Department for
Energy Security
& Net Zero

Hy4Heat Evaluation

Annex A: Evaluation Plan and Methods

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Contents

1 Introduction

This report has two main purposes. The main focus is to provide an evaluation framework; setting out the methods and strands of data collection that the study should follow to ensure that it addresses the evaluation questions. Secondly, the report also establishes a baseline position for UK hydrogen for heating Research and Development (R&D) activity. As part of our assessment of Hy4Heat's impact, we will assess the extent to which the programme has led to changes to this baseline position. The report is structured as follows:

- The rest of Chapter 1 introduces the study, its purpose, and the progress made to date
- **Chapter 2** provides an introductory overview of the Hy4Heat programme, its aims, and objectives
- **Chapter 3** presents our programme **Theory of Change** as well as discussion of the key issues and assumptions underpinning it and other external factors which may contribute towards intended impacts
- **Chapter 4** provides a baseline review of the hydrogen for heat technology development landscape. Including a review of the extent to which international hydrogen R&D programmes aim to achieve similar objectives
- **Chapter 5** provides a process evaluation framework
- **Chapter 6** provides discussion of the approach to impact and economic evaluation.

A first version of this report was produced in May 2020, prior to undertaking research fieldwork and analysis. An addendum was added to Chapter 5 following completion of the research in December 2021, in order to set out how the number of achieved fieldwork interviews compares with the target sample and discusses any limitations in the evidence gathered.

Purpose of the evaluation, its aims and high-level questions

The Department for Energy Security and Net Zero (DESNZ) appointed Technopolis Ltd in collaboration with Ipsos MORI, Hinicio and George Barrett to conduct a process, impact and economic evaluation of the Hy4Heat programme, with specific focus on:

- Identifying the overall programme benefits and impacts
- Assessing the extent to which the programme has achieved its objectives, success criteria and KPIs for the programme, including whether the needs of the policy team's client have been met
- Assessing the cost effectiveness of the programme by understanding the issues associated with value for money and comparing Hy4Heat's cost effectiveness to other similar programmes
- Understanding the effectiveness and efficiency of programme implementation, including an assessment of the effectiveness and efficiency of the contracted project management, procurement structures, and internal governance and management structures.

DESNZ has established a series of high-level evaluation questions that the study will need to answer. A full list of sub-questions is included in the ITT. In summary, the five high-level evaluation questions the evaluation aims to address were:

1. What impact has the programme had?
2. How has the programme achieved these impacts?
3. How effective and efficient has the programme delivery plan been?
4. What is the overall cost-effectiveness of the programme?
5. What is the wider learning from the evaluation for DESNZ?

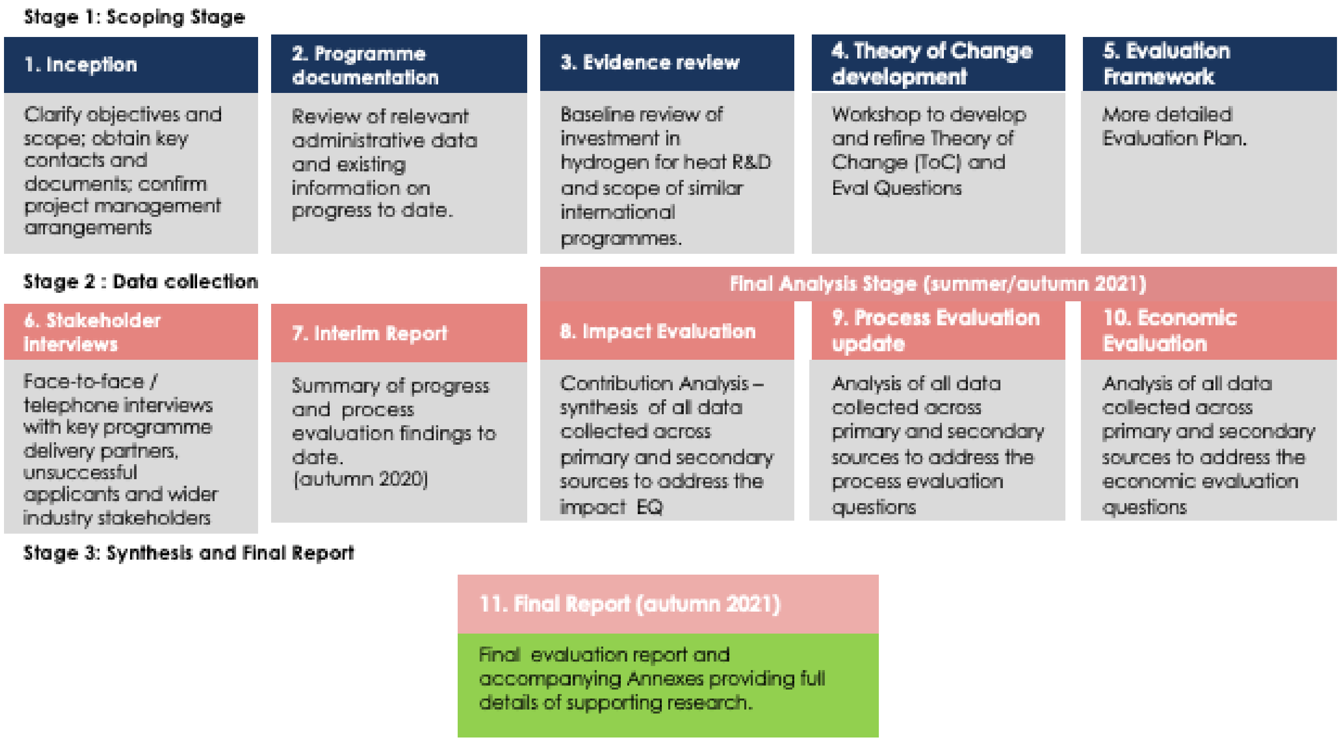
Overview of approach to the evaluation

The evaluation takes a mixed-method, theory-based approach; specifically, a Contribution Analysis, using Process Tracing to test the programme's contribution claims, with an economic Cost Effectiveness Analysis alongside this. The evaluation has four main interlinked components;

- **Process evaluation**: to help determine the effectiveness and efficiency of DESNZ's and Arup+'s and work package (WP) suppliers management and delivery processes; and identify any ways in which delivery processes may be improved. At the interim reporting stage, this provided insight on progress with delivery to date, what was working well/not so well in design and delivery of the programme and lessons learned. The process evaluation also aims to provide learning to inform design of future innovation funding programmes.
- **Impact evaluation**: to assess the extent to which Hy4Heat has met its intended objectives around providing evidence needed to de-risk the use of hydrogen for heat in buildings. Plus, the contribution of Hy4Heat towards future intended impacts, such as stimulating wider industry to invest in and undertake further programmes of R&D.
- **Economic evaluation**: to assess the extent to which government investment in Hy4Heat represents good value for money.
- **Overall synthesis and Theory of Change (ToC) review**: a final stage overall assessment of the contribution made by the programme towards achieving intended impacts, over above external contributing factors, with a revised ToC narrative describing the revised contribution claims.

The evaluation will draw upon data from interviews with multiple stakeholder groups, analysis of secondary data sources (including Pitchbook, Gateway to Research and PATSTAT), programme documentation and reviews of published literature. Data collection and analysis will be organised across a series of three main stages, as outlined in Figure 1 below, and as originally anticipated in the evaluation proposal.

Figure 1 Overview of the study workplan



We have completed Tasks 1 to 7 of the workplan to date. This report provides an update to the Task 5 deliverable (an Evaluation Plan). An Evaluation Plan was first drafted as part of the Scoping Stage of the project, prior to the first round of Stage 2 fieldwork to produce the end of 2020 interim report. The Evaluation Plan has been updated (in spring 2021) to inform the approach to the final stage of the evaluation. This takes account of lessons learned from evidence gathered for the interim stage and changes to the wider policy context, as summarised below:

- The lack of good quality company valuation data on firms participating in Hy4Heat led to a review of the suggested approach to economic evaluation in Stage 2. As discussed in Chapter 6, Stage 2 will now focus on a Cost Effectiveness Analysis, rather than the Cost Benefit Analysis suggested in the previous draft Evaluation Plan.

- Evidence gathered for the international review of hydrogen for heating R&D programmes found that whilst several international programmes are underway, there is a small number with similar objectives. The approach to following up the international review in Stage 2 will concentrate on in-depth case studies of programmes where there is greater potential for transferable learning, rather than repeat a 'broad but shallow' review of all international programmes. The approach to case studies in outlined in Chapter 4.

- Policy development on support to progress hydrogen for heating trials. The Prime Minister's Ten Point Plan[1] (Nov 2020) announced government support to develop hydrogen heating trials, starting with a Hydrogen Neighbourhood (by 2023) and scaling up to a potential Hydrogen Town by 2030. The Contribution Analysis framework has been updated to outline how Stage 2 of the evaluation will assess the contribution of Hy4Heat towards this decision to progress with community trials.

[1] The Ten Point Plan for a Green Industrial Revolution. HM Government. November 2020.

- Recent developments with the Hy4Heat programme itself. For example, commissioning the development of two demonstration hydrogen houses in Gateshead, to be built at Northern Gas Networks' site in Low Thornley, Gateshead.

This report's primary purpose is to provide an overarching framework for the upcoming process, impact and economic evaluation (workplan tasks 8-10). Central to this is our development of a Theory of Change (ToC), including a programme logic chain, which describe the outcomes and impacts which are considered measurable within this evaluation's scope. The ToC also includes discussion of how the programme is expected to contribute towards intended impacts alongside other external contributing factors.

Drawing on the ToC, a Contribution Analysis and Process Tracing framework (in a supporting Excel file) sets out; the specific hypotheses (or contribution claims) that the evaluation will test, and what evidence will be used to help prove or disprove each hypothesis.

2 Hy4Heat Programme overview

Introductory overview of Hy4Heat aims and objectives

Hy4Heat's overarching mission is to determine whether it is technically possible, safe and convenient to replace natural gas with hydrogen for domestic heating and cooking. This will help determine the feasibility of using hydrogen to meet the UK's heat decarbonisation targets.[2]

The programme has its roots in the Climate Change Act 2008, which established a legally binding target to reduce the UK' greenhouse gas emission by at least 80% below 1990 levels by 2050. Since the development of the original business case for Hy4Heat, this target was updated in 2019, to bring all greenhouse gas emissions to net zero by 2050.

A 2016 KPMG report[3] recognised that to meet these carbon reduction targets, it was necessary to explore options for decarbonising heat. The study highlighted that the decarbonisation of electricity was already well advanced but that heat in buildings was lagging significantly behind. With gas being a major source of heat (and CO2e emissions) a decarbonisation strategy for heating was needed. The study found that it was technically feasible for the country to adopt hydrogen-based heating, using much of the existing gas infrastructure. The potential for hydrogen gas usage was well understood but a conversion to it had not yet been tested at national scale in any country. Similarly, a report into the H21 Leeds City Gate project to convert the natural gas network to hydrogen found that a conversion of the UK gas distribution network to hydrogen was technically possible and economically viable, and could enable a 73% reduction in UK emissions from heat, transport and power generation.[4]

According to the programme business case, heating and cooling in the UK accounts for nearly half of the country's primary energy consumption, and one third of carbon emissions. With 80% of UK homes and businesses being supplied by gas, the country will need a near complete decarbonisation of heat. Several potential technology options exist to achieving this including increased use of biomass, electric heating, heat pumps, and use of hydrogen case on the grid. Currently however, it is unclear which of these heating decarbonisation options is likely to be the most cost-effective solution in the longer term but as highlighted above, previous studies suggest that hydrogen usage offered real potential. To make a more informed decision, the government needs more thorough understanding of the hydrogen gas chain (from production to end-use) and issues that could affect the use of hydrogen for heating. In particular, further evidence is needed on hydrogen's suitability for heating in terms of[5]:

- Safety
- Cost and affordability
- Practical performance – integrity (e.g. porosity), and efficiency

[2] Adapted from Hy4Heat website
[3] KPMG (2016) 2050 Energy Scenarios: The UK Gas Networks role in a 2020 whole energy system, pp. 8-9
 Northern Gas Networks et al, Leeds City Gate H21. Available at https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Executive-Summary-Interactive-PDF-July-2016-V2.pdf
[4] Northern Gas Networks et al, *Leeds City Gate H21.* Available at https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Executive-Summary-Interactive-PDF-July-2016-V2.pdf
[5] BEIS (2017) *Full Business case: Hydrogen Innovation Demonstration Project*, p. 8

- Durability/longevity
- Capacity
- Consumer usability and impact acceptance in residential buildings, and in gas appliances.

To date, there has been insufficient industry-led work on these areas owing to a range of market failures, namely[6]:

- High upfront capital costs to adapt the existing network and heating technologies
- Coordination barriers caused by a fragmented market, with different network operators and multiple appliance manufacturers
- Imperfect information with firms being unsure of the safety, feasibility or level of demand for hydrogen heating technologies
- A lack of clear signals for a growing market and consumer demand has given little industry incentive to engage in the area.

To tackle the issues raised above, in October 2017 DESNZ approved the Hydrogen Innovation Demonstration Project, subsequently rebranded Hy4Heat following the appointment of Arup+ as the programme and technical management lead. The £25 million programme seeks to fund the work needed to demonstrate and de-risk more end-use hydrogen for heating technologies and solutions, focused on the gas appliance and equipment sectors, and consumer research. In doing so, the programme looks to determine whether it is technically possible, safe and convenient to replace methane on the gas network, with hydrogen in residential and commercial buildings, and the gas appliances used in them. The evidence will help DESNZ determine whether to take hydrogen for heating testing to the next stage – a community trial.

More specifically, the programme has two primary objectives:

- To provide the technical, performance, usability and safety evidence needed to de-risk the viability assessment of hydrogen heating in buildings
- To stimulate industry to undertake a parallel programme of technical, performance and safety work on the distribution network.

