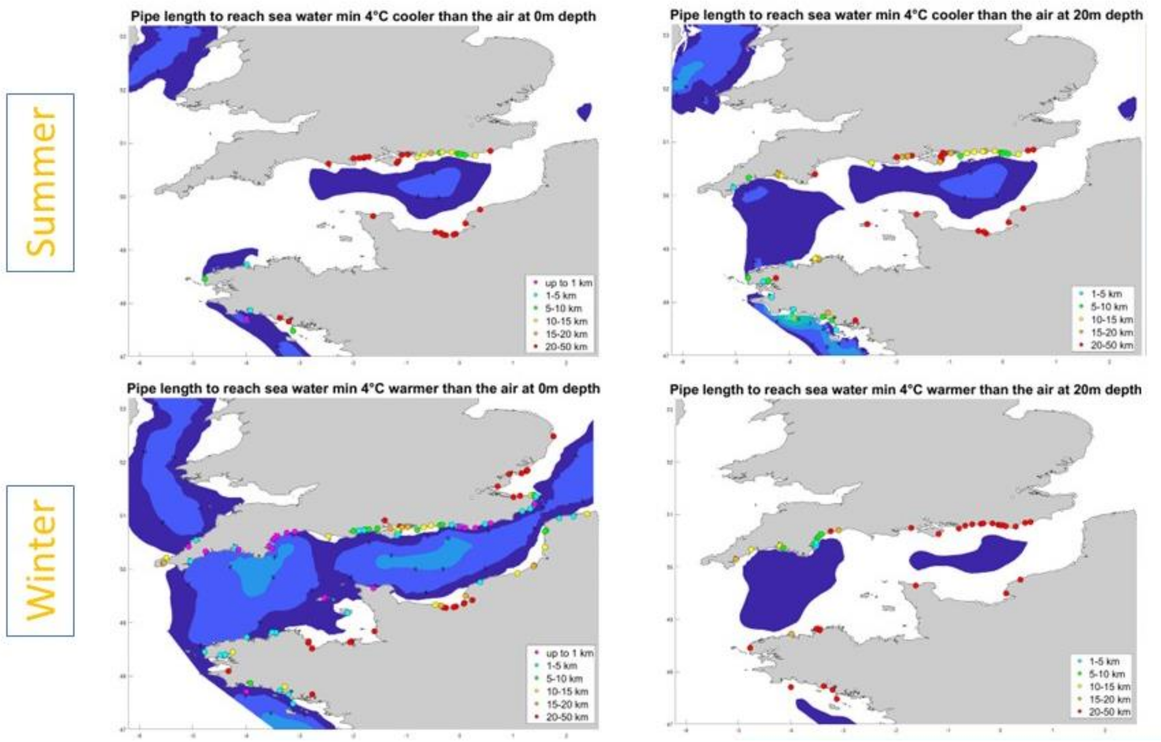
Figure 5: Summer and Winter sea temperatures at a depth of 30m.



For sites located in these zones which require year-round heating and cooling, a SWAC installation coupled with a reversible heat-pump is likely to be feasible and to offer substantial energy savings. These areas therefore present an opportunity for future, short-term replication, with a particular focus on coastal sites within the salient market segments which demonstrate an ability to invest. Generating the maps showing where the air-sea temperature difference is exceeding 4°C (Figure 6), allowed to calculate a minimum pipeline length to each potential replication site. This was used to asses the overall cost of the SWAC system at each site (Ola to add the map).

The two demonstration sites of the EUROSWAC project – Brixham Laboratory and the NLH in Newlyn – have benefited from being situated within optimal areas (Section 3). Various potential, short-term sites in France, including Océanopolis, and the Glacière Municipale d'Étel, are also all situated in or near the optimal zone of Brittany's Atlantic coast. These and other potential short-term sites are detailed further below.

Figure 6 The lenght of pipeline needed to reach a 4°C air sea difference for the potential depths.



4.3. Short-term replication – individual sites

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As noted, 601 short-term replication sites in England and France were identified based criteria set out in the Project Plan and the bathymetrical evaluation. Initial engagement was conducted with six large, individual end-users. Those in the French Channel Area were identified by ENSTA Bretagne, and those in the UK by the University of Exeter. Key contacts at each site were contacted directly via email, phone or visit – or were approached indirectly via professional bodies (e.g., fishers associations, energy providers, aquarium managers groups). Some sites have already benefited from interaction with the EUROSWAC project itself, and have provided important data on temperature requirements. It may be possible to install SWAC systems in some or all of these sites within the next two to three years, should external funding be available (see Section 8). When assessing the potential of a given site identified in market research, the SWAC decision tree (Section 4.6) and SWAC design optimisation tool (Section 2.10.1) can be deployed rapidly to check feasibility at an initial stage.

4.3.1. Carbis Bay Hotel and Resort (UK)

Carbis Bay Lodge & Estate is a luxury hotel resort situated near St Ives on the northern coast of Cornwall, and hosted the G7 summit in summer 2021. An introduction was held between Carbis Bay and the University of Exeter in April 2022. Carbis Bay was interested in SWAC technology, given that it was also reviewing the air-conditioning options for its beach lodges. Whilst the initial introduction promised further meetings regarding technical questions, further communication was not received until May 2022, when it was agreed by the project partners that the feasibility studies in France would be all that is possible within the agreed timelines of the project. Nonetheless, Carbis Bay could become a short-term replication site should a review of its air conditioning needs take place in the future. Sited towards the end of the Cornish peninsula, Carbis Bay is ideally located for year-round SWAC usage for heating and cooling, allowing the hotel to potentially reduce its emissions.

4.3.2. Les Glénans (France)

Les Glénans is a non-profit organization based in Brittany, France, which operates a sailing school in the Gulf of Morbihan and a tourist resort on the island in the same Gulf (Les Glénans Île D'arz). DPI has led promising discussions with Les Glénans who have shown an interest in the SWAC technology. Given the small size of this end-user it is unlikely that SWAC alone would be a viable solution, although there may be potential when used in combination with other renewable energy technologies (as per sites such as NLH Newlyn (Section 3.2)).

4.3.3. Glacière Municipale d'Étel (France)

Situated in Étel, Morbihan, La Glacière Municipale d'Étel (France) is a former ice-making facility: fishers used to take ice out with them, but in modern times fishing vessels no longer require this facility. Today, the cooling building is used for the storage and refrigeration of tuna, with the city hall spending considerable sums on air-conditioning each year. SWAC could be deployed for the refrigeration and maintenance of both tuna, and the ice used to cool the produce. SWAC provides great potential for Étel, since it already has a pipeline for pumping in seawater, allowing for the use of seawater to cool tuna during the entire year. Mairie d'Étel was identified by ENSTA Bretagne as being open to the SWAC concept, and like Falmouth, is located in one of the 'optimal' zones (indicated in Figure 5) for a hybrid SWAC-heat pump installation. Working closely with ENSTA Bretagne, DPI and the University of Exeter, Mairie d'Étel is the site of a feasibility study, in which basic designs for a SWAC will be developed based on inputs to be provided by the site. The feasibility study calculates Mairie d'Étel's thermal needs (i.e. heating and cooling the building, and drying the air) to ascertain whether the existing pipe can be used for a SWAC installation.

4.3.4. Nausicaá Centre National de la Mer (France)

Located in Boulogne-sur-Mer in northern France, the Nausicaá Centre National de la Mer is the largest public aquarium in Europe, and again was identified by ENSTA Bretagne as potentially interested in a SWAC installation. Nausicaá's location in Boulogne-sur-Mer means that it is ideally positioned for SWAC-based cooling during the winter months, thanks to coldstreams from the North Sea. Nausicaá provides further commercialisation potential for SWAC, exploring the use of SWAC and its positive usage towards Nausicaá's main aim, the exploration of the relationship between mankind and the sea.

