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Shape of Things to Come: Stakeholders' Views on the Route to Net-zero

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ABSTRACT

The Decarbonisation of Heat Theme within the UK Centre of Research in Energy Demand Solution (CREDS) has been a three-year programme of work, which has sought to explore possible strategic directions for heat decarbonisation through a dialogue with stakeholders using system architecture concepts and tools. In September 2020, a Concept Evaluation workshop was held with key stakeholders, with the aim of capturing their views on expectations, requirements, and possible architectures for a future decarbonised system. The evaluation and discussion of options were structured using the Pugh Matrix Method: a pair-wise comparison of technology options against system criteria. This paper presents and analyses the results of this evaluation exercise. Pugh Score sheets returned by individuals showed that the Hybrid Heat Pump Option was positively valued over other systems but was neither deeply explored nor exhaustively articulated in group discussion. The analysis of the discussions showed that the stakeholders were both challenged and stimulated by the way that discussion was structured. Their responses to the concept evaluation exercise revealed the dynamics and combinations of technological options under consideration for fulfilling the joint goal of decarbonising heat and of building a system that is robust enough to withstand short term stresses and shocks, while having the capacity to evolve under changing conditions in the medium-to-long term. Implications for policy and modelling practices are briefly discussed.

Keywords: zero carbon heat, technological solutions, energy systems architecture, policy, decision-making, Pugh Score

NOMENCLATURE - SYSTEM CONCEPTS AND CRITERIA

Evolvability: response of costs, infrastructure and technology to unexpected technical, economic or trading developments (> or < than expected) e.g rapid onset of demand for cooling, unexpectedly cheap H_2 etc.
Flexibility: short term response of the energy system to factors such as weather and demand-supply variability, through a mixture of demand response, storage, interconnection, operating reserves and back-up, enabled through tariffs and contracts within an overarching governance framework.
Resilience: response to shocks that temporarily reconfigure the energy system (loss of inter-connectors, generation, storage etc.).
Feasibility: policy simplicity (governability), soft infrastructure, infrastructure requirements, supply chain diversity, scale up potential, meeting peak heat demand.
System Cost: Net Present Value of energy system cost from 2020-2050.

1. INTRODUCTION

Whole energy system models have been key tools for generation of insights into various aspects of system transformation as the UK works towards net-zero emissions [1]. The Heat Challenge Theme in CREDS has adopted a system architecture approach [2,3] to explore the increasingly complex issues brought on by the introduction of new heating technologies, and system-wide changes in electricity generation and control. Locating system modelling within an Energy System Architecture framework provides, among other things, a way to structure discourse between modellers and energy system stakeholders around different possible choices and decisions [4].

A literature review undertaken by the research team revealed that system goals have become increasingly complex over time. Zero Carbon is not the only goal of the UK energy system. Additional goals include: keeping the lights/heat on (resilience), integrating an increasing share of renewables (flexibility), doing the foregoing affordably (cost), while leaving no one behind (fairness) [5-8]. There is a recognition that it is difficult for existing energy system models to capture all of the above. Most notably, conceptualisation and quantification of the benefits of system evolvability and flexibility, as energy system properties needed to cope with uncertainties, is proving to be challenging [9]. Although modellers are actively developing new and improved techniques to accommodate these complex requirements, the overarching concepts and tools of system architecture have hitherto not been considered explicitly as part of the process.

Stakeholder analysis in Energy Research is not new. However, research has tended to focus upon issues related to the policy domain [e.g.10, 11], to specific projects or schemes [e.g. 12, 13] or for example to determine social acceptability of new generation [14] However, these attempts have failed to reflect the interdependence of the policy, infrastructure and modelling domains. Other research has made use of technical representations of the energy that tend to be too broad to reflect underlying physical and engineering realities [15]. While outlining an approach to capture stakeholders' requirements of Microgrid systems based on system engineering principals, [16] presents no empirical evidence of the results of implementing this approach.

Eliciting stakeholders' requirements is an essential initial step for system architecting [2]. In the work described here, this step was approached in two-stages:

Stage 1: Interviews with experts across the supply and demand sides of the energy system using Q methodology in which experts were asked to prioritize policy goals and express their views on technological options that they considered would support these goals. Factors extracted from the ranking exercise were than subject to qualitative data analysis. We identified that experts held two distinct sets of views on decarbonising heat in the UK :

- The adaptive view, in which resilience is ranked at the top of of the list of energy system requirements, with hydrogen playing a key role in the integration of renewables.
- The transformative view, in which experts' rankings of priorities were more diverse. Narratives within this view reflect, among other things, the idea that achieving net zero requires combinations of technical options based on diverse local needs and opportunities [17].

