Milford Haven
Energy Kingdom

Strategic outline case for a smart local energy system

Prospering from the Energy Revolution

Contents

Navigating this report

Iconography

Below shows the three propositions

- Milford Haven Marina SLES
- Pembrokeshire Food Park SLES
- The Pembroke Schools, Leisure Centre and Dock SLES

Below shows the commercial models that could apply across the propositions

- Community owned model
- Disaggregated market model
- Centralised model
- SPV / Partnership model

Page navigation

This is an interactive report, please use the buttons to help navigate throughout this report

- Return to contents
- Back a page
- Forward a page

Figures list

Tables list

Disclaimer

This report has been prepared by Arup on behalf of Pembrokeshire County Council in connection with the Milford Haven: Energy Kingdom (PfER) project and takes into account their particular instructions and requirements. It is not intended for and should not be relied on by any third party and no responsibility is undertaken to any third party.

In preparing this report we have relied on information provided by others, and we do not accept responsibility for the accuracy of such information.

We emphasise that the forward-looking projections, forecasts, or estimates are based upon interpretations or assessments of available information at the time of writing. The realisation of the prospective financial information is dependent upon the continued validity of the assumptions on which it is based. Actual events frequently do not occur as expected, and the differences may be material. For this reason, we accept no responsibility for the realisation of any projection, forecast, opinion or estimate.

Foreword

The Council is proud to lead the Milford Haven: Energy Kingdom project which is positioning the Milford Haven Waterway as a frontrunner for breakthrough renewable energy and hydrogen technologies to provide increased flexibility to the way we consume electricity and gas, as we deliver greater amounts of green, affordable onshore solar, and offshore wind, tidal and wave generation in the Celtic Sea and beyond.

Having already established itself as the UK's Energy Capital, the Milford Haven Waterway is now at the centre of a renewable energy revolution, with huge potential to become the low carbon energy capital of the UK, safeguarding thousands of local jobs and creating thousands more new ones.

The projects heating and transport demonstrators showcase what can be achieved through collaboration with our partners and Pembrokeshire can use these innovations as we work to become a net zero carbon local authority by 2030.

To get to net zero, we must deliver net zero power, transport and heat across a smartly connected whole energy system with progression to regulatory & policy frameworks to support truly multi-vector trading platforms.

We have all the necessary components here on our doorstep in Pembrokeshire to act as a vital cluster of national significance and to provide opportunities in the green energy sector for both current and future generations.

Steve Keating
Project Lead for MH:EK and Pembrokeshire County Council Energy & Sustainability Team Lead

This project, funded by Innovate UK, and delivered by the many project partners has significantly advanced the existing evidence base in support of the route to a net zero energy system.

The study has incorporated the following:

- a review of existing policy and regulation;
- developed thinking around new commercial models and structures looking out to a changing future system;
- detailed whole system energy modelling of three smaller-scale smart local energy systems (SLES) which is a draft view on potential roadmaps out to 2050, bringing together insights on direction of travel from across the existing energy industry in the region (such as RWE's Pembrokeshire Net Zero Centre and the South Wales Industrial Cluster programme);
- consideration of the role of trading platforms within the future system and the enablers and barriers to current implementation; and
- recommendations towards ensuring that Pembrokeshire is aligned with the national Modernising Energy Data Access programme.

Across all these areas, this report intends to summarise the collective work carried out by the project partners and present recommendations and next steps for different actors from the local community, to potential investors, to Ofgem and BEIS in setting future policy and regulation.

If we're to reach our goal of decarbonising the energy system, we need to think of the transition not as one giant leap but as a series of smaller, more achievable steps. These involve establishing individual low-carbon 'clusters' and joining them together to unlock greater benefits.

This project has set out a "series of smaller, more achievable steps" for Milford Haven, and the Pembrokeshire region on the journey to net zero.

Alan Thomson
Arup Global Energy Leader

01
Executive Summary

Executive Summary

The Milford Haven: Energy Kingdom project

The Milford Haven: Energy Kingdom (MH:EK) project is part of the Prospering from the Energy Revolution (PfER) programme funded by Innovate UK (IUK) as part of the UK research and Innovation (UKRI) Industrial Strategy Challenge Fund (ISCF).

MH:EK has reviewed the current energy landscape in the local area, to investigate options for a future Smart Local Energy System (SLES) by identifying proposition (opportunities) that are investable in the short-term and could provide the initial smaller steps towards larger scale decarbonisation and realisation of a Pembrokeshire wide SLES.

The project team consists of ORE Catapult, Port of Milford Haven, Wales & West Utilities, Riversimple, Energy Systems Catapult, Arup; led by Pembrokeshire County Council. Project non-funded collaborators and supporters include Western Power Distribution (WPD) and RWE; and Welsh Government Energy Service, Simply Blue and Community Energy Pembrokeshire respectively.

Routes to net zero

This research has explored a range of different scenarios, or possible pathways, to net zero across both immediate actions that could be taken now, out to decisions across the period to 2050. The study has drawn on the existing literature base, previous studies, extensive stakeholder engagement and Arup analysis to inform the scenarios considered.

The scenarios are not intended to present a recommended outlook but to enable exploration of a wide spectrum of outlooks that future decisions will influence, to support 'no regrets' decisions in the short-term.

The role for SLES

Smart local energy systems are shown to have significant benefits in terms of costs and carbon emissions.

This is the case where there is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen), supporting system balancing and greater flexibility of supply.

The study has highlighted a strong case for a hierarchy of energy usage as the system transitions to net zero. Energy should be used locally where possible and unnecessary transition between vectors should be minimised.

However, SLESs and heat networks are not always the preferred solution, this is dependent on the mix and scale of demand energy vectors.

The role for hydrogen

A national transition from natural gas to hydrogen is increasingly seen as a necessary component of full decarbonisation by 2050.

Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor offshore wind and marine resources.

Electricity is shown to be more cost and carbon effective for power and heating in the SLES propositions modelled, with locally produced hydrogen playing a role in absorbing excess electricity to create green hydrogen for local transport. The case for hydrogen in transport is seen to be most viable in heavy goods vehicles, particularly whilst the market is nascent, as highlighted by other studies [10].

Short-term propositions

This feasibility study has focused on three shortlisted 'propositions' to assess their viability as a SLES and set out recommended 'no regrets' opportunities that if pursued would kickstart the journey to decarbonisation.

A 'proposition' in this report is defined as a project or development opportunity to make an intervention to the existing energy system of the local area that results in a linked multi-vector (power, heat, and transport) system where there is (potential for) smart connectivity between assets or component parts, resulting in better balancing of local energy supply and demand.

The three shortlisted propositions (summarised overleaf):

Proposition 1: The Milford Haven Marina SLES;

Proposition 2: The Pembrokeshire Food Park SLES;

Proposition 3: The Pembroke Schools, Leisure Centre and Dock SLES

Proposition 1
The Milford Haven Marina SLES

Proposition 2
The Pembrokeshire Food Park SLES

Proposition 3
The Pembroke Schools, Leisure Centre and Dock SLES

The propositions

Proposition 1

Proposition 2

Proposition 3

Proposition 1: The Milford Haven Marina SLES

Proposition 1 focuses on the assets owned by the Port of Milford Haven (PoMH). The proposition considers the existing Liddeston Ridge Solar farm as a key supply asset alongside prospective PV and wind extensions, as well as the potential for rooftop PV on the PoMH buildings. The demand assets across the heat, power and transport vectors include the existing and proposed buildings and the commercial vehicle fleet owned by PoMH.

The analysis showed that further expansion of renewable assets and closer integration between those assets and the demand at the waterfront would be beneficial. The preferred option for expansion is a 2.5MW wind turbine with a 3.5MW solar PV expansion as second preference. Either a power purchase agreement (PPA) or a private wire connection to the waterfront demand is also recommended.

Modelling for proposition 1 has been undertaken to a greater level of detail due to additional funding and therefore has only been run for the 2020 scenario at this higher level of detail.*

2020 CAPEX with 66% Optimism Bias (£million)	2050 CO2 emissions (kg/kWh)	2020 LCOE (£/kWh)	MCA Score
16.4	0.002*	0.081	3.4

Figure 1
View of the Milford Haven Marina and Liddeston Ridge site. © Port of Milford Haven

Key messages

The study has highlighted:

- The need for whole system energy modelling at a wider scale that optimises across supply and demand, and balances between energy vectors. Doing this will enable informed decision making around the level of renewables development required, alongside storage technologies (batteries or hydrogen) so that utilisation of assets remains high and losses within the system are minimised.
- Electricity is likely to be the dominant low carbon energy vector, preferred for power, heat and a proportion of transport demand. As new renewable generation assets are developed locally supporting decentralised low carbon electricity options and the UK electricity grid continues to decarbonise, as back-up to decentralised local systems, the emerging hierarchy is to use low carbon electricity first ahead of green hydrogen generation.
- Hydrogen will play a role, but the degree to which it does, and to which it presents an efficient, low carbon, cost effective alternative will depend on external factors and policy and regulatory decisions.
- Future decisions made around the UK's transmission network will be significant in influencing development of new renewable generation, balancing, flexibility and trading. Regulatory barriers currently present a significant challenge to local trading platforms.
- The most significant regulatory risks arise from "Newer Market Entrants", particularly those with an undeveloped regulatory framework (e.g., networked hydrogen, heat networks), market access, and asset co-ownership.
- Establishing a robust data ecosystem at a local level, that integrates beyond the local boundary, is key to benefit from and support the national modernising energy data access (MEDA).
- The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should develop a roadmap for everybody to understand their role to get to net zero by 2050.

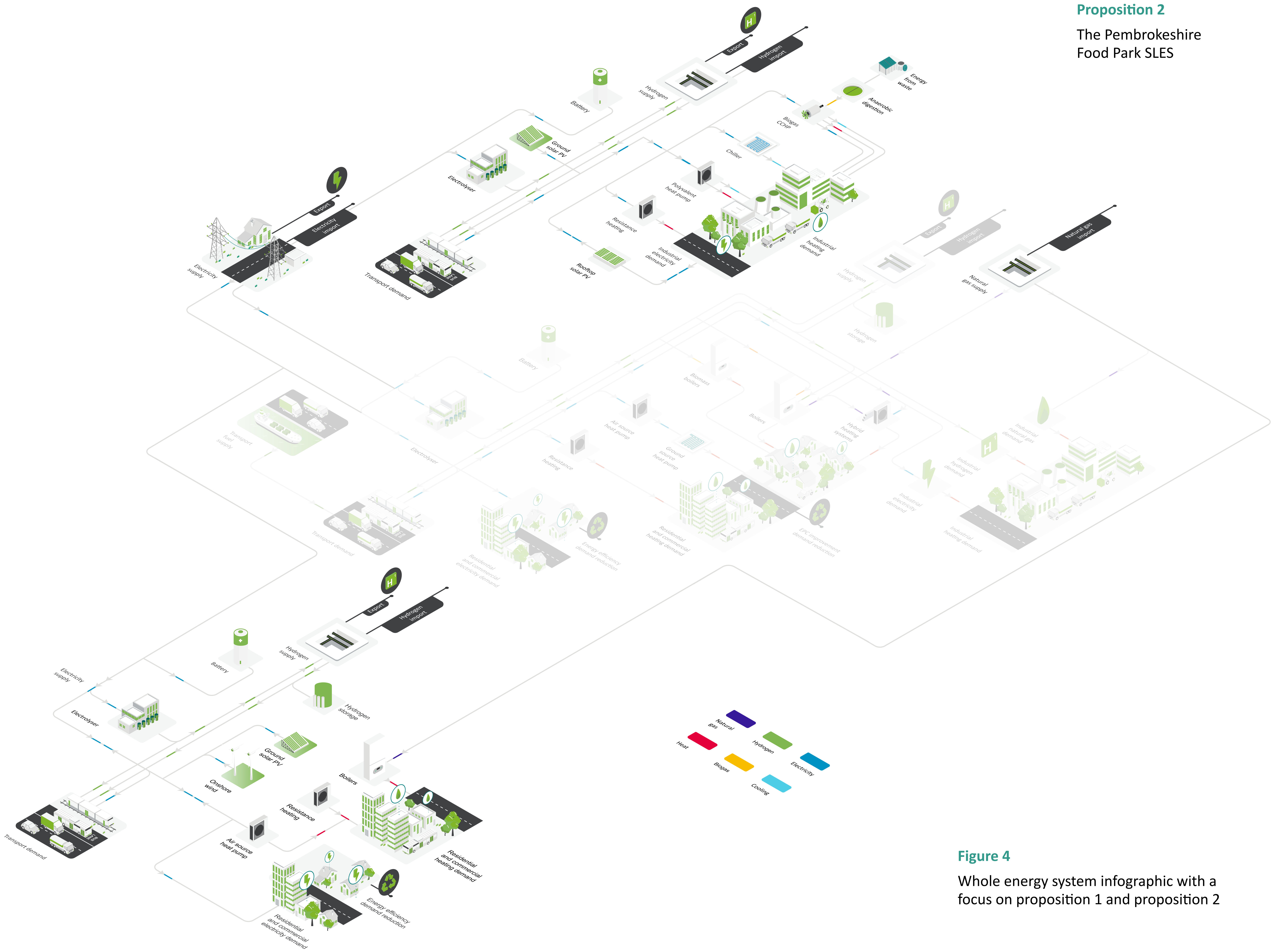
Credit

© Port of Milford Haven

Whole energy system infographic

Proposition 2

The Pembrokeshire Food Park SLES



Proposition 1

The Milford Haven Marina SLES

Figure 4

Whole energy system infographic with a focus on proposition 1 and proposition 2

02
Introduction

Project introduction

Introduction to the Milford Haven: Energy Kingdom project

The Milford Haven: Energy Kingdom (MH:EK) project is a £4.5m project within the Prospering from the Energy Revolution (PfER) programme funded by Innovate UK (IUK) as part of their Industrial Strategy Challenge Fund (ISCF).

The objective of Milford Haven: Energy Kingdom (MH:EK) is to establish seed markets for use of hydrogen around the Milford Haven waterway, by integrating a wide range of major energy facilities, renewable energy generators and energy consumers in the community, using a systems architecture that can be implemented with commercial-ready solutions and which focuses on underlying fundamentals and is therefore robust in the face of regulatory change.

Over a period of two years, the project team has explored what a decarbonised smart local energy system could look like for Milford Haven, Pembroke and Pembroke Dock. The team has also explored the potential of hydrogen as part of a multi-vector approach to decarbonisation. The project aim is to gather detailed insight into the whole energy system around Milford Haven, to identify and design a future smart local energy system (SLES) based on a truly multi-vector approach and comprehensive energy systems architecture.

Central to the project, and to achieving net zero, is a commitment to engage with the community and local industry, providing insight and opportunities for growth.

The project team consists of ORE Catapult, Port of Milford Haven, Wales & West Utilities, Riversimple, Energy Systems Catapult, Arup; led by Pembrokeshire County Council. Project non-funded collaborators and supporters include Western Power Distribution (WPD) and RWE; and Welsh Government Energy Service, Simply Blue and Community Energy Pembrokeshire respectively.

Our vision is to create a whole energy system which shines a light on the potential of hydrogen as a renewable energy source as part of an integrated SLES and the future potential and net zero transition pathway for the predominantly hydrocarbon reliant Haven.

Our ambition is to have a positive impact on local communities and help the UK achieve net zero greenhouse gas emissions by 2050.

Our mission is to explore how hydrogen can help us decarbonise across multiple vectors.

Figure 5
MH:EK project partners

Project objectives

The primary objective of MH:EK is to develop a conceptual proposal for what a 2050 decarbonised Milford Haven: Energy Kingdom energy system could look like and the short-term investments to achieve this, on the route to net zero by 2050.

The project aims to develop a detailed concept design of a preferred Smart Local Energy System (SLES) for Milford Haven in 2030 that is in transition towards being fully decarbonised by 2050.

A series of questions and objectives set the frame for the project, under an overarching question of **how 'best' to integrate hydrogen into the energy system to decarbonise energy supply?**

The project aims to develop a detailed concept design of a preferred Smart Local Energy System (SLES) for Milford Haven in 2030 that is in transition towards being fully decarbonised by 2050.

To develop a detailed concept design of a SLES for MH:EK that is investable in the short-term (2030) and is in transition towards Milford Haven being fully decarbonised by 2050, we adopted a bottom-up approach of identifying a longlist of opportunities for SLESs within Milford Haven, Pembroke and Pembroke Dock.

In order to set the limits of the study and data gathering for existing supply and demand energy assets and opportunities, the first step was to define the project boundary (Figure 13). This boundary is designed to be sufficiently large to allow the study to identify key opportunities while also remaining focused on the local area.