4.3.5. Océanopolis (France)

Located in Brest in Brittany (so not directly on the Channel shore), Océanopolis is an ocean discovery park which boasts 77 aquaria, housing 10,000 animals in over 4 million litres of seawater. As an aquarium, Océanopolis requires simultaneous year-round heating and cooling of seawater to maintain habitable conditions for the numerous animals in its care. This consumes millions of Euros-worth of energy annually. Its location on the Atlantic coast of Brittany means that it would benefit from the potential of year-round heating and cooling from SWAC usage (as indicated in Figure 5). Océanopolis, was identified by ENSTA Bretagne as potentially interested in a SWAC installation, and as an external partner it has maintained interactions with the project during the duration. Working closely with ENSTA Bretagne and DPI, Océanopolis is the site of another of the feasibility studies due for completion by March 2023, in which basic designs for a SWAC will be developed based on inputs provided by the site. The site's simultaneous requirement for both heating and cooling means that a SWAC system could be extremely efficient. This is because thermal energy from the warmed water discharged from the cooling loop (e.g., used for the penguins) could be directed to a heating loop (e.g. used for tropical fish species), rather than being lost back into the sea.

4.3.6. Big industrial site (France)

Situated in La Hague on the Normandy coast, the plant represents a potential future site for SWAC due to its need for large-scale, year-round cooling and location close to the sea. It is the site of one of a feasibility study led by DPI and Doris Marine due for completion by March 2023, in which a basic pre-design and costing of pipelines and subsea structures for a SWAC are being undertaken. As the maps in Section 4.2 indicate, the facility's location allows for the ideal use of seawater for cooling during the winter months. It may also have the infrastructure already available to abstract seawater. Should the collaboration with them be successful this could lay the groundwork for other equivalent sites hosting a network of SWAC installations in the future, depending on the optimisation required for its local area.

4.4. Short-term replication – district-scale sites

A further four coastal communities that, in the short-term, could benefit from district-scale SWAC installations, in which a single abstraction pipeline is shared by multiple sites, were also identified.

4.4.1. Brighton (UK)

A seaside resort, Brighton is located in East Sussex and home to approximately 290,000 residents. For SWAC, Brighton represents an opportunity for growth thanks to the number of potential sites within one kilometre of the coast. Brighton boasts a wide network of hotels (including smaller and larger chains) in addition to tourist and leisure attractions. SEA LIFE is also located in Brighton, affording the possibility of providing a replication site within an aquarium setting. Optimisation analysis show that Brighton – and its wide variety of industries - is ideally situated for winter cooling through SWAC technology.

4.4.2. Calais (France)

Similarly to Southampton, Calais benefits from a port which would be able to host the infrastructure for a SWAC system for winter cooling. The benefit of using the port of Calais would enable the uptake of SWAC cooling within other industries within the town centre. Of further importance, however, would be the potential of deploying SWAC technologies within the marine transport sector, as discussed by the Project during Sea Tech 2022. With numerous vessels docking daily in Calais, the region provides potential for the growth of SWAC technology within the marine transport sector.

4.4.3. Falmouth (UK)

Falmouth on the southern Cornwall coast is located in one of the 'optimal' zones (indicated in Figure 5) for a hybrid SWAC-heat pump installation, with cooling provided in the summer and warming in the winter. One future feasibility study could be for the Falmouth Harbour Commission as scope exists for a district-level heating and cooling project in which multiple sites in and around the harbour benefit, including a hospital, the Maritime Museum and residential buildings.

4.4.4. Plymouth (UK)

Located on the border between Devon and Cornwall, Plymouth is a port city which also carries significant potential for future SWAC installation. Plymouth benefits from a shipbuilding dockyard which may be able to carry the infrastructure for SWAC installations, whilst also benefitting from numerous businesses close to the shoreline which may be interested in future SWAC uptake, including the National Marine Aquarium. Given its position on the border with Cornwall, Plymouth benefits from the potential of year-round SWAC usage, with heating available in the winter and cooling available in the summer.

4.5. Long-term market sectors

The long-term upscaling of SWAC systems requires them being adaptable to a wide range of industries. A simple analysis was conducted of the 601 sites identified to ascertain which market sectors were most commonly represented. Within the Channel Area, the most prevalent market sectors in terms of outlets consist of **tourism and leisure attractions**, **hotels** and **retail**. The benefits of SWAC technology and subsequent energy savings are substantial, depending on the nature of heating and cooling required for each industry. For longer-term scale up of SWAC in the Channel Area, communication and dissemination efforts should be targeted at these sectors.

4.5.1. Hotel accommodation

The predominant market sector within the Channel Area was hotel accommodation with 219 outlets. Hotels maintain a year-round need for heating and cooling to ensure the comfort of guests and staff alike, whilst some hotels may also require SWAC for use within swimming pools and in-house spas. Given that the temperature of seawater in the Channel Area is relatively constant, between 14 and 16°C, throughout the year, and that swimming pools need to be at around 18°C, a relatively small margin of additional heating would be needed. The hotel industry also maintains significant potential within the Channel Area. The 51 hotels outlined were evaluated to have fulfilled the criteria, which also included the "ability to invest". Many hotels were excluded from the sample on the researcher judgement that they may not be able to afford the capital expenditure required. Indeed, smaller hotels may need reassurances over performance and cost savings before taking any decision to investment.[8] As SWAC uptake increases, and the infrastructure becomes more prevalent thus guaranteeing further widespread performance, more smaller chain hotels will be in a position to install SWAC, depending on the business model offered. As noted above, partners in the EUROSWAC have already engaged with the Carbis Bay Hotel and Resort in the UK (Section 4.3.1).

4.5.2. Tourism and leisure

"Tourism and leisure" was the second most common market sector represented, with 128 outlets, comprising a diverse range of activities. The most prevalent tourism activities within the Channel Area are museums, spas, aquaria, and casinos (the latter of which appeared mostly on the French coast). Other outlets include seafront restaurants. Each site contains its own demand for heating and cooling. Museums will seek to provide year-round heating and cooling for visitors and staff, but may also need to be mindful of the maintenance of temperature to protect artefacts. Spas not only require air conditioning, but also the cooling and heating of water for therapeutic treatments. Aquaria, meanwhile, require the regulation of water to protect the animals in their care. In summary, the tourism and leisure sector provide the biggest opportunity for growth within the Channel Area, but future suppliers of SWAC systems will need to consider the specific heating and cooling needs of each attraction. As noted above, partners in the EUROSWAC have already engaged with the tourism not-for-profit Les Glénans (Section 4.3.2), as well as with two major aquaria in France: Nausicaá (Section **Erreur ! Source du renvoi introuvable.**) and Océanopolis (Section 4.3.5). It is also worth noting that in the UK, the National Trust, which owns a large number of tourist sites and visitor attractions with a heritage appeal, has already demonstrated an interest in marine renewables: in 2014 the country's largest marine source heat pump was installed at the National Trust's Plas Newydd mansion in North Wales.[9]

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[8] López-Bernabé et al., 2021. Factors affecting energy-efficiency investment in the hotel industry: survey results from Spain. *Energy Efficiency*. https://doi.org/10.1007/s12053-021-09936-1.
[9] https://www.imeche.org/news/news-article/national-trust-installs-uk%27s-largest-marine-source-pump-220514-01

4.5.3. Retail, including supermarkets

Retail, including supermarkets, was the next most common market sector, with 102 outlets, the majority sited on the England side of the Channel Area. Retail outlets of all sizes maintain a year-long need for heating and cooling not only for the comfort of staff and customers, but also for the production and maintenance of produce.[10] Furthermore, large-chain supermarkets often have the financial and technical resources to invest in innovative, more sustainable technologies, while including sustainability reporting among their key performance indicators. Representatives from a major UK-based supermarket chain met with researchers from the University of Exeter during the course of the project, and were interested to learn how SWAC technology would generate energy and carbon savings. The supermarket, while not yet ready for a feasibility study, wished to see more data on the deployment of SWAC within a retail setting.