Stage 2: Informed by the results of Stage 1, the Heat Challenge Team hosted a stakeholders' workshop in September 2020. Preliminary insights in the form of future energy scenarios were presented to participants by the modelling teams. After the presentations, participants took part in a Concept Evaluation Exercise in which they were asked to evaluate four technological options against six system criteria using the Pugh Score Method (PSM) [18].

This paper presents the insights gained from the Stage 2 workshop and the implications for the design and implementation of strategies for decarbonising heat in the whole UK energy system.

The objectives of the workshop were to 1) share modelling insights with stakeholders and to 2) capture their expectations, requirements, and thoughts on strategies and architectures for decarbonising heat.

2. DESIGN & METHOD

21 of 30 stakeholders invited from across the energy system participated in the Concept Evaluation Workshop. To prepare the stakeholders for the evaluation exercise and subsequent discussions, a range of options for decarbonisation of heat based on modelling undertaken with UKTM (an optimising whole energy system model) and ESTIMO, a dispatch model [20] were presented by modelling teams.

After the presentations, stakeholders were divided into small groups in which they were asked to carry out a pair-wise evaluation of four technological options: Hydrogen dominant, District Heating dominant, Energy Efficiency dominant, and Hybrid dominant, with a Heat Pump dominant system as a base case, against six system criteria of evolvability, flexibility, resilience, feasibility, system cost, fairness, using a Pugh Score Sheet (see Figure 1).

A typical guiding question that was used for starting discussions was:

How *evolvable* do you consider a Hydrogen dominant system to be in comparison with the base case Heat Pump dominant system? If the answer is 'Better than', give a score of +1; if 'Worse than', give a score of –1; if no difference, score 0. At the end of the process,

	Technology options for decarbonisation of heating (2050)						
	HP dominant	H_2 dominant	DH dominant	Efficiency dominant	Hybrid	Other	Other
individual HPs						Mixed picture – no dominant tech	
individual H_2 boilers							
DH (HP, boilers, CHP)							
efficiency (insulation)							
Criteria							
Evolvability	0	0	0	0	0	+	
Flexibility	0	+	0	0	+	+	
Resilience	0	-	0	+	+	+	
Feasibility	0	0	-	-	0	0	
System Cost	0	0	-	0	+	-	
Fairness	0	-	0	+	-	0	
Other...							
Consumer acceptability	0	+	-	-	+	+	
Scoring	"1"=better than base case; "-1"=worse than base case; "0"=same as base case						
Σ+	0	2	0	2	4	4	
Σ-	0	2	3	2	1	1	
Σ0	7	3	4	3	2	2	
Net score	0	0	-3	0	3	3	
Rank	3	3	6	3	1	1	

Fig. 1. Pugh Score Sheet

scores given against all criteria were summed and ranked.

3. FINDINGS

3.1 Scoring Results

Only 9 out of the 21 stakeholders returned score sheets. Amongst these stakeholders, a system dominated by hybrid technologies was highly favoured (overall score=22), while the least favoured was a hydrogen dominated system (overall score= -6).

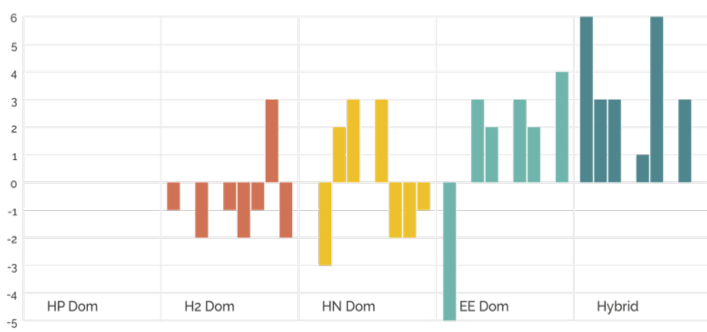

Figure 2. Results from returned Pugh score sheets

Some stakeholders interpreted 'hybrid' broadly to represent 'a balanced mix of all different technology mixes, that are suitable to local geographies, housing stocks, and populations.' For those who favoured both hydrogen and 'hybrid' options, hybrid meant specifically the packaging of 'an electric heat pump with a gas boiler' (either methane or hydrogen) in an appliance serving a single dwelling.

