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Review article

A critique on the UK's net zero strategy

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A R T I C L E I N F O

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A B S T R A C T

Before the Covid-19 pandemic UK passed net-zero emission law legislation to become the first major economy in the world to end its contribution to global warming by 2050. Following the UK's legislation to reach net-zero emissions, a long-term strategy for transition to a net-zero target was published in 2021. The strategy is a technology-led and with a top-down approach. The intention is to reach the target over the next three decades. The document targets seven sectors to reduce emissions and include a wide range of policies and innovations for decarbonization. This paper aims to accomplish a much needed review of the strategy in heat and buildings part and cover the key related areas in future buildings standard, heat pumps and use of hydrogen as elaborated in the strategy. For that purpose, this research reviews key themes in the policy, challenges, recent advancement and future possibilities. It provides an insight on the overall development toward sustainability and decarbonization of built environment in the UK by 2050. A foresight model, Future Wheels is also used to visualize the findings from the review and provide a clear picture of the potential impact of the policy.

Introduction

UK net zero strategy

The significant role of buildings in carbon emissions is widely recognized worldwide. Studies report between 20 % and 40 % of total carbon emissions from buildings in developed countries with an annual increase between 1.8 and 2 %. In the UK the growth has been at a rate of 0.5 %, in most European countries and North America the rate is at 1.9 % [1]. With the rapid development of green building certification and incentives from the government, more attention has been placed on novel technologies to meet and exceed the carbon emissions target. The most recent report from IPCC suggests 'limiting human-induced global warming to a specific level requires limiting cumulative CO2 emissions, reaching at least net zero CO2 emissions, along with strong reductions in other greenhouse gas emissions' [2]. In line with the IPCC report, UK government published its net zero strategy in 2021.

UK's net zero strategy follows the UK's Nationally Determined Contribution (NDC) agreed in Paris in 2015. In its NDC, the UK committed "to reduce economy-wide greenhouse gas emissions by at least 68 % by 2030, compared to 1990 levels" [3]. The UK's net zero strategy also demonstrates the country's vision for green economy in 2050 [4]. Fig. 1, demonstrates the current emissions rates in different sectors in the UK and how the government plan to cut the emissions from each sector until 2035 and beyond. Fig. 1 also confirms the significant role/potential to reduce emissions from this sector compared to others such aviation, waste and agriculture. In 2019, the share of emissions in heat and buildings was 17 % and the expected reduction by 2035 from 1990 is 47–62 %. According to the report, this makes up almost a third of all UK carbon emissions. The strategy sets achieving the target through the energy efficiency of buildings and by investments in building fabric as well as efficient, low-cost heating appliances with heat pumps and hydrogen boilers.

The National Grid Electricity System Operator (ESO)'s *Future Energy Scenarios* considers net zero carbon by 2050 is achievable for the UK subject to rapid technological development in carbon capture and hydrogen storage as well as further incentives in markets and reducing complexity by digitization [5]. Centre for Alternative Technology (CAT), an educational charity, also emphasized achieving net zero by 2050 is feasible by powering down energy demand by 60 % and powering up the renewable to replace existing share of fossil fuels. However, they consider UK and poorly insulated building stock as major issue to achieve the target [6]. The committee on Climate Change' recommendations also sees net zero achievable by 2042 in a highly optimistic scenario. They see possibility of achieving net zero depends on the following [7]:

1. Certain development in key technologies and behaviors.
2. Significant contribution by government in carbon—intensive activities and taking up low carbon solutions (moving away from meat

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and dairy products, reductions in waste and travel demand with further reduction by improving insulation of buildings and transport efficiency).
3. Expansion of low carbon energy supplies (low carbon electricity from renewables and low carbon hydrogen).
4. Planting (growing UK woodland from 13 % to 15 % by 2035).

Several other committees, organizations and research institutes also published reports about UK decarbonization plan such as Energy Systems Catapult, Grantham Research Institute on Climate Change and the Built Environment, Royal Academy of Engineering, etc. However very limited literature exist to analyze the pathways and predications. Dixon, et al. in 2022 conducted a comparative analysis between the seven of them and reported similarities among the reports. Heavy electrification will reduce final demand, storage and flexibility is a necessity, gaseous fuel like hydrogen are required but their production must be low carbon [8]. Four years before the publication of UK' net zero strategy, [9] look at the UK energy systems model for delivering policy insights under deep uncertainty. Their study highlighted that with an 80 % reduction until 2050 in GHG Emissions, investments in the UK energy stay in the range of £1-6bn/year as opposed to £1-2bn/year with no action strategy. More studies in from 2018 until 2021 about UK decarbonization policy also predicted feasibility of zero carbon electricity if low carbon technologies are deployed on a large scale [10,11,12,13]. The key technologies target energy efficiency (insulations and efficient heating) and fuel switching to renewables and hydrogen.

UK share from renewables in 2020 was about 43.1 %. Fig. 2 compares UK position in terms of share of renewable to the EU countries, US, Japan and China in the world's top 5 biggest economies. This graph shows while the UK has a relatively strong position, it still can, similar to, Iceland and Norway significantly power up and cover the most energy needs in the country. The UK aim to have sustained increase in land based renewables beyond 2020. The Smart Export Guarantee (SEG) is the scheme where the strategy hope to maximize investment in solar energy. [14] conducted a techno-economic assessment for grid-connected photovoltaic (PV) system and found the annual saving for a household using with SEG with fixed and variable export tariffs are £84.16 and £146.43 respectively. Their study used a semi-detached house as a case study in Nottingham with total floor area of 117.18 m^2 and collected data from 05/2017 to 04/2018. No further study is found to look at potential saving for customers under the SEG scheme in the UK as the scheme commenced less than 2 years ago in January 2020 [15].

The beginning of the strategy provides further enlightening overview into policies and ambitions with key areas of focus without entering into the comprehensive details. The strategy then explains the importance of green technologies, 'low-regret' strategies for buildings and highlights the importance of refurbishment and upgrading Energy Performance Certificates (EPC). The fact that UK has about 27.7 m dwellings and 1.7 non-domestic buildings [22] and has the oldest stock in Europe (37.8 % pre 1946, 39.7 % from 1946 to 1980, 15.6 % from 1980 to 2000 and 6.9 % from 2000) makes the refurbishment more of priority [23].