4.5.4. Other promising market sectors

A number of other market sectors should also be investigated for SWAC replication, as detailed below:

- **Ports and maritime transport:** Another potentially fruitful market to explore is marine transport, including the ship-building industry. Some 47 port and transport sites were identified in the Channel Area with a potential for SWAC installation. These included a number of harbours, which as noted elsewhere, offer the potential for district scale SWAC installations. Ports and maritime transport also emerged as a key market sector during Sea Tech Week,[11] a major international biannual event held in Brest, France, dedicated to marine and maritime science and technology, at which the EUROSWAC project was represented in September 2022. For instance, large passenger cruise liners are, in effect, floating cities with many thousands of passengers on board, with swimming pools, etc. Currently, they consume significant quantities of energy, in the form of bunker oil for combustion, or sourced from the quayside. SWAC could play a role here, particularly as many such vessels ply the tropical waters of the Mediterranean or Caribbean further increasing their need for cooling. As well as at future Sea Tech Weeks, the maritime transport industry could be engaged with via major conferences such as SMM in Hamburg, Germany, which in 2022 attracted 2,000 exhibitors from many technology areas, and over 30,000 visitors from over 100 nations.[12] Another possibility would be to contact technical committees from international conferences such as the International Ship and Offshore Structures Congress (ISSC), a forum for the exchange of information by experts undertaking and applying marine structural research,[13] or the International Symposium on Practical Design of Ships and Other Floating Structures (PRADS), a series of triennial symposia, aiming at an international exchange of new knowledge

[10] Pardiñas et al., 2021. Modeling of a CO2-Based Integrated Refrigeration System for Supermarkets. *Energies,* 14, 6926. https://doi.org/10.3390/en14216926
[11] https://www.seatechweek.eu/
[12] https://www.smm-hamburg.com/
[13] https://www.issc2022.org/overview/

and achievements with regard to the design, research and development of ships and other floating structures.[14]

- **Data centres:** A conclusion of the EUROSWAC project is that for small sites, with seasonal needs an adapted, scaled-down design of SWAC is often likely to be appropriate. A more 'traditional' SWAC installation is however suited for large sites with uniform cooling needs. This includes data centres, which are a promising replication opportunity. There is growing public pressure on technology companies to address the environmental impacts of cooling their servers, and in fact some data centres are already being directly submerged in the sea for cooling.[15] The market analysis revealed very few data centres currently located in the Channel Area ikn close proximity to the shore. Thus, a key recommendation is that future data centres, supporting large private and public sector organisations (e.g. universities, local authorities, large manufacturers, etc.), are sited close enough to the shoreline for SWAC to be a viable option.

- **Nuclear facilities:** Like data centres, nuclear sites plants have uniform cooling needs. For safety reasons, nuclear combustibles after their use must be cooled in pools for several years prior to geological storage. As they cool the combustibles release heat causing the pools to boil. SWAC might have potential in cooling the pools, and preventing evaporation given that many nuclear facilities are located along coastlines.
- **Marine energy:** The outputs have relevance to the marine energy section. Some EUROSWAC outputs could be targeted beyond air-conditioning. For instance, the studies on a self-burying pipe system (Section 2.8.1), on flexible pipes (Section 2.8.2), and on sacrificial anode cathodic protection (SACP) to slow corrosion of subsea components (Section 2.8.3) will be of great interest to the offshore renewable energy sector, as well as for those engaged in oil and gas exploration. SWAC itself, as a form of renewable energy, may be of interest to oil and gas companies for reputational reasons; for example, Total, a French petrochemical business, is interested in using seawater in a related but distinct process known as 'ocean thermal energy conversion' (OTEC),[16] rather than fossil fuels, to power air-conditioning on their drilling platforms. Stakeholders in the marine energy sector can be targeted via industry events such as FOWT (floating offshore wind turbines) and OEE (Ocean Energy Europe).

- **Aquaculture:** As the NLH Newlyn demonstration project shows in the case of lobster rearing, there is also the potential to link SWAC systems with processes within the aquaculture sector. Research conducted by NLH shows that the discharge water from a shallow-water SWAC system may be suitable as a growing medium for hatchlings given its temperature, pH, carbon dioxide and dissolved nutrient levels.

[14] https://prads2022.fsb.hr/
[15] https://natick.research.microsoft.com/
[16] NB. OTEC is different to SWAC in that it uses the difference between hot and cold water to create electricity. But in SWAC, the thermal energy in seawater is used directly.

4.5.5. Job creation potential from SWAC

As well as those jobs created from the need to install, maintain, repair and/or refurbish a SWAC system, further employment opportunities may also be created linked to the environmental surveys which always need to be carried out prior to the installation, and in business development and marketing functions. Additional jobs may also be created for decommissioning SWAC systems at the end of their operational life. An initial conservative analysis, whose methodology and assumptions are detailed in report 216-T4.3-UNE-002 Buisness and Market Analysis, indicates that between 50 and 200 new jobs could be created based on the number of potential new SWAC installation sites identified in the Channel Area. The lower numbers are if SWAC replaces an existing conventional system at a site, and the upper figures represent cases where a new SWAC system is installed. The jobs creation potential is likely to be highest in the case of circular economy-orientated SWAC systems. This is because people would be needed to develop specialist designs for modular-style SWAC systems, enabling repair and refurbishment of an installation without interruption to function.

4.6. Decision frame

When determining whether or not a SWAC installation is viable in a given location, many geographic, technical, environmental, social, financial and other factors have to be considered. Some are difficult and costly to measure, and gauging their likely impact on the performance of the asset can be complex. In practice, before deciding to proceed an end-user will almost certainly need to procure the services of environmental consultants, engineers, designers, business experts and others. These specialists are expensive to hire, which can be a significant barrier to proceeding with an installation. However, some key factors, which non-specialists can assess for themselves, strongly indicate a site's potential for SWAC:

- **How much power the site requires**. If a site uses more than 100 kW for heating and/or cooling, then SWAC may be worth considering. The amount of energy required will be a function both of the amount of space to be heated or cooled, and the total period over which the thermal function is needed. As a rule of thumb, SWAC may only be feasible where the minimum floor area needing air-conditioning exceeds 1,000m^2, which could include multiple floors of a multistorey building. Likewise, SWAC is more likely to be appropriate if heating and/or cooling is uniformly needed, 24 hours per day, 365 days of the year, rather than during normal office hours only. Thus, a hospital would, in principle, be better suited than an office block. In the Channel Area, continuous year-round use ensures a rapid return on investment for a SWAC installation.

- **The target air temperature required.** While SWAC can play a role in reducing the energy needed to achieve extreme temperatures it works best when non-extreme heating or cooling is needed. For cooling, the higher the temperature needed, the better the coefficient of performance (i.e., the more savings made), while for heating the lower the temperature needed, the better the performance.

- **The nature of the site's thermal requirements.** Rather than requiring cooling or heating alone, an ideal site for SWAC will simultaneously need both heating and cooling. This means that the thermal energy in seawater released from a cooling system can be used for a second task, rather than being lost back into the sea. Examples might include industrial laundries, such as those cleaning hospital textiles, where both heat (for cleaning) and heat and cool for drying is needed all year round or aquariums, with cold-water and warm-water species on display (as it the case at Océanopolis, discussed in Section 4.3.5).

- **Access to the sea.** As a rule of thumb, the site should be located no further than two kilometres from the shoreline, to ensure that the temperature of the seawater pumped into the site has not warmed up (or cooled down) too much before it reaches its destination. The site should be located within a coastal region of the Channel Area able to access to optimum sea temperatures, in other words, waters whose mean temperature is sufficiently different to that of the air to support a SWAC system (as detailed in Section 4.2). Moreover, the physical profile of the sea shore should favour easy access to deep water, minimising the length of pipeline required to reach deep water. Also, the smaller the tidal range, the shorter the pipeline required to reach deep water, although, as noted, the EUROSWAC project has demonstrated that shallow-water systems are feasible within the Channel Area. Ideally, the sea from which water is abstracted is protected from storms, for instance by a breakwater, reducing the investment needed to protect the pipeline.

- **The presence of obstacles** Access to sea is not just a function of distance but also whether or not roads, railway lines, buildings, and other infrastructure obstruct the path of a future seawater pipeline to the shore. Similarly, protected parts of a shoreline, for instance, areas designated as a nature reserve or Site of Special Scientific Interest (SSSI), can constrain the choice of construction materials permissible to use, or prevent construction altogether. Furthermore, multiple landowners may be required to give permission; for instance, the entities owning a harbour front, a beach and a seabed, across which a pipeline may need to be laid, may all be different. Sites with an existing right of ownership over the point of entry to the sea are well placed to benefit from SWAC.