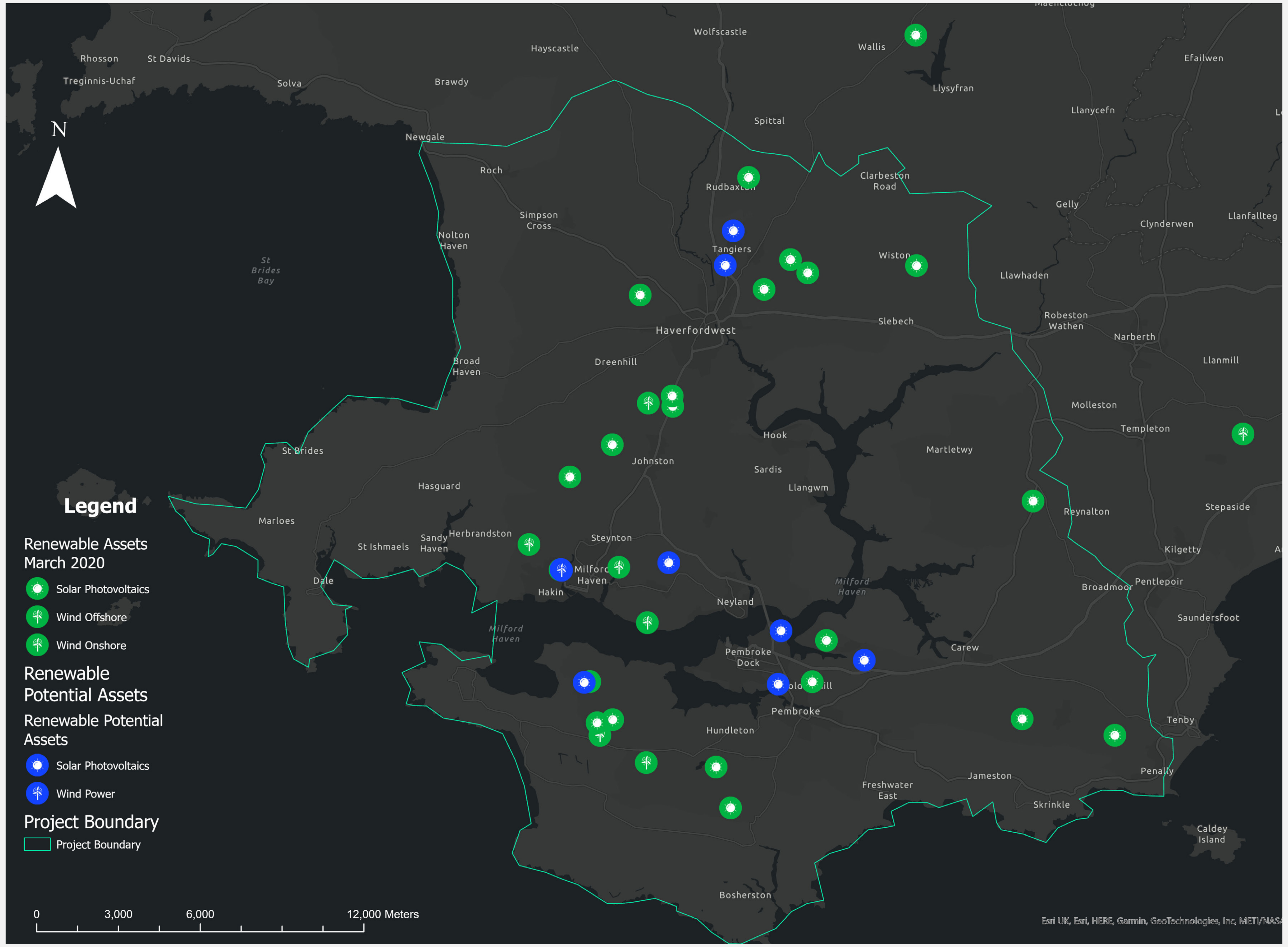


Figure 6

Milford Haven: Energy Kingdom project boundary

03
The Case for Change

The case for change

"Climate change is real, and it is happening all across the world and impacting on local communities in Pembrokeshire.

Sir David Attenborough in 2019 called climate change 'our greatest threat in thousands of years', adding, 'while Earth has survived radical climactic changes and regenerated following mass extinctions, it's not the destruction of Earth that we are facing, it's the destruction of our familiar, natural world and our uniquely rich human culture.'

It is up to us all to change this."

Cllr Joshua Beynon

Chair of the Net Zero Carbon 2030 Group, Pembrokeshire County Council [1]

The UK and Welsh Government net zero targets by 2050 require whole system decarbonisation at scale and at pace.

The Case for Change – net zero by 2050

Everyone has a role to play as individuals, local communities, private organisations, industry, public sector actors and financiers to ensure we reach these targets.

This will require technological adoption and innovation, economic, financial and regulatory innovation, business transformation, and behavioral change.

The fastest and most effective way to deliver against country level decarbonisation targets, is to decarbonise the energy sector as a priority.

Pembrokeshire and more specifically Milford Haven, Pembroke and Pembroke Dock are uniquely positioned to take a leading stance on this decarbonisation journey.

The Port of Milford Haven is the UK's largest energy port, with associated industrial processes, jobs and skilled workforce, and Pembrokeshire has significant offshore and onshore renewables potential.

The Case for Change – energy sector decarbonisation as a priority

Whole energy sector decarbonisation is establishing behaviours, processes and infrastructure that bring about net zero emissions across all electricity, heat and transport.

The UK Government has set a more ambitious target for the electricity sector of reaching net zero by 2035, in support of whole system decarbonisation by 2050. This will need to be met with significant additional renewables as part of the UK electricity network than exists today, as well as some degree of carbon capture & storage in order to meet:

- Decarbonisation of current electricity demand
- Increasing electricity demand linked with expected population growth
- Shifts in locational demand as urban centres grow
- Increasing electricity demand linked to electrification of heat and transport

There is a shared commitment across Government and industry to deliver against these targets as evidenced by the presence and contributions of the private sector at COP26 and through many collaborative industry studies that are referenced throughout this report.

"We believe decarbonising energy is possible but also that it will be complex, not least because there are many ways to reach net zero, each with their own trade-offs." National Grid ESO

Amongst the many ways to reach net zero, Smart Local Energy Systems (SLES) are expected to have a significant role in supporting decentralisation of the energy system, greater local balancing and through enabling a greater number of (new) actors to engage.

"Smart Local Energy Systems can help to achieve these targets. Smaller scale, decentralised energy systems utilising smart technologies can be delivered at a local level to offer a route to net zero, while providing considerable market opportunities associated with the transition." EnergyREV

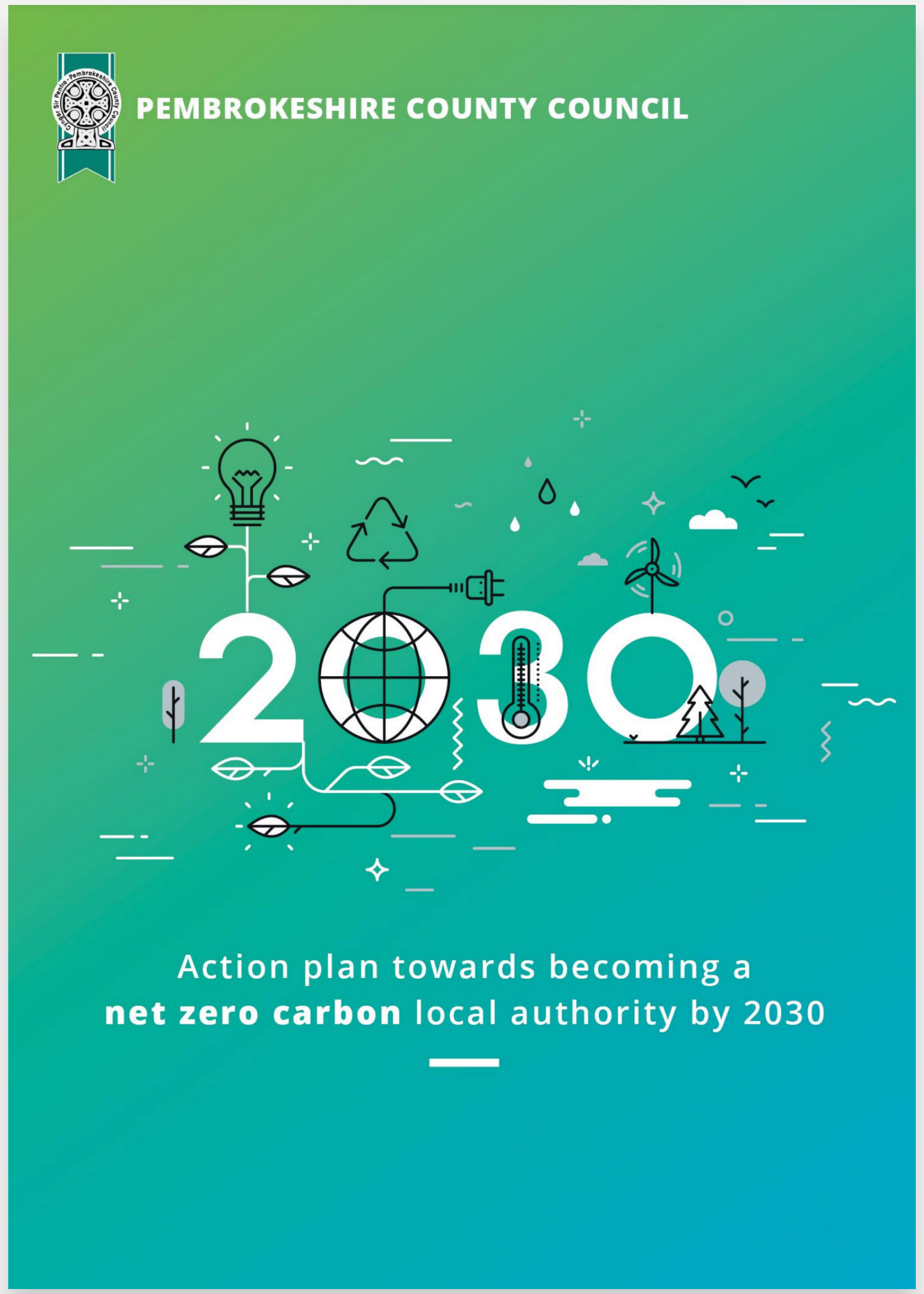


Figure 7
Pembrokeshire County Council Net Zero 2030 action plan [1]

Smart local energy systems

"If we're to reach our goal of decarbonising the energy system, we need to think of the transition not as one giant leap but as a series of smaller, more achievable steps. These involve establishing individual low-carbon 'clusters' and joining them together to unlock greater benefits."

Alan Thomson
Arup Global Energy Leader

Smart local energy systems are shown to have significant benefits in terms of costs and carbon emissions, where there is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) supporting system balancing and greater flexibility of supply.

The role for SLES – what this study has shown

The key facets of SLESs are electricity, heating and mobility interaction and being mutually supportive of one another towards net zero goals. This project demonstrates the value of interconnected SLESs and the potential for hydrogen production as an alternative vector where electricity networks are currently constrained.

However, SLESs and heat networks are not always the preferred solution, this is dependent on the mix and scale of demand energy vectors. Where a SLES is not appropriate, adoption of low carbon technologies would be encouraged on an individual basis for example, rooftop PV, retrofit of air source heat pumps (ASHPs), and further development of renewable generation projects.

The value of an interconnected system may not always be demonstrated where there are fewer component parts, and the supply-demand is not balanced within a geographic or system boundary. For instance, if the intervention consisted solely of hydrogen derived from grid or local electricity, and the local electricity generation was not used to satisfy the local electricity demand first, this would not be considered a SLES.

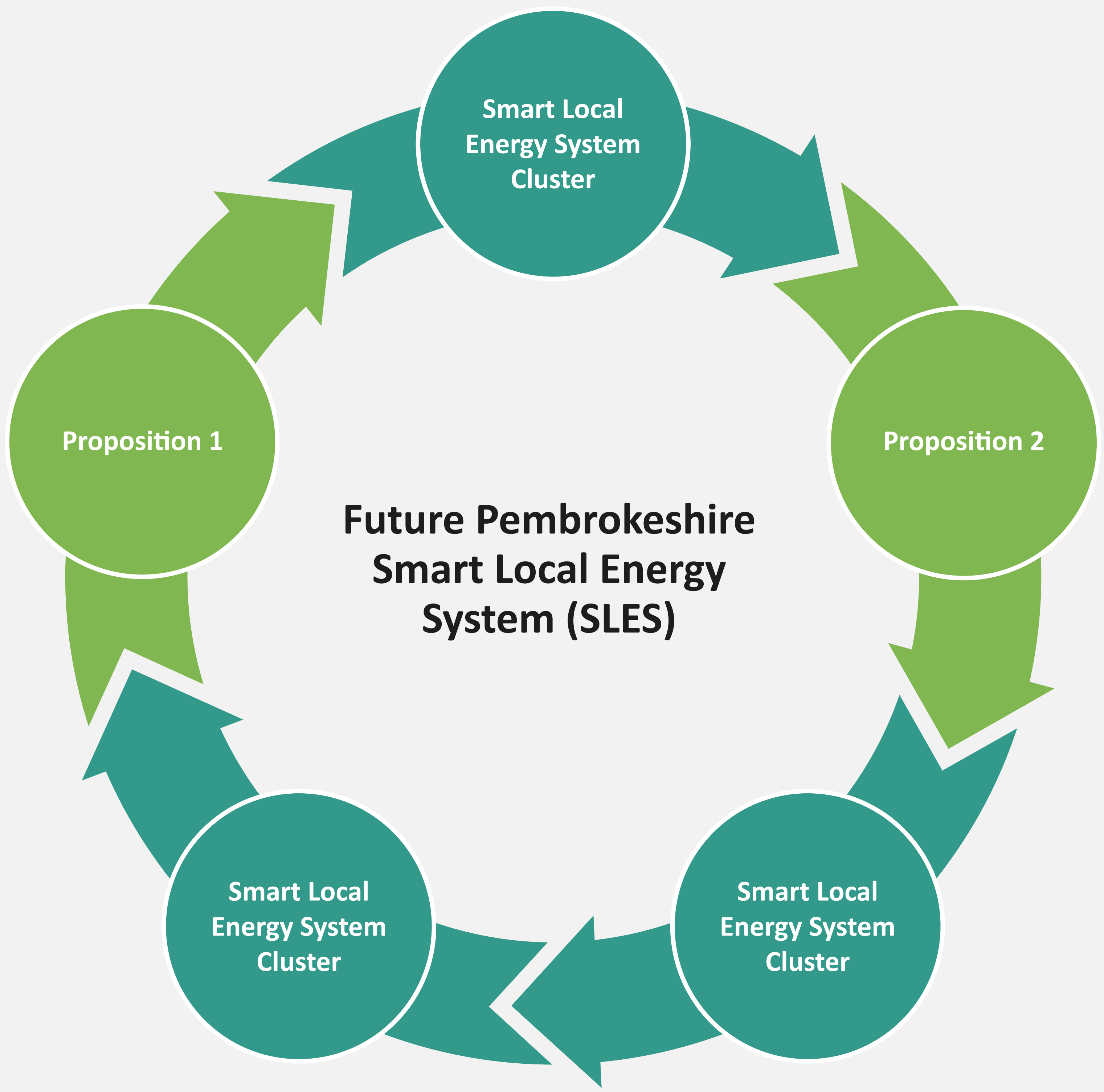


Figure 8

Propositions identified during this study could result in acting as 'stepping stone' projects or catalysts for other SLES clusters developing towards a Future Pembrokeshire Smart SLES

Why hydrogen?

"As the UK's largest energy Port, we are responsible for the supply of 25% of UK energy needs. It is becoming increasingly clear that to achieve net zero by 2050, we need renewable electrons and molecules. Gas plays a very significant role in the UK's energy mix and the gas network is able to be used for hydrogen transportation and storage. As a vital component of the energy system, the gas network can support the already-constrained electricity grid when at capacity with renewable energy or when renewable energy is unavailable."

Tom Bardell
Port of Milford Haven

A national transition from natural gas to hydrogen is increasingly seen as a necessary component of full decarbonisation by 2050. The reason for the focus on hydrogen within this project is threefold:

Large scale hydrogen markets may provide essential cross-vector system balancing and inter-seasonal energy storage for an energy system dominated by the UK's abundant renewables, especially high-capacity factor, offshore wind and marine resources.

1. The MH:EK boundary is uniquely located around the Port of Milford Haven, the UK's largest energy port, with an associated highly skilled workforce in the fossil fuel industries – people who understand about dealing with hydrocarbons, the processes involved, and safe working practices. We need to harness their skills for hydrogen. It is critical that we develop new skills and transition communities, in parallel with the changes to the physical components of our energy systems.
2. The MH:EK boundary includes other significant national energy assets, which will continue to retain a supporting role in the transitioning energy sector such as the Pembroke Power Station which is central to RWE's proposed Pembroke Net Zero Centre (PNZC). Similarly, Pembrokeshire is considered to have a key role in new renewables developments both onshore and with offshore wind in the Celtic Sea, as well as being the site of the nationally significant Greenlink interconnector which will support balancing of the GB energy system with Ireland.
3. Hydrogen can be created using excess electricity generated by renewable technologies, and then it acts as a chemical energy store, releasing energy when needed to support electricity grid balancing which will be increasingly important as the energy sector decarbonises and electricity demand increases. What we need to look at is how to make using hydrogen financially viable within the different energy vectors of heat, power and transport, and doing so both at scale and at a local level; whether it's putting in a hydrogen-fuelled heating system, running a hydrogen vehicle, or building a hydrogen manufacturing facility. This is something that the project aims to explore in detail.