The strategy also took into the consideration the importance of tackling fuel poverty and improving health of the occupants by highlighting the importance of building energy performance and good ventilation without entering into technical details and reference to existing standard or how the existing standards could be improved. Perhaps the spread of Covid-19 proves the lack of knowledge in devising right ventilation strategy in buildings.

The strategy priorities no or low-regret policies and highlight insulations, draught-proofing and capability of products as examples of such policies. The strategy moves on illustrating three scenarios for the UK future heating technologies. Table 1 shows the scenarios and the key outcomes. In all of them, improvement in energy efficiency and low-cost operation remain imperative.

As climate change is a growing issue and more prominent each day, governments are increasingly under pressure to lower carbon emissions. The Climate Change Act 2008 meant the UK Government committed to an 80 % reduction in carbon emissions of the levels in 1990. This was updated in 2019 to net zero by 2050 which is a target of "at least 100 %" compared to the previous Climate Change Act 2008 [24]. In line with this, the strategy also envisage new regulations from 2025 in England claiming 31 % reduction in carbon emissions compared to existing standard and highlight net zero homes possibility before 2050 through cost-effective, practical and affordable measures.

The strategy further targets EPCs and set long-term regulatory standards to upgrade privately rented homes to EPC C by 2028 and EPC B by 2030. Over 15 million EPC have been lodged in the UK [25] and so

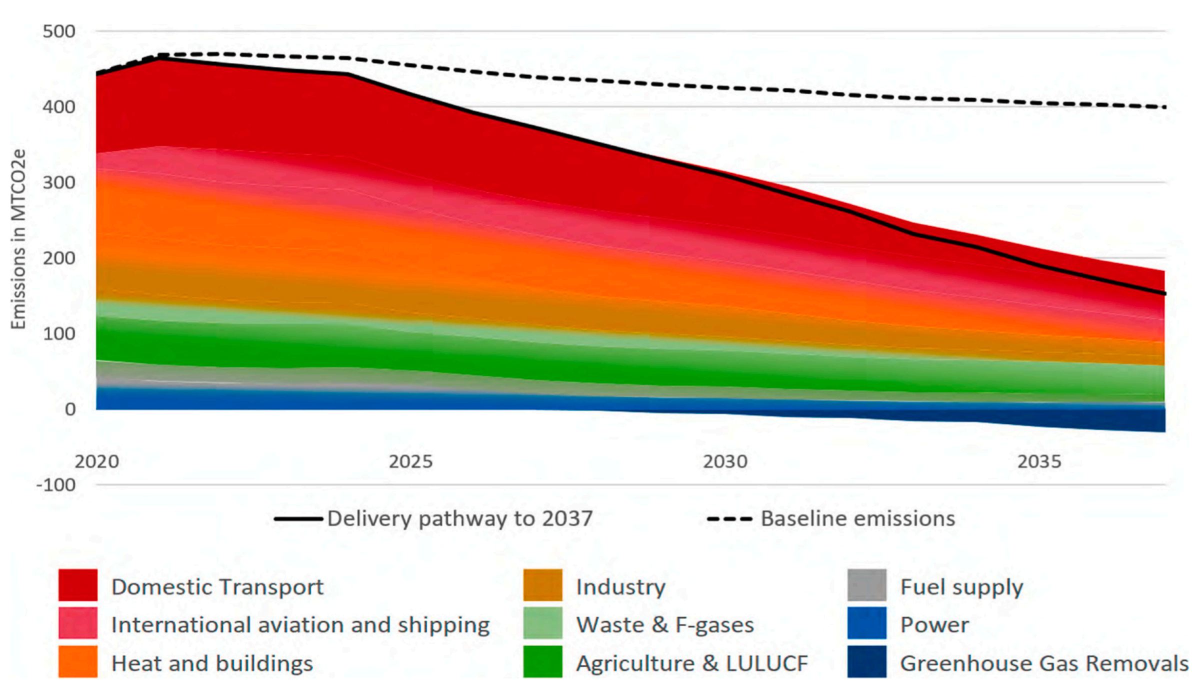

Fig. 1. Current emissions rates in different sectors in the UK and pathway to 2037.

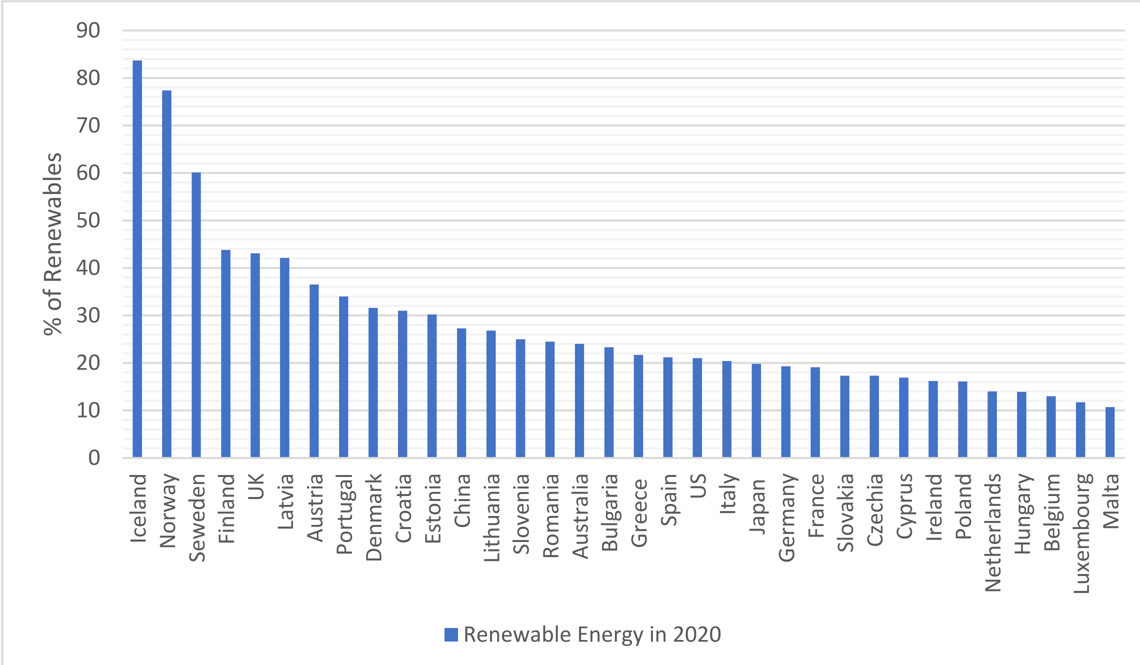

Fig. 2. Share of Renewable Energy in 2020. Data from: [16,17,18,19,20,21].