- **The presence of key SWAC system components**. The most expensive element of a SWAC system is the installation of an abstraction pipeline into the sea. If a site is already pumping water for processes, as is the case with Brixham Lab (Section 3.1) and NLH Newlyn (Section 3.2), this can considerably reduce the capex needed – assuming the installation is of the appropriate design (e.g., pipe diameter, pump flow rate), as can an existing licence to abstract and release seawater.

- **The opportunity for a district-scale installation.** As noted above the viability for SWAC improves with scale, with large sites consuming significant quantities of energy most suited to the technology. However, if several sites located close to each other can be cooled and/or heated with seawater abstracted from a single pipe, then even smaller sites in the Channel Area might benefit from SWAC because its costs would be spread across multiple end users.

Based on these factors, the following simple decision tree has been developed which can be used whenever assessing a site for its SWAC potential (Figure 7).

Figure 7: SWAC Decision Tree

Choose A or B:			A		B
1.	What is your site's current power need for heating and/or cooling?	More than 100 kW		Less than than 100 kW	
2.	How often is heating and/or cooling needed at your site?	More than 2,080 hours/annum (i.e., 8 hours per day, 5 days per week, 52 weeks per annum)		Less than 2,080 hours/annum	
3.	For heating, how warm do you need the site to be?	Between 18°C and 20°C		18°C or less / 20°C or more	
4.	For cooling, how cool do you need the site to be?	Between 5°C and 18°C		Less than 5°C / More than 18°C	
5.	What are your site's thermal requirements?	Heating & Cooling		Heating only / Cooling only	
6.	How far is your site from the sea?	Less than 1 km		More than 1 km	
7.	Are there any potential obstacles between your site and the sea (e.g., rail, roads, buildings, nature reserve, etc.)?	No		Yes	
8.	Do you have rights of ownership over the point of entry to the sea?	Yes		No	
9.	Does your site have any of the following elements of a SWAC system already installed (e.g., pipeline into the sea with pump, heat- exchanger)?	Yes		No	
10.	Does your site have a licence, permission or Environmental Impact Assessment for abstracting or releasing seawater?	Yes		No	
11.	Are there other potential end users in your vicinity (i.e,. within 2 km) with whom you might be able to share the costs and benefits of a SWAC system?	Yes		No	
TOTAL 'As' and 'B'					

SCORING	
How many As?	**SWAC potential ?**
4 or fewer:	**SWAC is very unlikely to be viable**
Between 5 and 8:	**SWAC may have potential and is worth investigating**
More than 9:	**SWAC has definite potential**

5. Target groups and exploitation activities

5.1. Target groups

This section discusses the target groups which may play an important role in the dissemination of SWAC, and in some cases may themselves also become potential SWAC end-users (as summarised in Table 1). In practice, for an end-user the distinction between public and private may be less important than the size of their thermal energy demand. For any large installation, whether publicly or privately owned, SWAC offers the potential of a significant reduction in operating costs.

Local and regional governments can assist relevant permitting processes as well as potentially providing future assistance. Following the work undertaken at Brixham Lab, University of Plymouth researchers are already engaging with Torbay and Plymouth City Councils about the potential for SWAC. At the same time, local and regional government sites located in coastal areas might themselves benefit from SWAC installation. In the UK local enterprise partnerships (LEPs) can signpost to sources of funding.

National government departments (e.g., BEIS, Le Ministère de la Transition Écologique, Defra, Ofgem) can design new policy interventions, such as incentive schemes, funding and legislative change, that would favour marine renewables such as SWAC. The work on circular economy (CE)-orientated SWAC designs could be used as evidence to drive regulatory changes. A key barrier to extending the life of an asset, as per CE principles, is that components become obsolete so that end-users are unable to replace them. Governments can address this issue by extending the 'right to repair' and requiring standardisation of those SWAC components most likely to fail, such as heat-exchangers and pumps. Again, national government sites may also themselves function as end-users.

Sectoral agencies (AnR, ADEME, Agence pour Biodiversité, Environment Agency, MMO (Marine Management Organisation, UK), UK Research & Innovation (UKRI)) are relevant to the permitting and impact of SWAC technologies, as well as potential future research.

Infrastructure and large (public) service providers, such as energy utilities, airports and hospitals, are likely to be a receptive to SWAC given that their requirement for continuous cooling or heating. They may also be able to host SWAC systems to the benefit of other users. Large electricity suppliers, such as EDF (a EUROSWAC project partner), may also play a role in disseminating results to clients. While SWAC might reduce demand for energy, this can in fact be in an energy supplier's commercial interest because the sector is typically subject to over-demand.

Providers of HVAC and pumping equipment and their representative **trade associations,** such as AREA (Air Conditioning & Refrigeration European Association), ACRIB (Air

Conditioning and Refrigeration Industry Board) and HVCA (Heating & Ventilating Contractors Association), may be receptive to innovative, low-cost, low-carbon technologies such as SWAC. They are important to engage with since they are likely to be the first port of call for end-users seeking HVAC solutions. HVAC providers could also benefit from new circular business models which would see them leasing out rather than selling SWAC equipment and components (see Section 2.10.2).

Universities and research institutes not only benefit from the research conducted within the Project, but also play a valuable role in exchanging knowledge with a wide range of industry sectors likely to have an interest in SWAC. For instance, the National Lobster Hatchery, a potential end-user (see Section 3.2), reports close engagement with academia – indeed, this was the route by which NLH became involved in the EUROSWAC project. As with government sites, coastally situated universities, may themselves be end-users of SWAC technology (as is the case with Brixham Lab, which is owned by the University of Plymouth); universities could play a valuable role as 'early adopters'.

Other **education and training centres, including schools**, could benefit from – and disseminate – information on SWAC, in addition to being themselves end-users, possibly as part of a district scale installation, should they be appropriately located. Some of these organisations may have a specialist interest in the development of renewable energy (e.g., ESITC Caen, Oxford Energy Academy).

A number of **interest groups and networks including NGOs** can play a role in promoting SWAC as a form of renewable, marine energy (e.g., Centre for Sustainable Energy (UK); Ocean Energy Europe, Energy UK, Bretagne Ocean Power, Energies de La Mer, Cornwall Marine Network).

Permitting processes can also be aided by **international organisations** whether under national or international law. Some organisations such as IEA (International Energy Agency), IRENA (International Renewable Energy Agency) or OCEANERA-NET, which coordinates national research activities on Ocean Energy, may be able to assist with the dissemination of SWAC technology, with a focus on local settings.

Private enterprises in the key market sectors identified in Section 4.5 should be prioritized as future SWAC users, directly investing in their own systems, or benefiting from district scale installations. These companies can be approached directly, or indirectly via relevant sector-specific **trade associations** (e.g., UK Hospitality; Sustainable Restaurant Association, British Retail Consortium; Data Centre Alliance (DCA)) and **business support organisations** (e.g., Chambers of Commerce or pôles de compétitivité). These trusted intermediaries alert SMEs, in particular, about new technologies and funding opportunities.

Finally, the **general public** of the Channel Area and beyond should also be alerted to the social, environmental and economic benefits of SWAC technology, with a focus on populations living near pilot sites or potential future replication sites. Support from local communities may be important when permission is being sought for new SWAC developments.