Figure 9
MH:EK hydrogen refueller demonstrator at Milford Haven marina

04
Approach

Approach

Getting to a preferred option

The process to develop a preferred option for a conceptual decarbonised SLES for MH:EK included investigating the Economic case for short-term investments that are in transition to a decarbonised system by 2050, supported by review of commercial models, trading mechanisms and the system architecture required to deliver this. Figure 10 overleaf shows the process to get to a preferred option for a scalable, replicable and investable SLES for MH:EK which consisted of:

- Data gathering and stakeholder engagement to gain a detailed insight of the physical energy system within the project boundary
- Infrastructure mapping to identify opportunities or propositions for investable, replicable and scalable SLESs based on the project objectives and critical success factors to act as stepping-stones to deliver system level change and energy transition.
- A longlist of 16 propositions identify through spatial analysis of the existing and planned physical assets, high-level energy demand and supply balance estimation and a RAG (Red, Amber, Green) triage against the project critical success factors (CSFs).
- Multi-criteria assessment (MCA) assessment against project CSFs and key stakeholder and expert review against SLES requirements for success using a SLES Decision Tree.
- Shortlist of three propositions based on the results of the MCA supplemented by the SLES Decision Tree, expert review and stakeholder engagement:

Proposition 1
The Milford Haven Marina SLES

Proposition 2
The Pembrokeshire Food Park SLES

Proposition 3
The Pembroke Schools, Leisure Centre and Dock SLES

- Detailed techno-economic modelling of the three propositions considering a variety of future energy scenarios to produce an optimised system for each proposition and cost-benefit model with associated carbon emissions.

Credit

Approach

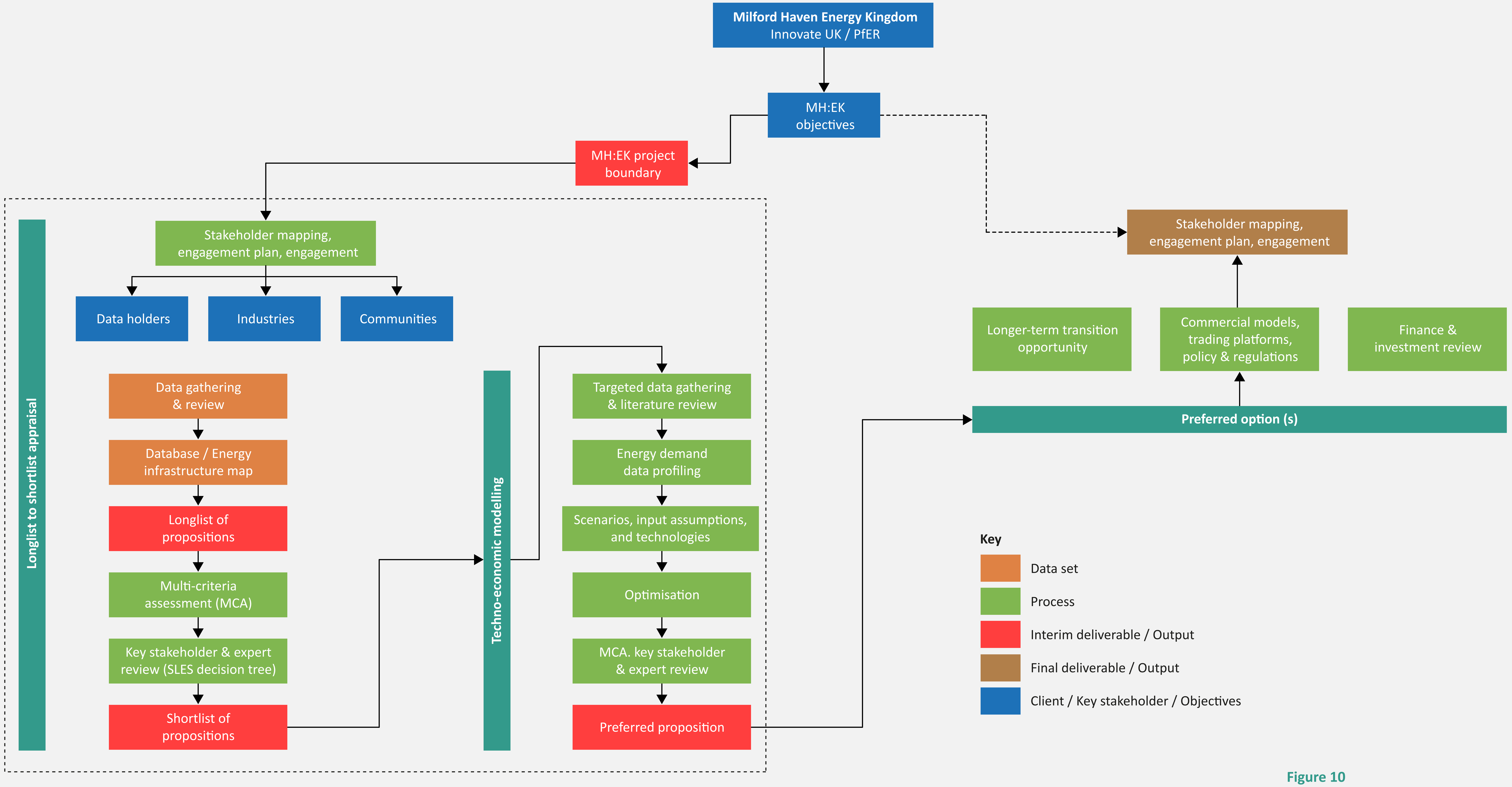


Figure 10
Workflow to get to a preferred SLES option for MH:EK

Modelling the propositions

The techno-economic modelling for multi-vector SLESs considers demand centres across the heat, electricity and transport vectors and supply assets within the proposition boundary. The techno-economic modelling optimises the system considering whole life cost and carbon emissions in order to meet the energy demand up to 2050, for different scenarios or 'world views' from high electricity to high hydrogen.

We used a targeted approach to gather data specific to each proposition. Where gaps were identified in the gathered project data, we used industry datasets and benchmarks, supported by a series of modelling assumptions.

We used Arup's suite of whole system energy modelling (WSEM) tools, to optimise the energy supply and storage capacities based on the cost and carbon emissions objectives - for three different future energy scenarios across two-time horizons - 2020 & 2050 allowing for multi-vector energy system analysis across two different world views.

For each proposition and the modelled scenarios, the outputs of the techno-economic modelling are:

- Capital expenditure (CAPEX) of the technologies to be installed to implement the proposition
- Operational expenditure (OPEX) of the technologies annually over the lifetime of the proposition
- Levelised Cost of Energy (LCOE in £/kWh) – blended and individually across electricity, heat and hydrogen
- Carbon emissions (kg/kWh)
- Energy capacity by technology (MW)

The modelling provides insight on 'no regrets' options that are readily investable (2023-2025) and an optimised energy system solution for each proposition across the modelled scenarios.

The output of the modelling was reviewed alongside re-running an MCA assessment in the context of the more detailed modelling output to recommend a preferred solution. The modelling process is illustrated on Figure 11.

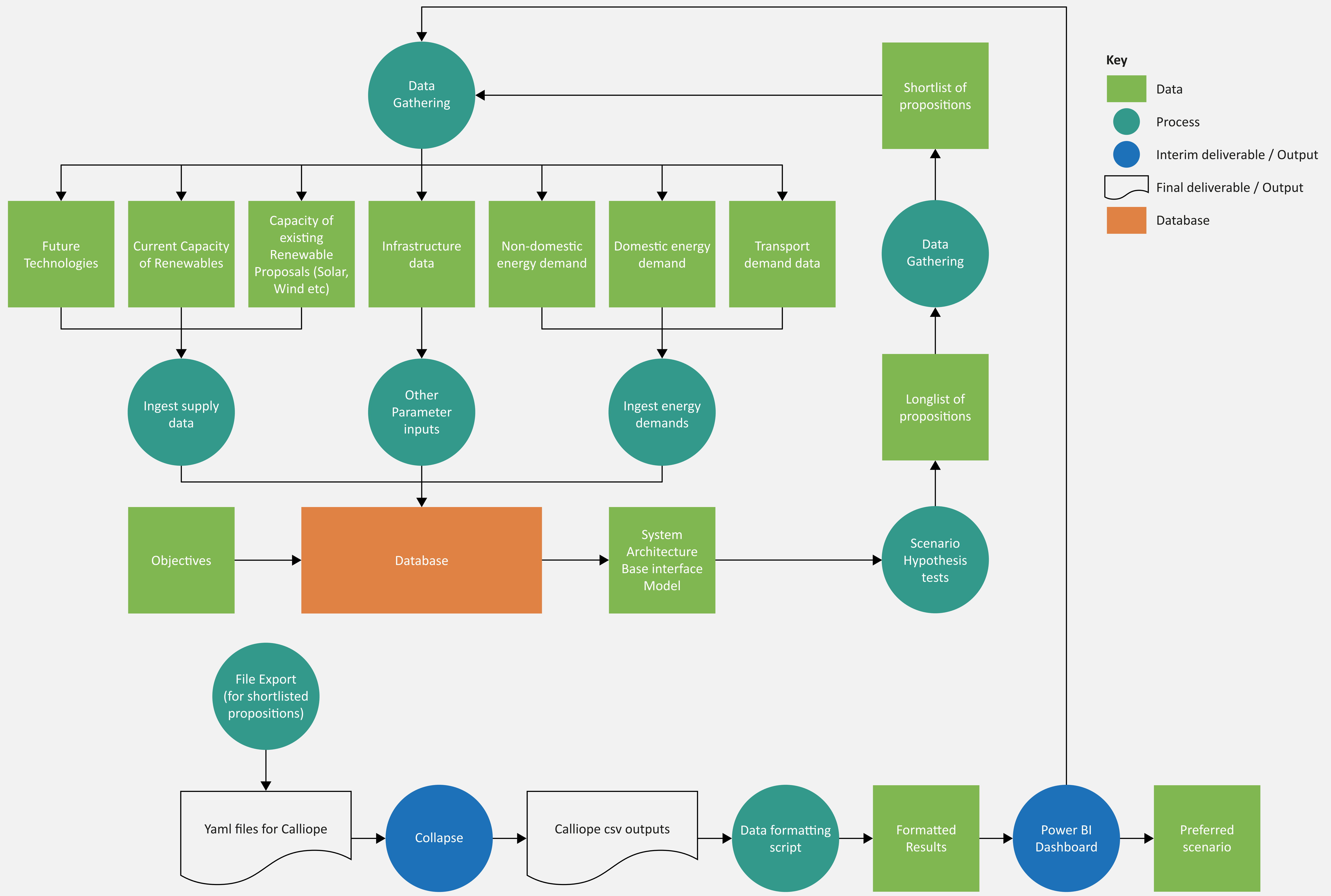


Figure 11

Workflow diagram for the techno-economic modelling process

Technology options

Technology options to supply energy to the demand assets across heat, electricity and hydrogen generation out to 2050 were established based on a high-level screening process. We carried out a first screening to qualitatively assess each technology and considered if the deployment of the technology would be consistent with Pembrokeshire County Council's goal of net zero by 2030 [1].

We undertook a high-level resource assessment for each technology to estimate how much heat and electricity can be generated from each technology within each proposition, considering the associated site constraints and opportunities and discounted the technologies with low resource availability. We used the scenarios definition and assumptions to undertake a further screening of the technologies resulting in a shortlist of technologies to be modelled.

Using gathered cost data and findings from stakeholder engagement with network operators, we added whole life cost information to the technologies, existing and predicted fuel costs and network operational costs to the database.

Cost assumptions

To model the costs of different technologies or distribution, we viewed each proposition from the lens of the project 'anchor' or driving organisation. We assumed that national level costs such as grid or gas network upgrades are covered by network distributors. Only the cost of the technologies required to implement the proposition at the local scale are assumed to be paid for by the anchor to enable more accurate cost attribution to modelling of the propositions. More details on the cost assumptions are provided in the Technical Summary Report [29].

Fuel costs / prices

A similar hierarchical approach to estimating building energy consumption was applied to derive the fuel costs – real cost data where available was applied and otherwise we used industry standard benchmarked figures from parties such as BEIS. We calculated forecast energy prices using an Energy market simulation tool. Where only wholesale prices were available, the import cost was multiplied by a factor of 2.4 to represent the expected retail price for the end consumer. The reverse operation was completed to determine export prices where only retail prices were available. More details on the fuel costs and prices assumed and sources are provided in the Technical Summary Report [29].

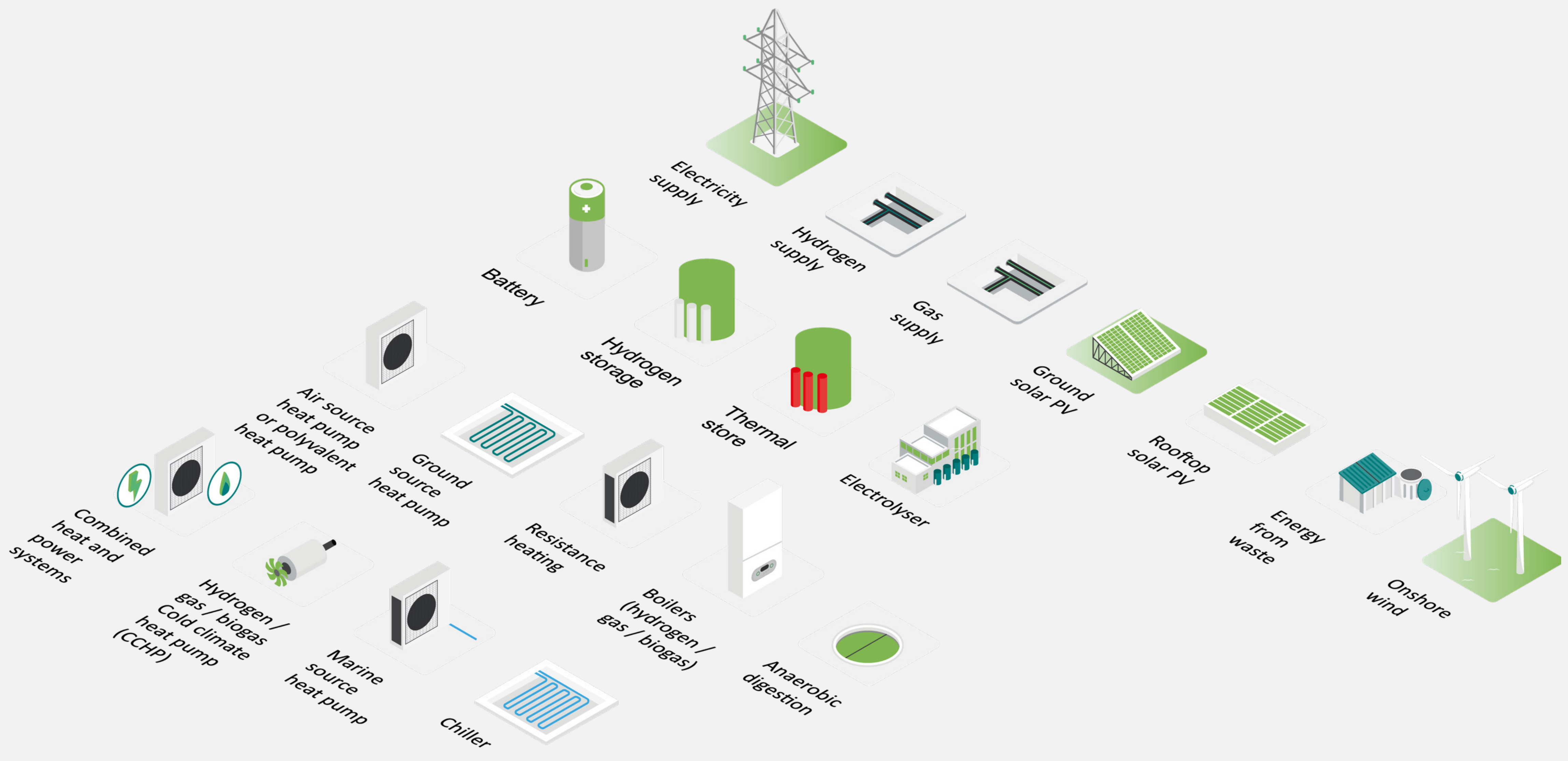


Figure 12
Technology options modelled

05
Findings

Findings

What are the short-term actions within the Milford Haven project boundary to deliver net zero by 2050?