Table 1
Three scenarios in heating systems for 2025.

Scenario 1 High Electrification	• No significant growth of hydrogen • Heat pump is the main source of heating system
Scenario 2 High Hydrogen	• Hydrogen replaces gas in the UK network
Scenario 3 Dual Energy System	• Hydrogen and heat pumps are replacing gas and equally taking shares in the UK

EPC is a significant metric for the UK policy making. However, [26,27,28] questioned the accuracy of EPCs and reports from the Department of Energy and Climate Change [29,30] criticized the consistency in the result. EPCs are widely used and are required by law for any building. To generate an EPC, the following information is required:

- Floor plans, sections & elevations for existing dwelling & extension
- Orientation
- Construction specification of walls, roofs and floors for existing dwelling & extension (this include U-Values)
- Specification for all windows
- Primary & secondary heating systems
- Renewable technology (if applicable)

Heating system and envelope are key to achieve high rating in EPCs. In order to achieve higher rate, building fabric (improving insulation levels and windows) could be the lowest cost strategy for existing and new development. As observed, the strategy covers a wide range of fields and is dependent on technological and structural change in how energy is consumed and produced.

This study is the first attempt to evaluate the UK's net zero strategy based on evidence with a specific focus on heat and buildings. The objectives are to highlight the key areas of strengths and weaknesses based on the most recent literature and visualize the consequences of the UK's decarbonization policy by using an established method in modelling future possibilities/uncertainties. The author focused on review studies that quantitatively and qualitatively assess the heating technologies and building performance. The major contribution of this research is that it reveals the hidden complexities of moving toward decarbonization and the use of enabler technologies. It includes empirical studies that uncovers potentials in the policy and highlights areas for development in the country. The uncertainties in using the technologies, concerns and inconsistency in government policies, possible change of consumer practices and renewable energy trends are also documented in this research.

Methods

The author used a systematic review and used key terms in the UK's policy to find most recent advancement in three key areas of insulations, heat pumps and hydrogen from 2018. The strategy is technology-led and so the systematic review exclude studies older than five years. The author restricted the analysis to studies in the UK context or with significant connection/similarities to the UK in terms of energy policies and climate. The Future Wheels (FW) method are used to visualize the outcome of the systematic review. FW is a method, established by Glen 1972 [31], that uses trends and consequences of certain events to create a model/s. It is a qualitative method and rely on the existing knowledge about certain subject. The model create chains of consequences and starts with identification of change (for this study, this is derived from the UK's decarbonization policy) and then direct impacts of the change (first order consequence) and the indirect impacts (second, third, fourth, etc. order consequences). Any outcome is traceable and so weak/strong signals can be modified. This method helps to simplify, visualize and organize findings from a systematic review. Fig. 3 shows the FW framework.

To develop the FW models, A Preferred Reporting Items for Systematic Reviews and meta-Analyses (PRISMA) is used for reviews and documenting evidences. The content of the FW is created and validated by the systematic literature review [32]. Fig. 4 shows the overall methodology adapted from PRISMA [33] for this research:

Insulations

Currently, the UK government has Energy Company Obligation

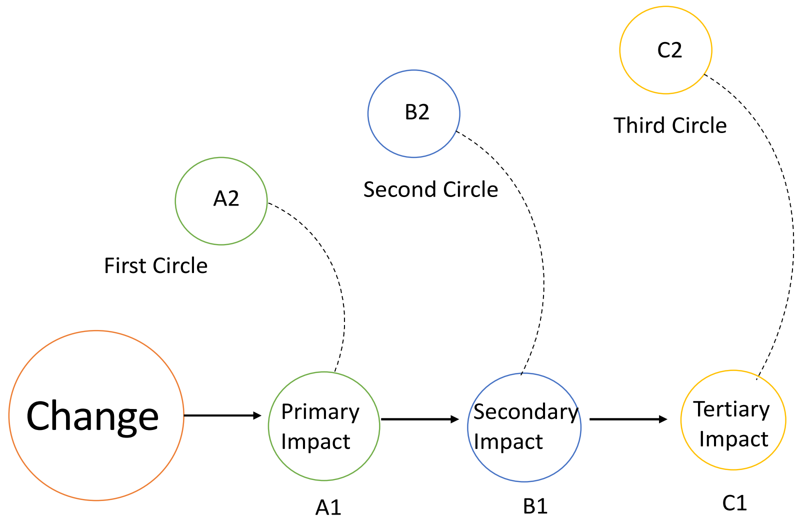

Fig. 3. Future Wheels Framework.

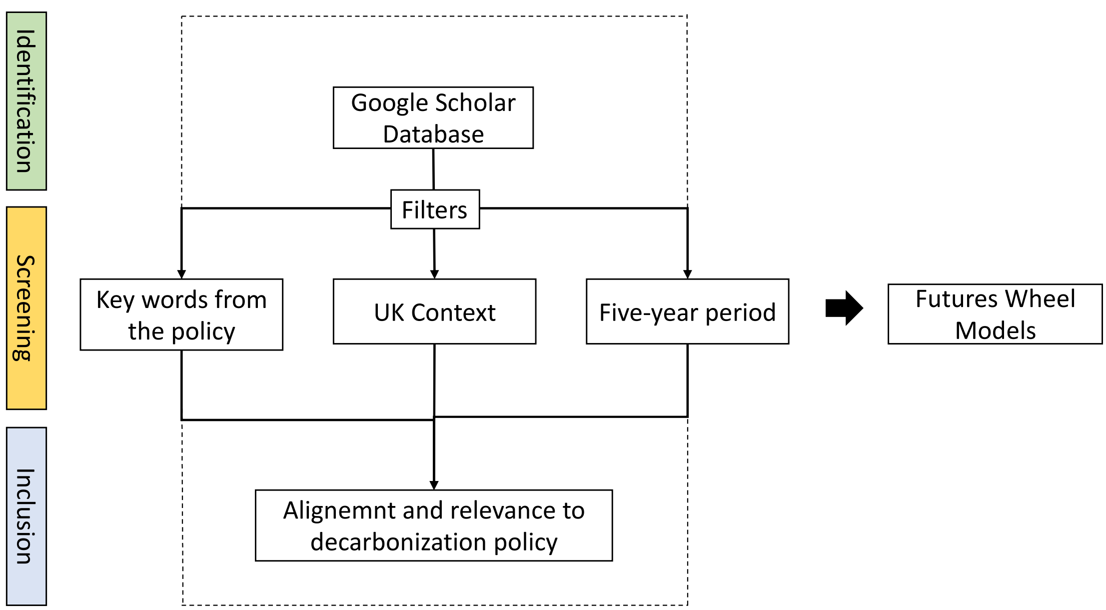

Fig. 4. Overall Methodology.