Since the launch of Hy4Heat has progressed, subsequent industry reports have highlighted need for research programmes to tackle not only market failures, but also ongoing and long-lasting technical barriers to the implementation of hydrogen-based heating systems. A June 2019 report by the Institution of Engineering and Technology (IET) found that hydrogen could now be considered as a safe and viable replacement to natural gas on the UK grid but highlighted that for this to happen, the UK needed to address some important technical issues[7], most notably:

- The need to deploy critical new technology: any large-scale deployment of hydrogen in homes and businesses will require the introduction of new heating appliances for which there is limited development. Previous evidence suggested that it can take between 20

[6] Ibid

[7] The Institution of Engineering and Technology (2019) *Transitioning to hydrogen: Assessing the engineering risks and uncertainties.* Available at https://www.theiet.org/media/4095/transitioning-to-hydrogen.pdf

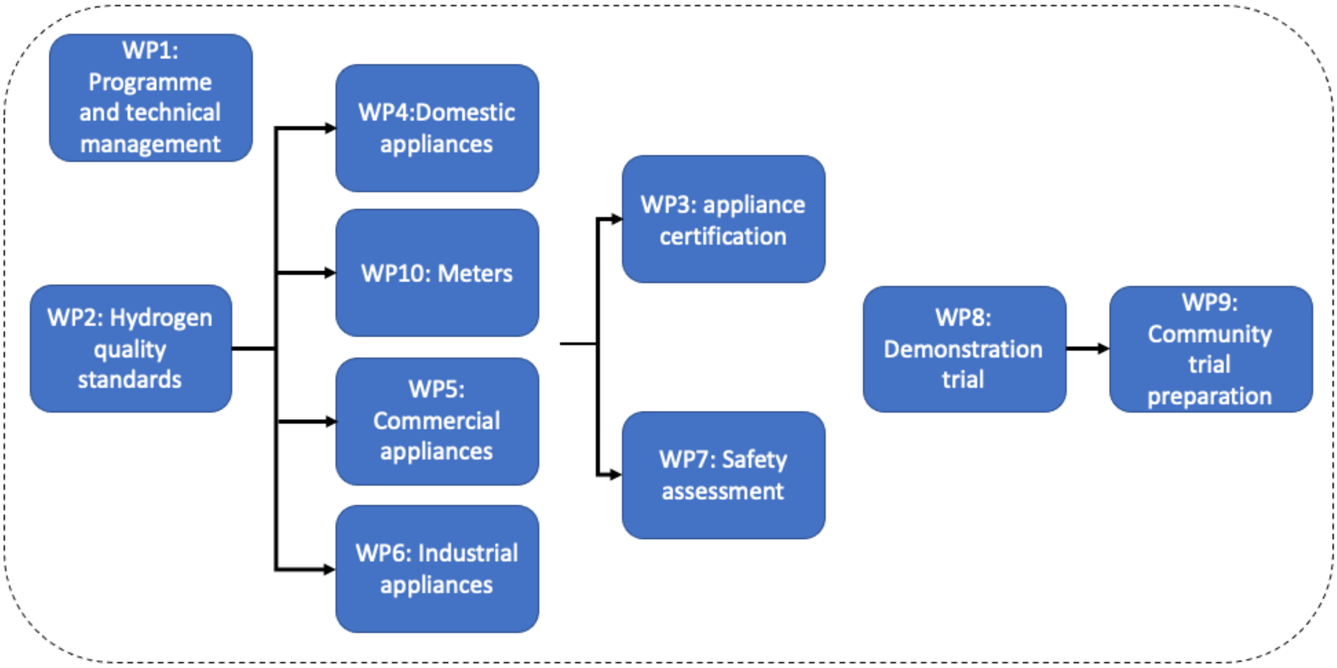
and 70 years for energy supply and energy end use technologies to reach widespread deployment.[8]

- Insufficient progress of carbon capture, utilisation and storage (CCuS) infrastructure may be a barrier. In the immediate future, the bulk of hydrogen production will require gas reforming technologies which produce large volumes of carbon dioxide. Without sufficient CCuS infrastructure, hydrogen production will rely on electrolysis powered by low-carbon sources, which risks not creating the volume of hydrogen supply needed for large-scale heating.

- Currently, there are not enough trained technicians, planning and design engineers, and academic and industrial researchers needed to enable the transitions to hydrogen.

DESNZ has designed Hy4Heat with this changing context in mind. The programme currently consists of ten different but inter-linked work packages (as per Figure 2 below), each of which operates to different procurement and delivery timescales. The dynamic and flexible nature of the programme design means that it can introduce new work packages or work strands to help address newly identified and/or ongoing technical concerns such as those revealed by the IET in 2019. The interim evaluation report provided an overview of progress in delivery up to the end of 2020.

Figure 2 Summary Overview of Hy4Heat work packages



Source: adapted from Hy4Heat website[9]

[8] Gross, R., Hanna, R., Gambhir, A., Heptonstall, P. & Speirs, J (2018). 'How long does innovation and commercialisation in the energy sectors take? Historical case studies of the timescale from invention to widespread commercialisation in energy supply and end use technology.' *Energy Policy, 123 ©, 682-699. Cited in Ibid.*

[9] https://www.hy4heat.info/wp1

3 Hy4Heat Theory of Change

Theory of Change

This section provides an overall Theory of Change (ToC) for the Hy4Heat programme. Developing a ToC is a key first step of any evaluation plan, particularly when a theory-based evaluation is suggested. It sets out an agreed understanding of what the programme is expected to achieve and contribute towards, and therefore what is important to measure and assess in order to evaluate. This starts with providing an overall programme level logic chain, which gives an illustration of how the programme's inputs and activities are expected to translate through to their intended outputs, outcomes and impacts.

There are mixed views expressed in evaluation methods literature on the role of logic chains in developing a 'Theory of Change' (ToC). Some guidance (such as the Rainbow Framework[10]) describe a logic chain itself as providing an overall representation of the programme theory, or theory of change. As described by Patricia Rogers (2014[11]) the logic chain may be considered a presentation of the theory of change, and should be accompanied by an intervention logic (a description of that change), which also discusses risks and assumptions to the impacts being achieved as well as other external contributing factors which may account for change. Others view logic models as being one distinct tool, whereas a ToC is a broader description of the step-by-step sequence of events that are needed to achieve the programme's ultimate goals. As described by Denis Bours et al. (2014[12]):

"Logic models have a narrower scope than ToC. They focus on aligning the component parts of a programme into a hierarchy of clearly specified goals, outcomes / objectives, outputs / results, inputs / activities, (usually) together with a set of measurable indicators to demonstrate progress. A theory of change, by contrast, is broader. It lays out an ultimate goal (sometimes called a 'long-term outcome', 'vision', or 'mission') which is broken down into a causal pathway with preconditions ('intermediate outcomes'), indicators, thresholds, and assumptions for each step along the way. It is usually presented as a flow chart".

There are a variety of different tools and models that may be used to represent a programme's ToC. As noted in the UK government's Magenta Book (March 2020)[13], "*the most appropriate tool to use will depend on the characteristics of the intervention, the complexity of the system it is applied to, and the type of evaluation that is being planned*". The ToC provides a framework to identity what outcomes and impacts are within scope for the evaluation and the causal links to be assessed. The type of ToC chosen should fit with the evaluation's methodological approach and ways of assessing these causal links. For example, if taking a *realist* approach, the ToC would be broken down into a series of three-stage 'Context Mechanism Outcome (CMO)'[14] configurations.

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[10] Rainbow Framework by the BetterEvaluation consortium: https://www.betterevaluation.org/en/rainbow_framework/define/develop_programme_theory
[11] Rogers, Patricia 2014. Theory of Change. Unicef Methodological brief. Impact Evaluation no.2.
[12] Bours et al. 2014. Guidance for M&E of climate change interventions. Theory of Change approach to climate change adaptation programming. SEA CHANGE and UKCIP.
[13] HM Treasury (2020) *Magenta Book.* Available at https://www.gov.uk/government/publications/the-magenta-book (accessed 12 May 2020)
[14] Ibid.

As described in Chapter 6, the approach taken to developing, testing and refining a ToC for Hy4Heat is primarily based upon a Contribution Analysis approach. CA is a theory-based approach designed to reduce uncertainty about the contribution the programme is making to the observed results, taking into account the roles played other external factors. For example, one intended impact of Hy4Heat is to stimulate parallel programmes of R&D by wider industry on the hydrogen network. Whilst the outcomes of Hy4Heat may *contribute towards* this, the R&D investment decisions by external stakeholders will also take into account other factors, outside the scope of the programme, that affect their perception of the likelihood of hydrogen gas conversion on the network, such as whether or not hydrogen supply is likely to be produced at sufficient scale, or other signals by government such as consulting on potential regulation for new domestic boilers to be hydrogen ready.

The approach taken to developing a Theory of Change for the Hy4Heat evaluation involved three steps:

- Step One: Begin with an overarching **logic chain** for Hy4Heat, setting out the main programme inputs and activities, as well as the intended outputs, outcomes and impacts. The list of impacts helps prioritise which goals the Contribution Analysis and Economic Cost Effectiveness Analysis (CEA) (described in Chapter 6) will focus on.
- Step Two: Discussion of the risks and assumptions that underpin the delivery of the ToC. Identification of risks and assumptions has informed development of the process evaluation framework (see Chapter 5). The process evaluation will address questions around how effectively the programme was designed and delivered, how risks and barriers to delivery were overcome and any wider **learning** that may be gathered to inform delivery of other DESNZ innovation programmes.
- Step Three: Development of a series of **contribution claims** that the evaluation will assess. This will focus on specific impact pathways within the overall logic chain. This ‘contribution to impact’ ToC, provides an outline of how the outputs of Hy4Heat can be expected to contribute towards intended impacts over and above the role of other external contributing factors. The methods for assessing these contribution claims is discussed in Chapter 6 on Contribution Analysis, with a list of specific contribution claims provided in the supporting CA-PT Excel file.

Step One: Developing an overarching logic chain

Figure 1 below provides an overall programme level logic chain for Hy4Heat. A draft of this logic chain was developed by the study team following an initial review of programme documentation during the Scoping Stage. The draft was discussed at a theory of change workshop involving DESNZ programme leads and members of the Arup+ consortium on 26 February 2020 and then subsequently revised, resulting in Figure 3 below. The main evaluation report provides a final version, alongside an assessment of the extent to which intended outcomes and impacts have been met.

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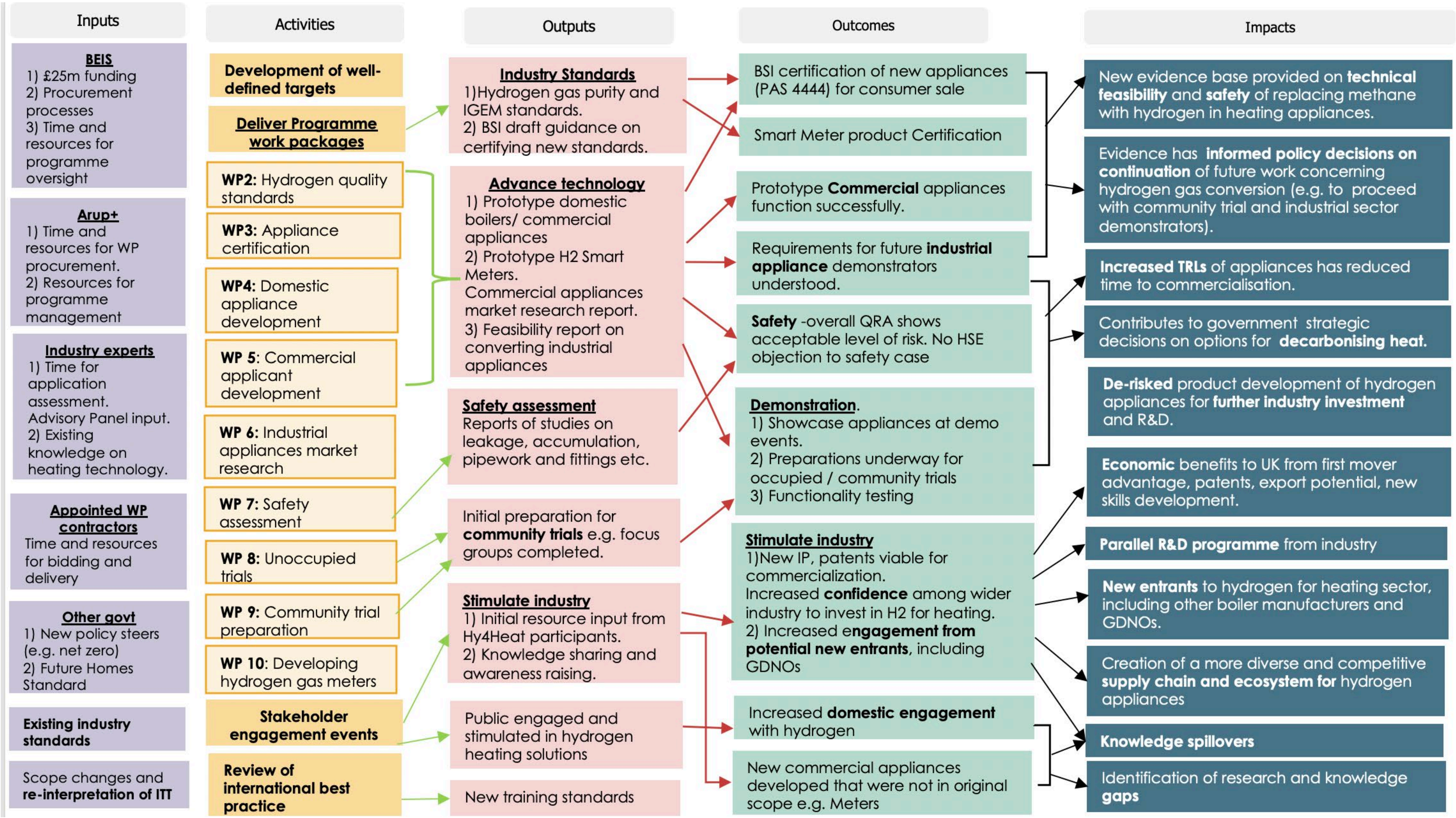
Figure 3 Hy4Heat Logic Chain[15]



[15] BEIS changed its name to the Department for Energy Security and Net Zero (DESNZ) in February 2023.

Source: Technopolis

Step Two: Understanding the risks and assumptions

There are a number of risks and assumptions that could affect the ability to move along the logic chain, as outlined below. Some of these factors exist within the programme itself, while others are external to it. The table below provides a summary of potential risks and assumptions that are implicit in the links between each stage of the chain e.g., from activities to outputs, outputs to outcomes and outcomes to impacts.

Note that this table is not providing ‘findings’ on the likelihood of risks occurring, or suggestions that Hy4Heat will not meet its objectives due to these risks. The purpose of this pre-fieldwork stage is to outline the different types of risks that are considered within scope for the next phase of the evaluation to assess, and to provide any learning on how the programme design may have successfully mitigated and overcome these risks.

Table 1 Assumptions underpinning links in the logic chain

Stage of logic chain	Programme Factor	Assumptions	External factors
Activities to Outputs	Delivery of Work Packages: Interdependencies between the work packages	Hy4Heat involves adapting or creating new technologies and standards, with many of the work packages being interdependent. For instance, finalising the design of hydrogen smart meters (WP10) depends on the purity of hydrogen gas to accurately measure the rate of flow, which in turn depends on outcome of WP2 to determine hydrogen quality standards and inclusion of odorants and colourants. The certification of new appliances (WP3) will also require the development of new hydrogen quality standards (WP2), plus new safety assessment approaches (WP7). Decisions on whether to proceed to a community trial, ultimately depends on all of the preceding work-packages being successful (at least for the WPs	

		relating to the types of appliances considered within scope of the trial). For all of the work packages to successfully finalise their outputs, any interdependent WPs will also need to finalise and feed in their outputs on time. Delays of one WP risks causing delays to others. The programme design also assumes that knowledge sharing mechanisms between the different work packages and contractors are effective. For example, to ensure that boiler manufacturers who are normally competitors are willing to share information from product testing.	
	Outputs developing prototype appliances, certification and standards (WPs 2,3, and 4). Dependencies with the rest of the market	The development of hydrogen heating infrastructure and appliances is an innovative and evolving market, albeit one that may be heavily influenced by Hy4Heat. Hy4Heat will therefore need to ensure that its own work is consistent with R&D developments in the wider gas system, even if non-Hy4Heat activity here has been limited. For example, findings from safety testing by GDNOs of using 'pure hydrogen' on the gas network. Or whether standards proposed align with hydrogen appliances that may be produced by international competitor firms. The domestic appliance development work package assumes it is feasible to create appliances that are "convenient to use" e.g., appear to be replacing like-for-like to the end user, in order not to deter consumers from participating in a trial. For example, that hydrogen gas cookers will cook food in the same way as existing methane (natural gas) cookers. It also assumes that new appliances developed do successfully meet the standards developed in other Hy4Heat packages.	Findings from ongoing external R&D programmes e.g. H21 or other GDNOs. Development of hydrogen appliances by international competitors (e.g. industry, other foreign government sponsored activity).
	Providing a sufficient evidence	There is only likely to be further development and take-up of hydrogen heating technologies, if wider	Government policy decisions on continuing to fund hydrogen for heating R&D may be