Across all the propositions, scenarios and sensitivity testing modelled, the resulting optimum hierarchy of the energy supply-demand relationship has been:

1. Use locally generated electricity locally where possible, first for power and then to satisfy heating (using heat pumps) and EV transport.
2. If excess electricity is generated beyond the power and heat demand baseload, this is used to support local electrolysis and green hydrogen production, where there is a local hydrogen transport demand.
3. Any remaining excess electricity (or where an electrolyser is not sized to the maximum seasonal excess such that it is not underutilised) is exported to the regional or national grid, in preference to exporting excess electricity to the national grid.
4. Imported electricity is used to support balancing of fluctuations for both power and electric-heating, where new technologies have been installed.
5. Where existing buildings are connected to the gas network (2020 scenarios), these remain until gas boilers are phased out. In 2050 scenarios, where natural gas is no longer an option electric heating systems dominate with hydrogen boilers featuring to a lesser extent and dependent on the scenario. Hybrid heating systems can provide resilience to future system but the timescales of system level transfer from natural gas to Hydrogen (including 20% hydrogen blend to 100% transition over time) are unknown.
6. Locally produced hydrogen is not favoured for heating demand. New hydrogen boilers are generally a much lower proportion of the overall heating mix due to their lower efficiencies, even once gas is phased out, in the current market context.
7. If electricity export prices decrease, a greater proportion of locally generated electricity may be used to produce hydrogen to satisfy a greater proportion of any hydrogen transport demand (though generally not heating).
8. Where there is a significant proportion of hydrogen transport demand, this is only partially met locally with hydrogen imports. This presents an opportunity for greater local hydrogen production if hydrogen transport demand does develop in the region.
9. Batteries feature in all scenarios, but are not a strong 'no regrets' option, we suggest they are kept in review. Based on the battery price assumptions taken in the model across 2020 (higher cost) and 2050 (lower cost), batteries are at a price tipping point and are expected to feature more predominantly and be a more favourable balancing solution soon.

Additional low carbon generation is adopted in most scenarios, with the cost-benefit and pay-back demonstrated as part of a whole systems view.

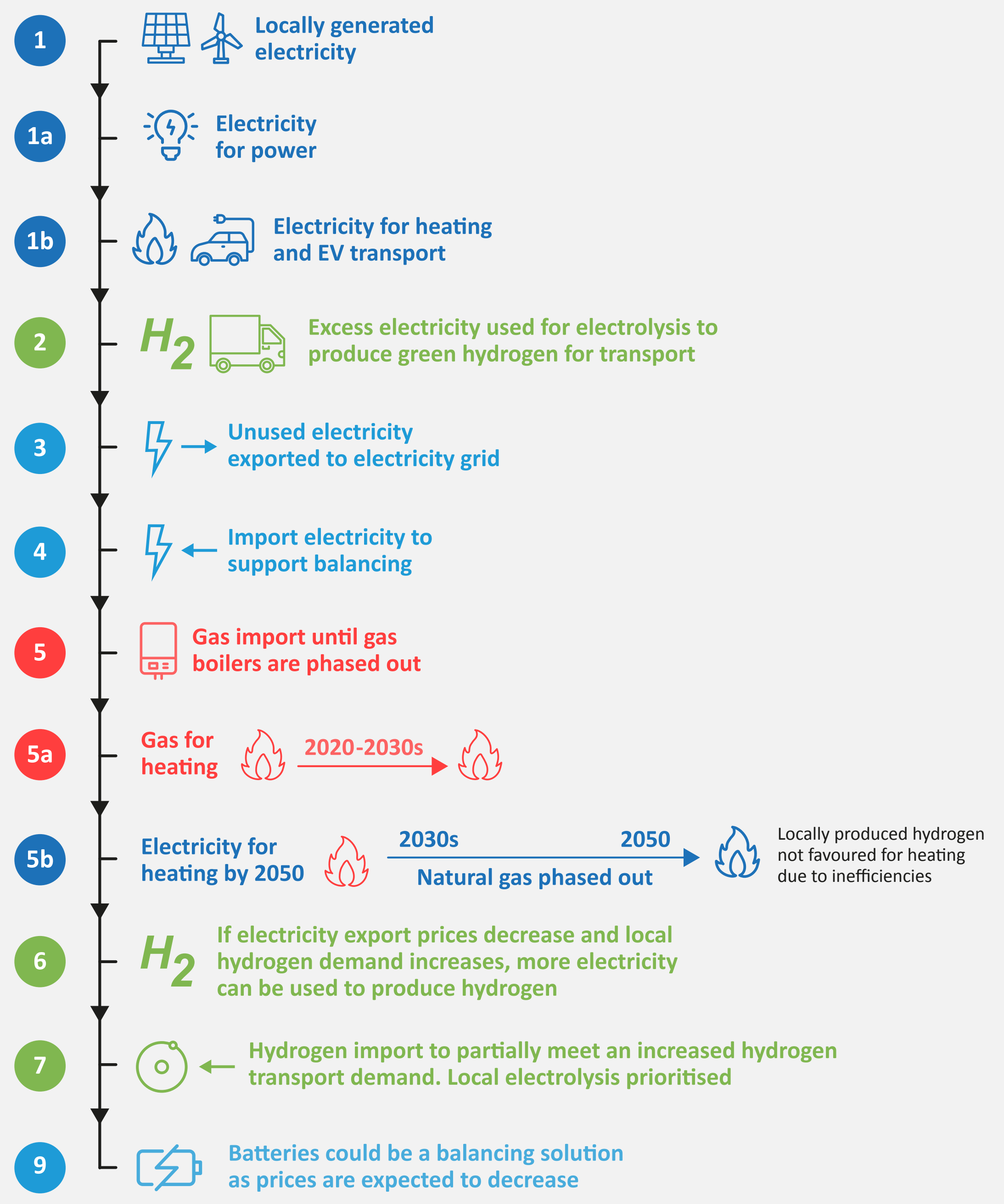


Figure 13

Hierachy of energy supply-demand relationship based on a 2020 world view and short-term actions to support reaching net zero by 2050

Summary of the propositions optimised outcomes

Table 4 provides a summary of the CAPEX, OPEX, LCOE and carbon emissions for each proposition. The CO_2 emissions have been scaled to the size / capacity of the proposition to allow for ease of comparison between propositions.

The upfront capital cost (CAPEX) for the recommended system for each proposition is provided in Table 16. In line with the HM Treasury Green book guidance, an optimism bias (OB) of 6-66% should be allowed for non-standard Civil Engineering projects. At this stage of the project, the upper bound 66% is applied, as there is not enough information to reduce the optimism bias. This total CAPEX represents the upfront budget for each proposition (also provided in Table 16.).

Carbon emissions from Proposition 1 are relatively high when compared to Proposition 2 and 3 across the same year. This is because all scenarios for Proposition 1 are based in 2020, so they still have significant carbon for electricity imports, and remains a predominantly natural gas-based heating system. The carbon emissions shown for Proposition 1 with a 2050 view in Table 4 have been adjusted to exclude gas heating emissions that are present in 2020 in order to compare 'like-for-like' with Proposition 2 and 3. The three propositions are then broadly comparable.

It should be noted that these quantitative outputs present only part of the picture, and the following notes should be considered alongside the recommendations.

Proposition		1 - Milford Haven Marina SLES		2 - Pembrokeshire Food Park SLES		3 - Pembroke Schools, Leisure Centre and Dock SLES	
Scenario		Onshore wind expansion with private wire	Onshore wind expansion with private wire and no gas*	Hybrid	Hybrid	Hybrid	Hybrid
		2020	2050*	2020	2050	2020	2050
KPI	Capex (£million)	8.12	9.87*	15.6	14.5	13.6	13.4
	Capex with 66% OB (£million)	13.5	16.4*	25.9	24.1	22.6	22.2
	Opex (£m/year)	1.704	2.204*	0.765	0.075	-0.176	-0.236
	CO_2 emissions (kg/kWh)	0.076	0.002*	0.01	0.003	0.102	0.001
	LCoE (£/kWh)	0.061	0.081*	0.079	0.074	0.024	0.03

Table 1

Summary of the CAPEX, OPEX, LCoE and carbon emissions for each proposition scaled to the size / capacity of the proposition.
* CO_2 emissions are shown adjusted to a 2050 view and excluding gas heating emissions in order to compare like-for-like with proposition 2 and 3.

The propositions

MH:EK SLES project recommendations include;

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2.
- Further work and more detailed analysis of both propositions is required, as these propositions progress along their development journeys.
- Both present real opportunities for a catalytic stepping-stone SLES that could result in a longer term larger SLES for the Pembrokeshire region, through expansion over time to include a broader boundary of residential and industrial demands.
- These two propositions present differences in 'flavour' with Proposition 1 being more focused around local community demand and Proposition 2 encompassing more commercial / light industrial use.
- The outcome of Proposition 3 suggests that it is not a strong SLES candidate, so is not recommended to be progressed. It does highlight the commercial opportunity for onshore wind development if network constraints can be reasonably addressed.

Proposition 1 recommendations

The analysis shows that further expansion of renewable assets and closer integration between those assets and the demand at the waterfront would be beneficial. The preferred option for expansion is a 2.5MW wind turbine with a 3.5MW solar PV expansion as second preference.

The preferred method of integrating waterfront demand with Liddeston Ridge supply is via a private wire. However, a private wire would cost an estimated £4.4m (without OB) which accounts for most of the CAPEX in all private wire scenarios. This would pay for itself over the 40-year lifetime, but the initial investment could be challenging.

If the commercial, legal and managerial challenges associated with a private wire prove insurmountable, the virtual PPA option could be preferrable to the business-as-usual operation, if it can be achieved at the 33kV scale.

Proposition 2 recommendations

This proposition represents a viable opportunity for a SLES. There is strong interplay between the demand energy vectors (heating, cooling, electricity and hydrogen) and a significant opportunity to utilise local waste products to fulfil this demand.

A core aspect essential to each scenario is a solar farm located at Haverfordwest airfield connected to the food park via private wire. The renewable energy is beneficial to minimise the amount of electricity purchased via the national grid. However, it does account for a significant proportion of the CAPEX (£9.5m-£10.5m) for every scenario.

Given that Proposition 2 represents a new-build proposal, the food park could be designed from the beginning to take advantage of no regret technologies, particularly anaerobic digestion, biogas CCHP and polyvalent heat pumps. These can be integrated via heating and cooling distribution networks with no disruption to existing services or replacement of legacy assets unlike Proposition 1 and 3.

Utilising excess PV generation to electrolyse hydrogen locally would be a cost-effective method of meeting some of the hydrogen transport demand although the majority would still be imported.

If local hydrogen transport demand becomes a reality and regular, consistent, consumers are identified, this proposition could begin to form the core of a local hydrogen transport hub. Further work on the Hydrogen refueller costs and business case would be required.

When a clearer understanding of end user demands is available, further analysis is required to understand the feasibility of the proposed solution and adjust efficiencies if necessary. We would also recommend to undertake a more detailed level of modelling to model different system configurations (as with Proposition 1).

Proposition 1

Proposition 2

Proposition 3

Proposition 1: The Milford Haven Marina SLES

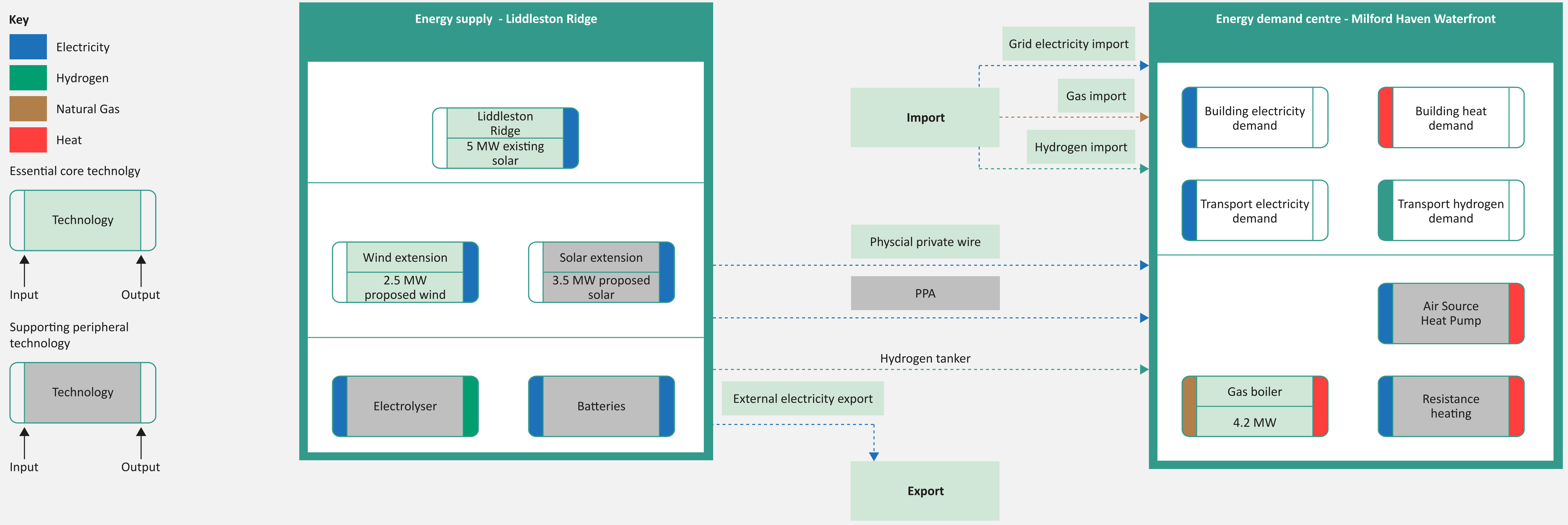


Figure 14

Schematic view of the preferred system for Proposition 1 – Milford Haven Marina SLES

06
Deliverability

Commercial models options overview

The three propositions differ both in the assets included within the proposition perimeter, and the stakeholders relevant to those propositions. The commercial models therefore differ across the different propositions, in order to reflect their attributes.

The following presents an overview of the different commercial models that could apply across the propositions.

Community owned model

Disaggregated market model

Centralised model

SPV / Partnership model

Community owned model

- The community owned model is one where local community group or groups has overall responsibility for owning and operating assets
- The priorities of the local community are likely better reflected through a community ownership model, however risk allocation will need careful delineation between project partners.
- While the financial returns of the various propositions are unlikely to be a key driver under this model, project funders and financiers will still require some remuneration for the deployment of capital.
- Some elements are unlikely to be able to fall under community ownership – and would have to be retained by public sector/private sector ownership model. Clear delineation of roles and responsibilities would be needed under each proposition.

Disaggregated market model

- The disaggregated market model opens up the various propositions to competitive market forces and dynamics. Under this model, a range of stakeholders interact to deliver the SLES, responding to market signals to deliver investment.
- Ownership of assets varies across technologies, and investors require returns commensurate with the wider market.
- Under the disaggregated market model, risk is allocated to those best placed to manage it, resulting in an efficient operating model. However, there is the potential risk of investment not materialising if there is insufficient demand – and vice versa – known as the chicken and the egg dilemma.

Centralised model

- Under the centralised model, the various propositions would be driven by a single entity. Decisions are centralised, and benefits can be optimised through the community how the 'leader' sees fit.
- This entity could potentially make use of sub-contractors to deliver specific elements of the proposition, but ultimate responsibility for the delivery of the programme would sit with the leading entity, either the Port of Milford or Pembrokeshire County Council in the context of the propositions.
- The leading entity will assume overall responsibility for organizing the funding of the propositions and is likely to be the owner of many of the assets under consideration. Where specific risks are better managed by other parties, this is where the leading entity could look to subcontract certain responsibilities out.
- Under this model, the leading entity , as centralised decision maker, has the power to make decisions almost unilaterally, and can enact change in ways in which market dynamics might not be able to.

SPV / Partnership model

- Under an SPV / Partnership model, a consortium of key project partners would come together to form a special purpose vehicle entity, under which the project would be run, and propositions developed and operated.
- This would likely include generation asset owners, IDNOs and private wire owners/operators, and local authority/landowners. This will enable the pooling of expertise, and the appropriate allocation of risk across SPV entities.
- This type of model, a partnership arrangement between developers, local authorities and other relevant bodies would also help to facilitate investment in the propositions.

The recommended commercial model

SPV Model: Summary impact across propositions

The SPV model has been identified through the options as the highest scoring commercial model in the longlist.

In determining that, the following looks to consider the SPV model in further detail, highlighting the applicability to the different propositions, and how the risks, challenges and potential actions under the SPV model differ between the propositions.

Proposition 1: The Milford Haven Marina SLES

Best fit

- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues

- Potentially conflicting commercial interests given number of stakeholders involved in the SLES.
- Potentially complex interfaces will require more sophisticated optimisation of the trading platform.
- Prioritisation of SLES will need identifying, e.g. which party to prioritise.

Actions

- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks

- Identified in the following section

Proposition 2: The Pembrokeshire Food Park SLES

Best fit

- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues

- Commercialisation and revenue streams for hydrogen transportation less clear.
- Potentially complex interfaces will require more sophisticated optimisation of the trading platform.
- Prioritisation of SLES will need identifying, e.g. which party to prioritise.

Actions

- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks

- Identified in the following section

Proposition 3: The Pembroke Schools, Leisure Centre, and Dock SLES

Best fit

- Despite small differences between the three propositions, we consider the SPV model to be the best fit across all three.

Challenges/ issues

- Proposition 3 is not a good example of a SLES and the project lead or 'anchor' is unclear. Delineation of roles may be more difficult under this proposition.