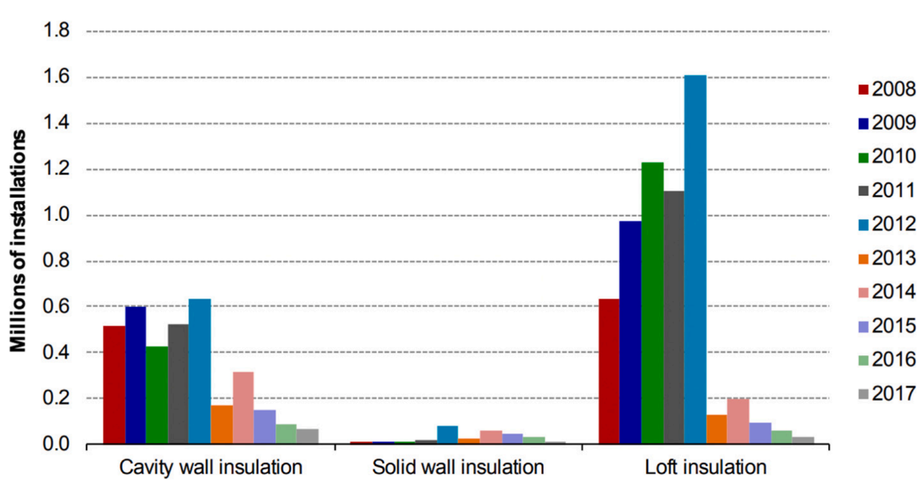

Fig. 5. Number of insulation installation in the UK from 2008. Source: [36].

(ECO) scheme for energy efficiency. The UK ended the Green Deal in 2015 [34]. Reports suggest that before 2020, around 963,900 homes had at least one improvement measure installed under ECO or the green deal [35]. Fig. 5 demonstrates the number of insulation installation in the UK from 2008.

Fig. 6 shows ECO Measures per 1,000 household in the UK by type and Local Authority, up to end December 2019. Cavity Wall Insulation (CWI), Solid Wall Insulation (SWI), loft insulation and other types played a key role in the scheme with inhomogeneous concentration across the UK. Other energy efficiency schemes such as Warm Home Discount Scheme (WHD), Feed-in Tariff (FiT), the Domestic Renewable Heat Incentive (RHI), the Winter Fuel Payment (WFP), Carbon Emissions Reduction Target (CERT), Community Energy Saving Programme (CESP), Carbon Emissions Reduction Obligation (CERO), Carbon Saving Communities Obligation (CSCO), Domestic Renewable Heat Incentive, Winter Fuel Payment, Fuel Poverty Network Extension scheme, Housing Health and Safety Rating System, Heat Network Investment Project and Affordable Warmth Obligation (AWO) were also launched since 2013. All of them aimed to reduce carbon emissions, tackle fuel poverty and making energy cost affordable. [37] modeled and evaluated these policies and found although these policies worked to tackle fuel poverty but simultaneously caused more energy consumption and carbon emissions.

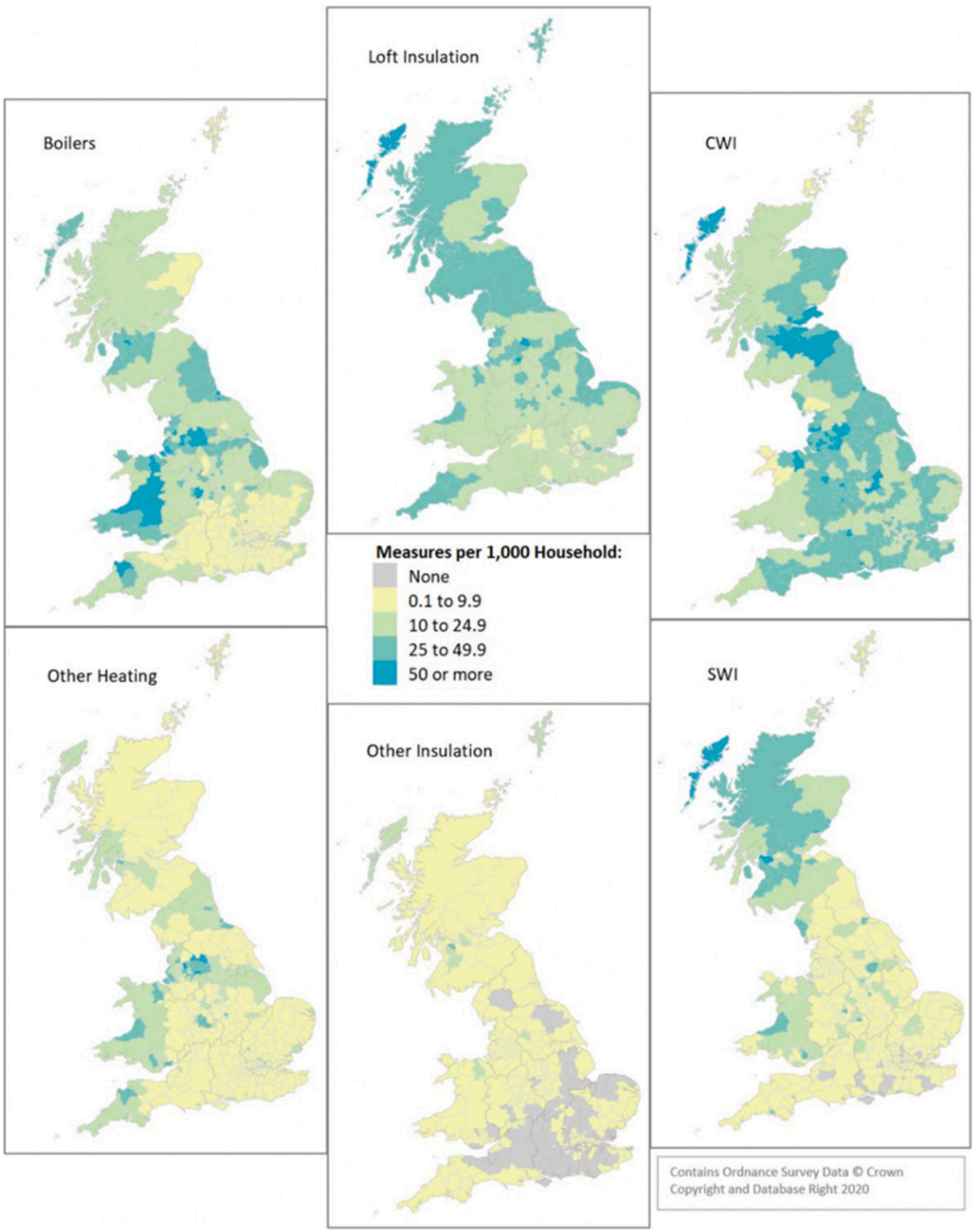

Fig. 6. ECO Measures per 1,000 household in the UK by type and Local Authority, Source: [44].