Table 1: Target groups

Target Groups	Examples	Disseminator	End-User
Local and regional governments	Torbay Council; Plymouth City Council; Cornwall Council; Brest Métropole; Mairie de Calais; Regional Council of Brittany; Mairie d'Étel	✓	✓
National government departments	BEIS; Defra; Ministère de la Transition Écologique	✓	✓
Sectoral agencies	ADEME; Agence pour Biodiversité; Environment Agency; MMO	✓	
Infrastructure and (public) service providers	Energy utilities (e.g. EDF), airports; hospitals	✓	✓
HVAC technology providers and representative associations	ACRIB; HVCA; AREA	✓	
Universities and research institutes	University of Plymouth; ENSTA Bretagne	✓	✓
Education and training centres, including schools	ESITC Caen; Oxford Energy Academy		
Interest groups, networks and NGOs	Ocean Energy Europe, Energy UK; Bretagne Ocean Power; Energies de La Mer; Cornwall Marine Network	✓	
International organisation under national law	OCEANERA-NET; IEA; IRENA	✓	
Private enterprises; business support organisations and trade associations	Chambers of commerce; Pôles de compétitivité; Sustainable Restaurant Association, British Retail Consortium	✓	✓
General public	Citizens living within the CA, with a focus on populations living near pilot sites or potential future replication sites.	✓	

5.2. Past and planned exploitation activities

The Project has – as part of its outputs – already maintained contact with external shareholders in order to raise awareness of the project. Table 2 demonstrates the diversity of activities already undertaken to introduce EUROSWAC project and the potential of SWAC technology.

Table 2: Past and planned exploitation activities

Date	Event (Location)	Description
12/10/2021 - 14/10/2021	OceanBusiness (Southampton, UK)	Leaflets distributed targeting the ocean science and technology community
06/12/2021	Ocean Energy Europe (Brussels, Belgium)	DPI (Bruno Garnier) gave a talk
15/03/2022 - 17/03/2022	Oceanology International (London, UK)	Leaflets distributed targeting the ocean science and technology community
30/03/2022	UCA Congress (Congres de l'Union des Conservateurs d'Aquarium) (France)	ENSTA student (Angélique Vallee) made a speech about EuroSWAC at this aquarium managers conference. 32 French aquariums were represented.
11/04/2022 - 13/04/2022	British Applied Mathematics Colloquium (BAMC) (Loughborough, UK)	Talk given by University of Plymouth (Simone Michele) to applied mathematics community
22/04/2022	Introduction – the University of Exeter and Morrisons (Exeter, UK)	Introduction of the Project to Morrisons. Morrisons interested in SWAC technology, but wished to see more data of SWAC system in retail setting.
29/04/2022	Introduction – the University of Exeter and Carbis Bay Hotel and Resort (Virtual)	Introduction of the Project to Carbis Bay. Carbis Bay initially keen to undertake live feasibility study. Timeline of communication meant live feasibility was not possible.
12/05/2022	Project Public Event (ENSTA, Brest, France)	Public event, presenting progress of the project to external stakeholders.
12/05/2022	European Lobster Centre of Excellence Conference (NLH, Padstow, UK)	NLH (Carly Daniels) gave talk introducing the potential benefits of SWAC for aquacultural stock growth to other stakeholders in the industry.
19/05/2022	Meeting between NLH, the Department for Environment, Food and Rural Affairs (DEFRA), and the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) (UK).	Talk given by NLH on the work carried out, including the progress of EUROSWAC.
19/05/2022	Meeting between NLH and Syracuse University (UK)	Talk given by NLH on Hatchery operations, including progress of EUROSWAC.
01/06/2022	Interview on *France Inter*	Radio interview between *France Inter* and DE, introducing Project and SWAC technology to French public.
15/06/2022	Seanergy Conference (Le Havre, France)	Range of posters introducing EUROSWAC to interested stakeholders in offshore renewable energy. Attended by the University of Plymouth, NLH, DPI, Oceanide, DG.

28/06/2022 - 30/06/2022	Euromaritime (Marseille, France)	Introduction of the Project to external stakeholders in renewable energies at sea and biodiversity. Meetings held with Université de Toulon, and the Mayor of La Seyne-sur-Mer. There was a stand/round table with DPI (Bruno Garnier)
06/07/2022	PRIMaRE Conference (University of Exeter, Penryn Campus, UK).	EUROSWAC-sponsored morning session, as well as talk titled "Exploring Marine Infrastructure from a Circular Economy Perspective" by Wheaton, J., Alexander, A.T., Zawalna-Geer, A., and Johanning, L.
26/09/2022 – 30/09/2022	Sea Tech Week 2022 (Brest, France)	A stand representing the EUROSWAC Project, in addition to parallel session 'Highly-efficient innovative water-based Sea Water Air Conditioning solutions'. A student from ENSTA made a video about the SWAC technology for Sea Tech Week. EUROSWAC partners including NKE were present.
30/09/2022 – 01/10/2022	FUTURES 2022, University of Plymouth (UK)	Creation and provision of material (quiz), raising awareness of the benefits of SWAC (Bordbar, A., and Georgoulas, K).
18/10/2022	Paper Submission - Exploring circular, high-value innovations with Life-Cycle Assessment-based methodologies: A review of empirical studies, by Wheaton, J., Alexander, A., Zawalna-Geer, A., and Johanning, L.	Paper based on the literature review informing the methodology which informed the results of T4.2. Paper submitted to Journal of Industrial Ecology.
08/11/2022 – 10/11/2022	Renew 2022 (Lisbon, Portugal)	Online presentation given at international conference on offshore renewable energy, communicating work on EUROSWAC by University of Exeter (Ola Zawalna-Geer). The presentations was entitled "Technical potential for sea water air conditioning (SWAC) in the Channel Area" by Zawalna-Geer, A., Menon, P., Garnier, B., Johanning, L., and Pradillon, J.
25/11/2022 - 27/11/2022	6th DualSPHysics Workshop (Barcelona, Spain)	University of Plymouth (Konstantinos Georgoulas) represented the EUROSWAC project at a workshop. DualSPHysics is the CFD solver used by University of Plymouth for CFD on WP T1.
08/12/2022	Innov-SWAC Webinar	Online conference hosted by DM, DPI and ClubSWAC to communicate progress made on the EUROSWAC Project.
10/2/2023	Brixham Lab Public Workshop (Brixham, UK)	An in-person and online hybrid event at which the key results from EUROSWAC were presented, with a focus on T4 (replication).
10/3/2023	Lille Public Workshop (Lille, France)	An in-person and online hybrid event at which the key results from EUROSWAC were presented. Its proximity to both Brussels and Paris helped raise the profile of SWAC among Europe-based policy stakeholders.
27/6/2023	PRIMaRE Conference (Bath, UK)	Dissemination of Project Results to Universities and Research Groups

Other ongoing activities include:

- A Project Newsletter periodically released to update on Project progress.
- Doris Engineering, ClubSWAC and the University of Exeter have led the communications on EuroSWAC. Activities have included the creation and maintenance of a website, posts on social media videos making to present the SWAC technology and the project, posters creations and display etc.
- The National Lobster Hatchery in Padstow prepared a full display about how SWAC works . Students from ENSTA built educational models on how SWAC works for demonstration at NLH.
- There is a YouTube channel for the EuroSWAC project: https://www.youtube.com/channel/UCy5Z_mf73V-pQSozwRjd27A
- There is a LinkedIn profile dedicated to the EuroSWAC project https://www.linkedin.com/company/euroswac/

5.3. Proposed future exploitation activities and timeline

To accelerate the uptake of SWAC technology in the Channel Area, a simple but ambitious three-year communication plan targeting key stakeholders is proposed (Table 3).