Actions

- Identification of potential SPV partners.
- Undertake more detailed mapping of revenue flows, SPV partners, and commercial relationship between parties.

Key regulatory risks

- Identified in the following section

The SPV / Partnership model

Ownership

- Ownership of assets under the SPV model would likely be spread across the various project partners, and there would need to be an exercise to determine the most efficient allocation of ownership and consequently risk.
- It is conceivable to envisage an ESCo could be established to own and operate generation assets, and potentially boilers, ASHPs etc.
- An independent network operator would likely own and operate any private wires/ distribution assets, while the Port Authority/local authority could coordinate priorities within and across the propositions.

Funding

- Under the SPV model, funding would be pooled between project partners, who would either put forward their own capital, or capital could be raised through borrowing.
- Further, it is likely that local authority representation could be secured through the provision of grant funding.

Revenue

- Revenue under this model would be collected by the various project partners. The IDNO/ private wire operator/owner would collect revenue through network charging.
- The owner of the generation assets would receive a revenue for the sale of energy, either to the demand within the proposition boundary, or through export to grid.
- Revenues would either be optimised through market dynamics, or by community need, depending on how the SPV is structured. Operating under an SPV model would allow for the cross-subsidisation of technologies, if for example certain technologies are not as profitable when delivering customer benefit.

Risks

- The SPV would be made up of a small number of projects partners, specialised in their field. Therefore, under this model, risks are likely to be best allocated to those able to manage and mitigate them.
- There is a risk that the objectives and priorities of different SPV partners conflict, and so terms of references and propositions would need to be clearly articulated.

Impact on net zero

- SPV/ Partnership model should be able to set its own priorities and objectives, acknowledging there may be different priorities between the project partners.
- Should the SPV decide that net zero ambitions are important – this model should help to further that objective.

Difference between propositions

- If the SPV was established at the proposition level, it is likely that the entities within each SPV will differ to reflect the specificities of that proposition. For example, under proposition 3, there is no private wire assumed, and so there is unlikely to be a need for an iDNO or other independent network operator.

Example Use case: SPV / Partnership model

Developing and articulating a use case can help to demonstrate how the Commercial case might operate in practice. A use case provides a set of interactions between users in an environment, and in this case, the relationships between stakeholders in the Milford Haven propositions.

Figure 17 presents a potential use case for the SPV/ Partnership commercial model under Proposition 1: Milford Haven Heat Network and Microgrid SLES. The SPV commercial model has been chosen as the highest scoring through the multi criteria options assessment.

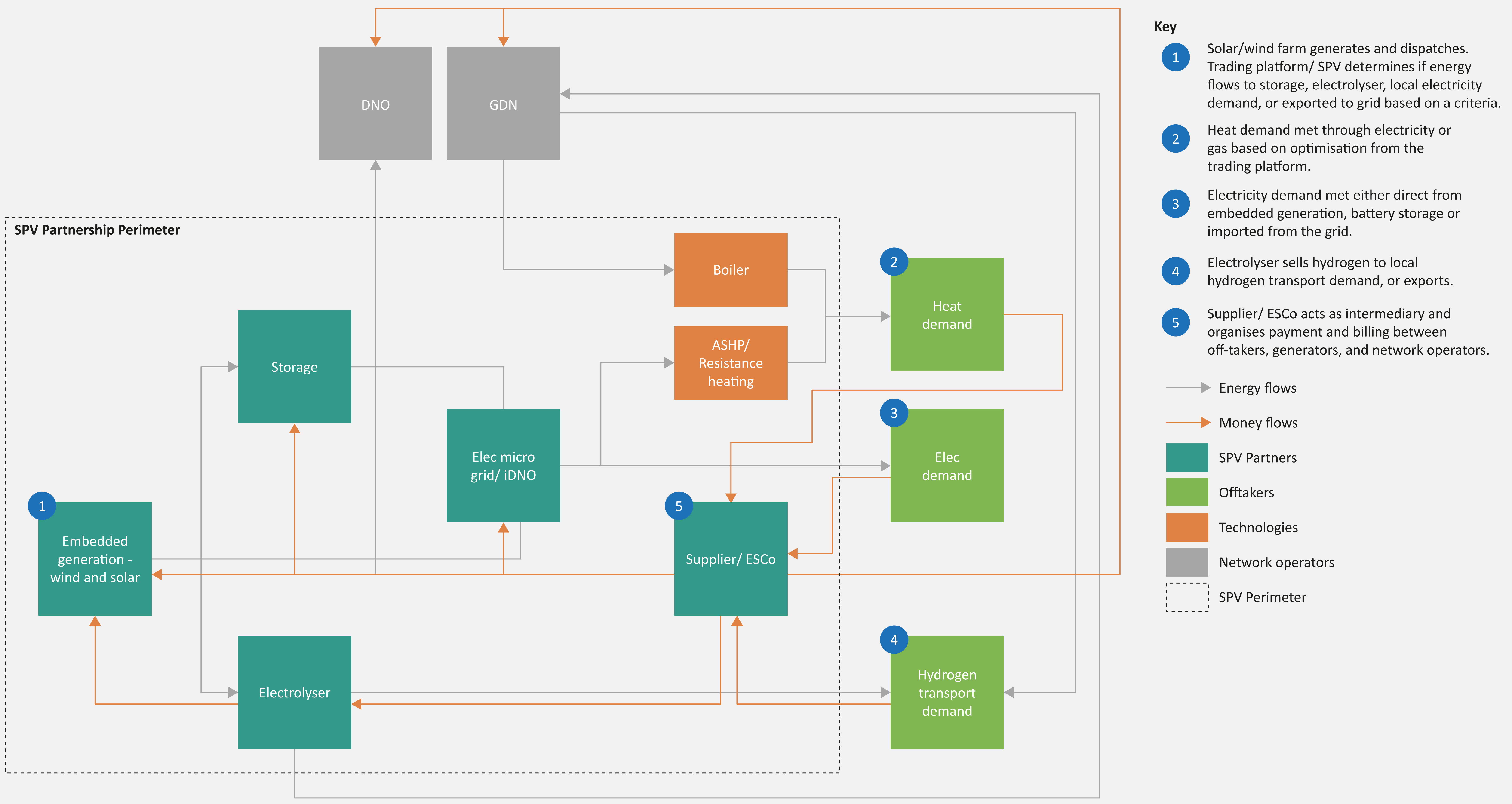


Figure 17

SPV Partnership model

Delivering the propositions

Steps for project delivery – the commercial model

The initial findings show that a commercial model made up of several project partners under a special purpose vehicle (SPV) type structure could potentially be viable. Through a multi criteria assessment the SPV/ partnership model scored the highest and delivered best against the criteria assessed. The SPV model would allow for an efficient allocation of risk as a range of entities would sit within the SPV as project partners, and risks could be allocated to those best able to manage them.

An SPV/Partnership model would be able to reflect the local communities' needs and priorities as we would expect that there would be some sort of community representation within the SPV. How the SLES is optimised would need to be decided by the SPV as there would ultimately be trade-offs between where energy is directed to, and which offtakers are prioritised.

As part of a next stage of the study, we would recommend that further work is done to explore the applicability of the SPV / Partnership model. We particularly recommend that specific use cases are worked through, to identify how each of the different stakeholders would interact under the model. This exercise would also further articulate the revenue flows between stakeholders.

We would also recommend that this potential model is started to be tested with the various stakeholders to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing it.

Finally, we would recommend exploring in more detail how the ESCo model would work in practice, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter.

Policy and regulations

Regulatory considerations

The regulatory review identifies, categorises, and contextualises regulatory risks, obstacles, and barriers that could be faced by the three propositions outlined in the techno-economic modelling. The regulatory review covers the following steps.

Existing Regulatory Arrangements

Key energy market stakeholders, systems, and technologies – and some significant relationships there between – are mapped. These are categorised as "Traditional Market Users", "Newer Market Entrants", "Networks", and "Government / Regulator". Existing regulatory arrangements are introduced, and relevant considerations identified at a high level.

Identification of Regulatory Barriers

For each of the three propositions, those market stakeholders, systems, and technologies most relevant to bringing the preferred arrangement to market are highlighted. Potential regulatory and related barriers are identified and mapped to the highlighted stakeholders, systems, and technologies. Barriers are rated on a three-colour scale from low to high risk. The most significant risks arise from "Newer Market Entrants", particularly those with an undeveloped regulatory framework (e.g., networked hydrogen, heat networks), market access, and asset co-ownership.

Routes to Market

Options are put forward to overcome some of the more significant regulatory risks; these include licensing exemptions, off-network hydrogen transportation, engagement with the market regulator, alternative means of selling surplus generation, consideration of commercial model suitability, and demonstrating innovation in the regulatory sandbox.

High Level Overview of Regulatory Environment

- The UK energy sector operates under a complex regulatory system: sector bodies face differing degrees of market freedom and must follow distinct sets of codes, licensing arrangements, and legal requirements.
- Energy policy in the UK is set by the government Department for Business, Energy, and Industrial strategy (BEIS).
- BEIS mandates the industry regulator, Ofgem, to protect consumers in market segments operating under regional or national monopolies.
- Ofgem is governed by GEMA, the Gas and Electricity Markets Authority. Interactions between key market bodies are illustrated in the following slide.

System Decentralisation

- As part of the energy transition, significant market transformation is underway. This is marked by system decentralisation, digitalisation, and flexibility.
- In a centralised system, market users perform distinct roles in the energy supply chain: a generator might own a generation plant, sell power to a separate supplier, and export it onto an energy network operated by a separate DNO, who then distributes the energy to a separate user.
- Decentralised, distributed systems can create overlap between these roles – in some systems, generation, supply, and distribution could be performed by one user.

Regulatory Challenges

- Although some technologies or market users feature more prominently between the three proposed SLES models, they face similar regulatory barriers. Some recent and expected regulatory changes affect the systems and technologies featured in the propositions.
- The three SLES propositions must be compliant with existing regulatory and legal requirements. Business model selection and development should consider regulatory barriers and opportunities for mitigation.

1. Existing Regulatory Arrangements
- Illustration of key systems and stakeholders
- Regulatory considerations

2. Identification of Regulatory Barriers
- MH:EK propositions: key users and systems
- Regulatory and related barriers by market user or system

3. Routes to Market
- Options to overcome regulatory and other barriers
- Policy recommendations

Figure 18

Overview of the policy and regulatory review

Stakeholder mapping under existing regulatory framework

The energy market map on Figure 19 illustrates, at a high level, the existing relationships between some of the market users, systems, and technologies most relevant to the regulatory environment.

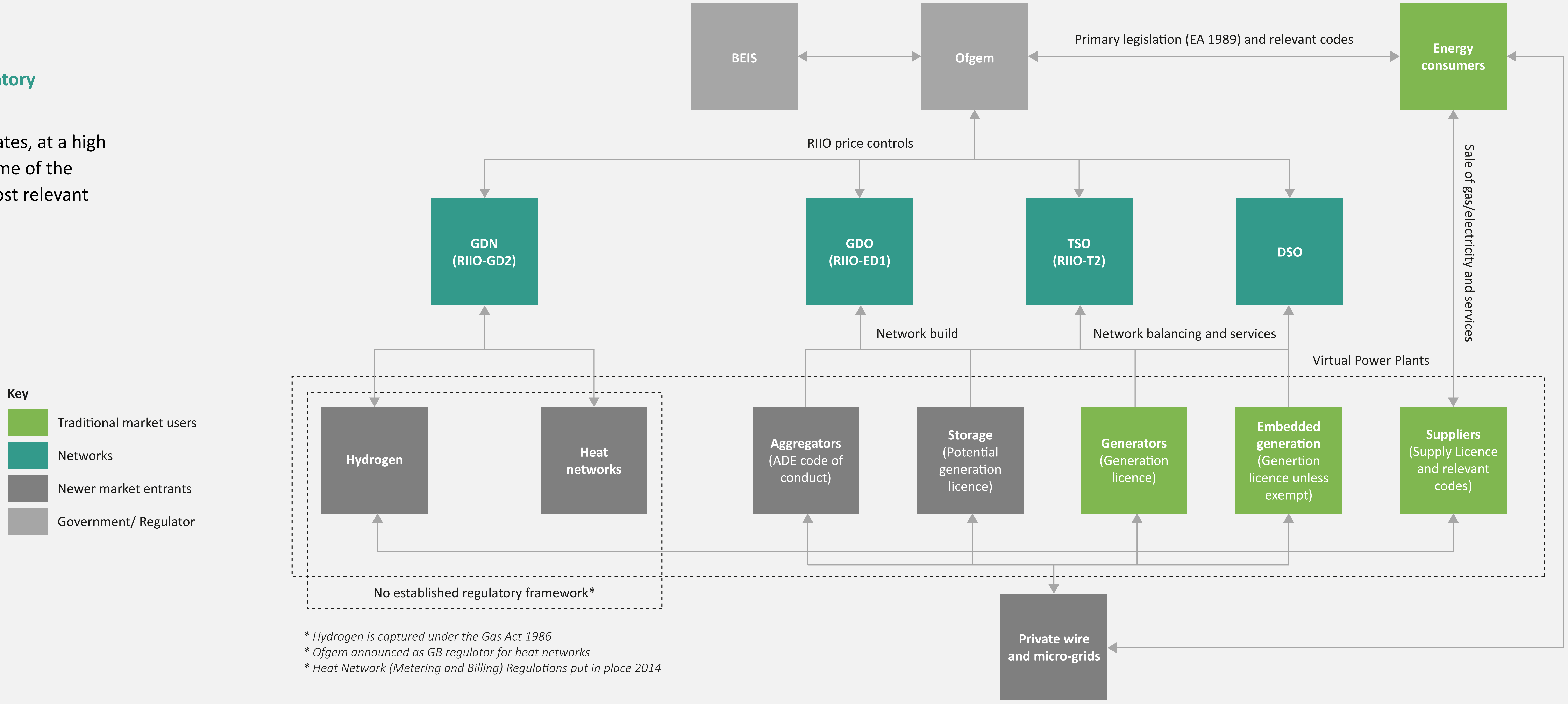


Figure 19

Summary of stakeholder mapping under existing regulatory framework

Recommendations

Key Findings and Policy Recommendations

Figure 20 outlines the key findings from the regulatory risk identification process, summarises market trends and changes, and defines some high-level policy recommendations to navigate the regulatory considerations relevant to the proposed SLES models.

Developing Frameworks

- Uncertain regulatory futures for networked hydrogen (which could affect future hydrogen demand) and heat networks could present a regulatory barrier.
- Mitigation strategies include avoiding networked hydrogen transportation, informal outreach to Ofgem in the short term, and potentially application to use the Regulatory Sandbox - to demonstrate innovation and value to consumers - in the longer term.

Monitor Developing Frameworks

Regulation Changes

- Recent and ongoing regulatory changes have removed some embedded benefits and increased network charges for decentralised generators, but have opened up new value streams to smaller market users.
- A trend of increasing support for local systems is part of Ofgem's ongoing work to increase system flexibility during the energy transition.

Take Advantage of Regulation Changes

Commercial Ownership Models

- Licencing and asset ownership regulatory constraints should be taken into account when selecting and developing the commercial model.
- Smaller, private wire generators and distributors can be licence-exempt. Allowing them to own these assets simultaneously.

Consider Commercial Ownership Models

Market Access

- Wholesale market access can be expensive for small generators and a PPA will likely not be attractive to a third party for exporting surplus generation.
- Using an aggregator, now with access to the balancing mechanism, as an intermediary is a potential route to access flexibility value streams. Aggregators in energy trading are discussed in the following slides.

Create a Market Access Strategy

Figure 20

Key findings from the regulatory risk identification process

Trading Platforms

The role for trading platforms in developing SLESs

Trading platforms facilitate the exchange of goods and services, often across multiple markets. In the context of energy, a trading platform might allow for the exchange of electricity or hydrogen, as well as acting as a local balancer and flexibility provider, optimising the use, and further development of, distributed energy resources, including local hydrogen production and storage.

They have the potential to unlock benefits to:

- the network (reduced energy losses, manage constraints and deferring/delaying investment),
- the consumers/community (improved hedging opportunities, supports local social objectives), and
- society (increased renewables, demand side flexibility).

MH:EK could benefit from a trading platform because export of electricity from Pembrokeshire is constrained. A local trading market could support more renewables development, hydrogen production capacity, and flexibility/storage within the system.

A local trading platform can be designed to meet local needs and exploit the benefits that local energy offers. The anticipated components of a trading platform ecosystem are shown in Figure 21. An initial specification for potential energy trading platforms has been developed by ESC in line with the systems architecture study [39].

Minimum passing criteria for a platform to be considered in our more detailed review are presented in the Figure 21 (in the grey boxes).

In addition, we scored the reviewed trading platforms against key criteria deemed necessary for the trading platform to be a success in the MH:EK context (in the light green boxes).