Majority of these policies failed to make an impact on decarbonization and the UK government closed them few years after commencing them.

[38,39] argued business model innovation are more successful and effective in transition toward zero carbon. Business models like Energiesprong from Netherland and Passivhaus from Germany deemed more effective, especially in deep retrofitting, in cutting carbon emissions than governmental schemes in the UK. [40] reported effectiveness of carbon reduction in such retrofit up to 80 % on average with Energiesprong. [41] reported carbon emission saving of up to 8.5 times lower for a refurbished university building in England retrofitted to Passivhaus standard. More studies since 2020 [42,43] also confirm significantly high effectiveness of such deep retrofitting in the UK.

The UK has always followed an incremental measures for carbon reduction. The general approach for decarbonization starts with simple and low cost measures such as insulations. To achieve higher standards, significant attention should be made on modern insulations although this is a short-term target but still fundamental to achieve zero-carbon. Thermal insulations delay heat flow and their efficiency depends on their conductivity rate and their robustness to maintain their thermal characteristic during their life span [45]. In recent years there has been significant development in improving the efficiency of insulations materials and the most efficient (lowest possible conductivity rate) are vacuum insulation panels (VIPs), gas-filled panels (GFPs) and aerogels.

Worldwide demand for lower U-values, stricter building regulations and lighter construction need modern insulations like Vacuum Insulated Panels (VIP) to building markets. [46,47,48,49,50,51,52] reviewed different types of VIP panels and reported the following as main areas of advantages and disadvantages:

- VIP panels have a greater environmental impact compared to the traditional insulation in terms of primary energy use, global warming potential, acidification and eutrophication potential but have lower negative impact in terms of ozone depletion potential
- VIP panels have significantly higher R-Value compared to the traditional ones and lower operational energy demand is feasible by using them in building envelope.
- The VIP performance depends on installation techniques and methods, only with robust detailing the optimum thermal performance can be achieved.
- The high inhomogeneous cost of VIP prevent developers using the insulation widely. Further complications are related to site transportation and the required delivery method.

The advantages of the VIP became more visible when five most commonly used UK construction systems including Brick and Block (BB), Timber Frame (TF), Structural Insulated Panel (SIP), Insulated Concrete Formwork (ICF) and Steel Frame (SF) are compared using traditional and super insulations to achieve 0.1 U-Value depicted in Fig. 7.

Another advancement in insulation is Gas-filled panels (GFPs), which are made up of a barrier envelope with infill gas between layers. The type of gas determine the conductivity rate for the panel. The only difference with VIP is that there is a gas instead of vacuum between two envelope layers [53]. The most common types are air-filled, argon-filled and krypton-filled panels. They are all odorless and non-toxic. However, because air contains moisture, Krypton and Argon are more durable options. According to [54] Krypton is a better insulator because it is denser but Argon costs less.

Aerogels are also a known material since 1930s [55] but relatively new to construction. The main advantages and disadvantages reported in [56,57,58] are as follows:

- Aerogel is an excellent barrier for sound, average attenuations of − 60 dB has been found for a total thickness of just 70 mm.
- Aerogels are non-combustible and recyclable
- The high and inhomogeneous cost of aerogel prevent developers using the insulation widely but the cost is decreasing

Thermal insulation improves energy efficiency but other factors such as fire resistance, cost and moisture resistance also play a key role in their market development. Most recent comprehensive reviews about insulations since 2020 are widely pessimistic about modern insulations due to their high cost and limited availability [59,60,61]. Fig. 8 shows the FM notation for the future of modern insulation development and likely consequences in the UK.

Heat pumps

Alongside building envelope solutions, in the strategy, heat pumps are seen as a key technology to decarbonise heating and no role is considered for bioenergy. 50 % of energy consumption worldwide is about heat [62]. According to [63] approximately 30 % of the total energy consumption in buildings is connected to HVAC systems even though this can be argued in different contexts and the figure can be questioned from various engineering viewpoints. The current trend in

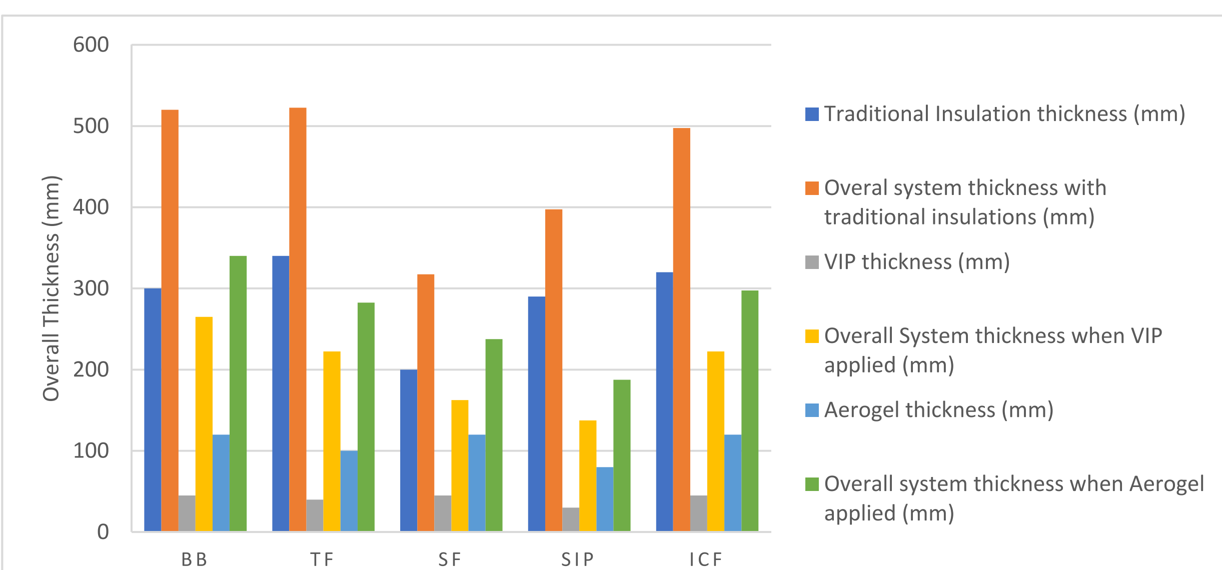

Fig. 7. Most common construction system in the UK when traditional (rockwool) and modern insulations applied to achieve 0.1 U-Value.