Outputs to outcomes	base to stakeholders	stakeholders are confident that outputs are grounded in sufficient evidence. The logic chain currently assumes that Hy4Heat collects relevant evidence for DESNZ that is provided in time to inform decisions around pathways to decarbonise heat, and that the evidence fills all the necessary knowledge gaps. It also assumes that the programme has been able to collect the views of all relevant parties, ranging from industry to consumers.	based on wider external evidence than Hy4Heat alone. For example, evidence on the feasibility and costs of producing hydrogen gas at sufficient scale (e.g., DESNZ Hydrogen Supply programme) as well as emerging evidence from the cost-effectiveness of alternative decarbonisation pathways e.g. electrification of heat.
	Stimulating industry to invest in further R&D		Consumers and industry may not buy-in to Hy4Heat-developed technologies, standards, and solutions, if they prefer solutions developed outside the UK. For example, they may consider international solutions to be safer and/or most effective and therefore decide to pursue these further rather than appliances developed via Hy4Heat. Industry's confidence to invest will also be influenced by wider considerations than the outcomes of Hy4Heat e.g. perceptions of the likelihood and timing of conversion of the gas network to hydrogen, and the relative development rates of other low carbon heating approaches.
	Good Public Relations (PR)	Domestic engagement in hydrogen technologies and recruitment to the community trials will rely in part on hydrogen heating technologies receiving as a minimum, indifferent public opinion and overcoming public or industry concerns on the safe use of hydrogen. An example of this being achieved to date is dispelling industry concerns that hydrogen heating appliances will lead to higher accumulation of NOx gases within the building, compared to standard gas appliances. Emerging findings from Hy4Heat safety	Other PR issues involve factors outside the programme. For instance, there could be a hydrogen related accident outside Hy4Heat that may cause adverse publicity, even if in reality, hydrogen appliances are less likely to create accidents than traditional methane or natural gas appliances.

		tests of domestic boilers and fires suggest the opposite is true. Cost overruns and any uncertainties with testing could lead to bad publicity, and the results of the activities not being sufficient to allay any consumer fears.	
	Development of standards	Hy4Heat-developed standards might be a barrier to potential future market entrants if they consider the standards to be too difficult to adhere to. To ensure this is not the case, Hy4Heat will need to ensure that all the appropriate stakeholders (including international manufacturers) have contributed to the standards' development, and that manufacturers are able to manufacture products according to the standards created.	Potential for dispute or disagreement over standards, with other international developers of hydrogen appliances potentially suggesting variations.
	Perception of costs	Perception among industry and the general public that the benefits of converting appliances to hydrogen outweigh the costs. For example, that it is worthwhile to mitigate climate change.	Increased interest and activity in hydrogen technologies by market incumbents and entrants alike will in part be dependent on cost – industry will be unlikely to pursue hydrogen heating technology R&D if the production costs are perceived to be too high. Similarly, if there are reports in trade press or media that estimate the wider gas supply conversion costs to be too high, then this could create a public acceptance barrier.
Outcomes to impacts	Commercial viability	Any lack of a clear signal of intention for a community demonstration may lessen the commercial viability for contractors (they may perceive the market to be unlikely to be developed in next 5-10 years)	Hy4Heat may help progress the technological development of prototype technologies (e.g. up to TRL 8), but to get to commercialisation stage may require a clear signal that hydrogen conversion of the gas network is likely. For example, regulation or a programme of trials that sets a date for all new domestic boilers being installed to be hydrogen ready. In the absence of this market pull, contractors may decide that it is

			not worthwhile to invest further in their commercialisation plans.
	Positive overall safety assessment	The implementation of a community trial is in large part dependent on the hydrogen for heat safety case being proven in earlier stages of Hy4Heat. While the previous H21 scheme has already contributed to making this safety case, it is possible that some stakeholders will not be completely convinced by the results of safety tests (e.g. whether hydrogen gas in network pipes leads to blow of waste dust into the heating system) until they are definitely shown in the community demonstrations. There are safety tests to be met of using hydrogen 'upstream of the meter' that are beyond the scope of Hy4Heat (e.g. leakage in district networks) which would also affect the overall safety assessment.	The public will only engage with hydrogen for heat solutions if they are convinced that all safety aspects have been mitigated prior to community demonstrations occurring. However, as a relatively unknown gas, the public may be more risk averse to hydrogen usage.
	Economic impacts	Economic benefits to UK from first mover advantage, patents, export potential etc.	Assumes UK can maintain first mover position, and that alternative hydrogen technologies and/or appliances are not commercialised first by international competitors.

Source: Technopolis

Step Three: Developing causal links and contributions

The final step involved in developing a Theory of Change is to better understand the causal links and contributions underpinning the risks, assumptions and logic chain set out above. This is particularly important for the **impact evaluation** element of this study where the central aim is to assess the extent to which Hy4Heat is contributing towards its intended longer-term socio-economic impacts (e.g., the factors listed in the Impacts column of the logic chain above, Figure 1). Given the focus on socio-economic impacts, this evaluation does not aim to assess whether Hy4Heat is meeting its technical or scientific objectives in individual work packages. For example, it is not within scope to provide a secondary independent assessment of the functional performance of hydrogen boilers and cookers, or to take independent samples of the hydrogen gas used to verify its purity. Reporting on the extent to which each WP has delivered on its intended technical outputs and outcomes is the responsibility of the Arup+ consortium.

We can group the socio-economic impacts into three impact categories – the impact evaluation will look to determine what causal links help generate each of these and the extent to which Hy4Heat is contributing towards these. The three impact categories are:

- **Developing an evidence base to inform future government policy decisions**. In summary, that sufficient and reliable evidence has been provided to de-risk hydrogen for heat and inform policy decisions on continuation of future work concerning hydrogen gas conversion (e.g. to proceed with community trial and industrial sector demonstrators). As noted in the Introduction chapter, the PM's Ten Point Plan has already announced the intention to progress towards a neighbourhood scale trial by 2023. However, it is still relevant for Stage 2 of this evaluation to assess the extent to which successful outputs from Hy4Heat contributed towards this decision, over and above wider political considerations or any wider external industry evidence on the safety, functional performance, costs and benefits of developing hydrogen appliances.
- **De-risking of hydrogen appliances to stimulate further industry investment and R&D**. If the outcomes of Hy4Heat WPs demonstrate that hydrogen appliances are safe, convenient to use and can be manufactured at commercially competitive cost, then this may result in wider industry stakeholders, including other boiler manufacturers (not directly involved within Hy4Heat), to invest in developing their own hydrogen appliances and stimulate the market for product development. Moreover, by demonstrating the viability of using hydrogen for heating and cooking, this will stimulate parallel strands of R&D in the wider hydrogen economy, not limited to heating and cooking appliances. For example, for GDNOs to test the safety of using hydrogen in their regional networks, or to give confidence to others in the supply chain to invest in the production of hydrogen gas at large scale.
- **Economic benefits**. Including benefits to manufacturers participating in Hy4Heat, through the potential future commercial value of new appliances the programme has developed. As well as potential longer-term economic benefits to the UK due to a first mover advantage from patenting these new technologies, their export potential, and employment benefits arising from new skills developed for heating appliance manufacturers and installers.

These three categories of impact link to three of the main hypotheses set out in the original ITT for the evaluation to test:

1) *Programme activities contributed to the de-risking of a hydrogen transition resulting in hydrogen continuing to be considered a viable option for heat decarbonisation.*

2) The Hy4Heat programme stimulated industry stakeholders to consider, prepare, and undertake parallel hydrogen R&D.

3) The Net Present Value (NPV) of government investment in Hy4Heat is positive and substantial, reliable evidence has been provided to de-risk hydrogen for heat.

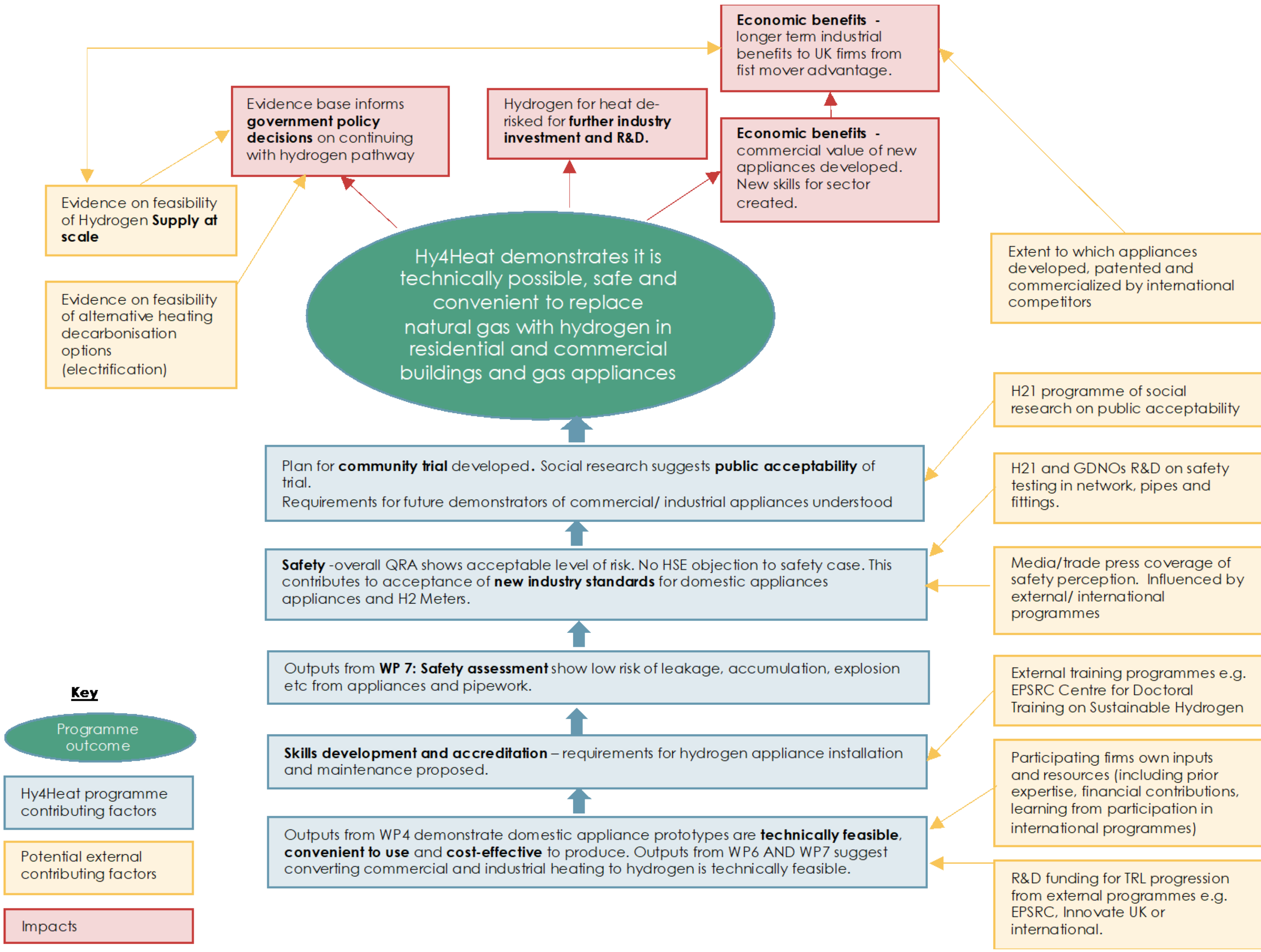
Regarding point 3) above, as outlined Chapter 6 on Economic Evaluation we have since revised the intention to provide an overall NPV estimate for the programme (through Cost Benefit Analysis), in favour of Cost Effectiveness Analysis and a more qualitative assessment of wider economic benefits.

Refining the ToC to account for external contributing factors

Having completed the three steps above, an additional strand of ToC development was undertaken to illustrate the potential role of external contributing factors towards achievement of intended impacts. Undertaking a Contribution Analysis (CA) requires taking the logic chain presented in Figure 3 one step further; to outline the expected sequence of causal factors that lead to the intended impacts, and how the programme outcomes contribute towards this, alongside other external contributory factors. These external contributing factors are discussed further in Chapter 6 on Contribution Analysis, and the accompanying Excel CA framework with details of how these external factors will be measured.

Figure 4 below provides an additional ToC diagram to illustrate how Hy4Heat outcomes are expected to contribute towards intended impacts and maps out the potential role of other key external contributing factors.

Figure 4 Hy4Heat Contribution to Impacts Theory of Change



4 Baseline reviews of the hydrogen for heating R&D landscape

Introduction

Part of the scoping stage of the evaluation was to carry out a baseline review of existing literature and analysis of secondary data sources on the extent of hydrogen for heating technology R&D and investment in the UK and internationally. The focus is on programmes with similar long-term goals to Hy4Heat, or which have looked to develop technologies similar to those that Hy4Heat is progressing. This provides an important foundation for the evaluation, helping to baseline the current state of industry on development of hydrogen for heating technologies, both in the UK and internationally. The baseline (see separate 2020 baseline report for findings), and subsequent follow-up review in 2021, will feed into the evaluation in a number of ways, as outlined below:

- Part of the purpose of the impact evaluation is to assess the **additionality** of DESNZ funding for Hy4Heat; to consider questions around whether or not industry may have developed such hydrogen heating appliances anyway, in the absence of government funding. If it is the case that certain types of appliances, meters, hydrogen purity standards, safety tests etc are being developed elsewhere, Hy4Heat may have some degree of 'deadweight' in its funding, as these technologies may be commercialised without the programme.
- One of the aims of Hy4Heat is to stimulate industry to **invest in parallel programmes of R&D** relating to the development hydrogen for heat technologies and/or their safe implementation in the gas network. The review provides a 'baseline' on the current extent of investment in hydrogen technology R&D. The follow-up review in 2021 will assess whether there has been increase in investment in R&D programmes or equity investment in the firms developing such technologies. Supplemented by interviews with wider industry firms, this will provide one source of evidence to explore whether Hy4Heat has contributed towards the investment decisions of wider industry.
- Linked to the point above, identification of firms which have patented technologies of interest or received equity investment can inform our sampling of firms for interviews with wider industry. If some investment decisions were influenced by Hy4Heat, this may be factored into the **economic analysis** of the programme (discussed further in Chapter 6).
- To provide an additional horizon scanning resource to the DESNZ and Arup+ Hy4Heat management team. As the review identifies international programmes that are aiming to achieve common goals with some of Hy4Heat Work Packages, this may open opportunities for further engagement and **shared learning**.

This baseline review is based on three main workstrands:

- Review of publicly available information on R&D programmes relating to hydrogen for heat technologies, in the UK and internationally (led by Hinicio)
- Analysis of the extent of existing patents for hydrogen heating technologies, using the PATSTAT database (led by Technopolis)

- Analysis of investment trends in firms developing hydrogen technologies (both publicly funded R&D and private equity investment) using the Pitchbook and Gateway to Research databases (led by Ipsos MORI).

An overview of these three baseline strands and how they will be followed up as part of the impact evaluation in summer 2021 is discussed in the sections below.

Review of published literature on hydrogen for heating programmes

As part of the scoping stage, Hinicio carried out a review of publicly available information to scope out the extent of other UK and international programmes that are researching and developing similar technologies as the Hy4Heat programme. The main objective was to form conclusions on the current state of the industry on hydrogen's use for heat (internationally).

Review methods

In order to identify and assess comparable programmes around the globe, a step-wise approach was followed. First, a set of indicators was established to identify different broad categories of potential uses of hydrogen and thematic areas of relevance to Hy4Heat. The first step was therefore to establish if other programmes address one or multiple indicators and if so, which and to what extent. The table below outlines the broad thematic categories and indicators selected.