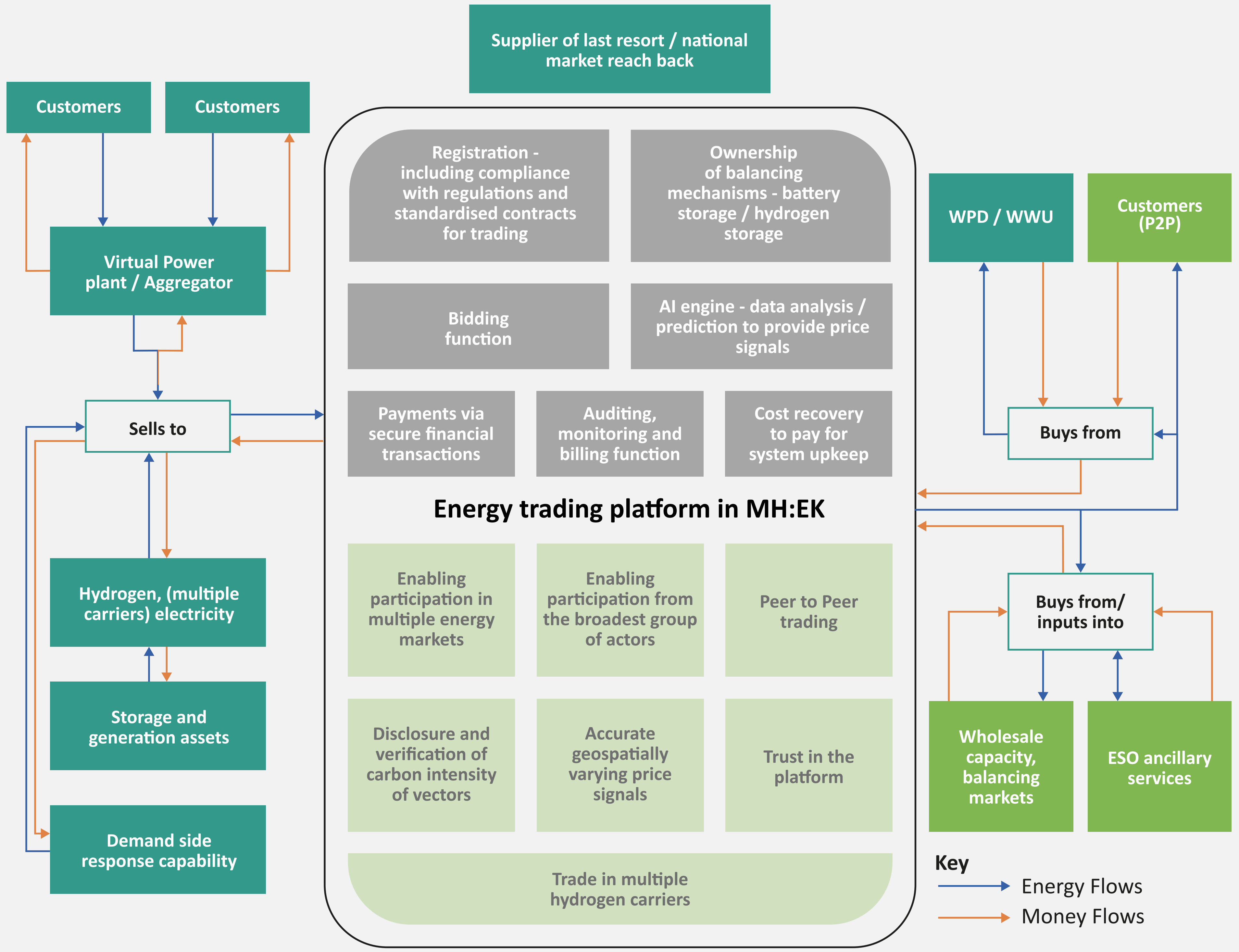


Figure 21
Components of a trading platform ecosystem

Review of exiting trading platforms

Introduction to different trading platforms

The Piclo Flex platform operates in the flexibility market. Whilst the scope of the platform may evolve over time to include generation, the current remit is to enable DNOs to signpost their future flexibility requirements, and for providers to register on the platform in order to notify the DNO of their availability – by technology type; location on the network and price. The platform therefore acts as the marketplace for signalling these tender opportunities and for providers, including aggregators, to submit offers.

Piclo Flex acts as a bulletin board, where DSOs post their customised and localised needs for flexibility (essentially a volume, a location, an up/down direction and a period plus some technical characteristics). Asset owners then respond to such “tenders” and submit their best availability and utilisation prices for a given volume (possibly with some limitations, such as maximum utilisation time). Granted offers consequently are made available to the DSO for congestion management at a later stage.

Origami Energy offers its clients a range of trading and automation solutions, supporting power production, planning and forecasting and energy trading.

Its range of services further includes battery revenue optimisation to derive maximum value from standalone or co-located (with renewable energy assets) batteries, participating in capacity, flexibility and balancing markets, as well as for other flexible assets.

Its forecasting and forecast management services supports clients in making informed trading decisions, utilising real time physical and market data.

Funded through the Prospering From the Energy Revolution (PfER) programme, the Liverpool Multi-vector Energy Exchange (LMEX) project will produce a detailed design of a city-wide energy marketplace for the trade of energy services across power, transport and heating/cooling.

The platform will comprise of a Smart Network Controller (SNC), a Flexibility Exchange Platform (FXP) and sensors installed in premises/homes of potential end-users. It therefore allows participants to act in both wholesale and flexibility markets.

In 2020, EEX kicked off its first-ever Hydrogen Working Group. The objective was to reflect on designing a sustainable wholesale trading market for hydrogen, together with all market players.

In parallel to commodity trading, they planned to certify the origin of hydrogen through hydrogen Guarantees of Origins (GOs). With Grexel, EEX Group supported the creation of the first ever unified European market for hydrogen through Guarantees of Origin: CertifHy.

The Cornwall Local Energy Market project was a three year trial from 2017 to 2020, funded through the EU Regional Development Fund and Centrica. It created a trial market for flexible demand, generation and storage.

The project trialled several propositions. It allowed the DNO and TSO to both procure flexibility from distributed renewable energy assets, allowing supply and demand side providers to participate in the market, optimising capacity on the network.

Further, it enabled peer to peer trading alongside demand-generation coupling solutions, ran a locational pricing trial, and provided routes for Distributed Energy Resources (DERs) to market.

The Community Urban Neighbourhoods Internal Trading of Energy (CommUNITY) was a collaborative project between EDF, UKPN, Repowering London and the Bartlett Institute at UCL.

Solar panels were installed on a block of flats in Brixton, South London. Residents were able to trade excess electricity with each other using an app. Ofgem granted regulatory relief to the project to enable peer to peer trading.

A battery was also installed onsite to sell excess solar generation back to the National Grid.

Trading platform assessment

Matrix of trading platforms reviewed against key criteria

Key Criteria for Trading Platform Success*	*Liverpool Multi Vector Energy Exchange*	*Piclo Platform*	*CommUNITY*	*Origami Energy*	*European Energy Exchange - hydrogen working group*	*Cornwall Local Energy Market*
Enabling participation from the broadest group of actors that could add to or use the service (through aggregation and lowering barriers to entry)	Surpasses expectations	Surpasses expectations	Satisfactory	Surpasses expectations	Does not meet criteria	Surpasses expectations
Disclosing and verifying the carbon intensity of the energy vectors being traded on the platform, in real time.	Unknown - information not available	Unknown - information not available	Satisfactory	Unknown - information not available	Surpasses expectations	Does not meet criteria
Trade in multiple hydrogen carriers.	Unknown - information not available	Does not meet criteria	Does not meet criteria	Unknown - information not available	Surpasses expectations	Does not meet criteria
Accurately convey geospatially varying price signals for different vectors.	Unknown - information not available	Does not meet criteria	Satisfactory	Unknown - information not available	Satisfactory	Satisfactory
Enabling participation in multiple energy markets (capacity mechanisms, balancing services, network constraint services etc) which would facilitate revenue stacking for participants, and optimal use of Distributed Energy Resources (DERs).	Surpasses expectations	Does not meet criteria	Does not meet criteria	Surpasses expectations	Unknown - information not available	Surpasses expectations
Peer to Peer trading without the necessary involvement of a licensed supplier	Surpasses expectations	Does not meet criteria	Surpasses expectations	Unknown - information not available	Does not meet criteria	Does not meet criteria
Trust in the Platform by participants and owners of DERs	Unknown - information not available	Unknown - information not available	Surpasses expectations	Surpasses expectations	Surpasses expectations	Surpasses expectations

Key

- Surpasses expectations
- Satisfactory
- Does not meet criteria
- Unknown - information not available

*Criteria that are specific to **energy** trading platforms are the focus. More general requirements for markets/trading platforms to function, such as sufficient market liquidity, sufficient participants, a facility to cover costs, auditable, secure etc. are assumed a priority.

Table 2

Platforms reviewed against key criteria deemed necessary for the trading platform to be a success in the MH:EK context

Barriers for MH:EK

There are technical, regulatory and market barriers that must be overcome.

In the electricity sphere, the largest technical barrier to participating in wider flexibility and capacity (electricity) markets is that export is constrained. There also need to be improvements in the network, and forecasting ‘prosumer’ data available from DNOs. Local, peer-to-peer trading could be utilised to overcome the export constraint, but this would need to be done with regulatory relief from Ofgem.

In the hydrogen sphere, the maturity of the market remains a barrier. Market liquidity calls into question the utility of using a trading platform over securing long-term contracts. Fulfilling orders remains difficult without transport infrastructure, and electrolysers participating in the electricity balancing, flexibility and capacity sphere are competing against CHP and battery incumbents. Securing jobs in the region would likely be better served through production assets securing long term contracts with transport, or chemicals firms.

As such, it seems unlikely that establishing a digital trading platform represents the most beneficial approach at this time. Trading platforms do not work in isolation and there needs to be a trading ecosystem that hosts trading collateral, enables administrative actions and counterparty risk management and more. Once a more robust hydrogen market is established, a trading ecosystem that has access to electricity and gas markets is recommended.

07
Looking Out To 2050

Looking out to 2050

"RWE is looking to deliver 2GW of hydrogen projects by 2030, including a green hydrogen project in Pembrokeshire. Key to this is the economic viability of projects producing hydrogen for use across a wide variety of sectors such as transport, power and industry. RWE welcomes the work of MH:EK in helping to make the storage, use and distribution of hydrogen cost effective."

Jeremy Smith
RWE

The journey to decarbonisation of the UK energy system by 2050 is uncertain. The National Grid Future Energy Scenarios (FES) [2] set scenarios under which the UK energy system could achieve net zero by 2050 - with differing level of societal, sector level and policy changes required. Three of the four FES 2021 [3] modelled scenarios meet the net zero target, however immediate action for deployment of new technologies at scale; demand flexibility; trading flexibility; digitalisation and whole energy systems approach is needed.

By applying this UK wide view to a local context, the MH:EK project aims to develop a conceptual proposal for what a 2050 decarbonised Milford Haven energy system could look like and provide a roadmap for short- to mid-term steps to reach net zero by 2050.

The longer-term pathways represent possible future energy systems for High-Electric, Balanced Green Hydrogen and Balanced Blue Hydrogen pathways.

The pathway approach is consistent with industry future energy system pathway development such as National Grid FES [2], the Climate Change Committee 6th Carbon budget [4] and the Regen Net Zero South Wales studies [5]. The pathways are a qualitative representation of our understanding of the various local and regional decarbonisation plans and show how they can be aligned to accelerate the transition of the Pembrokeshire energy system to net zero by 2050. They are based on information reviewed and received through stakeholder engagement and are based on implementation of the stepping-stone MH:EK SLES propositions and the materialisation of the regional plans such as South Wales Industrial Cluster (SWIC) and the RWE Pembroke Net Zero Centre (PZNC)

The Balanced Green Hydrogen pathway is well aligned to the CCC 'balanced pathway' demonstrating the potential balance of electric and hydrogen technologies. By transitioning large industrial sites to hydrogen production and storage, there is opportunity to retain jobs through skill shifting supporting a just transition.

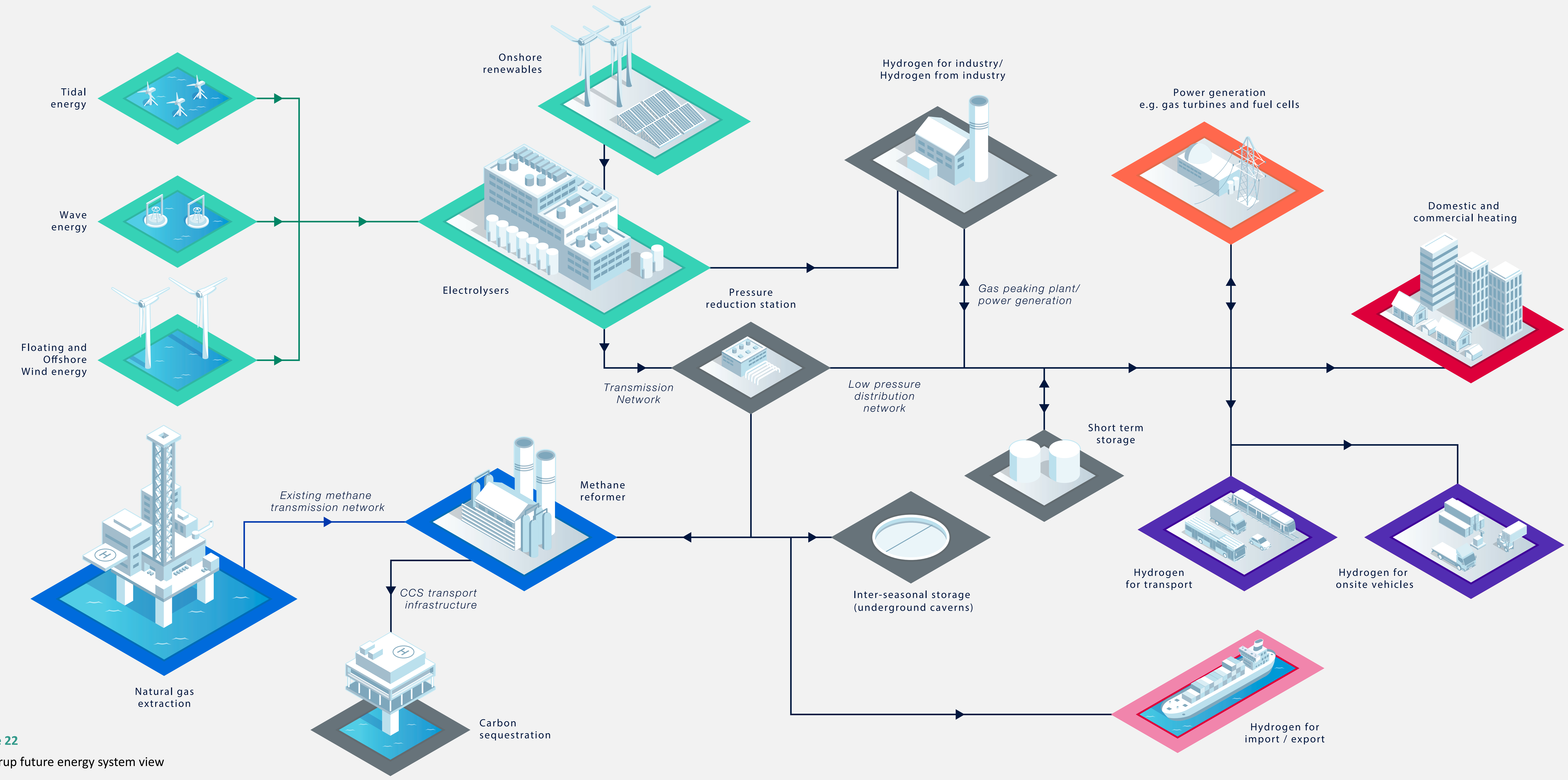


Figure 22

The Arup future energy system view

The MH:EK pathways

The High Electric pathway

The Green Hydrogen pathway

The Blue Hydrogen pathway

Timeline of events

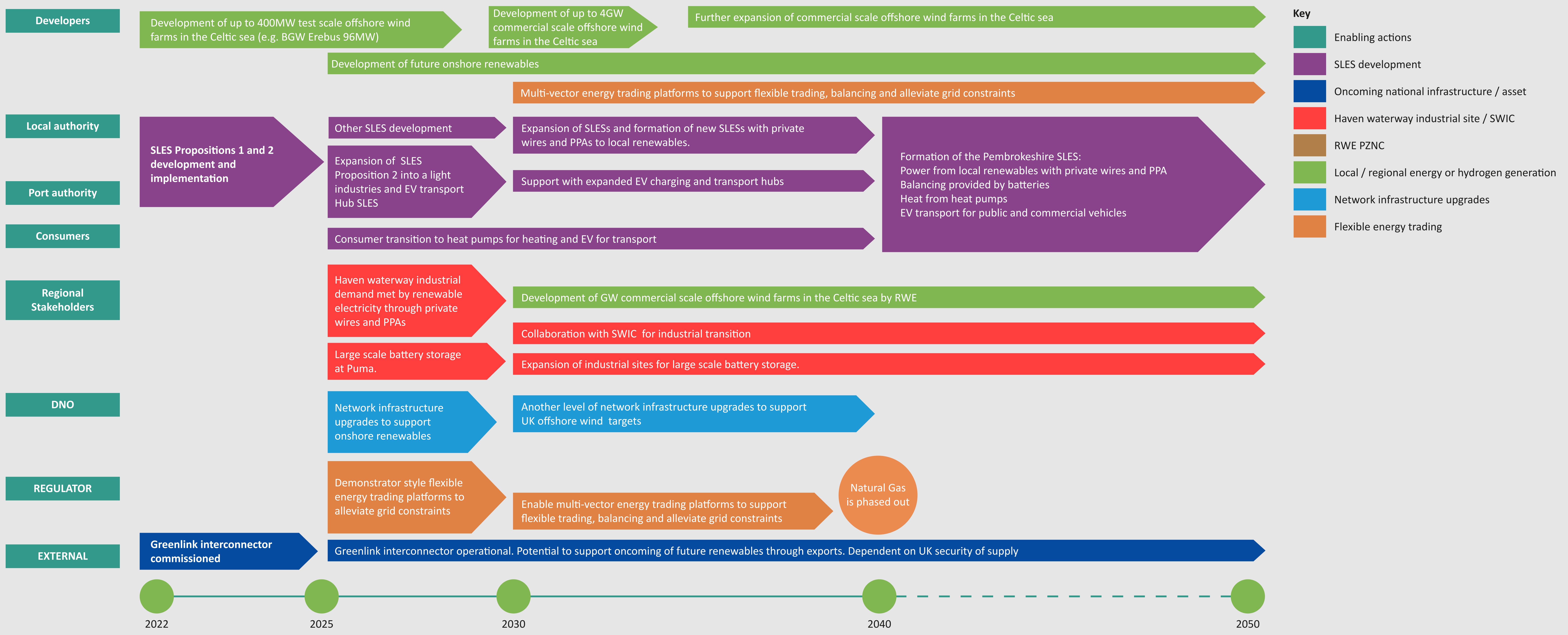


Figure 23

Timeline of events for the MH:EK High Electric pathway

Future low carbon technologies demonstrations

Demonstration of future low carbon technologies to help shape the decarbonisation roadmap

The MH:EK project supported two demonstrations of low carbon technologies applied to local settings:

- Hydrogen hybrid heating system demonstration
- Fuel cell vehicle, Rasa and hydrogen refueller demonstration.