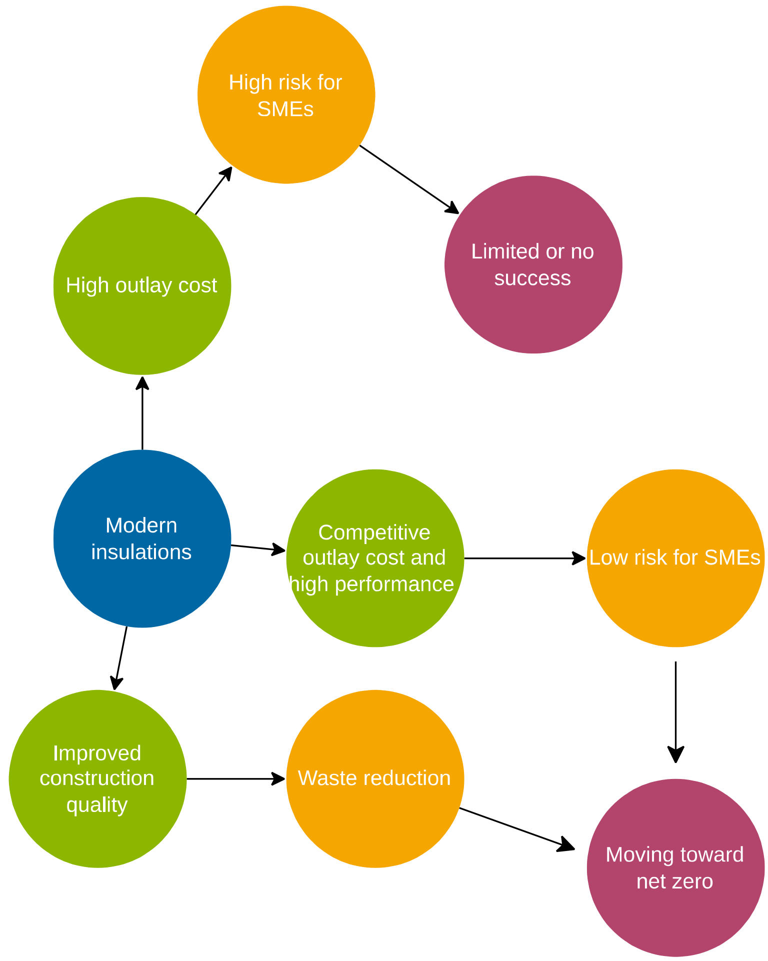

Fig. 8. FW notation for modern insulation development.

buildings energy management based on HVAC systems is on smart operations and heating efficiency. Heat pumps are now considered the most efficient heating systems as they use less electricity for the amount of heat they produce [64]. Therefore, the technology is an integral part of the UK decarbonization policy even though the renewable share in the UK's energy market rose from 24.5 per cent in 2016 to 43.1 per cent in 2020 [65].

The UK's net zero policy did not cover a crucial question/challenge in relation to the expansion of heat pumps. This was the high capital cost of the heat pumps that could be over 20 times higher than a gas boiler according to [66,67]. The challenge seems reasonably strong that despite all the benefits of heat pump their growth has been relatively and arguably slow [68]. Several additional challenges are also reported by [69,70] in the maturity of the technology in terms of availability of refrigerants with low GWP and missing technical knowledge across the sector. [71] studied the impact of heat pumps on fuel poverty and social inequality in the UK and expected the change between + £200 and - £30 per month for the UK households' energy bills. Their study also shows an increase in social inequality toward north due to the impact of climate on the performance of heat pumps. [72] estimates 19 million heat pumps are required in the UK to reach net zero by 2050. As of 2020, 265,000 heat pumps are installed in the UK [73]. This is deemed to be a slow growth compared to Nordic countries and [74] found that cultural habits has affected heat pump growth. The public attitude is in conflict with the strategy's plan. In one survey [75] more than half of the UK adults "would only replace their heating system when the current one breaks down or deteriorates". With the increasing Consumer Price Index (CPI) and public attitude toward new heating system, accelerating the growth of heat pump seems unlikely and challenging [76].

There are many different types of heat pumps. Fig. 9 shows a summary of different kinds. The ASHP, GSHP and WSHP work similarly but have a different structure, requirements and set up. Because ASHP extract energy from external air, they are suitable choice for high density housing even though their exposure to outside air can cause frost. GSHP offers more consistent performance [77] and WSHP normally have higher COP compared to ASHP [78]. Several systematic reviews are also conducted by [79,80] about HP control, optimization and use of artificial intelligence to improve their efficiency and demonstrate challenges in their future developments.

Among them GSHP are less common globally but AAHP have seen a rapid growth. The majority of existing heat pumps in the UK are Air Source (87 %) and only 9 % are ground and water source [81]. The Heat Pumps seasonal performance have grown thanks to investments, regulations and labelling policies worldwide [82]. [83,84] studied combined use of heat pumps with renewables and demonstrated promising efficiency in the UK climate.

All heat pumps are the most prevalent technologies for the electrification of heat. However, according to [85] a heat pump with a CoP of 3 (mostly observed from [86,87]) would require 4,000 kWh of electrical energy for a heat pump to supply which means a significant extra load on the power grid. This will create a load for the UK infrastructures which is currently not in a position to cope with higher demand [88]. National Infrastructure Commission [89] added more concerns as "2/3 of the existing power stations in the UK are expected to be closed down by 2030".