Table 2 Thematic areas and indicators

Thematic areas	Indicators of thematic area and description
Injection into the gas grid, transport and distribution	Although not within the scope of Hy4Heat, this topic is related given that such programmes may involve relevant aspects, such as developing hydrogen gas for heating (testing purity and odorant levels) or safety testing in pipework and was therefore included in the investigation.
Appliances	H2 Gas boilers FC CHP on NG or H2 Cookers and /or (domestic) gas fires Commercial appliances Industrial appliances
Cross-cutting	Safety Hydrogen quality (incl. Odorants & colouring) Appliance certification Personnel training/ workforce standards Meters & sensors Legal/ regulatory aspects Public attitudes and awareness
Other (secondary indicators)	Overall budget (>1 M £) Duration & start year (only projects that have started in or after 2010)

These indicators were used to guide and focus the initial search. This constituted a combination of mining Hinicio's own internal databases, complemented with extensive web-research (using different combinations of keywords derived from the primary indicators, such as:

heat; heating; decarbonisation; hydrogen; boiler, cooker, meter, safety, hydrogen quality, etc.

Different search engines were used, delivering a first overview of other relevant programmes. To further complement and deepen the search, academic research paper databases as well as websites of National, EU and international hydrogen associations (e.g., Hydrogen Europe, FCHAE (US), California Fuel Cell Partnership, the French Hydrogen Association – AFHypac, IPHE) were consulted, in addition to trawling through major public research and innovation agency websites (E.g. NOW NIP, FCH JU, US DOE H2, Japan METI H2 strategy, ARENA (Australia)).

This initial search resulted in an inventory **list of 41 hydrogen R&D programmes**. These programmes and their key coverage of the different indicators are recorded in an Excel sheet (in a separate file), allowing for easy comparison and further selection. From this long-list, a further selection of the most relevant programmes was made for further analysis, based on their objectives and the number of topics they address (based on having a topic of relevance to a Hy4Heat WP).

This resulted in **a short-list of 21 programme** that were identified as most relevant. From this short-list, **three projects** are described in more detail as illustrative case studies (summarised below). These programmes were selected on the basis of; having more than 2 topics of relevance to Hy4Heat, relatively large budget size and the depth/ ambition of the research of the project/programme. The DESNZ client team then reviewed a draft list of proposed case studies to advise on which were most relevant for providing transferable learning.

As a final step, three telephone/video conference interviews were carried out with the Project Managers or Coordinators of the three international programmes selected for case study (one interview for each of the three programmes). These interviews were used to; a) verify information gathered from publicly available information on the aims and scope of the programmes, b) gather insight into any further work within these programmes which is of relevance to Hy4Heat and c) update information on the current status of these programmes and timescales for completion.

The findings from the review provided as a separate stand-alone report in summer 2020.

The baseline review suggests that Hy4Heat is unique in that it deals with multiple interlinked topics in an iterative and holistic way. No other programme was identified which is addressing the same set of work packages. However, some programmes contain R&D that are relevant to certain strands of Hy4Heat, including; development of domestic hydrogen boilers, meters, safety tests, development of product standards and work to design community level trials, which may feed in relevant learning for Hy4Heat. Three international programmes were identified as undertaking particularly relevant R&D in these areas, which were shortlisted as brief case studies in the baseline review:

- German Hydrogen Power Storage and Solution East Germany (HYPOS) programme: H2-netz and H2-Home
- Rozenburg Power-to-Gas Demonstratieproject – led by the Netherlands Gas Network Operator, Stedin.
- Testing Hydrogen Admixture for Gas Applications (THyGA) project - led by the EU Horizon 2020 funded ‘Fuel Cells and Hydrogen Joint Undertaking (FCH JU)’

The original intention had been to update this international review of comparable programmes, helping us determine the extent to which any new programmes had been introduced in parallel to Hy4Heat, and therefore help our assessment of additionality and Hy4Heat's ability to stimulate further industry R&D activity. However, in the context of the Covid-19 pandemic and the delays this has caused to large-scale R&D programmes over the past year, we do not envisage that the overall landscape of comparable international programmes will have substantially changed from the baseline assessment in 2020. In addition, the baseline review found that while there are several hydrogen R&D programmes underway (>40), Hy4Heat is fairly unique in its objectives and there is only a small number of programmes with comparable aims to certain Work Packages within Hy4Heat, with scope for transferable learning. We have therefore re-profiled the work.

Instead of conducting a follow-up 'broad but shallow' review to identify the basic characteristics of all international programmes underway, the next stage will concentrate on gathering more detailed insight on progress with the three in-depth case study programmes where there is greater potential for transferable learning. The aims of these case studies will be to;

- Gather insight on whether emerging outcomes from Hy4Heat have influenced the direction of international programmes. For example, whether the prototype hydrogen boiler developed by Baxi via Hy4Heat led to the adoption of a boiler with similar design in the Rozenburg demonstration project (by BDR Thermea, the parent company of Baxi). Or vice versa, whether IP gained through R&D as part of the Rozenburg project by BDR Thermea was used to develop the prototype by Baxi in Hy4Heat.

- Gather insight from case studies to inform the development of future UK hydrogen for heat R&D programmes. For example, lessons learned from Stedin's work to develop to convert a town in the Netherlands to hydrogen gas by 2025 may provide useful evidence to inform the design of community trials in the UK.

The study team selected the three case studies outlined in the baseline review in conjunction with DESNZ, based on their topic relevance to Hy4Heat, the comparability of budgets, and the similarity in programme ambition. Updating these three in-depth case studies will help us understand how these most similar programmes have progressed since the baseline.

Case study outline

The three case studies will be 5-6 pages in length and focus on the following:

Introduction to the programme

This will set out the basics of the programme such as its scope and remit, aims and objectives, and the geographical areas it is operating in.

Contractors involved

This will set out the main contractors/organisations involved in programme delivery, and also state whether any of those involved have also participated in Hy4Heat.

Project timeline

This section will set out the key project dates, including when work strands or work packages began, and when notable findings from the project were published.

The section will also include note any key developments and progress made over the lifetime of Hy4Heat.

Key achievements to date

Drawing on published literature, stakeholder interviews, and desk reviews, this section will outline each case study project's key achievements to date. It will focus on three areas:

- Technical (e.g., key findings from the work, including those published in academic papers)
- Strategic and industrial (e.g. the level of traction that the work has had in industry, and whether it stimulated additional activity either from contractors, or those unconnected to the programme)
- Policy (e.g. whether the work has had any bearing on policymakers' interest or confidence in hydrogen for heating solutions)

Comparisons with Hy4Heat

This section will examine whether the programme has been similar to Hy4Heat, in terms of:

- Overlap of contractors
- Comparability of programme scope (i.e., what intended outcomes of the programme are similar to the outcomes of Hy4Heat WPs?)
- Comparability of findings (i.e., do findings either support or refute Hy4Heat's findings. For example, any emerging of safety issues emerging from the adoption of hydrogen boilers internationally?)
- Progress made (a qualitative assessment of whether the case study project is more advanced relative to Hy4Heat in certain areas e.g., testing the use of hydrogen boilers in a residential building, while aspects of Hy4Heat may be more advanced than the case study programmes e.g. developing wider appliances).

We will also include some commentary, where appropriate, how of any interaction that may have taken place with Hy4Heat projects either formally or informally (e.g., whether case study programme managers have drawn upon published results of Hy4Heat).

Case studies will largely be qualitative in nature and draw in large part on desk research. Likely evidence sources will include; the programme website, websites of programme contractors, and press coverage. To better understand the technical progress made via the programme, we will also search online databases such as ResearchGate to understand if each programme has contributed to the publication of any academic papers.

We will supplement this desk research with some primary research. For all three case studies, we will interview the programme lead to gain a more detailed a nuanced understanding of the programme. Where appropriate, we will also hold shorter interviews with prominent programme contractors (e.g., those leading particularly strategically important work strands, or those involved in work that has been successful) – we will identify these organisations and individuals through our desk research, and also through our discussion with the programme leads. We will be especially interested in speaking with contractors that have also participated in Hy4Heat, to help understand whether there has been any knowledge exchange between the programmes.

Analysis of global patents on hydrogen heating technologies

A review of published literature on international research programmes does not capture all R&D relating to hydrogen for heat technology as many projects are led by private firms, who may not have published results or commercialised the technologies. Analysis of patent data provides another indicator of trends in hydrogen technology development, which countries are most active in this space and the types of technologies being developed. Patent descriptions are not necessarily a reliable indicator of what types of technology will actually be commercialised, because some patents are more an expression of ideas and concepts which are being developed, but may not prove to be technically or commercially viable. Nevertheless, analysis of patent data formed a complementary strand to the baseline review as it can identify broader global trends in the international hydrogen R&D landscape.

A search for global trends on patenting hydrogen heating technologies was carried out through analysis of the European Patent's Office PATSTAT Global Database. PATSTAT Global[16] contains bibliographical data relating to more than 100 million patent documents from leading industrialised and developing countries. This was based on a keyword search of the titles of patents filed globally, since 2010 to 2019. The search terms used were:

> Hydrogen odour; Hydrogen odor; Hydrogen purity; Industrial hydrogen heat; Hydrogen heat; Hydrogen boiler; H2 Heat; Hydrogen meter; Hydrogen gas boiler; Heat hydrogen; Hydrogen cooker; Hydrogen cooking; Hydrogen safety; Hydrogen sensors; Hydrogen heater; Hydrogen fire; Hydrogen network; Hydrogen hob; Hydrogen stove; Hydrogen oven; Hydrogen Gas fire; Hydrogen thermostat; Hydrogen burner; Hydrogen CHP

Each term was searched for individually in PASTAT. This search returned 496 unique filed patents. An Excel database is provided separately with details of each patent, including their unique ID identifier, country of origin, date, name of person or company which filed the patent and their abstracts.

A follow-up to this baseline review will be carried out in summer 2021 to assess; a) whether Hy4Heat has directly led to filing of new patents (among appliance developers funded by Hy4Heat), b) whether similar appliances have been patented internationally (e.g., domestic hydrogen boilers) offering potential competition in the market and c) to provide an overview of trends in the number of hydrogen appliances being patented over time and whether this has increased over the last year.

Investment trends in hydrogen technologies

In addition, the baseline review presented analysis of investment in companies or projects relating to hydrogen. As noted in the introduction, one of the aims of Hy4Heat is to stimulate industry to invest in parallel programmes of R&D relating to the development of hydrogen for heat technologies and/or their safe implementation in the gas network. The review provided a 'baseline' on the current extent of investment in hydrogen technology R&D. The follow-up review in 2021 will assess whether there has been increase in investment in R&D programmes or equity investment in the firms developing such technologies. Supplemented by interviews with wider industry firms, this will provide one source of evidence to explore whether Hy4Heat has contributed towards the investment decisions of wider industry.

[16] https://www.epo.org/searching-for-patents/business/patstat.html

This analysis assessed the feasibility of identifying firms participating in Hy4Heat which have received recent equity investment. Tracking an increase in firm valuation, and using supporting interviews to assess whether the extent which Hy4Heat contributed towards these investment decisions, may be factored into the economic cost benefit analysis of the programme (discussed further in Chapter 6).

The sources used for this data analysis are:

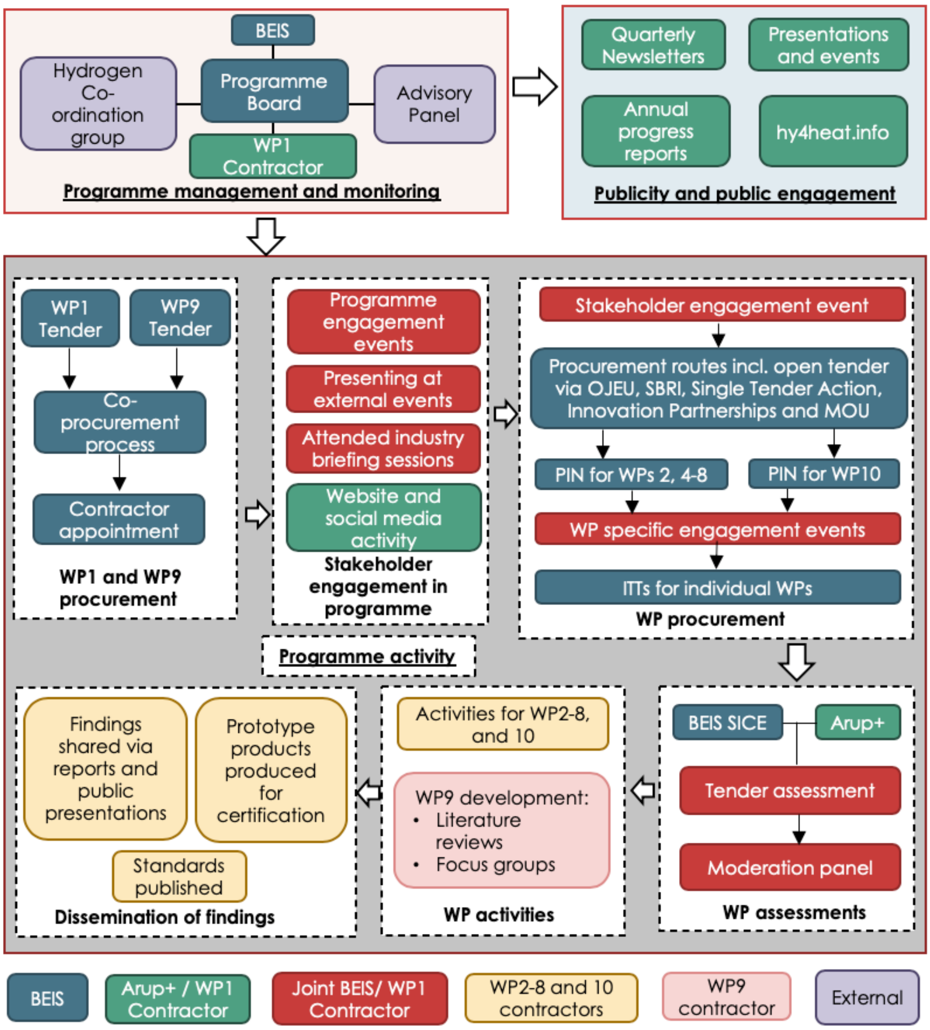
- **Pitchbook**. Pitchbook is an online platform that provides close to real time information on UK high growth companies, with a focus on financial data. The data from these sources can be used to acquire information relating to the fundraising efforts of organisations, including the number, location and size of private equity deals secured, and the valuation of firms. This includes a description of the primary activities of organisations raising finance. Organisations and deals relating to hydrogen have been identified and the data analysed, alongside a review of the data for firms involved in the Hy4Heat programme. For equity deals and finance raised, Pitchbook is a strong and robust data source. However, it does not provide information for smaller value deals or have a complete coverage of smaller firms. It also does not include information about firms which self-finance (use their own resources to fund expansions). Therefore, the findings do not provide complete coverage of all hydrogen R&D funding in each country.
- **Gateway to Research**. Gateway to Research provides data about publicly funded grants awarded to firms from Innovate UK and the seven Research Councils. This includes information about the size of grants, the level of collaboration, the year of the award and a description of the innovation project being funded. The description of the funded projects was reviewed to discover if the research project included hydrogen-based research, and the number, date and value of these projects has been analysed.

Findings from this analysis can be found in the Hy4Heat evaluation baseline report (2020).

5 Process Evaluation

This section sets out the key processes that underpin Hy4Heat management and delivery before setting out a framework to assess the effectiveness and efficiency of them. As outlined in the figure below, Hy4Heat programme delivery involves a range of process stages. The 2020 interim process evaluation report assessed the majority of these stages. For stages of delivery that are now complete, such as initial tendering and procurement of Hy4Heat contractors, there would be little new evidence to be gained from using interviews in 2021 to repeat discussion of these completed stages. Instead, the process evaluation in 2021 will focused on processes of management and delivery of WP since January 2021 until programme close. The final report will provide a synthesis of findings across all stages of the process evaluation. The stages for delivery are described further in the section below the diagram.