3.2 Results from discussions

3.2.1. Evolvability

Despite a definition of the concept being given on the evaluation sheet (See Box 1. Nomenclature), stakeholders found it difficult to judge options against this criterion. Some stakeholders suggested that systems in which heat supply was dominated by a single technology might not be as evolvable as systems in which several heat technologies were in play. Conversely, others suggested that the potential of individual technologies might well be the key to system evolvability, variously citing the fact that heat pumps are an old technology, but hydrogen is relatively new and may therefore have greater potential to evolve, with hydrogen appliances under active development. Another perspective came from the consideration of the amount of investment required by different technologies, suggesting that a Heat Network dominant system might require a larger up-front investment than heat pumps, and thus be less evolvable.

3.2.2 Flexibility

Of all criteria, system flexibility was the least discussed, with only 7 mentions of flexibility across all discussions. Those stakeholders who mentioned flexibility, did so explicitly in the context of system architecture, intimating that decisions could be taken to reconfigure existing infrastructure so as to allow new system architectures to emerge. This means that they were aware that the concept could refer not just to short term operational flexibility, but also to a longer term perspective in which investment decisions change the trajectory of the energy system. They stated that the concept of evolvability and resilience were closely allied to that of flexibility. Investment decisions made with these three criteria in mind would tend to result in an energy system that was capable of coping with a wide range of future uncertainties. Some participants saw Heat Networks as an enabling technology that was capable of accommodating different energy sources (electricity, natural gas, hydrogen, biomass) and associated energy conversion technologies such fuel cells or heat pumps, and could also support flexibility through provision of sites for energy storage. However, other stakeholders suggested that hydrogen could also support architectures that could provide flexibility through interplay of production and storage.

3.2.3 Resilience

Resilience is needed to deal with system stress arising from technical failures, extreme cold weather and, in the context of future energy systems with very high renewable fractions, prolonged lack of wind or sun [4]. Some suggested that Hydrogen dominant systems would be more resilient because of storage inherent within the distribution network. In contrast, in Heat Pump dominant systems (the base case) peak demand falls directly and immediately on the electricity generation and transmission system, albeit supported by interconnections between the UK electricity and gas systems and to electricity and gas systems of other countries. This would impact on costs and system reliability/resilience. Stakeholders felt that heat pumps would be more resilient if implemented with hybrid technology. Some suggested that combining heat pumps with Heat Networks would improve resilience and flexibility.

3.2.4 Feasibility

Looking at this criterion from a market share perspective, one stakeholder speculated that heat pump and hydrogen options would both be able to dominate since the former could 'supply up to 2/3 of the UK housing stock and the latter up to 3/4, since the gas grid currently covers 85% of the UK. Some stakeholders cautioned that although, in an ideal world, Heat Networks supported by cheap renewables would protect consumers, a target 70% share of the heat market would be neither realistic nor feasible.

3.2.5 System costs

Some stakeholders perceived evolvability through the current development of technology. With hydrogen as an example, they suggested that as a technology, it is less evolved than heat pumps, which means that a wider range of future options is available. Transportation and storage of electricity were the two elements of the system infrastructure not well considered. One stakeholder stated that 'It currently costs between 5 and 30 times as much to transport electricity as to transport hydrogen, [and] it currently costs between 1,000 and 10,000 times as much to store electricity in batteries or pump storage as it does to store the equivalent amount of energy in hydrogen…' To focus on the levelized cost of generating a kWh of heat while overlooking the balance of the system needed to support different technologies made comparison of different options impossible. It was essential to consider impacts across the system, including full storage and transportation costs for each specific solution. Current methods of costing that are implementd in energy system models were not helpful, because 'a heat pump-driven electricity system will be vastly different from the one that currently operates, and a hydrogen system will be a very different thing to the natural gas system that we currently have'.

3.2.6 Fairness

Although this criterion was less well covered than other criteria in the discussion, it elicited a range of interpretations from stakeholders. Some interpreted fairness to refer to the way different systems would protect the fuel poor (end-users), others to the way system costs would be 'allocated or distributed' vertically across different levels of system governance, and horizontally across system stakeholders and ultimately consumers. The latter interpretation poses the question, does each consumer pay for the cost they impose on the system as a whole? A further aspect of fairness that was articulated related to whether consumers could make, or could be enabled to make rational choices about their heating provision.