Table 3: Proposed exploitation activities

Year	Activities	Purpose	Target group(s)
1	Dissemination of results and outputs **to social and national media.**	To raise awareness and generate public support for SWAC	General public; Interest groups, networks and NGOs
	Launch **academic papers**	To boost expert confidence in SWAC technology	Universities and research institutes
	Continue engagement with the 12 **short-term replication sites** outlined in Sections 4.3 and 4.4.	To encourage SWAC installation	End-users
	Engage with **potential champions** of SWAC technology	To raise profile and boost confidence in SWAC among trusted experts	HVAC technology providers and representative associations; Universities and research institutes; Education and training centres, including schools; Interest groups, networks and NGOs
	Engagement with policy-makers	To identify and foster new funding opportunities; effect favourable policy changes (e.g. new incentive schemes)	National government departments; International organisation under national law
	Engage with **general public** to (e.g., via videos)	To raise support for SWAC technology among coastal communities	General public

	Attendance at **key specialist conferences** (e.g., PRIMaRE, Sea Tech Week, FOWT; OEE; SMM; ISSC; PRADS)	To raise profile and boost confidence in SWAC among trusted experts	Universities and research institutes; HVAC technology providers;
2	Engagement with the **key longer-term market sectors** outlined in Section 4.5 Activities could include 'advertorials' in a specialist sector-specific publications, such as *The Cooling Post*, a review of air-conditioning technologies.	To investigate and promote upscaling opportunities	Private enterprises and other end-users; business support organisations and trade associations
	Engagement with organisations representing coastal communities to identify opportunities for **place-based and district scale** SWAC installations	To continue raising support for SWAC technology among coastal communities	Local or regional public authorities; local infrastructure providers
	Engagement with agencies responsible for **licencing and permitting**	To mitigate permitting barriers to SWAC	Local and regional governments Sectoral agencies
	Continued engagement with **policy-makers, champions of SWAC and public**	To continue fostering support for SWAC	Various
3	Direct engagement with 50 further **potential replication sites** identified via representative trade associations of the key long-term market sectors.	To encourage more SWAC installations	End-users
	Continued engagement with **policy-makers, champions of SWAC and public**	To continue fostering support for SWAC	Various
	Engagement with sectoral experts to create a **new industrial standard** for air-conditioning in maritime environments, which points to the existing option and a seawater option.	To ensure SWAC is routinely considered for coastal contexts.	Standards bodies; business support organisations and trade associations; National government departments; Sectoral agencies
	Creation of **training and upskilling information** related to SWAC	To ensure skilled workforce is available for building, maintaining and decommissioning a SWAC system	HVAC installers and suppliers; education/training centres and schools.

Table 4: Target groups

Target Groups	Examples	Disseminator	End-User
Local and regional governments	Torbay Council; Plymouth City Council; Cornwall Council; Brest Métropole; Mairie de Calais; Regional Council of Brittany; Mairie d'Étel	✓	✓
National government departments	BEIS; Defra; Ministère de la Transition Écologique	✓	✓
Sectoral agencies	ADEME; Agence pour Biodiversité; Environment Agency; MMO	✓	
Infrastructure and (public) service providers	Energy utilities (e.g. EDF), airports; hospitals	✓	✓
HVAC technology providers and representative associations	ACRIB; HVCA; AREA	✓	
Universities and research institutes	University of Plymouth; ENSTA Bretagne	✓	✓
Education and training centres, including schools	ESITC Caen; Oxford Energy Academy		
Interest groups, networks and NGOs	Ocean Energy Europe, Energy UK; Bretagne Ocean Power; Energies de La Mer; Cornwall Marine Network	✓	
International organisation under national law	OCEANERA-NET; IEA; IRENA	✓	
Private enterprises; business support organisations and trade associations	Chambers of commerce; Pôles de compétitivité; Sustainable Restaurant Association, British Retail Consortium	✓	✓
General public	Citizens living within the CA, with a focus on populations living near pilot sites or potential future replication sites.	✓	

6. Knowledge ownership

The above outputs have benefited from the collaboration between numerous project partners. Such collaboration has devised a bank of knowledge in relation to SWAC systems, whether through methodologies, the creation and testing of new technology, or the measurement and reporting of impact. The control of intellectual property is important, considering that background expertise knowledge will have been used by some partners in the creation and dissemination of project outputs. The dissemination of project outputs – and control of intellectual property rights – will be carried out as specified within the Grant Agreement.

6.1. Intellectual property rights

As per the Grant Agreement and the Grant Offer Letter between the partners and the Joint Secretariat (JS), any intellectual property, outputs, deliverables and results – whether tangible or otherwise – belong to the project partners. Project results and outputs which have emerged from project activities are to be made openly available to the public. Indeed, the project partners see their work as a 'public good' which must be as freely disseminated as possible.

However, the intellectual property rights (IPRs) of individual project partners must still be respected, especially if outputs from the project are to be made commercially available. If this is the case, then project partners which propose commercial dissemination should assess in advance whether individual partners' IPRs are at risk. This applies where background expertise – such as specialist software, methodologies or other extant, specialist resources - has been used by project partners within the production of project output. Any income or other economic advantage generated by the IPRs should be managed according in compliance with the relevant territory's rules regarding revenue and state aid.

6.2. Publications and open access

It is a condition of the Project that the outputs of activities are made public. This also extends to research publications which should also be made open access. The implication therefore is that publications will be shared with project partners and the JS as soon as possible in the interest of making findings available to the public. However, publications which have been produced across partners should not be published until explicit permission is given by each partner. This is to ensure that partners can verify the omission of sensitive information which may – if included – infringe upon a partner's IPRs.

7. Potential barriers and solutions

7.1. Introduction

The EU Commission's policy is that within 10 years all properties must use a renewable system for air-conditioning, with fossil energy sources (e.g., gas, coal and oil) being phased out. The favoured solution for decarbonisation of both heating and cooling is the use of air- and ground-source heat pumps, which exploit differences in temperature. The SWAC technology is based on the principle, and indeed, since the temperature difference between air and sea is relatively significant, the technology can be extremely efficient. However, despite SWAC's potential, there are a number of barriers to its replication in the Channel Area and beyond, which are briefly discussed below. Where possible, solutions are offered, many being EUROSWAC outputs.

7.2. Cost

Although there are operating costs due to the energy needed to run pumps, as well as maintenance and inspection, the single greatest barrier to replication of SWAC systems are the upfront, capex costs, which are usually very significant given the complexities entailed in any form of marine installation. A high capital investment is in particular required for installing lengthy abstraction pipes needed to collect seawater from beyond the tidal range, and to return the warm output water to the deep in order to avoid disruptions to the ecology of the sea. As discussed below, the full cost of installing a SWAC system depends on a variety of factors, however, regardless of the size and design of planned installation, certain costs (amounting to as much as €200k) must often be incurred in pre-project studies (e.g., design studies and environmental impact studies) to determine whether or not a project is viable. These costs will almost certainly exceed those for installing a conventional HVAC system. For a viable return on investment, a SWAC system would need to be used continuously for all or a very large proportion of the year. For this reason, small and medium-sized users in particular, but even larger organisations, are unlikely to decide to substitute their HVAC technology with a SWAC installations without some form of external funding. This was indeed reported as a barrier by representatives from several of the sites in France where feasibility studies have been conducted by the EUROSWAC project partners.

Linked to the potentially high cost, is uncertainty about precisely what the cost would be, both of installing and operating a SWAC system. This is due to the diverse range of physical, engineering, economic, permitting and other factors which can influence the optimal design of a SWAC system. Difficulties in estimating the investment likely to be needed can block progress.

Sometimes elements of a SWAC system may already be present, such as a seawater extraction pipe and pump which can significantly reduce the cost of a new installation. End-users whose existing HVAC system is reaching the end of life, and who therefore have a budget allocated for a replacement may also be receptive to SWAC, it is possible to make a proposal for a SWAC system at the same cost. Nevertheless, even in these cases, it is likely that progress will depend on a level of additional, external funding. Information on possible funding support is provided in Section 8 for those wishing to install SWAC in the Channel Area.

A major objective of EuroSWAC has therefore been to develop solutions that address the cost barriers associated with a SWAC installation. Some relevant project outputs are noted below:

- The optimisation tool uses genetic algorithms (Section 2.10.1) to help potential end-users minimise installation and operational costs of SWAC without affecting performance. Not only can the tool reduce the overall cost, it can improve the reliability of any estimates of capital investment likely to be needed in a proposed new SWAC project.
- New business models such as sale of service or leasing for SWAC installations can also significantly reduce costs, with end-users potentially paying equipment manufacturers only for the service provided by SWAC, rather than the full cost of ownership. This approach is particularly valuable for circular designs which are likely to have higher capex and opex costs than an optimised, linear counterpart (Section 2.10). Here, end-users pay only for the service provided, while manufacturers retain ownership of the SWAC components (and responsibility for repair, refurbishment, remanufacture or replacement). This arrangement can significantly reduce costs for users, while providing a new, stable income stream for suppliers over multiple lifecycles of the SWAC system. It also aligns incentives for manufacturer and user, as both would have an interest in ensuring the longevity of the asset.
- The development of a self-burying pipe system and the use of flexible pipes (Section 2.8) holds the potential to significantly reduce the installation costs.