Figure 5 Hy4Heat programme process map[17]



Source: Technopolis

[17] BEIS changed its name to DESNZ in February 2023.

1) Programme management and monitoring

Hy4Heat has established a management structure with clearly defined lines of responsibility and a variety of mechanisms in place to provide management support and oversight. DESNZ is the body ultimately responsible for overseeing the project. It leads the Hy4Heat Programme board, chaired by a DESNZ Senior Responsible Owner (SRO). The Programme Board oversees the work of the contractor appointed via WP1 (Arup+) who in turn is responsible for day-to-day management of Hy4Heat, including the monitoring and oversight of all project activities. Two bodies provide expert advice to the DESNZ Programme Board and Arup: the Hydrogen Coordination Group (consisting of representatives from Gas Distribution Network Operators (GDNOs), the National Grid, IGEM, and Ofgem), and the Advisory Panel (consisting of industry and academic experts, Ofgem, the Health and Safety Executive (HSE), and GDNOs).

2) Publicity and public engagement

Aside from overseeing programme activity delivery (explained in greater detail below), Arup+ also leads on publicity and public engagement for Hy4Heat. It is involved in a variety of activities which look to disseminate information about the whole programme, including its remit, anticipated work, and the results achieved to date. These activities include the publication of quarterly newsletters and annual progress reports, plus involvement at publicity events. It has also set up and managed the hy4heat.info website which is one of the programme's most widely used public engagement mechanisms.

3) Programme delivery activities

The programme delivery process itself has consisted of a variety of work strands.

WP1 and WP9 Procurement

One of the first steps in the programme activity phase involved the procurement of a contractor for WP1 and WP9. While DESNZ issued separate tenders for each work package, it ran the respective competitions at the same time and via the same procurement process. Through the competitive co-procurement tendering process, DESNZ appointed a contractor group headed by Arup to lead both WP1 and WP9.

Stakeholder engagement in the programme

With Arup+ on board, the programme management then began to engage with the wider stakeholders, both industry and domestic, to increase awareness of the programme, and to secure the interest of potential applicants for the different work packages. Central to this was Arup+ setting up the Hy4Heat website, giving the programme its own brand and identity and providing a single point for all publicly relevant information on the programme. Acting together, DESNZ and Arup+ have also engaged in variety of stakeholder engagement activities. For instance, in March 2018 and March 2019, they ran day-long Stakeholder Engagement Events where DESNZ and the Hy4Heat programme team introduced the aims of the programme and provided progress updates. The events have also included roundtable discussions with industry and facilitated networking opportunities.

DESNZ and Arup+ have also participated in external events and conferences, including involvement in hydrogen briefing events for industry and international stakeholders. For example, presenting at the COP25 conference in Madrid in December 2019.

WP procurement

Having engaged the wider community in the Hy4Heat programme to generate interest, the programme management then used this interest as a platform to invite and receive applications for the different work packages. This began with an initial event to introduce stakeholders to the different work packages, and what each one aims to achieve. Following this event, Hy4Heat began the formal procurement processes for work packages 2, 4 and 8. The programme has used a variety of different procurement routes depending on what is more appropriate and relevant to the intended contractors of each respective work package. Consequently, Hy4Heat has used a mixture of open tender routes (via OJEU), the Small Business Research Initiative (SBRI), innovation partnerships[18], memoranda of understanding (MOU), as well as single tender routes. Initially, DESNZ began by issuing a single prior information notice (PINs) for work packages 2, and 4 through to 8, with a separate PIN for WP10 at a later date once the need for hydrogen ready smart meters became apparent. Hy4Heat did not issue a PIN for WP3, choosing instead to engage directly with potential providers.

Following the issuing of PINs, DESNZ and Arup+ ran a series of pre-tender briefing events, focusing on specific work packages. These sought to clarify details of the work package requirements, and to address any concerns of questions that potential bidders had. Following the issuing of work package specific PINs and invitations to tender (ITTs), Hy4Heat received sufficient numbers and quality of applications to award contracts to deliver the various work packages.

WP assessments

Tender assessments have involved technical experts at DESNZ and Arup+, typically five individuals from across the two organisations. Moderators also conducted final reviews of each assessment. In the case of competitions run via SBRI, a portfolio moderation panel sense-checked the scores alongside all other SBRI applications. For competitions run via OJEU, there was a bespoke moderation panel focusing on the appropriate work package only. The Hy4Heat Advisory Panel (consisting of industry and academic experts) additionally provides guidance and expertise in assessing the applications and appointing work package contractors.

WP activities

Once appointed, contractors have progressed with activities for their work packages, with Arup+ providing oversight and strategic advice. Work for WP9 (preparation for a community trial) has not yet progressed as far as envisaged in the original programme plan. The Programme Board has decided to take more time to review

[18] This a form of procurement which allows “public authorities to launch a call for tender bids without pre-empting the solution, leaving room for suppliers to come up with an innovation in partnership with the authority.” Further details are available at http://www.govopps.co.uk/innovation-partnerships-a-new-route-to-market/

the results from relevant WPs to determine the feasibility of a trial (e.g. the results of WP activity on safety tests). Therefore, WP9 will be a more distinct work package, not operating in parallel with the others, but learning from their outputs. Nevertheless, some preparatory work for WP9 has commenced, including commissioning CAG consultants to run four focus groups with members of the public to review potential willingness to participate in a trial, as well as research to scope the characteristics required for potential locations.

The interim report provided a summary of progress in delivery of each WP up to the end of
2020.

Dissemination of findings

Contractors have disseminated findings in a variety of ways. Published reports with results from each WP (once finalised) are provided on the Hy4Heat website. The website also shares slide packs used for public presentations at seminars and briefing events (including the Hy4Heat Stakeholder Events). For those involved in appliance development (WPS 4, 5, and 6), engagement with the wider community has been through communicating the design of prototype products for certification; while for WP2 and 3, the emphasis has been on the publication of draft standards for comment by industry.

Process evaluation framework

The Invitation to Tender for this evaluation project set out a number of process evaluation questions that should be addressed. Including;

- How effective and efficient has the delivery of the programme been?
    - How effective has the organisation of a contracted project management and procurement structures been?
    - How effective and efficient have the internal (DESNZ and Arup+) governance and internal management structures been?
    - How effective and efficient has the interaction with the assurance review been?
    - Have the different approaches to commissioning WPs been effective at delivering innovation and standards (although this was not aim of commissioning strategies)?

We have developed a process evaluation framework (Figure 20 below) that presents the key evaluation questions, metrics, and data sources that will enable an assessment of the processes that Hy4Heat used. The framework includes a range of proposed additional specific questions to address, drawing upon suggestions made during consultation interviews at the scoping stage of the evaluation.

We anticipate the process evaluation drawing on the following evidence sources. Many of these strands will provide data to inform both the process and impact evaluation.

- **Programme documentation:** there are a variety of different programme documents that will be used to understand how the programme overall and individual work packages have operated, as well as helping to make an assessment of how well the different processes have worked. Sources will include work package ITTs, numbers of applications received, assessment scoring sheets, number and profile of attendees at engagement events, benefits reporting plans, quarterly update reports from Arup+, and reports of results arising from each WP.
- **WP monitoring data:** it will also be helpful analysing any bespoke monitoring data collected by the respective work packages. In particular, they will help reveal the depth of monitoring data produced, how comprehensive this is, whether risks are being identified, mitigated and overcome etc to help infer the extent to which monitoring arrangements are sufficient to support adaptive management decisions.
- **DESNZ programme data:** we anticipate DESNZ and/or Arup+ holding a range of programme-level data which will help with the process evaluation. This includes information on the make-up of the Hydrogen Co-ordination Group and Advisory Group, details and minutes of programme engagement meetings held, and the reach of publicity material.
- **Assessor interviews:** we aim to interview a handful of assessors for their view on the effectiveness of the different work package procurement and assessment processes.
- **DESNZ stakeholders:** these are likely to include policy and SICE leads working closely with Arup+ to provide management oversight, as well as representatives of policy teams who may use evidence generated by Hy4Heat to inform future decisions on heating decarbonisation options. We also propose to consult SICE representatives sitting outside of direct involvement with Hy4Heat programme who can give a view on how the design of Hy4Heat, and its implementation compares and contrasts with those of other DESNZ innovation programmes.
- **Successful applicants:** speaking with the project managers of successful work package contractors will help reveal more about the effectiveness of the tendering process, plus the quality of help and support provided during the work package delivery phase.
- **Unsuccessful applicants:** we propose interviewing a small selection of unsuccessful applicants to help understand whether any process or delivery issues (e.g., insufficient time or support to complete the application, or lack of clarity on certain eligibility criteria etc) may have caused the unsuccessful bid.
- **Potential applicants who did not apply:** interviewing manufacturers of gas boilers and other heating appliances who are active in the UK market and may, in theory, have been eligible to apply but did not. This will provide insight

into whether any of the programme design features or contractual terms (e.g. over ownership of IP) deterred their application and why.

- **Wider Industry stakeholders:** speaking to representatives from industry stakeholders not actively involved in Hy4Heat will help better our understanding of the programme's standing in the wider community, the effectiveness of publicity dissemination, and the extent to which the programme is calling on the right expertise and skills through the Hydrogen Co-ordination Group and Advisory Group. Potential interviewees could include boiler manufacturers not participating in the programme, and GDNOs. This strand will also feed into addressing impact evaluation questions around the extent to which Hy4Heat is stimulating external investment and R&D in development of hydrogen appliances.

- **WP1 contractor:** Arup+ representatives will continue to be engaged to feed into each key milestone of the evaluation. Their views will be sought on the effectiveness of the WP1 procurement process, the ways in which individual WPs were procured differently, views on what has worked well/ less well on WP delivery and why, how potential risks or barriers to delivery were mitigated, views on DESNZ approach to managing the programme and any wider learning that may feed into development of future innovation funding programmes.

Primary Research Interviews

Multiple groups of stakeholders are to be interviewed in order to meet the different forms of data collection required for the process, impact and economic evaluation. The same interviews will be used to collect information for each strand, to avoid overburdening the same respondent with multiple request for interview. However, certain groups may be interviewed twice; those first interviewed in 2020 to feed into the interim report, and then a follow-up round in 2021, shortly after the Hy4Heat programme ends, to feed into the final stage assessment of outcomes achieved and lessons learned. Table 13 below provides a breakdown of which groups were interviewed in 2021 and which stakeholder groups will be interviewed in 2021.

The ITT for the evaluation outlined a suggested breakdown of number of interviews with different stakeholder groups, which has been used as the basis of the proposed approach here, although some updates on specific groups for inclusion and notes on their purpose have been added. In summary, key stakeholder groups to be interviewed include:

WP contractors - with 15 organisations interviewed in 2020, and then 15 follow-up interviews in 2021 after Hy4Heat programme completion (as listed in table below). These will be used to understand the advance of technical innovations during the Hy4Heat programme, how knowledge and skills have been advanced in their company and what work in this area they will continue to do after the Hy4Heat programme has finished.

Representatives of firms who applied to complete the work packages but were not successful; with 2 interviews per key Work Package. The purpose of this is to understand what work surrounding using hydrogen for heat they are doing outside of

Government-funded initiatives. This will also include an understanding of the impact of other related programmes of work. In addition, these interviews will address certain process evaluation questions, for example if there were aspects of the application process that were unclear or could be improved for similar future innovation programmes.

Interviews with individuals from companies who attended pre-tender supplier engagement events for Hy4Heat, such as the launch event, but decided not to bid. These will be used to inform process evaluation questions such as whether there were any feature of programme design or contractual terms that deterred them from bidding (such as ownership of IP) and also feed into impact evaluation questions around the additionality of the programme. For example, if non-bidding appliance manufacturers have begun developing their own hydrogen heating appliances in the absence of Hy4Heat funding, this will inform assessment of additionality.

Interviews with wider industry/sector stakeholders. Including; representatives of all GDNO companies, HSE, Ofgem, BSI, Gas Safe Register, Heating and Hot Water Industry Council (HHIC), consortium leaders of international programmes undertaking hydrogen technology R&D (to understand extent of similarities and differences in their aims), equity investors in firms developing hydrogen heating appliances (to understand whether the future commercial value of hydrogen heating contributed towards their investment decisions) academics (who are either pro-hydrogen or anti-hydrogen as an option for heat decarbonisation) and representatives of Committee on Climate Change.

These interviews will feed into assessment of a range of contribution claims in the CA-PT framework, primarily around the extent to which Hy4Heat has stimulated wider industry R&D and investment in hydrogen technologies or can be expected to in future.

Interviews with officials in DESNZ. These interviews will primarily be used to understand whether, and how, the Hy4Heat programme has advanced policy thinking surrounding using hydrogen for heat in the future in the UK, what evidence gaps there are, whether Hy4Heat has added to the wider DESNZ hydrogen approach/thinking and whether their needs have been met with the programme.

interviews with Arup+ programme management leads – to gain the programme manager's perspective on what has worked well and not so well in the delivery of Hy4Heat, in addition to what learnings we can take from the approach to contracted project management and the different ways of procuring individual work packages. This will provide learning to apply to other innovation programmes.

The table below provides a breakdown of the number of proposed interviews for each stakeholder group, split across the two stages in 2020 and 2021.

Table 3 Split of interviews by group and year[19]

Target group	Names of organisations	No. of Interviews 2020 (interim stage)	Target No. of Interviews 2021 (final stage)	Total
Hy4Heat WP contractors All lead contractors to be interviewed twice – at Stage 2 and 3.	WP1 (covered in separate row below) WP2 – IGEM, DNV-GL WP3 – BSI WP4 – Baxi, Worcester Bosch, Clean Burner Systems, Enertek, Samad Power WP5 – ERM WP5b – Solid Power (re developing commercial appliances) WP6 – Element Energy WP7- Steer Energy WP10 – Pietro Fiorentini, MeterSit Competency Framework for skills and training – Energy and Utility Skills	17	20	37
Firms who applied to complete the work packages but were not successful.	Names of organisations not known [To be contacted via online survey in Stage 2 rather than interview]	5	8	13
Companies who attended relevant Hy4Heat events, such as	Names of organisations not known [To be contacted via online survey in Stage 2 rather than interview]	4	5	9

19 Addendum: The table above shows the intended target number of interviews for each group, prior to fieldwork. The tables in the section below show how the number of achieved interviews compare with the targets.

the launch event, but decided not to bid.				
Wider industry/sector stakeholders. Including; representatives of all GDN companies, HSE, Ofgem, BSI, Gas Safe Register, Heating and Hot Water Industry Council (HHIC), consortium leaders of international programmes undertaking hydrogen technology R&D, equity investors in firms developing hydrogen heating appliances, academics and representatives of Committee on Climate Change.	4 Interviews with GDNs. There are eight gas distribution networks (GDNs), each of which covers a separate geographical region of GB. These eight networks are owned and managed by the following 4 companies: Cadent Gas Ltd Northern Gas Networks Limited Wales & West Utilities Limited SGN – Scotland and Southern England 6 x UK industry/policy bodies: 1 x interview with Ofgem rep 1x National Grid – potentially Future Energy Scenarios (FES) lead. 1x Committee on Climate Change (CCC) (potentially Jenny Hill) 1 x Gas Safe Register 1x HHIC 1xHSE 6 x International organisations: 1x rep of IEA Hydrogen 1x rep of Mission Innovation - lead of IC8 programme (clean hydrogen). 1 x rep of Hydrogen Council 3x interviews with leads of international programmes identified in Hinicio review to develop case studies. 2x Standards governance agencies: 1x ISO (International Organization for Standardization) 1X BSI (British Standards Institution)	12	12	24

	2 x Academics: interviews with academics focused on use of hydrogen for heat in decarbonisation (1x pro-H2 and 1x sceptic to get a balanced view) 3 x private financial investors – any investors in manufacturers of H2 heating appliances identified through Pitchbook/ interviews to determine extent to which H2 appliance development influenced investment decisions. 3x Public Sector Innovation funding bodies: UKRI/Innovate UK Energy Systems Catapult EPSRC -Head of Centre for Doctoral Training on Sustainable Hydrogen (interesting to consider overlaps with EPSRC role in developing skills/training. Also interesting to explore whether PhD students are developing similar appliances/technologies with their industrial partner sponsors).			
Interviews with officials in DESNZ		3	8	11
interviews with Arup+ programme management leads	Arup, Kiwa, Progressive Energy, Embers and Yo Energy	5	3	8
Total		**46**	**56**	**102**

Addendum: achieved numbers of interviews

The tables in this section summarise how the number of achieved interviews compare with the pre-fieldwork targets outlined in the section above.