The design, installation and operation of these demonstrators has enabled key learning on the future deployment of these low-carbon technologies at scale within the local context. The demonstrators have also been a first introduction of these technologies to the communities, making them visible to the public and raising awareness on how these technologies could form a key part of their future lives and energy system.

The findings and learnings are valuable to understand how these technologies could fit in the longer term decarbonisation roadmap for Pembrokeshire and the partnerships formed should continue to support the development of the roadmap.

Hydrogen hybrid heating system demonstration [31]

The MH:EK Hydrogen hybrid heating system trial is a world first demonstration of a smart hydrogen hybrid heating system comprising of a natural gas boiler and air source heat pump, and then for short term trials converted to a smart hybrid heating system comprising a hydrogen boiler and heat pump. The system used smart controls to coordinate operation for the decarbonisation of heat. The advantages of the hybrid system is to balance the electricity network with hydrogen for heat during high demand times.

The demonstrator consisted of a heat pump with smart controls provided by Passiv UK which was deployed in an office building within the PoMH complex at Milford Haven in 2021. A Samsung heat pump and a Worcester-Bosch boiler, initially operating on natural gas provided heating to the building during the winter of 2021-2022. During two weekends in January 2022 when the office building was unoccupied, the boiler operated on:

1. 20% hydrogen mix (the same boiler with gas supply replaed with bottled mixed gas), and
2. 100% hydrogen (the boiler was replaced with a pure hydrogen boiler)

Figure 26

Hybrid heating system demonstration
© Port of Milford Haven

This was to simulate the scenario of the gas grid is blended with 20% hydrogen in the medium term and then a gas network completely converted to 100% hydrogen.

The trials were run successfully. The heat pump provided 60-80% of the building's heat demand. For the hybrid heat pump and gas trial period, the heat pump provided the 'baseload' and the boiler (natural gas) was only used to top-up the heat when the thermostat temperature was increased. For the hybrid heat pump and the 20% and 100% hydrogen trials, network constraints were simulated by setting a peak electricity tariff signal on the smart controls, which triggered the heat pump to switch off and be replaced by the hydrogen boiler.

This provided a real life example of how a hydrogen hybrid system could be used with most of the heat being provided by a heat pump powered by renewable electricity, backed up by hydrogen which can be stored and used when really needed. The smart controls were key to enable the system to prioritise heat pumps as much as possible switching to hydrogen supply when the electricity supply is under strain to ensure the building demand is always met.

The hybrid heat pump system showed a 50-65% carbon reduction compared to the business as usual scenario of providing heating by natural gas. This could increase to up to 90% if the hydrogen boiler runs on green hydrogen. In a future where heat pumps only run on renewable electricity and green hydrogen is available, this system has the potential to become zero carbon. The details of the trials can be found in the Milford Haven Energy Kingdom Hydrogen Hybrid Field trial report [31]

This demonstration showed the potential for hybrid heat pump and hydrogen systems to be part of the decarbonisation of heat for on-gas consumers. The upcoming UK Hydrogen Strategy due 2026 will make strategic decisions for hydrogen for heating and will help inform the future role of hydrogen hybrid systems. Consumer adoption and investment in insulation and home upgrades will also be key.

Furthermore, as part of the Welsh Government HyBRID Hydrogen fund, the following projects are further investigating feasibility of hydrogen for heating [28]:

- HyProspect project builds on the Milford Haven Energy Kingdom (MH:EK) project to design and develop the tools needed for a new micro-grid service operator (MSO) functionality. This innovative service proposition will balance localised generation of power and hydrogen by optimising heat demands from buildings in the same area.
- HyMaker Heat builds on a successful field trial in the Milford Haven: Energy Kingdom (MH:EK) project which deployed a smart hydrogen hybrid heating system in single domestic scale building. HyMaker Heat will develop a new system for delivering heat to multi-occupancy scale buildings using intelligent controls paired with a hydrogen boiler and an air-source-heat pump. This will be at Pier House Pembroke Dock.

Demonstration of future low carbon technologies to help shape the decarbonisation roadmap (continued)

Hydrogen Fuel cell vehicles, Rasa and hydrogen refueller demonstration

The Hydrogen fuel cell vehicle demonstration in Milford Haven includes two Riversimple Rasa vehicles, operating on routes mimicking journeys of the PoMH, PCC and NHS fleet and collecting driving data such as H2 consumption, journey distance/duration, driving style, topography. The vehicles are refuelled by a demonstrator hydrogen refueller.

At the time of writing this report the vehicle trials are ongoing. The demonstration will provide real world data in terms of driving patterns and actual hydrogen use which will enable an assessment of the actual hydrogen demand for light duty vehicle. The driving patterns will also allow an assessment of hydrogen demand for other hydrogen passenger vehicles and vans. In addition, the incremental demand associated with other transport sectors such as medium and heavy duty trucks, buses, construction and agriculture will be assessed in the Promoting hydrogen mobility report [32] .

The hydrogen refueller and all associated works including the AEM electrolysers by Enapter, compressors, water treatment units, dryer units necessary to electrolyse, store and dispense hydrogen has been successfully installed by Fuel Cells systems. Through the design and installation, the project learnt valuable lessons around the technical requirements, environmental legislation and planning requirements of installing hydrogen refuellers. The visibility of the Rasa vehicles being refuelled by the hydrogen refueller is proving to be very effective for community awareness raising.

The Promoting hydrogen mobility report [32] will assess the degree of alignment between the potential demand for hydrogen in the Milford Haven area, and the investment required to meet that demand. If a commercial gap exists, recommendations will be made regarding potential solutions to close the gap such that a sustainable business case can be developed. The report will explore potential locations for hydrogen refuellers (a broad view) considering the real-world journey data that has been gathered from the trial. The Promoting hydrogen mobility report [32] will be published in May 2022.

Figure 27

Riversimple Rasa vehicle and hydrogen refueller demonstration © Riversimple

The MH:EK project has developed a set of Key Stage (KS) 2 primary and KS 3 secondary curriculum resources based around the MH:EK H2 refueller, electrolyser, fuel cell vehicles and hybrid hydrogen ready heating applications. The resources are being used during and post visits to schools to stimulate interest in young minds regards the existing MH:EK project, our energy history and the future whole energy system. They are designed to engage young people in the conversation around climate change and their contribution to the journey net zero as well as the prospects for employment that are emerging in the future hydrogen and renewable energy economy. It paves the way for further engagement with schools including visits to the MH:EK demonstrators and ultimately we aim for the resources set to be shared beyond the project throughout the education system. [41]

Figure 28

Extract from the MH:EK reducational resources [41]

What could change the picture?

Delivering energy system transformation at the scale and pace needed to reach net zero by 2050 will require balancing multiple complex factors. Our work has consolidated the current evidence base to help build an understanding of the 'no regrets' first steps that could support broader system level change, whilst meeting a broad range of key objectives and critical success factors. We have produced a view of what could be developed and where in a range of future world scenarios.

However, there are still several unknowns, uncertainty and gaps in the evidence base, and different assumptions, or higher quality datasets, could create different outputs.

The impact of hydrogen import prices

Our sensitivity analysis showed that current hydrogen prices of 0.135 to 0.18 £/kWh (£4.50 to £6.00/kg based on a lower bound heating value of hydrogen of 33.3kWh/kg) are close to a tipping point in making electrolysis viable. If the grid export price decreases slightly, or the hydrogen import price increases slightly, electrolysis is a good use of excess electricity after local electrical demand is met.

No natural gas

With no natural gas supply, heat is largely electrified with air-source heat pumps with a small amount from hydrogen boilers. Electrolysis and electricity exports were decreased with renewable electricity for heat being prioritised. This led to very large decreases in carbon emissions, but an inevitable increase in cost. This suggests that electrification of heat is preferable to hydrogen boilers if gas was removed from the system and for any new buildings, air-source heat pumps are likely to be cost competitive.

Lower electricity price, higher gas price

In this sensitivity analysis, the system started to switch over to electrification of heating via air-source heat pumps resulting in lower national grid exports and higher national grid imports. This result suggests a prioritisation of meeting the heating demand with the local renewable generation rather than only the electrical demand.

Lower battery prices

With lower battery capital costs, batteries were selected by the WSEM optimisation process to be part of the optimised system in every scenario, but with varying capacities. Higher capacity batteries resulted in less national grid electricity import and export and instead promoted self-consumption. These changes produced a very marginal decrease in annualised costs and carbon emissions. With grid price fluctuations, it may be possible to buy low-cost electricity at certain times to be stored for periods of higher demand.

Key areas as highlighted in the recommendation and next steps section overleaf could be further developed to support greater understanding of the optimal pathway to a net zero energy system.

08
Recommendations

Next steps

Short-term: development of proposition 1 & 2

- Further work and more detailed analysis of both propositions is required, including:
- taking the whole system energy modelling undertaken to date to the next stage of detail to support a more detailed design;
- exploration and use case testing of the SPV / partnership commercial model;
- specific stakeholder engagement to explore their appetite for such a model, and to better understand what risks or barriers there might be in implementing;
- exploring in more detail how the ESCo model would work in practice, what the relationship would be with other project partners, and the commercial relationship with entities outside of the SPV partnership perimeter;
- financial modelling to further understand the potential pay-back or revenue to different parties; and
- establishing a detailed management plan, including: an implementation programme, data management, risk management and contract management approaches.

Short-term: data ecosystem

- Establish a data working group within the MH:EK organisations to ensure that the various data initiatives recommended in this report, and within the energy sector, are discussed and championed locally in a coordinated way.
- Through the above data working group, engage with key national energy sector initiatives which are underway such as Open Energy [6], Virtual Energy System [7] and Future of Gas [8] which will enable a much better integration of MH:EK SLES into the wider energy market through better data sharing and standardisation.

Mid-term: setting a roadmap

- Identify a project lead to take forward establishing a roadmap in line with the mid-term recommendations.
- Continued stakeholder engagement, in particular with other key regional initiatives such as SWIC and RWE PNZC, alongside increasing community engagement to support all parties in taking a role in the local energy transition.

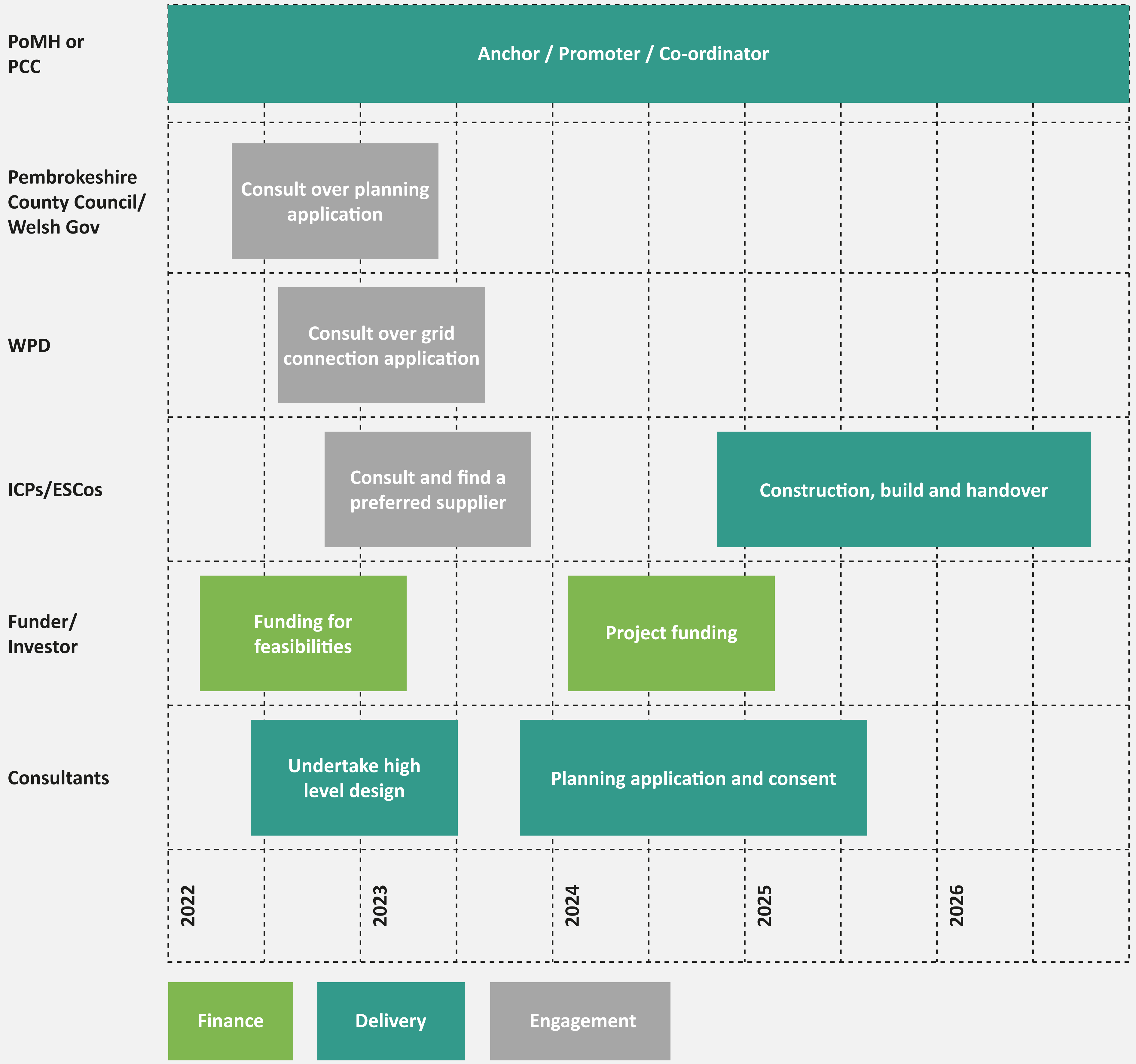


Figure 29
Indicative implementation programme for the recommended SLES

Recommendations

Recommendations are provided across the short-term and mid-term time horizon in support of reaching net zero by 2050. Longer term recommendations are difficult to set out at this point and should be established over the next decade(s) reflecting on progress to that point and required targets for reaching net zero.

Short-term

Early action through development of the recommended SLES propositions by taking the 'no-regret' steps will jumpstart the journey to decarbonisation.

- It is recommended that the MH:EK project pursues both Proposition 1 and Proposition 2.
- The outcome of Proposition 3 suggests that it is not a strong SLES candidate, so is not recommended to be progressed. It does highlight the commercial opportunity for onshore renewables development if network constraints can be reasonably addressed.

Flexibility (supply, demand, trading) is a key part of the future energy system as demonstrated by industry net zero pathways. Regulators should provide regulatory relief to set up demonstrator flexibility platforms by 2030 to support flexible energy trading by 2040.

- Future decisions made around the UK's transmission network will be significant in influencing development of new renewable generation, balancing, flexibility and trading. Regulatory barriers currently present a significant challenge to local trading platforms.
- Engagement with network operators should be coordinated to ensure integration of network capacity and planned upgrades into further whole system energy modelling and the future roadmap.