It is also worth noting that the rising cost of energy, and that of emitting greenhouse gas emissions, may in fact improve the viability of SWAC systems in the near future. As the price of carbon rises, so investors are likely to be increasingly attracted to 'green technologies', especially if policy interventions are favourable.

Finally, for some end-users, the reputational benefit in being able to demonstrate to customers and other stakeholders the use of a low-carbon, 'environmentally friendly' form of air-conditioning may be enough to greenlight a project even where the financial costs of a SWAC system may exceed those of a conventional HVAC equivalent.

7.3. Lack of awareness

Among the most fundamental obstacles to the replication of SWAC in the Channel Area is a lack of awareness among prospective end-users as to the existence and value of this technology. For marine renewables, the focus to date has been almost exclusively on wind and, to a lesser extent, tidal power. Financial resources are required to disseminate

EUROSWAC's findings beyond the end of the current project. Club SWAC,[17] a not-for-profit organisation comprising various project partners (e.g., DPI and Doris Engineering) has been established to promote SWAC in the Channel Area and beyond, but it has a minimal budget and no employees. Section 5 sets out a range of activities which have been done, or could be in the future, to raise the technology's profile.

7.4. Seasonal fluctuations in thermal needs

The thermal requirements for different potential sites in temperate regions are often varying and complex due to seasonal factors. This can act as a barrier to adopting SWAC, a technology designed originally for situations where relatively constant, year-round air-conditioning is needed (as in tropical regions). For instance, the NLH's Newlyn site has a long thermal range(i.e., during the winter the hatchery water needs warming up, but in summer needs cooling down). However, as noted a major finding of the EUROSWAC project is that seawater air-conditioning, when combined with other renewable energy technologies and energy efficiency measures (e.g., insulation), can deliver significant benefits in a seasonal context. It is this insight that has informed the design of the system proposed for NLH at Newlyn (Section 3.2).

7.5. Environmental barriers

The use of chemicals, such as chlorine, for preventing biofouling of SWAC components is a potential barrier due to the potentially negative impact on marine ecology. The EUROSWAC project has sought to address this issue through studying a range of biofouling mitigation solutions that use less or no chemicals. While alternatives to chemicals are available, or the use of chlorine in a closed circuit enabling it to be disposed of safely, they add to the cost of a SWAC installation. The project has also investigated the environmental impacts of SWAC discharge water (Section 2.4).

7.6. Access barriers

As noted in Section 4.1, access to the sea can be problematic, with many factors to be considered, some of which may prevent the installation of a SWAC system altogether. Any access problems likely to be insurmountable should be identified as early as possible in a project to avoid wasted investment.

7.7. Permitting requirements

[17] https://www.clubswac.fr/

Any marine installation is subject to various licencing conditions which can be onerous to satisfy. Permitting requirements are likely to delay rather than stop a project altogether. In the UK an abstraction licence is needed to take water from the sea, and a discharge licence to return the used water to the sea. These licences come from the Environment Agency. Obtaining a discharge licence is particularly burdensome as applicants must show how the planned system would affect the natural environment and that it would not contravene specific regulations. There has also to be consideration of the effect of water discharge on other industries, especially commercial fishing. There is no guidance for this, so this can be complex to undertake. Each would-be SWAC site has its own specific complexities. For instance, at NLH, Newlyn, the seawater used for thermal regulation comes into contact with the hatchling lobsters and thus on its release is classed as 'effluent,' not 'discharge', requiring further permissions from the relevant authority. An application has also to be made to the Marine Management Organisation (MMO) in order to undertake any kind of construction works in the sea (e.g., installing new pipework, pumps, etc.).

The rules in France are different and more burdensome still, notably the requirement to undertake a full environmental impact assessment (EIA), almost certainly obliging the end-user hire a specialist consultant. Sites or zones may also be subject to a water quality discharge order or decree issued by the water quality department of the French national government.

It is also possible, in both the UK and France contexts, that local communities may oppose a new SWAC development should it be perceived to impact on business, recreational and other activities, especially if the proposed system is a sizeable one. The regulator (e.g., the MMO in the UK) may require a public consultation. It is therefore advisable that those wishing to replicate SWAC in new sites prioritise early engagement with both relevant authorities and the local community to build support for the project.

Outputs from the EUROSWAC project designed to tackle some of these barriers is the guidance on permitting requirements (Section 2.5) and the water quality monitoring system using instrumented buoys (Section 2.4).

7.8. Disturbances to a site's operations

There may be sites where the installation and running of a SWAC system may disturb other activities. For example, at the Brixham Lab, a tenant's use of seawater acted as a barrier to a SWAC system being switched on. Adaptations to this system, funded by the EUROSWAC project, have resolved this problem (Section 3.1).

7.9. Restricted equipment lifespan

Given that seawater can be an aggressive medium, the operational lifespan of submerged SWAC equipment can be short compared to conventional HVAC systems. Ferrous materials quickly corrode underwater and biofouling by marine organisms can block pipes and hamper the functioning of pumps. Recent trials demonstrated that the 14-year-old water abstraction system at Brixham Lab still functioned (Section 3.1), but significant corrosion of the pipework was nevertheless evidenced. While some of the impact can be mitigated through the choice of non-metallic components, such as the use of HDPE plastic for the pipeline, reliance on ferrous materials in components such as pumps and heat-exchangers cannot be avoided entirely. The high risk of corrosion necessitates frequent inspections of subsea assets, which adds to the operating costs of a SWAC system. This was addressed in a research conducted by EUROSWAC partners on a technology with anti-corrosion potential (216-T2.3-NKE-001 Corrosion Potential[18]) (Section 2.8.3). There is also the option to over-engineer certain critical components to mitigate corrosion and extend lifetime; while this would increase cost, this obstacle can be mitigated through the implementation of circular business models (Section 2.10).

7.10. Skills barriers

Given that SWAC is a relatively new technology, a shortage of people with the necessary skills to install, maintain and repair the system may be a barrier to installation. However, other applications have similar components (e.g., pipes, pumps, heat exchangers) – for instance, many coastal facilities already need to pump water for other purposes. Therefore, once a new SWAC system has been designed, technicians familiar with heat-exchange systems will probably be available to install it. There may nevertheless be a requirement for some specialist training, and for smaller organisations seeking to run a SWAC system, external technical support may be needed.

7.11. Supply chain barriers

There can sometimes be lengthy lead times when installing a new SWAC system. Some specialist components, including seawater-resistant items, may be manufactured outside Europe and take many months to be delivered. Pipelines used in subsea application are however generally available from European manufacturers (e.g. in Germany and Norway) given that such bulky products would be too costly to source from further afield.

7.12. Insurance and investment barriers

Since SWAC remains a relatively untested technology, obtaining investment and insurance coverage is difficult, as is sourcing components with warranties necessary for a marine environment. While an estimated 10-20 deep water SWAC sites are reported worldwide, and perhaps 20-50 shallow water SWAC sites in France, this number of installations is still too low to provide a statistically significant verification of the longevity of a SWAC in real-world conditions. The calculus of the risk of an installation failing is therefore difficult. In short, many investors may deem SWAC as still too risky to back, or if finance is offered the interest rate demanded may be too high to allow a project to proceed. As noted in Section 5.1, large public organisations such as universities may be best placed to take this risk as early adopters since installations may have a research value (even if they ultimately fail).

[18] English version only

7.13. Legal or contractual barriers

An end-user may be constrained by contractual arrangements with the provider of an existing HVAC system to switch to a rival technology such as SWAC.