As outlined in 4 below, the target number of interviews for all groups was either met or almost met. Personnel changes in ‘wider industry stakeholder group’ since the 2020 interview programme (for the interim report) made it difficult to secure follow-up interviews with this group. Representation from a wide variety of sector stakeholders was secured, including GDNOs, trade associations (international and domestic), public sector delivery agencies and energy sector regulatory bodies.

Table 4. Phase 2: interviews achieved against targets

Target group	Target interviews	Interviews achieved	Achievement rate
WP Contractors	20	18	90%
Wider industry stakeholders	12	9	75%
DESNZ stakeholders	5	4	80%
WP1 and 9 contractors	3	3	100%
Total	40	34	85%

An extensive interview programme was carried out to inform the 2020 interim report, focusing more on process evaluation issues. Relevant findings from these interviews also fed into the main report, in particular understanding the efficiency and effectiveness of Hy4Heat’s delivery. The table below summarises the overall numbers of achieved interviews for each stakeholder group compared with their targets for both Phases combined.

Table 5. 2 Phase 1 and Phase 2 combined: interviews achieved against targets

Target group	Target interviews (Phase 1 and Phase 2)	Interviews achieved (Phase 1 and Phase 2)	Achievement rate
WP contractors	35	35	100%
Wider industry stakeholders	25	21	84%
DESNZ stakeholders	10	7	70%
WP1 and WP9 contractor	6	8	133%
Unsuccessful applicants for Hy4Heat support	8	5	63%
Companies that attended Hy4Heat engagement events but did not bid for funding support (i.e., non-applicants)	5	4	80%
Total	89	80	90%

Limitations in data gathered for this report

While interviews and other sources listed above have generated a wealth of evidence, there are some gaps and limitations in the evidence gathered for this study, including:

1. While we successfully conducted interviews with vast majority of WP contractors, we did not carry out a census of all contractors involved in Hy4Heat delivery (i.e., all sub-contractors involved). This means there is some potential for unknown bias if sub-contractors have difference in experience of WP delivery.

2. There were relatively low response levels to requests for interview with representatives of organisations that had tendered for Hy4Heat WPs and been unsuccessful or had attended pre-tender supplier engagement events and decided not to bid (9 interviews out of a target of 15 in Phase 1). A request to participate in a short online survey was sent to this group of stakeholders in Phase 2 (summer 2021) to fill evidence gaps, however this received no response. This could create potential for positive bias in views towards the procurement process and project management processes, if we assume that unsuccessful applicants would view the application process more negatively. However, the feedback that we have been able to secure does indicate that the procurement processes were fair.

3. Fieldwork for the impact evaluation was carried out during summer 2021. At this stage most Hy4Heat WPs had delivered their final outputs, but the programme was still ongoing (completing in October 2021). It is therefore not a full 'ex-post' evaluation and some expected impacts outlined in the programme Theory of Change will take longer to materialise than could be observed within the timeframes of the evaluation.

Nevertheless, even with these limitations, we have collected sufficient data to be able to answer the high-level evaluation questions set out in the first chapter.

Process Evaluation Framework

The table below provides a framework for the process evaluation, setting out each evaluation question addressed, and the main sources of data collection used.

Figure 6 Process evaluation framework[20]

			Secondary data				Primary data					
Process	Process evaluation question	KPI/Metric	Document review	WP monitoring data	BEIS data		Assessors	BEIS stakeholders	Successful applicants	Unsuccessful applicants	Industry stakeholders	WP1 Contractor
WP procurement	**Overarching question:** How effective has the organisation of contracted project management and procurement structures been?											
	How aligned were the tender documents to the aims and objectives of the programme?	No. of quality applications received	xxx					xxx				xx
	How effective was the programme in engaging with potential applicants for each WP?	No. of organisations attending engagement events; No. of applications received for each EP			xxx							
	To what extent were applicants aware of the needs and objectives of their respective work package, and the whole Hy4Heat programme?	No. of quality applications received; perceptions on programme clarity from applicants	xx						xxx	xxx		
	Do applicants receive the necessary level of support in the application process?	Perception of support provided (e.g. via application guidance, FAQs, and engagement events)							xxx	xxx		
	Is the time provided to complete applications sufficient?	Number of applications received	xxx						xx	xx		
	Is the WP procurement and application process conducive to the preparation of high-quality proposals?	Distribution of assessment scores			xx				xx	xx		
WP1 procurement	How effective was the design and preparation of the WP1 call?	No. of suitable applications received			xxx							xx
	How efficient was the appointment of the contractor?	Perception on the timeliness of assessment and appointment process						xxx				xxx

[20] BEIS changed its name to DESNZ in February 2023.

			Secondary data			Primary data					
Process	Process evaluation question	KPI/Metric	Document review	WP monitoring data	BEIS data	Assessors	BEIS stakeholders	Successful applicants	Unsuccessful applicants	Industry stakeholders	WP1 Contractor
Stakeholder engagement and dissemination	Has stakeholder engagement activity generated good interest levels in Hy4Heat?	No. attending engagement events and industry briefing sessions; number of hits to Hy4Heat website; number of likes on social media			xxx					xx	xx
	Has stakeholder engagement activity generated good interest levels in Hy4Heat?	No. attending engagement events and industry briefing sessions; number of hits to Hy4Heat website; number of likes on social media			xxx						xx
	Are findings shared with the public in a timely manner?	Time between output finalization and publication		xx	xxx						
	To what extent is the programme management team successfully sharing publishable outputs?	No. of outputs published on Hy4Heat website; no. of downloads and/or website visitors to relevant pages		xxx	xxx						
	Have the different approaches to commissioning WPs been effective at delivering innovation and standards (although this was not aim of commissioning strategies)?	Extent of TRL progression achieved. Industry acceptance of new standards. Views on extent to which programme design facilitated innovation e.g.									

			Secondary data			Primary data					
Process	Process evaluation question	KPI/Metric	Document review	WP monitoring data	BEIS data	Assessors	BEIS stakeholders	Successful applicants	Unsuccessful applicants	Industry stakeholders	WP1 Contractor
WP assessment	Are assessment criteria appropriate and their weighting proportionate to select applications aligned with WP objectives?	Level of alignment of applications to WP objectives	xxx			xx					
	Are assessors allocated enough time, resources and guidance to complete rigorous application assessments	Variability in assessment scores; extent to which scores are changed post-moderation				xxx					
	Do assessors have enough technical expertise to provide a rigorous assessment of applications	Extent to which scores are changed post-moderation	xxx			x	xx				
	Do applications provide enough technical and commercial information to an effective assessment of the project?	Perception of application quality by assessors	xx			xxx					
WP activities – governance and monitoring	**Overarching question:** How effective and efficient have the internal (BEIS and Arup+) governance and internal management structures been?										
	Are the WP leads receiving enough guidance and support from the WP1 contractor and BEIS to inform their project design and implementation and decisions?	Perceptions on the quality of advice provided; number of meetings/communication between WPs and BEIs/WP1 contractor		xxx				xxx			xx
	Do ongoing monitoring and reporting arrangements provide BEIS with sufficient information to inform any adaptive decisions?	Perceptions of how comprehensive monitoring and reporting arrangements are and timeliness to feed into programme board decision making.	xx				xx				
	Is there sufficient information and data available to enable a rigorous assessment of WP progress?	Completeness and accuracy of project monitoring forms		xxx			x				xxx
	To what extent is there sufficient interaction between activities in different WPs to share learning between?	Evidence of outputs from one WP informing the decisions of another dependent WP. No. of meetings between different WP					x	xxx		x	xxx

6 Impact: testing and refining the Theory of Change

Our approach to developing, testing and refining a Theory of Change for the Hy4Heat will be based around a synthesis of evidence from various strands of evidence using a Contribution Analysis framework, as outlined by John Mayne (2012[21]):

> *"Contribution Analysis (CA) is based on the existence of, or more usually, the development of a postulated theory of change for the intervention being examined. The analysis examines and tests this theory against logic and the evidence available from results observed and the various assumptions behind the theory of change and examines other influencing factors [alternative theories]. The analysis either confirms – verifies – the postulated theory of change or suggests revisions in the theory where the reality appears otherwise. The overall aim is to reduce uncertainty about the contribution an intervention is making to observed results through an increased understanding of why results did or did not occur and the roles played by the intervention and other influencing factors".*

In essence, CA aims to draw defendable conclusions on what contribution a programme has made to observed outcomes, over and above alternative explanations. For example, the contribution that Hy4Heat has made towards stimulating wider industry to invest in further R&D, over and above other market signals on the case for hydrogen conversion. This is achieved through an increased understanding of:

- **Why the observed results have occurred (or not)** – for example, why some manufacturers that are not funded via Hy4Heat may have begun product development of hydrogen heating technologies.
- **The roles played by the intervention over and above other internal and external factors** – for example, the contribution claim is that government funding for Hy4Heat sends a signal that conversion to hydrogen gas heating is feasible. Competitor firms may be stimulated to undertake similar product development so as to be 'hydrogen-ready'. However, Hy4Heat is not the only hydrogen R&D programme and others such as H21 may contribute towards stimulating investment decisions of wider industry.

CA helps to build a credible contribution story – about making a well-reasoned case and drawing a plausible conclusion. This answers questions such as, "*Is it reasonable to conclude that policy X was an important influencing factor in driving change?*" (Mayne,2008).

CA is a useful approach in impact evaluations where experimental or quasi-experimental designs (that might answer these questions) are often not feasible or not practical (as is the case with the Hy4Heat programme) but there is an interest in assessing whether observed outcomes can confidently be attributed to the intervention. It is more commonly used to draw qualitative conclusions around the plausibility of attribution, rather than quantifiable levels of impact (e.g., the effect size of an intervention). However, it may be used to inform assumptions that underpin wider quantitative modelling. For example, if we can reasonably demonstrate that

[21] Contribution Analysis: Coming of Age? Evaluation 2012 18: 270. Sage

technologies developed by Hy4Heat have played a role in a firm securing additional equity investment and increasing their company valuation.

CA is an iterative approach to developing, testing and refining theories of change on the contribution to outcomes that a programme has made. The lead proponent of the approach, John Mayne (2012), recommends this follows a six steps process:

1. **Setting out the attribution problem to be addressed**: As outlined in the ITT for the evaluation, the 'attribution problem' the project seeks to address is the extent to which core intended outcomes (such as de-risking the use of hydrogen for heating to stimulate further investment and R&D) can be attributed to the programme, or would have happened anyway.
2. **Develop a Theory of Change (ToC)**: outlining the expected steps taken for the programme inputs to meet their intended outcomes and impacts, as well as postulating the role of other potential contributory factors (as shown in Chapter 3, and the accompanying Excel Framework of hypotheses and tests).
3. **Populating the Theory of Change with existing data and evidence:** This involves gathering existing evidence about the ToC, with further consideration of the underlying assumptions, risks and other external influencing factors. The primary research carried out in 2020 for the interim report was used for this step.
4. **Assemble and assess the intervention logic**: Emerging evidence from the interim report stage in 2020 was used to revisit and revise the contribution claims in the CA Framework.
5. **Seek out additional evidence**: In summer 2021, a second round of interviews will be carried out with Hy4Heat stakeholders, shortly after the programme has completed. This will provide new insights on what outcomes have actually achieved by each WP on completion, the likelihood of these leading to future impacts, and the relative contribution of other external factors. The baseline international review of hydrogen technology innovation and investment trends will also be followed-up through in-depth case studies of in 2021, to update our understanding of the potential role of external programmes in contributing to impacts (for example, whether IP developed by boiler manufacturers through international programmes was used to develop the Hy4Heat prototypes).
6. **Revise and strengthen our understanding of the intervention logic:** Stage 3 of the evaluation will provide an overall syntheses phase in 2021, which will triangulate results across all strands of the evaluation to test the programme contribution claims and provide a final narrative on the extent to which Hy4Heat has met, or is on track to meet, it's intended impacts.

Approach to synthesising evidence to assess strength of contribution claims

The approach will follow DESNZ's general good practice guidance[22] for assessing causal claims in theory-based evaluation, including:

1. A clear hypothesis is developed and agreed
2. Clear statement in advance of evaluation implementation (e.g. fieldwork, analysis) of what evidence you expect to see to refute and to strengthen the credibility of your

[22] BEIS Internal Slide Pack by Marianne Law and Julia Raybould. 2020

hypothesis. In this case, following a Contribution Analysis approach, this will involve developing alternative hypotheses on what external factors may have attributed to change in outcomes (see Excel CA Framework)

3. For each evidence statement, in advance of evaluation implementation, state the causal claim test(s) that will be used and identify the quality of evidence you would expect to see

4. Assessment of the evidence collected against those statements to make a judgement about causal claims.

Whilst the CA approach developed by John Mayne provides a useful overall iterative process to testing and refining contribution claims, it is neutral on the precise methods that may be used to make judgements on the strength of evidence in support of causal claims. It is proposed that Process Tracing methods are used within our overall CA framework, as a means of stating the causal claim test(s) that will be used in the evaluation and to assess the quality of evidence in support of these.

Process Tracing

Process Tracing makes causal inferences by identifying types of 'clues' that would either support or reject programme hypotheses if observed. This can be used in combination with Contribution Analysis to develop a series of clues (types of evidence) that would support contribution claims around whether observed outcomes (such as stimulating parallel programmes of R&D) may be attributable to aspects of Hy4Heat or other external factors. The approach also allows an evaluator to highlight evidence of which features of the programme have positively influenced results. Process Tracing frameworks provide transparency, in advance of fieldwork, of what criteria will be used to judge whether programme theories hold true or not and how conclusions will be drawn.

There are four types of causal tests commonly used in process tracing that relate to the above detective example: hoop, straw-in-the-wind, smoking gun and double decisive. These tests define the "clues" that we would expect to observe if the hypotheses are true.

The tests are based on the principles of certainty and uniqueness; in other words, whether the tests are necessary and/or sufficient for inferring the evidence. Tests with high uniqueness help to strengthen the confirmatory evidence for a particular hypothesis, by showing that a given piece of evidence was sufficient to confirm it. Tests with high certainty help to rule out alternative explanations by demonstrating that a piece of evidence is necessary for the hypothesis to hold true (Befani and Mayne 2014[23]).