Furthermore, the UK has the highest tax component on electricity

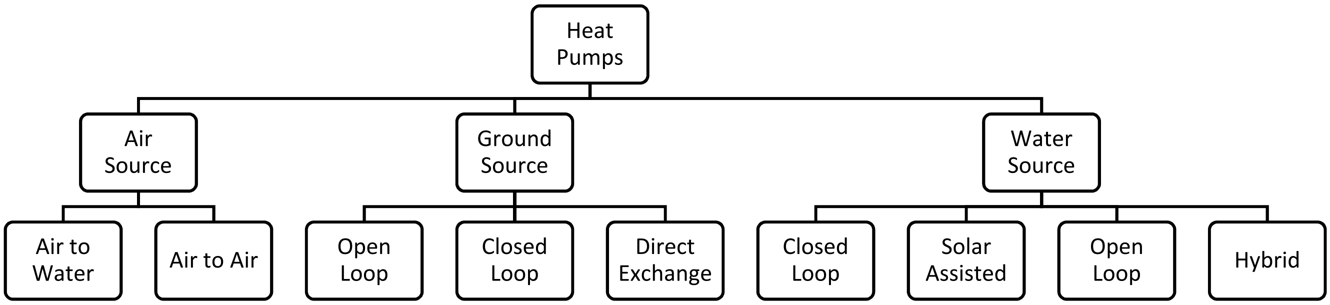

Fig. 9. Heat pump types.

and it can be argued that heat pumps can deliver the most technologically feasible solution to decarbonising the majority of heat in the UK. However, it is expected that hydrogen will capture a greater proportion of the market share due to significant market power of fossil fuels. Solar technologies offers a unique solution as a complimentary technology to providing a decarbonised supply of heat, as it does not require renewable electricity, as heat pumps and hydrogen both do. Fig. 10 shows FW notation for the future of heat pumps and likely consequences from their development in the UK.

Hydrogen

UK decarbonization policy put great emphasis on hydrogen. The Levelized Cost of Energy (LCOE) projections for wholesale hydrogen in 2030 across all projections exceed that of the projections for wholesale natural gas. The largest proportion of hydrogens cost are in its production [90]. [91] qualitatively assessed the cost of hydrogen production and found the most financially advantageous is from non-renewable sources. Therefore, in a scenario where a hydrogen transition of the grid is realised it is paramount to have strong enough carbon pricing to ensure it is cheaper and more profitable to produce hydrogen from renewable sources at the time of the transition. [92] argued that to heat buildings with hydrogen, a higher carbon cost is required. They highlighted with the UK plan for large-scale and long-term solutions in decarbonization of the gas grid, a significant role of hydrogen is possible.

Hydrogen will undoubtedly play an important role in achieving net zero as in 2021, the UK government launched its first-ever vision to start a world-leading hydrogen economy with a 4 billion pounds investment by 2030. This is also in line with the government's 10-point plan for the

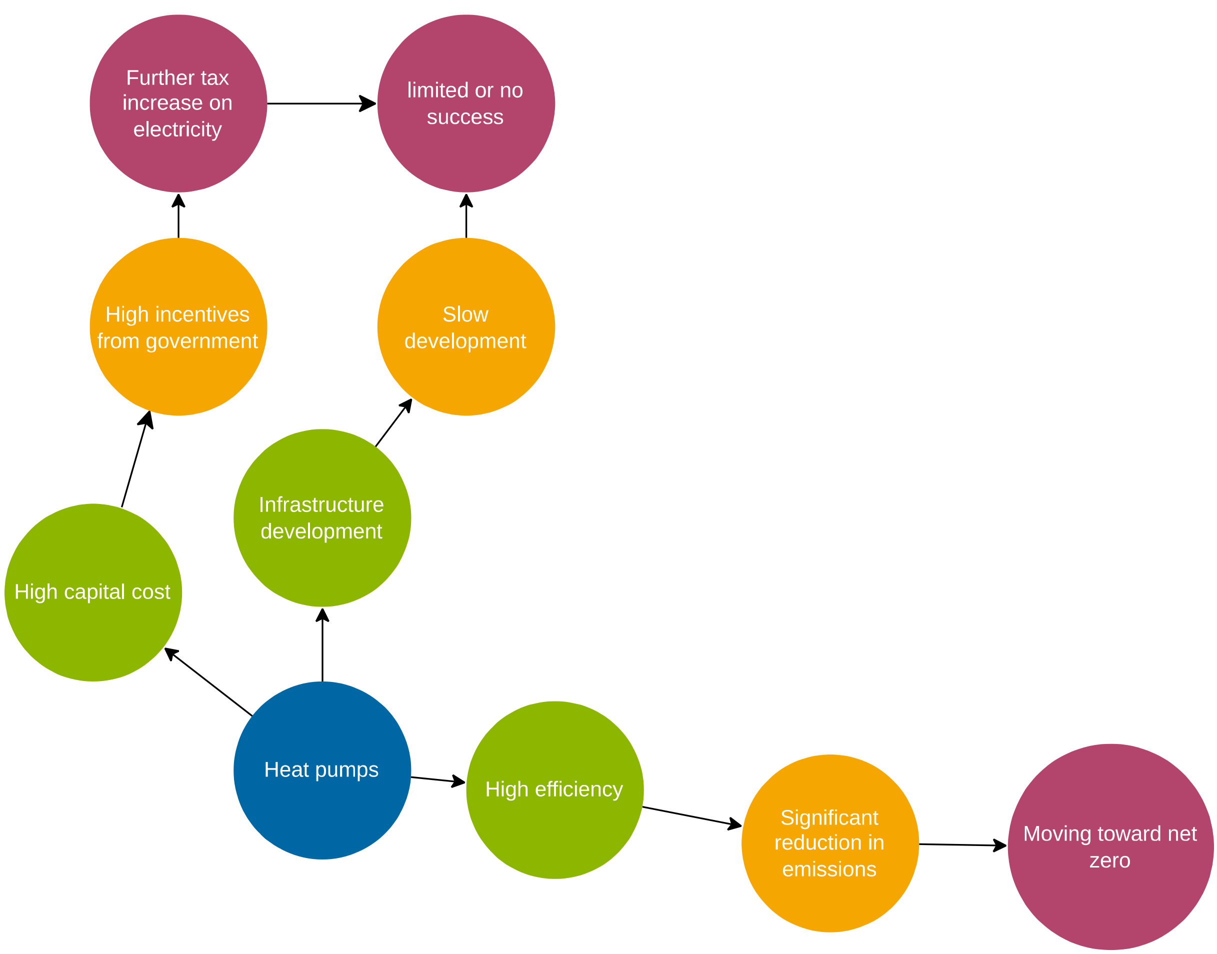

Fig. 10. FW Notation for Heat Pumps.

green industrial revolution. Government analysis further suggests 20–35 % of the UK's energy consumption by 2050 could be hydrogen-based leading to 100,000 new jobs [93].