7.14. Low energy prices

When prevailing energy unit prices are low enough, this can undermine the business model for installing and operating a SWAC. This is evidenced by the projections of the Brixham Lab SWAC system based on the first months' monitoring; where the carbon footprint decrease is undeniable, the cost efficiency is not interesting with current energy prices. Furthermore, energy prices are rarely stable which makes it almost impossible to construct a business plan with confidence. This only increases the risks for investors. However, over time the threshold of financial viability for pricier low-carbon technologies, such as SWAC, may become easier to reach as the cost of carbon rises. Moreover, SWAC also avoids dependence on energy sources such as natural gas, where the market is controlled by a relatively small number of producers, and which is subject to significant price volatility.

8. Funding opportunities for SWAC installations

As noted in Section 7.2, given the cost of a SWAC installation, many projects are likely to need external funding to progress. While public funding is often available for renewable energy developments, often there is a need to demonstrate that a project is in some way 'innovative.' There are however a number of sources of funding in the UK and in France which could be explored.

8.1. UK funding opportunities

Following Brexit, the public sector funding landscape for low-carbon installations including SWAC remains in flux, with the UK's future participation in - and ability to benefit from - former EU funding sources such as Interreg and Horizon Europe unclear. UKRI (UK Research & Innovation) is coordinating programmes post the UK leaving the EU and would be able to recommend potential funding routes. BEIS (Department for Business, Energy & Industrial Strategy) is also currently investigating alternatives to Horizon.[19] Opportunities for receiving financial support from local and national government appear limited in the UK. For instance, until recently, the UK Government ran the Non-Domestic and Domestic Renewable Heat Incentives (RHI), supporting the installation of water source heat pumps in commercial and residential sites. This scheme is now closed, but new ones could be opened in the future. Indeed, the UK Government's forthcoming Boiler Upgrade Scheme, administered by BEIS, will offer similar support in providing grants towards the installation and capital costs of air-

[19] Personal communication (BEIS, 3 February 2023)

source heat pumps which as noted in this Exploitation Plan can form part of a hybrid SWAC installation for smaller sites. BEIS also oversees the Green Heat Network Fund (GHNF) which aims to development new and existing low and zero-carbon heat networks, and may be of value for those seeking to create district-scale SWAC systems. A future version of the Coastal Communities Fund, which ran between 2012 and 2022,[20] may support touristic sites seeking to install SWAC systems. Furthermore, some parts of the Channel Area may also be eligible for support from the Department for Levelling Up, Housing & Communities. Relevant Local Enterprise Partnerships (LEPs) sited in the Channel Area[21] may also be sources of advice and future funding.

The ocean energy sector in the UK is developing rapidly[22] and research grant mechanisms may be available, for instance, from Innovate-UK, the Knowledge Transfer Networks and UKRI for renewable energy technology – as long as there is an innovative, research and development element. The UK aquaculture sector also receives support from the government, again through UKRI, and may be eligible to receive support should businesses consider a SWAC installation (as per NLH Newlyn). A number of private venture funders have an interest in supporting ocean technology, including Vala Capital[23], Ocean 14 Capital[24] and pH3.[25] Maritime UK South West, focuses on offshore renewables, marine autonomy and clean ocean technology in the Channel Area and beyond, and coordinates several 'Maritime Investment Sites'[26] in the region where district-scale SWAC installations may be possible. This organisation may be able to signpost to imminent public, private and third sector funding opportunities.

Given that funding landscape is constantly changing, it is recommended that those wishing to invest in a SWAC system closely monitor the following websites for announcements of new schemes:

- BEIS: https://www.gov.uk/business-finance-support
- Centre for Sustainable Energy: https://www.cse.org.uk/local-energy/funding-your-project
- Grantfinder: https://www.grantfinder.co.uk/funding-highlights/funds/environment/
- Maritime UK: https://www.maritimeuk.org/priorities/innovation/funding-opportunities/
- Local Enterprise Partnerships (LEPs) sited in the Channel Area:[27] https://www.lepnetwork.net/

[20] https://www.gov.uk/government/collections/coastal-communities
[21] Cornwall and Isles of Scilly LEP; Heart of the South West LEP; Dorset LEP; Enterprise M3 LEP; Solent LEP; Coast to Capital LEP; South East LEP; New Anglia LEP.
[22] Depellegrin et al. 2022. Innovating the Blue Economy: A Novel Approach to Stakeholder Landscape Mapping of the Atlantic Area Sea Basin. *Frontiers in Marine Science*, 9. https://doi.org/10.3389/fmars.2022.889582
[23] https://www.valacap.com/
[24] https://www.ocean14capital.com/
[25] https://ph3.co.uk/
[26] https://maritimeuksw.org/maritime-investment-sites-south-west-uk/
[27] Cornwall and Isles of Scilly LEP; Heart of the South West LEP; Dorset LEP; Enterprise M3 LEP; Solent LEP; Coast to Capital LEP; South East LEP.

- Ofgem (Office of Gas and Electricity Markets): https://www.ofgem.gov.uk/information-consumers/energy-advice-businesses/find-business-energy-efficiency-grants-and-schemes
- UKRI: https://www.ukri.org/councils/innovate-uk/guidance-for-applicants/guidance-for-specific-funds/

8.2. French funding opportunities

Unlike the UK, French schemes can of course still benefit from EU funding mechanisms. Green energy being one of the EU priorities, there are many financing and funding opportunities for renewable energy projects. Main ones being:

- Horizon Europe

Funding programme for research and innovation (until 2027).

Its Cluster 5 is dedicated to climate, energy and mobility. One of its objectives is to fight climate change by improving the energy sector, making it more sustainable, more efficient and more resilient.

- Connecting Europe Facility - Energy

Grants to support sustainable energy infrastructure projects, allocated to cross-border projects in the field of renewable energy.

- ERDF (European Regional development funds)

A greener, low-carbon and resilient Europe is one of this fund priority.

Information on the many European funding opportunities can be found on the French government website: https://www.economie.gouv.fr/entreprises/conseil-financements#

ADEME[28] (French Agency for Ecological Transition) is regionally implemented and can be a good entry point to seek for information regarding financing opportunities for SWAC projects as they oversee funding in French Territory coming from the European energy policies. The “Renewable heat fund” certainly being the most adapted to the SWAC technology implementation (https://fondschaleur.ademe.fr/).

The rules, budgets and definition of all these financial mechanisms are fast evolving so one should check on the national and European exiting opportunities when considering a SWAC project. Much information can be found on the institutions’ official websites.

One other potential source of funding for new SWAC schemes in France could be the *pôles de compétitivité*, a network of competitive business clusters which support projects at regional, national, and European level. The key region-linked clusters dedicated to sea activities would be: Pôle Mer Bretagne Atlantique (PMBA)[29] and Pôle Mer Méditéranée

[28] *Agence nationale de Développement et de Maîtrise de l’Énergie*
[29] https://www.pole-mer-bretagne-atlantique.com//fr/

(PMM)[30]. Those dedicated to energy include Pôle Fibres-Energivie,[31] Capenergies,[32] DERBI,[33] S2e2[34] and Tenerrdis.[35] The *pôles de compétitivité* are associated not just with authorities, but also private investors including banks and insurance companies with an interest in funding. Those seeking funding can present their project to the *pôle de compétitivité* and might be offered favourable lending rates.

9. Conclusions

The overall finding of the EUROSWAC project is that seawater air-conditioning can be a very effective and efficient, low-carbon alternative to conventional HVAC in the Channel Area, and therefore plays an important role in the transition away from reliance on fossil fuels. Given the significant capital costs of installing a system, exploitation activities must focus on replicating the technology at sites in the Channel Area with a large, year-round demand for heating and cooling. However, the research shows that an opportunity for exploitation also exists among smaller facilities with seasonally varying requirements, with a combination of heat pump and SWAC offering great potential. It should also be remembered that the SWAC principle also works with rivers and lakes, so dissemination to sites close to these should also be considered. The outputs from the project also have value far beyond the Channel Area, indeed to any coastal location with a temperate climate.

[30] https://www.polemermediterranee.com/
[31] http://www.fibres-energivie.eu/en/node/1
[32] https://www.capenergies.fr/en/
[33] https://pole-derbi.com/
[34] https://www.s2e2.fr/en/
[35] https://www.tenerrdis.fr/en/