CA aims to produce defendable conclusions on whether a programme has contributed towards intended impacts, but it is not prescriptive in the methods used for judging the strength of evidence. Process Tracing takes a probabilistic approach to the interpretation of evidence - by assessing the likelihood of observing different types of evidence if programme theories hold true. As outlined by Befani and Mayne 2014[24] Process Tracing is a case-based approach which works well "…*within an overarching CA framework; thus shifting the focus of impact evaluation from 'assessing impact' to 'assessing confidence' (about impact)".*

[23] Befani, B. and Mayne, J. (2014) 'Process Tracing and Contribution Analysis: A Combined Approach to Generative Causal Inference for Impact Evaluation', IDS Bulletin 45.6: 17–36

[24] Befani, B. and Mayne, J. (2014) As above.

A draft CA – Process Tracing framework has been provided as a separate Excel file. Some brief definitions of Process Tracing (PT) tests are provided below.

- "Hoop tests" – disproves or considerably weakens the hypothesis if not found, but not sufficient to confirm the hypothesis. These are pieces of evidence that we would 'expect to see' if the given hypothesis is true
- "Straw-in-the-Wind" – evidence that lends more support to a causal claim in the hypothesis but not sufficient in itself to confirm it if observed, or to disprove with certainty if not observed. For example, evidence based on interview findings alone may be considered 'shaky' (like a straw-in-the-wind) if there is potential for positive confirmation bias among grant funded participants who wish to portray an overly positive picture of benefits achieved. This type of evidence is slightly more likely to be observed if the hypothesis is true, but might be observed even if it is false
- "Smoking gun" – evidence that provides a convincing cause-and-effect type contribution story. It strengthens the hypothesis if observed but does not disprove the hypothesis if not observed (although may slightly weaken it). These are pieces of evidence that are likely to be observed if a given hypothesis is true and unlikely to be observed if it is not true
- "Double-decisive" – strengthens or confirms the hypothesis if observed and if not observed the hypothesis is rejected or significantly weakened. In practice, such definitive evidence may be harder to uncover.

Process Tracing may be combined with Bayesian updating to mathematically estimate the probabilities of hypotheses being true or false based on whether each evidence test has been observed. This involves the specification of prior probabilities for the hypotheses being true according to each evidence test (in advance of fieldwork) and then the updating of these to posterior probabilities based on what evidence is actually observed. This can be well suited to evaluation of programmes based on a relatively small number of cases and evidence tests. However, in projects with large numbers of interviews and multiple strands of data sources and tests, Bayesian updating may overcomplicate the process given the assigned probability scores for each test are based on subjective judgement. When conclusions on a contribution claim are based on multiple tests across different strands of evidence, the overall scores are more sensitive to errors in judgement of individual tests and risk providing what can seem like arbitrary numbers that are difficult to interpret. Bayesian updating is therefore not considered appropriate for this evaluation.

The approach proposed for synthesising evidence across multiple tests has been informed by the *Evaluation* journal article *Making rigorous causal claims in a real-life context* by Delahais and Toulemonde (2017[25]). Delahais and Toulemonde describe four additional tests for assessing the strength of supporting evidence in theory-based evaluation:

- **Authoritative source** is a piece of evidence which has already passed a thorough test under the responsibility of credible authorities (e.g., peer reviewed papers) in so far as the point at issue is not in dispute among differing authorities. An example would be published reports on the safety test of hydrogen boilers, which have undergone the

[25] Thomas Delahais/Jacques Toulemonde (2017) Making rigorous causal claims in a real-life context: Has research contributed to sustainable forest management? In Evaluation, Vol 23, Issue 4, pp. 370 – 388

manufacturer's own testing, plus independent peer review and then acceptance by relevant bodies such as the HSE.

- **Signature** is when X causes Y therefore it may operate so as to leave a signature (a trace, a fingerprint) that unequivocally points towards to X. For example, if a manufacturer has been funded to develop a new hydrogen boiler, that may leave a signature record in the form of new patents arising.

- **Convergent triangulation** sources are independent from one another in so far as they stem from stakeholders having different vested interests. Pieces of evidence originating from such sources are mutually reinforcing as far as they converge. For example, if interview findings with the manufacturer confirm that a patent for a new technology, was for the same boiler as that funded for development through a public R&D programme.

- **Consistent chronology** is never a sufficient argument for confirming a contribution claim but it may be used for refuting an assumed contribution. For example, if an interview with a GDNO suggests they were influenced to commission some R&D by the emergence of the Hy4Heat programme, but then public records show their work was commissioned in year prior to Hy4Heat being announced.

Our view is that the four strengths of evidence tests described by Delahais and Toulemonde should not be considered a replacement for the four Process Tracing tests, but certain elements of them may complement a Process Tracing framework to provide an additional filter for drawing conclusions on strength of evidence. As described above, the Process Tracing tests have been designed to provide a framework of four mutually exclusive categories on a spectrum of how necessary and/or sufficient observing each is for supporting or refuting a hypothesis. The four tests listed above are less mutually exclusive and serve a different, albeit complementary, purpose of considering the strength or reliability of each source of evidence. For example, it is feasible (and likely) that one robust strand of evidence could be both a 'Signature' and based upon an 'Authoritative source' whilst also being 'Triangulated' with other sources.

The 'Consistent chronology' test serves a similar purpose to a 'Hoop test', although only relates to one factor: timing. As there are other forms of evidence that can usefully serve as initial checks of whether or not a hypothesis can be true, the proposed framework for this evaluation retains the 'Hoop test'. Similarly, 'Signature' serves a similar purpose to a 'Smoking Gun'. Overall, it is proposed that the four, well established Process Tracing tests are used as the basis of categorising types of evidence.

However, the framework will also take account of 'Triangulation' and 'Authoritative source' in the rules for assessing strength of evidence in support of a contribution claim. Many of the strands of evidence in the Process Tracing framework that rely on interview data are considered to be 'Straw-in-the-wind' tests. Stage 2 will interview a range of different stakeholders, who may have different views towards the programme, including firms funded directly by Hy4Heat, those who were unsuccessful in applying, as well as wider firms in the heating appliance manufacturing sector. Considering whether or not, and why, key findings are triangulated and expressed by all groups (as well as secondary data sources) provides another useful filter for considering their reliability in supporting the programme contribution claims. Similarly, considering whether or not a given hoop, or straw-in-the-wind test finding is based upon an 'Authoritative source' (such as peer reviewed publications) provides another factor to consider when making judgements on its likely 'strength of evidence'.

A draft table of rules for determining the relative strength of evidence in support of each contribution claim in the CA-PT framework is provided below. This should be read in connection with the separate Excel file listing each Process Tracing test. The 'overall syntheses' will be carried out against each 'contribution claim' – which links to each of the key impacts being assessed in the Theory of Change.

Table 6. Framework for synthesising evidence across tests to draw conclusions on overall strength of evidence in support of contribution claim

Strength of evidence in support of contribution claim	Criteria for passing tests
Strong support for programme theory that Hy4Heat played a significant contribution towards observed outcomes.	IF: All or vast majority of process tracing tests are passed, and the assessment of the evidence is strong in the majority of cases. No hoop tests fail. OR: All Smoking Gun and Double Decisive tests are passed in support of Programme Hypotheses (PH) AND Smoking Gun and Double Decisive tests fail for the Alternative Hypotheses (AH). Some Straw-in-the-wind tests in support of PH may fail and pass in favour of AH.
Moderate support for the contribution claim	IF: No Hoop tests fail. Evidence in support of some PH Smoking Gun or Double decisive tests may not have been found or are inconclusive. Most Straw-in-Wind tests pass. Evidence for Straw-in-wind test is Triangulated with other sources (for example, interviews with different group of manufacturers, investors and sector experts). AND: Following criteria above, more PH tests pass than AH tests. Evidence is stronger in favour claim that outcomes were driven by the programme – for example, evidence based on Authoritative Sources supports PH.
Mixed or weak support	IF: Some conflicting evidence in favour of PH e.g., some Smoking Gun evidence found but Hoop tests were failed (suggesting Theory of Change itself or the types of tests used need revised). OR: On balance, most evidence tests are in favour of PH, however, these are based on Straw-in-the-wind tests, with few based on Authoritative Sources.
No support for the programme theory OR stronger support for the alternative hypotheses that observed outcomes are primarily driven by other external explanatory factors.	IF: Fundamental tests in favour of PH are failed (e.g., Hoop tests). No Smoking Gun or double decisive tests are passed. OR: Evidence in favour of the AH is found that follows criteria for 'Strong support', but not for the PH. This suggests that outcomes are primarily driven by other external factors and not the introduction of the Hy4Heat programme itself.

The value of this scoring and categorical judgement approach is its simplicity in reporting and its transparency (relative to Bayesian updating). One can easily cross-check these results if a full testing framework is reported in an appendix. In addition, each conclusion on ‘strength of evidence’ for each contribution claim reported will be reported with an accompanying qualitative narrative and illustrative quotes to demonstrate what findings they are based on.

The draft CA/PT framework (in Excel) outlines what types of evidence will be needed to observe changes in key outcomes described in the pathway to impact above. Analysis of Process Tracing (PT) tests will be carried out at a case-by-case level i.e., each individual interview will be coded to demonstrate whether they provide findings in support of the contribution claim or alternative hypotheses. Some PT tests are based on a single source of evidence, for example, a review of a DESNZ Business Case to procure future R&D in support of community trials to assess whether Hy4Heat has contributed towards DESNZ plans in this area.

For individual PT tests that are based on interviews with a group of stakeholders, determining whether or not the hypothesis being assessed has passed/failed the PT test will be based on; a) coding each individual interview transcript (each case) for examples of findings that confirm/reject the hypothesis (using Nvivo, as described in section below) b) developing ‘nodes’ which record and count each strand of evidence, and then c) review the number of respondents which have given evidence to confirm or reject the hypothesis. Where there is a clear majority of responses in favour of the programme theory and a common rationale to explain why, the PT test will be judged to have passed. Or vice versa if the majority of responses reject the programme hypothesis. If there are mixed views among respondents, the evidence will be classed as ‘inconclusive’.

As outlined in the CA/PT Framework (and Annex D: Process Tracing Results), a series of individual PT tests will be used to determine whether there is sufficient evidence in support of each contribution claim (as part of overarching Contribution Analysis). Table 11 above outlines the rules to be followed for drawing results from each PT test together and assessing whether there is strong, moderate, weak or no evidence in support of a contribution claim. If some PT tests pass in favour of the programme hypothesis but others do not (or only pass in favour of alternative hypothesis) the criteria in the table above will be used to judge whether, on balance, there is sufficiently strong evidence in support of the contribution claim. For example, if Hoop tests and Smoking Guns pass and the evidence triangulates across different sources, there may be sufficient evidence to conclude strong support for a contribution claim even if some Straw-in-the-wind tests have failed. Where the evidence is mixed or conflicting, or no PT tests pass in favour the programme hypothesis then it can be concluded there is ‘mixed’ or ‘no support’ for the contribution claim.

A credible ‘contribution story’

To draw conclusions from multiple strands of evidence, the core aim of CA is to make a reasonable and robust case that a program has indeed made a difference. Development of this ‘contribution story’ would entail:

- Providing a well-articulated presentation of the context of the programme and its general aims, along with the strategies it is using to achieve those ends
- Presenting a plausible program theory leading to the overall aims (the logic of the program has not been disproven, i.e. there is little, or no contradictory evidence and the underlying assumptions appear to remain valid)
- Describing the activities and outputs produced by the program

- Highlighting the results of the contribution analysis indicating there is an association between what the program has delivered and the outcomes observed

- Pointing out that the main alternative explanations for the outcomes occurring, such as other related programs or external factors, have been ruled out, or clearly have had only a limited influence.

The final report will provide this ‘contribution story’ narrative and refine the ToC accordingly. This will be used in weighing up evidence to address the following core evaluation questions:

- What impact has the programme had?

- How has the programme achieved these impacts?

- What is the overall cost-effectiveness of the programme?

- What is the wider learning from the evaluation for DESNZ?

The process evaluation questions will be addressed through the separate framework described in Chapter 5. For process evaluation questions, where the aim is to gather insight into what has worked well/ areas for improvement in terms for programme design and delivery processes, the approach to analysis will be more ‘constructivist’ e.g., asking fairly open questions and then drawing conclusions that emerge ‘bottom-up’ from the data provided. Here, there is less need to specify in advance a series of ‘top-down’ hypotheses to test in advance.

Conclusions on the cost-effectiveness of the programme may draw upon evidence generated from the CA-PT analysis. The approach to cost-effectiveness analysis is discussed in the section below on Economic Analysis.

Approach to analysis of semi-structured interview data

The semi-structured interviews with various groups of stakeholders will produce a large volume of qualitative data that will require careful organisation and management for structuring the analysis processes. This sub-section provides an overview of our approach to collating, transcribing, verifying, managing and analysing this data.

All interviews will be audio recorded (with respondent’s consent) and then transcribed into individual Word documents. These Word documents will be structured using consistent templates, based around answering each of the questions in the Topic Guide. The write-ups will be reviewed for any missing information (e.g., where the audio quality was poor, or there was insufficient time to cover all questions), or where the meaning behind a response given is not clear. In cases where interview write-ups lack important information, or certain responses require further clarification, we will send summaries of the interview to the respondent to request their input to add, amend or clarify these sections. This opportunity to check write-ups is generally welcomed by respondents, who are often keen to ensure their views have been captured and interpreted accurately.

The interview transcript documents will be stored in Nvivo. Nvivo is a Computer Assisted Qualitative Data Analysis Software (CAQDAS) package which is used to provide structure to qualitative data and support systematic organisation of text, coding and analysis. It may be used to analyse interview transcripts and also to combine this with other supporting documentation to help classify information, such as background documents about what types of heating technologies have been developed by the firm interviewed.

It provides a way of highlighting text and placing it into an unlimited number of categories or concepts, usually by theme. These different concepts are assigned to “Nodes”; a function for assigning labels to different themes of interest. For example, lists of nodes may be developed to provide examples of evidence which support each contribution claim in the CA-PT Framework, in support of either the programme theory or the alternative theories, or indeed, new explanations of why certain outcomes have arisen that were not previously taken account of. This allows for both a ‘top-down’ analysis of results against the CA-PT Framework, as well as allowing for a ‘bottom-up’ emergence of new theories to arise from the data (a more inductive approach).

Once findings are assigned to their relevant ‘nodes we will run ‘data queries’ to produce quasi-quantitative overviews of the frequency distribution of metrics of interest. For example, to provide tables giving an overview of the proportion of cases (with a case being each individual interview) where the evidence observed supports the pass or fail of relevant Process Tracing tests.

7 Economic Evaluation

This section provides an updated overview of the approach to economic evaluation of the Hy4Heat programme. The economic evaluation will aim to robustly assess the value for money of the programme.

Key challenges

The key challenges to undertaking the economic evaluation of the Hy4Heat programme are:

- The major potential economic, social and environmental impacts will only be realised once hydrogen is used as a fuel for heating, but this is beyond the aims and objectives of the programme and will in any case be beyond the end point of the evaluation.
- For these economic, social and environmental benefits, there are other competing options (e.g., electrification of heating) which could achieve similar impacts, and it may take time for the future economic significance of the potential options within the future energy mix to become apparent. In the meantime, where there are multiple approaches targeting the same impacts, it may be difficult to disentangle the impacts of each option.

Therefore, the evaluation will need to focus on the more direct outcomes and near-term impacts that are achieved, although there are challenges to undertaking an economic evaluation of these outcomes:

- Some outcomes have the characteristic of a public good (non-rival and non-excludable) and are therefore difficult to monetise. These outcomes would include safety standards for hydrogen and feasibility information. Therefore, it will not be possible to monetise all the outcomes of the programme.
- There are limitations with the data available to measure these outcomes. These include investment in R&D, investment in R&D projects relating to hydrogen and company valuations. There are multiple data sources which can be used to identify some of these outcomes (for example Pitchbook or similar financial data sources, Gateway to Research / Innovate UK funding databases, and the Business Enterprise R&D (BERD) dataset from the ONS). However, Pitchbook and the financial data sources only have limited coverage of the companies involved in the Hy4Heat programme. It will not be possible to access the BERD dataset to examine the records of such a small number of participating firms, and it is possible that not all firms are included in the dataset. Therefore, it will be difficult to measure the intermediate outcomes robustly from secondary datasets.