Monitor and influence developing regulatory frameworks, take advantage of changes and create a Market Access Strategy.

- Uncertain regulatory futures for networked hydrogen (which could affect future hydrogen demand) and heat networks could present a regulatory barrier.
- Mitigation strategies include avoiding networked hydrogen transportation, informal outreach to Ofgem in the short term, and potentially application to use the Regulatory Sandbox - to demonstrate innovation and value to consumers - in the longer term.
- Recent and ongoing regulatory changes have removed some embedded benefits and increased network charges for decentralised generators but have opened up new value streams to smaller market users. A trend of increasing support for local systems is part of Ofgem's ongoing work to increase system flexibility during the energy transition.
- Wholesale market access can be expensive for small generators and a power purchase agreement will likely not be attractive to a third party for exporting surplus generation.
- Using an aggregator, now with access to the balancing mechanism, as an intermediary is a potential route to access flexibility value streams.
- Licencing and asset ownership regulatory constraints should be taken into account when selecting and developing the commercial model.

Establishing a data ecosystem

Establishing a robust data ecosystem at a local level, that integrates beyond the local boundary, is key to benefit from and support the national modernising energy data access (MEDA).

The main recommendation for the MH:EK project is that it has plans in place to prepare for initiatives such as open data, standards and a focus on the fact that having available and accurate data will be to its advantage when some of the outcomes from the national initiatives become a reality. Throughout the lifecycle of the design, construction and operation of the propositions, the data required from these assets for their maintenance, and for the wider energy sector will be required as part of the delivery.

Table 3 lists out the easiest to implement and more impactful project level recommendations to enable and prepare projects like MH:EK and other SLES's ahead of national standards and guidance being implemented. These are recommended to be part of the project management process for the future development stages of the SLES.

#	Recommendation
1	Common Energy Modelled Data Portal
2	Programme Data Catalogue
3	Adoption of a Data Openness Triage process to achieve 'Presumed Open'
4	Formation of a Milford Haven Energy System data management working group
5	Creation and implementation of an ongoing data management strategy to incorporate system changes into modelling
6	Open web based visualisation platform
7	Data requirements for future projects
8	National Digital Twin integration
9	Contribution and adoption of national energy data standards and access protocols

Table 3

The recommendations for data management for the MH:EK SLES. Refer to the Data Ecosystem report for the full list [40].

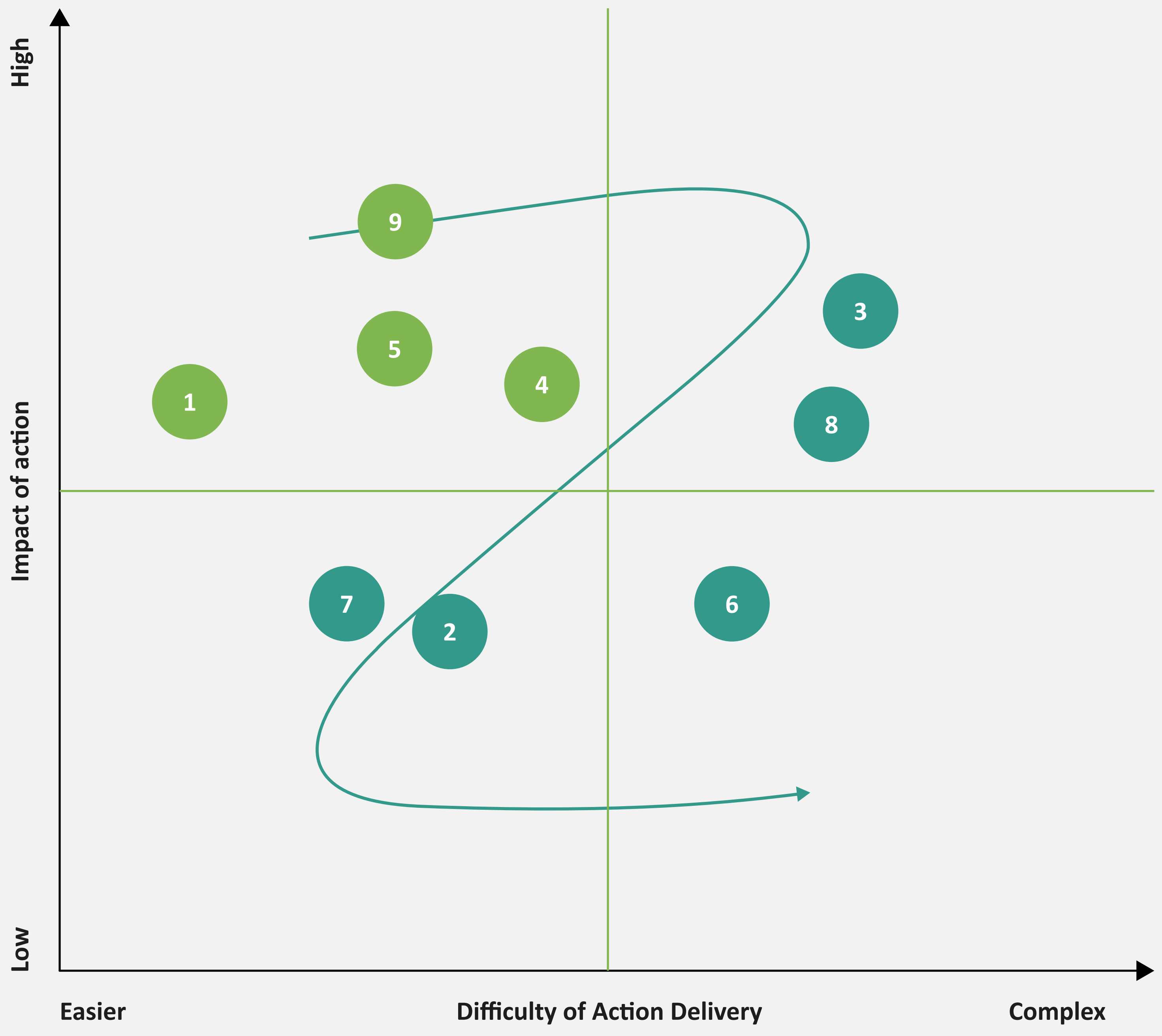


Figure 30

Roadmap of implementation of data management recommendations, with the easiest and most impactful ones highlighted.

Mid-term

A fully integrated and adaptable roadmap including key decision points and determinants for the decarbonisation of the Pembrokeshire energy system should be developed, stemming from the short-term SLES proposition and in close partnership and collaboration with the local and regional projects and network operators.

- We recommend that the next phase of the MH:EK project considers developing a roadmap for the decarbonisation of the Pembrokeshire energy system by 2050. We recommend that the starting point would be the short-term investable propositions for SLESs that is integrated with key projects and regional plans such as South Wales Industrial Cluster (SWIC), RWE Pembroke Net Zero Centre (PNZC) as well as the ERM Dolphyn project as they are further developed.
- As shown on the MH:EK pathways, early action up to 2025 will involve fewer actors and will therefore be less complex to implement. Actions taken now could have a catalytic effect to form larger energy clusters and eventually a decarbonised energy system.
- We recommend close partnership and collaboration with the regional plans such as SWIC, RWE PZNC and ERM to develop a roadmap for decarbonisation of the Pembrokeshire energy system by 2050. A fully integrated roadmap will enable the implementation of the short-term no regret steps with a view of integrating those with longer term local and regional plans on the journey to decarbonisation.
- Other upcoming studies such as the Pembokeshire Local Area Energy Planning (LAEP) which will include whole system energy modelling and optimisation of the Pembrokeshire local authority energy system, LAEP delivery pathways and local energy decarbonisation routemap are also key to inform the development of this roadmap.
- The future energy system will be based more around energy supply. Increased flexibility and interaction of multiple vectors and services will be required to flex demand, enable use and storage and trade different commodities. As such, technical, regulatory and market barriers around flexibility trading platforms would need to be overcome and local actors, network operators and regulators all have a role to play to realise these benefits by 2050. Further details on recommendations on how a trading platform could support the decarbonisation of Milford Haven and Pembrokeshire is provided in the Commercial case of the Milford Haven Energy Kingdom strategic outline case for a smart local energy system report [46].
- Engagement with network operators should be continuous to integrate the network capacity and planned upgrades into the roadmap.
- The roadmap should be kept under review and adapted as the regional picture evolves, more actors become interested in the transition including investors and energy sector level changes happen for example network upgrades and policy and regulatory changes.

The decarbonisation roadmap should have the community, stakeholders and wider sustainable development aims at the centre to ensure a just transition.

- The transition to net zero should put the community, stakeholders and wider aims at the centre and ensure a just transition for all. Through continual stakeholder engagement and adopting a theory of change approach, MH:EK should aim at developing a set of tangible actions and a roadmap for everybody to understand their role to get to net zero by 2050 whilst ensuring societal cohesion.

Glossary

ASHP	Air Source Heat Pump
BECCS	Bioenergy with Carbon Capture and Storage
BEIS	Department for Business, Energy, and Industrial Strategy
BEV	Battery Electric Vehicles
BGW	Blue Gem Wind
BM	Balancing Mechanism
BSC	Balancing and Settlement Code
BSUoS	Balancing Services Use of System
CAPEX	Capital Expenditure
CDM	Construction Design and Management Regulations
CCC	Climate Change Committee
CCGT	Combined Cycle Gas Turbines
CCHP	Cold Climate Heat Pump
CCUS	Carbon Capture, Use and Storage
CIBSE	Chartered Institution of Building Services Engineers
CO_2	Carbon Dioxide
CSF	Critical Success Factor
CUSC	Connection and Use of System Code
DACC	Direct Air Carbon Capture
DCODE	Distribution Code
DCUSA	Distribution Connection and Use of System Agreement
DER	Distributed Energy Resource
DNO	Power Distribution Network Operator
DSO	Distribution System Operator
ESC	Energy Systems Catapult
ESCo	Energy Supply Company
ESO	Electricity System Operator
EV	Electric Vehicle
FES	Future Energy Scenarios
GDN	Gas Distribution Network Operator
GO	Guarantee of Origin
GS(M)R	Gas Safety (management) Regulations
GW	Gigawatt
H2	Hydrogen
HGV	Heavy Goods Vehicles
HSE	Health & Safety Executive
ICP	Independent Connection Providers
IDNO	Independent Distribution Network Operator
IPCC	Intergovernmental Panel on Climate Change
ISCF	Industrial Strategy Challenge Fund
IUK	Innovate UK
kWh	Kilowatt hour
LCoE	Levelised Cost of Energy
LCT	Low Carbon Technology
LNG	Liquefied natural gas
LW	Leading the Way
MCA	Multi Criteria Assessment
MEDA	National modernising energy data access programme
MH:EK	Milford Haven Energy Kingdom
MRA	Master Registration Agreement
MW	Megawatt
MWh	Megawatt hour
NG	National grid
NTS	National Transmission System
OB	Optimism Bias
OPEX	Operational Expenditure
OREC	Offshore Renewable Energy Catapult
PCC	Pembrokeshire County Council
PfER	Prospering from the Energy Revolution
PNZC	Pembroke Net Zero Centre
PoMH	Port of Milford Haven
PPA	Power Purchase Agreement
PW	Private Wire
SEC	Smart Energy Code
SLES	Smart Local Energy System
SoLR	Supplier of Last Resort
SP	Scottish Power Transmission plc
SPAA	Supply Point Administration Agreement
SPV	Special Purpose Vehicle
SSEN	Scottish and Southern Electricity Networks
SWIC	South Wales Industrial Cluster
tCO_2e	Tonnes carbon dioxide equivalent
TCE	The Crown Estate
TCR	Targeted Code Review (Ofgem)
TGR	Transmission Generation Residual
TSO	Transmission System Operator
UNC	Uniform Network Code
V2G	Vehicle to Grid
VPP	Virtual Power Plant

References

1. Pembrokeshire County Council, Action Plan towards Becoming a net zero-carbon local authority by 2030, (Pembrokshire County Council, 2021)
2. National grid ESO, Future Energy Systems (FES) 2020, (National grid ESO, 2020)
3. National grid ESO, Future Energy Systems (FES) 2021, (National grid ESO, 2021)
4. Climate Change Committee, The Sixth Carbon Budget, (Climate Change Committee, 2020)
5. Regen, Net Zero South Wales 2050, Dataset companion report, (Regen, 2020)
6. Open Energy, Discover energy data. Accessed at: https://openenergy.org.uk/
7. National Grid ESO, Virtual Energy System. Accessed at: https://www.nationalgrideso.com/virtual-energy-system
8. National Grid, Future of Gas – GMaP. Accessed at: https://www.nationalgrid.com/uk/gas-transmission/future-of-gas
9. Zero 2050 South Wales, Main Report, (Zero2050, 2021)
10. Cadent, The Future Role of Gas in Transport, Green Gas Transport Pathways, (Cadent, 2021)
11. RWE, Pembroke Net Zero Centre – PNZC. Accessed at: https://uk-ireland.rwe.com/innovation/pembroke-net-zero-centre-pnzc
12. Greenlink Interconnector, Ten-E regulation information brochure. Accessed at: greenlink.ie
13. BEIS, Renewable Energy Planning Database: quarterly extract. Accessed at: gov.uk
14. Cardiff University, Smart Living Demonstrator –Zero Carbon Area Milford Haven Waterfront Pembrokeshire–“Outline Pathway”, (Cardiff University, 2020)
15. Hacer Developments, Pembrokeshire Food park. Accessed at: hacerdevelopments.com
16. Blue Gen Wind, Floating Offshore Wind A new generation of energy in the Celtic Sea, (Blue Gem Wind, 2020)
17. Llyr wind, Harnessing Welsh Energy. Accessed at: https://www.llyrwind.com/
18. White cross, White cross offshore windfarm. Accessed at: https://whitecrossoffshorewind.com/
19. The Crown Estate, Celtic Sea Floating Wind Programme. (The Crown Estate, 2021)
20. HM Government, Heat and Buildings Strategy, (HM Government, 2021)
21. Wales and West Utilities, 2050 Energy Pathfinder, (Wales and West Utilities, 2018)
22. Energy networks association, Gas Goes Green. Accessed at: energynetworks.org/
23. Guidehouse, Pathways to Net-Zero: Decarbonizing the Gas Networks in Great Britain. Accessed at: https://guidehouse.com/news/energy/2019/pathways-to-net-zero
24. Energy Data Taskforce, Energy Data Taskforce: A Strategy for a Modern Digitalised Energy System. Accessed at: https://es.catapult.org.uk/report/energy-data-taskforce-report/
25. Energy Data Taskforce, A strategy for a Modern Digitalised Energy System, (2019)
26. Energy Systems Catapult, Enabling Smart Local Energy Systems: The value of digitalisation and data best practice. Accessed at: https://es.catapult.org.uk/report/enabling-smart-local-energy-systems-the-value-of-digitalisation-and-data-best-practice/
27. Sky News, Britain’s biggest polluters. Accessed at: https://news.sky.com/story/climate-change-investigation-the-top-15-polluters-in-the-uk-revealed-12171349
28. Welsh Government SBRI, HyBRID List of Projects – SBRI Phase 1, (Welsh Government, 2021)
29. Arup, Milford Haven Energy Kingdom Technical Summary Report. (Arup, 2021)
30. Wales and West Utilities, Milford Haven: Energy Kingdom 2050 Energy Pathfinder modelling, (Wales and West Utilities, 2022)
31. Passiv, Milford Haven Energy Kingdom: Hydrogen Hybrid Field trial report, (Passiv, 2022)
32. Riversimple, Promoting hydrogen mobility report, (Riversimple,2022) – not yet published
33. Offshore Renewable Energy Catapult, Longer Time-Horizon Energy Generation Development Report , (OREC, 2022) - not yet published
34. Energy Systems Catapult, Co-designing a switch to hydrogen with customers, (ESC, 2022) – not yet published
35. Energy Local, Potential benefits of an Energy Local Cluster at Milford Haven Port , (Energy Local, 2022)
36. Arup, Milford Haven Heat Network: Phase 2 final report, (Arup, 2022)
37. Offshore Renewable Energy Catapult, Finance and Investment Activity Report, (OREC, 2022) - not yet published
38. Offshore Renewable Energy Catapult, Investor-facing outputs , (OREC, 2022) - not yet published
39. Energy Systems Catapult, Milford Haven: Energy Kingdom –system architecture report, (ESC, 2021)
40. Arup, MH:EK Data Ecosystem Report, (Arup 2022)
41. Milford Haven : Energy Kingdom, The future of energy in Pembrokeshire right now, (MH:EK, 2021)
42. Future Offshore Wind, Future offshore wind scenarios: an assessment of deployment drivers. (Arup, OREC, ABPmer, 2022)
43. Arup, Establishing a Hydrogen Economy, The future of Energy 2035. (Arup, 2019)
44. Arup, Hydrogen Transport, Fuelling the Future. (Arup, 2021)
45. Arup, Catalysing hydrogen investment. (Arup, 2021)
46. Arup, Milford Haven Energy Kingdom strategic outline case for a smart local energy system (Arup, 2022)

ENERGY KINGDOM
DEYRNAS YNNI