On one hand, many stakeholders viewed the option of providing heat by hydrogen as regressive compared with the heat pump option because of its higher whole system costs. But the balance between capital and running costs may also be important; technologies that are cheap to buy but expensive to run might still provide the option of switching. However, some vulnerable groups, such as elderly or low-income groups might not be able to switch or opt out of 'expensive to run' systems. In addition, there may be structural inequities in energy access. For example, due to bad credit ratings, some sections of the community would find it difficult or impossible to access the money needed to invest in a heat pump, although this might reduce their bills in the long run. Since currently, the costs of building and operating the energy system are paid for out of customers' energy bills, which are dominated by the per unit cost of energy, this would impact adversely on the poorest. A fairer way to deal with this inequity might be to pay for the transition through taxation. Heat Networks were perceived to be closely associated with the idea of fairness because they are a localised solution, and are seen as representing an interventionist approach rather than emerging from rational choices by individual customers.

4. DISCUSSION

The results from Stage 2 are ostensibly different from those of Stage 1, in which the adaptive approach favoured hydrogen as a priority to support system resilience, in contrast to the transformative approach, which favoured more diverse combinations of heat technologies. However, the interpretation of the results of the Pugh scoring exercise needs to be anchored to transcripts of small group workshop discussions, in which stakeholders' voices can be heard.

Stakeholders exhibited difficulties in defining and applying the concept of system evolvability in these discussions. This concept represents, in compressed form, the desirability of moving towards an energy system which can adapt over time in the face of inevitable surprises and disruptions that will emerge in the context and course of the transition.

Hydrogen was seen as new, and by some participants as comparatively unfamiliar. The latter appeared to be unaware of the UK Government's forthcoming publication of its Hydrogen Strategy [19]. This strategy begins with a focus on the decarbonisation of energy intensive industries, and with the overarching ambition for the UK to lead the world in the development of this technology.

Stakeholders deliberated over the importance of ensuring that investment in the system addressed the three interlinked criteria of flexibility, evolvability and resilience. This suggests the recognition that the energy system will need to respond to a myriad of uncertainties in the course of the transition. Reducing strategy to a choice between technological options for heat supply would be insufficient.

Discussion on resilience indicates a concern with system stress, such as may arise from endogenous technical failure or exogenous developments ranging from extreme weather – such as was experienced by the Texas gas and electricity system in February 2021 - through to energy market disruption and cyber attack, suggests a lack of confidence in technologies such as heat pumps and heat networks being able to guarantee continuity of supply and recovery from disruption in the medium term. These concerns highlight the importance of a focus on the stability of the energy system through the entire course of the energy transition. Stakeholders did not appear to be confident that existing energy system models provided sufficient insight into this. Dispatch models such as ESTIMO are capable of simulating the operation of future, fully decarbonised energy systems, but not of tracking the evolution of the energy system over time. Models such as UKTM provide insight into investment trajectory needed to decarbonise the UK energy system, but at the cost of significant simplification of operational questions. Neither does both.

Divergent views on routes to net zero began emerge during discussion of the topic of feasibility. Heat supply in the UK is dominated by natural gas. Compared with heat networks and heat pumps, some stakeholders viewed hydrogen as the most convenient route to decarbonisation for a large proportion of the UK housing stock. Yet others were concerned that hydrogen might be less evolvable. But stakeholders considered that thinking around costs of storage and the distribution of electricity was underdeveloped due to weaknesses in existing energy system models.

The question around system cost also raised the question of fairness. But a coherent conceptual framework for considering fairness remains to be developed. If governments are serious about addressing this goal, a consensus on such a framework is essential. But the current global energy crisis, in which the fuel poor are disproportionately affected by the consequences of high prices for natural gas and oil, has thrown up multiple questions that will need to be addressed throughout the energy system transition. There are fundamental reasons for expecting this crisis to be persistent and difficult to resolve quickly.

5. CONCLUSION

The case for applying system architecture thinking to the task of devising a strategy for decarbonising heat arises in part from the multiplicity and complexity of energy system goals. Existing whole energy system models with their limited spatio-temporal resolution and focus on carbon emission and whole system cost, struggle to address these goals. The stakeholders' responses to the concept evaluation exercise has revealed the dynamics at play when considering combinations of technological options for fulfilling not only the goal of decarbonisation but also of building a system robust enough to withstand stresses/shocks, yet flexible enough to evolve in response to unpredictably changing conditions in the longer term. This implies that modelling practices need to innovate not only to capture a broader policy agenda but also to accommodate the opportunities and constraints inherent in different topologies and and at multiple scales.

The concept of hybridicity implies the emergence of bundles of technologies for energy transformation and storage. How these bundles will be configured, begs a question that can only be answered by the adoption of system architecture thinking.

Although our approach to researching stakeholders' views on system objectives is at a relatively early stage of development, the radical and extended nature of a transition to a zero-carbon energy system suggests that such research should not be conceived as a one-off undertaking. Rather, what is needed is a continuous process of exploration and articulation of goals.

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