Potential approaches to economic evaluation

The approach to the economic evaluation of the Hy4Heat programme will primarily focus on those outcomes which can be measured and where possible monetised. We have identified and reviewed the potential to utilise four basic potential approaches to the economic evaluation:

- Cost Benefit Analysis (CBA)
- Cost Effectiveness Analysis (CEA)

- Use of wider indicators of programme success, in particular emerging trends in hydrogen investment; and,
- A qualitative value for money assessment.

Each of these have their own strengths and weaknesses and, following discussion with the client team, a CBA was ruled out, primarily due to the inability to attribute the value of future decarbonisation of heat to the Hy4Heat programme. It was therefore agreed to focus on a more qualitative assessment of value money, containing elements of quantitative cost-effectiveness analysis, as outlined below.

Value for Money Assessment

The approach to Value for Money Assessment (VFM) will be grounded within the overall '3Es' approach[26]. This can be useful as an alternative to CBA where, as here, outputs – and to some extent outcomes – can be identified but it is difficult to attach monetary values to these. Making comparisons of the costs of achieving particular outputs or outcomes through different interventions can be a useful way of assessing their value for money and pointing up where resources should be used in order to maximise the impacts/benefits which are achieved.

The approach is most readily applied where the interventions in question are essentially geared to the achievement of at least one common measure of success – for example, the creation of jobs through economic development programmes. Where this is not the case, it essentially requires, for example, that:

- The various output/outcomes of programme participants can be combined in some way into a common measure(s);
- That the costs involved can be attributed to, or at least apportioned to, the production of particular common outputs/outcomes in a reasonable way.

In this case a number of the work packages are clearly focussed on advancing technology development: WP 4 Domestic Appliances; WP 10 Meters; WP 5 Commercial Appliances; and, WP6 Industrial Appliances. Whilst the programme clearly includes some joint costs – in particular in relation to programme management – and perhaps safety standards, it is reasonable to allocate proportions of these costs between the various work packages on the basis of their direct costs. On this basis, the cost of achieving levels of progression in terms of Technology Readiness Level (TRL) progression through these work packages will provide measures of their cost-effectiveness as a basis for comparisons with the wider portfolio of DESNZ Energy Innovation Programmes.

Such an approach is clearly subject to the major caveats that the costs of achieving progression between different TRL levels and between different programmes can be expected to differ for all sorts of reasons, such as the varying extents of the technical complexities involved and equipment costs which have nothing to do with the economy or the efficiency with which the R&D is undertaken. However, such comparisons will be useful in highlighting whether the cost per unit of TRL progression for Hy4Heat is generally higher or lower than other DESNZ energy innovation programmes that were implemented since 2017.

The principal suggested source of comparative information is the DESNZ Energy Innovation Portfolio Key Performance Indicators (KPI) dataset which was developed through an earlier

[26] Economy, Efficiency and Effectiveness and sometimes a fourth Equity. Economy in this case in particular is largely a matter for the Process Evaluation

Technopolis study. This includes estimates of TRL progression which will be used to provide comparative indicators of the costs of achieving particular levels of progression by linking the data for the different projects involved to the relevant MI data on project costs.[27] The KPIs which are reported in this dataset also include other measures of relevance to the evaluation such as number of new business relationships formed with other contractors as a result of participation in the programme.

Following the positive discussions with the client group on this approach, we have also reviewed whether there are wider potential possibilities for comparisons with the KPIs from the Energy Innovation Portfolio, including with monitoring data for Hy4Heat which is to be assembled within the project closure reporting. At this stage it appears that the potential for further comparisons will be limited:

- It will be feasible to compare KPIs within the Innovation Portfolio dataset relating to 'New business relationships or collaborations supported to deliver/undertake the programme', however;
- The remaining four KPIs within the Energy Innovation Portfolio dataset (Advancements after project completion, Follow-on funding, Steps towards commercialisation and UK and international sales) are concerned with longer term aspects which will not provide useful comparators for the current evaluation.

The dataset is due to be updated over the summer which will fit well with the timescale of the current evaluation. No similar sources of potential comparative data have been identified at this stage, although the team will continue to be alert to other possibilities as the study proceeds.

Other Indicators of Programme Success – leveraging follow-on investment

Whilst evidence so far suggests that the numbers of patents registered have been limited, decisions by participants to register the IP developed through the programme are a useful potential indicator that it is seen as having significant commercial value, especially given the costs involved in registration. Conversely though, a decision not to register patents is not decisive evidence to the contrary as much of the commercial benefit may take the form of organisational knowledge which is unpatentable, or firms may decide against patenting for other reasons.

Whether or not the IP developed by participants is registered, decisions by participants and/or by competitors outside the programme to undertake further self-funded R&D *as a result of the programme* can clearly be taken as an affirmation that it has demonstrated the commercial potential of the technology and likely reduced the timescales within which it could feasibly be adopted.

The economic evaluation will therefore also include an assessment of how the long-term investment landscape has changed over time which, in combination with the Contribution Analysis, will highlight the emerging economic impacts of the programme. The trends in investment in hydrogen have been presented in Chapter 4, and this analysis will be repeated at the end of the evaluation. This will allow us to observe how investment in hydrogen has changed over time in the UK, both private and public investment. This would draw on information from Pitchbook and Innovate UK. We will then draw on more general investment trends and information collected from stakeholder interviews to draw conclusions about how much of the changes in investment are due to the Hy4Heat programme.

[27] Data for TRL progression is also collected in the project closure reports

Again, there will be a slight difficulty with this approach in that we will not be able to access information about what private companies spend their own money on – their internal R&D investment decisions. It is unlikely that we will be able to access ONS BERD data for such a small number of companies, and not all companies may be included in the data. One solution to this will be to collect information about follow-up R&D spending in participating companies through interviews with company stakeholders.

A potential addition - place based employment impacts and the 'levelling up' agenda

One approach which might be added – though not directly a measure of VFM – would be to assess the actual and potential localised employment impacts of the programme in terms of:

- Employment associated with the follow-on R&D investment which is being generated
- Employment and other economic impacts of the trials which have been announced
- Potential securing of employment in production activities which may otherwise be lost as a result of the longer term phasing out of natural gas for space heating
- Associated supply chain impacts.

Again, this would involve some extensions in the scope and scale of the originally proposed programme of interviews. Bearing in mind the competition with other replacements for natural gas-based heating, there are clearly issues of likely displacement associated with future production related impacts, dependant on where the alternatives would be likely to be produced. Therefore, this option has been ruled out.

Qualitative Assessment of Value for Money

A more qualitative approach will also need to be undertaken to assess the wider VFM benefits of the programme. This will involve collecting information from company stakeholders about:

- Their participation in the programme and its short-term economic impacts on the company in terms of employment (and whether this will be sustained beyond the life of the project), training/upskilling of the workforce, investment, etc
- Whether the company was able to deliver its project related outputs as planned, including to the expected timescale and budget – noting any issues which were encountered, how these were dealt with and any associated impacts on the company
- Whether it involved new business collaborations and whether and in what ways these are likely to be sustained beyond the life of the programme
- Whether it has led to the formation of new business collaborations or led to the company accessing new business networks and what, if any wider benefits are flowing – or are expected to flow – from these
- Their levels of R&D expenditure prior to the programme, and what types of projects they were investing in
- Their current and future plans for R&D expenditure, including the types of project that they intend to invest in

- How their participation in the project has influenced/is likely to influence their other investment decisions
- The projected returns from any R&D projects involving hydrogen
- The technology that has been developed from R&D projects relating to hydrogen, whether and when this can be utilised (even if it can be used in other, non-hydrogen technology areas)
- Other benefits to the company – for example, in terms of organisational knowledge and skills development, including in relation to the management of R&D projects
- Any spillover effects (knowledge sharing with other companies, other uses of technology etc.)
- Any wider lessons learned.

This would allow evidence to be collected about the likely contribution of the programme towards economic outcomes. This would not provide sufficient evidence to undertake a robust economic evaluation to Green Book standards and would not include an assessment of the counterfactual case. However, it would provide useful evidence of the value of the programme to those participating in it.

Recommended approach

There are strengths and weaknesses in using each of the approaches mentioned above. The main issues are around:

- A lack of data availability for company valuations. This would mean that any findings from the CBA are not a true reflection of all companies which have taken part in the programme. Therefore, it is recommended that we do not pursue a CBA approach.
- A lack of information about the likely future investment decisions of private firms means that a clear analysis of investment in R&D projects relating to hydrogen cannot be undertaken.
- The responses during qualitative interviews about investment decisions may be unreliable, unverifiable and subject to bias. Additionally, no counterfactual information could be collected from companies not taking part in the programme. This would affect the robustness of the findings from this approach.

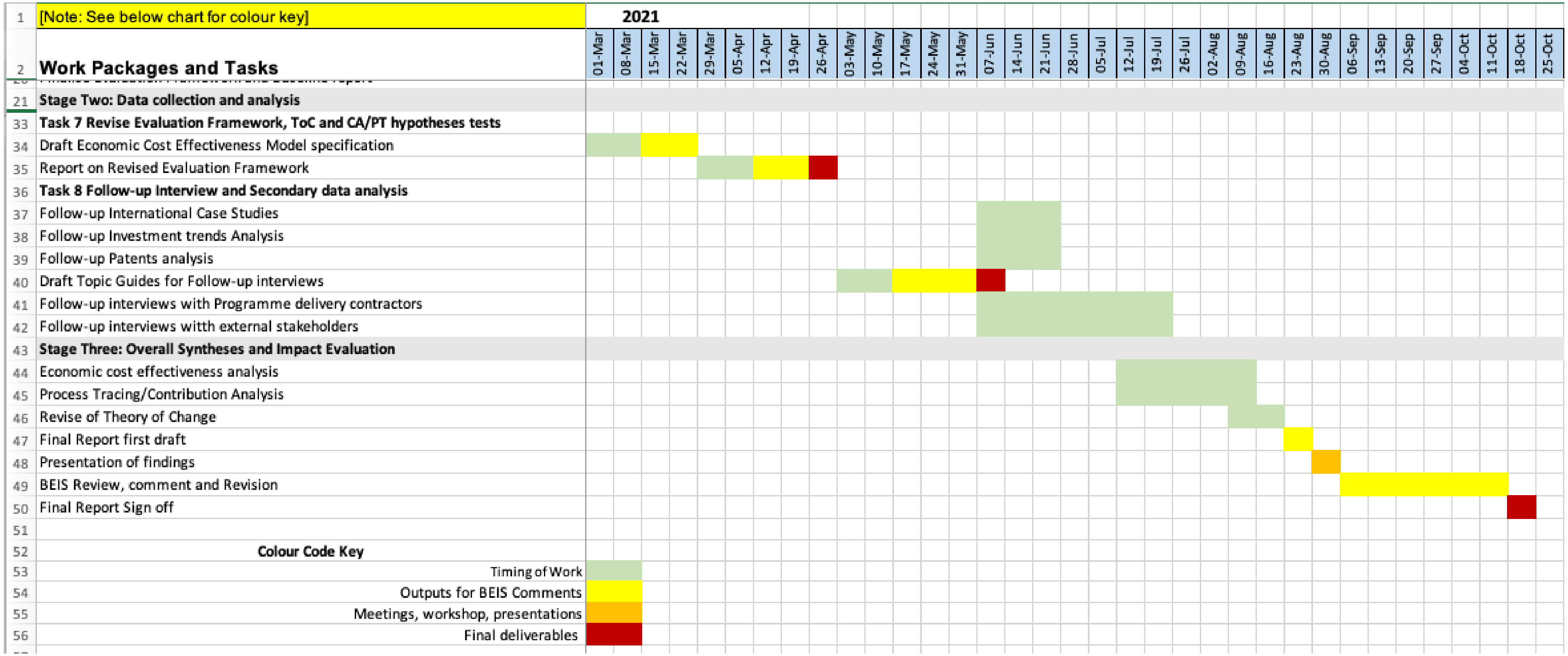
Therefore, we recommend qualitative assessment of value for money, following the principles of the NAOs 3Es approach. This will incorporate elements of quantitative cost-effectiveness in terms of comparing the relative cost of key outputs achieved (£ per level of TRL progression) in comparison to other DESNZ Energy Innovation Programmes. Triangulating the findings will allow the evaluation team to draw firm conclusions about the value for money of the Hy4Heat programme. A summary of each approach and the data sources to be used are presented in the summary table below.

Table 7. Summary of Approaches

Approach	Data required	Data sources	Strengths	Weaknesses

Cost-effectiveness analysis	Extent of -and costs of achieving - comparable levels of TRL progression under potentially analogous programmes	Updated data on DESNZ Energy Innovation Portfolio in particular, but also including project closure report information	Focuses on outcomes which are realistically observable at this stage	A range of differentiating factors such a technical complexity will limit the strength of the conclusions which can be drawn from observed differences
Long term trends in investment in hydrogen	Private investment in hydrogen	Pitchbook BERD Collect through qualitative interviews with company stakeholders	Would support an assessment as to whether the programme has had an impact on wider investment in hydrogen	Incomplete data available Data collected through qualitative interviews may not be robust Would not assess all benefits of the programme
	Public investment in hydrogen	Gateway to Research / Innovate UK		
Qualitative assessment of value for money	Qualitative assessment of outcomes achieved and the contribution of the programme towards these outcomes	Collect through qualitative interviews with company stakeholders	Would collect information about the value of the programme from all participants	Data collected through qualitative interviews may not be robust Data collected may not be quantifiable or monetizable. Companies may be reluctant to share some information with the research team.

Timescales



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[28] BEIS changed its name to DESNZ in February 2023

Glossary of Investment Terms

Term	**Definition**
Accelerators / incubators	Accelerators / incubators are defined as where a company joins a temporary program that provides funding, office space, technological development and/or mentorship. This is often in exchange for equity in the company.
Angel investment	Angel investment is when investment is made by an individual in a company from their personal funds and not using funds raised from other people.
Seed investment	Seed investment is defined as any investor type provides the initial financing for a new enterprise that is in the earliest stages of developing.
Early Stage VC	Early stage venture capital is an investment from a venture capitalist group during the early stages of the company's development, often in return for a percentage of ownership of the business. This is usually Series A to Series B financing.
Later stage VC	A later stage round of financing by a venture capital firm into a company. Later stage is usually Series B to Series Z+ rounds.
Merger/Acquisition	When an operating company acquires a control position in another company or will retain control of the combined business post-transaction. This may be achieved through cash or stock.
Corporate	When an operating company acquires a non-control stake in another company.
Initial Public Offering (IPO)	Initial Public Offering (IPO) is defined as investments open for the general public or retail investors after the company has complied with the registration requirements of new securities.
Second Offering	The issuance of new stock for public sale from a company that has already made its IPO.
Bankruptcy	A bankruptcy proceeding in which a company stops all operations and goes completely out of business. A trustee is appointed to liquidate (sell) the company's assets and the money is used to pay off debt.
Private Investment in Public Equity (PIPE)	When a private investor (such as a private equity firm) makes a non-control equity investment in a publicly-traded enterprise through the acquisition of securities issued directly by the company
Buyout/Leveraged Buyout (LBO)	Defined as the purchase of at least a controlling percentage of a company's capital stock.
PE Growth / Expansion	When a private equity firm makes a non-control, equity investment in a company. Cash is received by the company and not the selling shareholders

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