Currently, water electrolysis powered by renewable electricity is the most common technique for the production of green hydrogen even though other production methods from biological origin also exist. Hydrogen panels are also another method to produce hydrogen which has the most potential to be used like PV panels on houses. Two promising building-integrated fuel cells of Proton-Exchange Membrane Fuel Cells (PEMFC) and Solid Oxide Fuel Cell (SOFC) have also demonstrated significant potentials and promising performance. However, limited literature and guidelines exist for such systems and approaches in using hydrogen particularly for residential buildings.

As of 2022, there is still no hydrogen boiler available in the UK, the technology is at the prototype stage and that the UK do not have enough hydrogen supply [94]. [72] predicted the UK needs 270TWh low and zero carbon hydrogen in a year to achieve net zero in 2050. The report also emphasised the UK need to use its gas infrastructure and develop Carbon Capture and Storage (CCS) Infrastructure. Energy Network Association (ENA) [95] announce the UK five gas companies are ready to deliver 20 % hydrogen to homes from 2023 but the decision is yet to be made by the UK government. This would be around 85 % of total UK homes that are connected to gas, about 4 million homes are outside the gas grid [96]. The UK decarbonization report did not elaborate on decarbonization of off-grid homes.

A study by [97] found significant advantage in blending gas with hydrogen and noted the injection of low carbon hydrogen to the UK's gas network cause significant reduction of operational costs of the UK gas and electricity networks. [98] compared several low carbon technology with and without hydrogen for heating residential buildings in Germany and found hydrogen heating technology from zero-carbon electricity are the more costly solution compared to hyrbid heat pumps with renewables and heat pumps. Their study added more uncertainty about future development of the hydrogen technology. The uncertainty about hydrogen development was also acknowledged by the UK Hydrogen Strategy in 2021 [99]. According to the report, "The UK still looking for further evidence on the costs, benefits, safety, feasibility, air quality impacts and consumer experience of using low carbon hydrogen for heating relative".

The latest report from UK Energy Research Partnership [100]

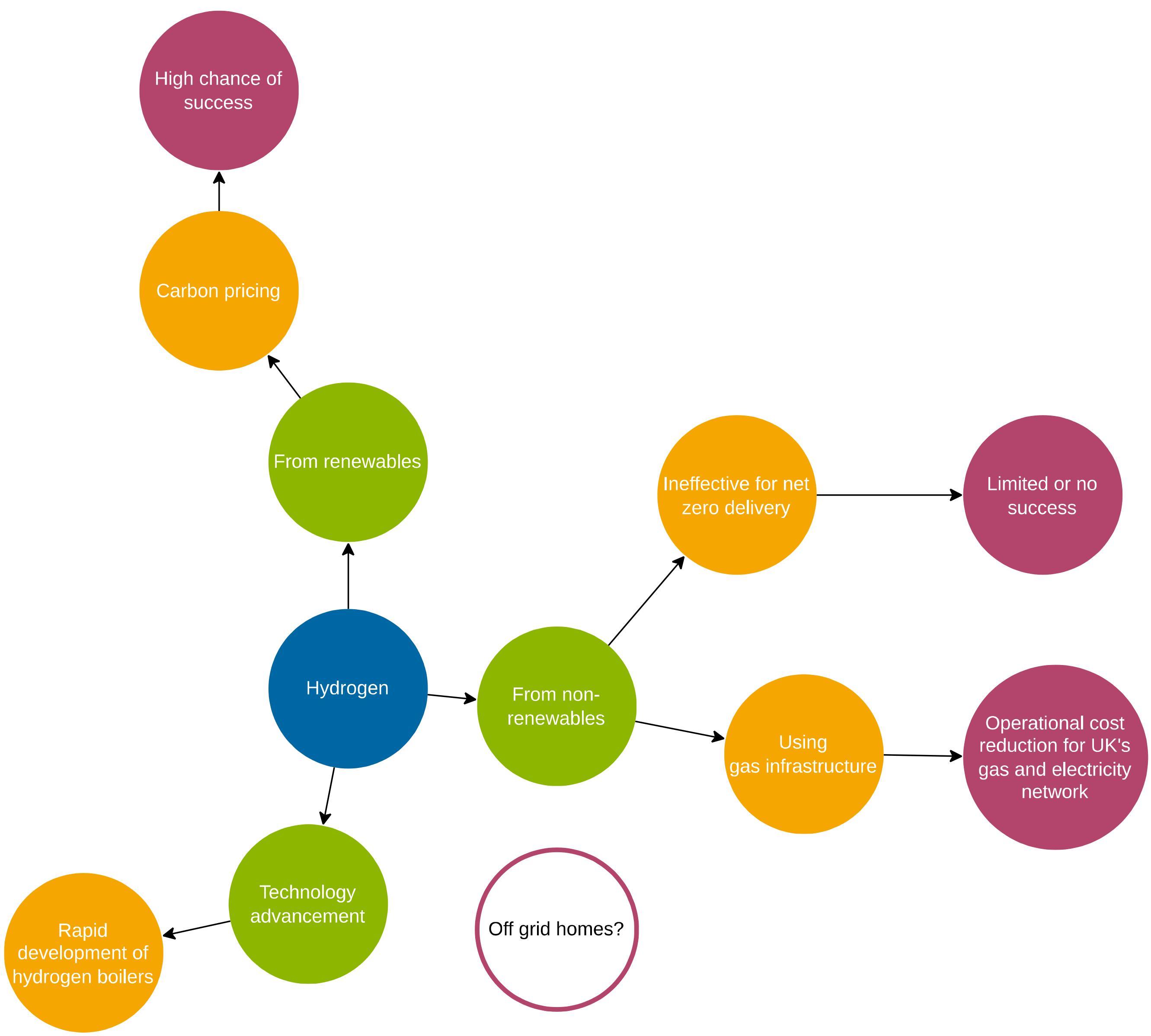

Fig. 11. FW Notation for Hydrogen.

claimed only 4 % of the global hydrogen is produced by electrolysis. The low carbon production from fossil fuels is possibly only with CCS technologies (known as blue hydrogen). [101] added lack of business models for hydrogen production and public acceptance could hinder further development in the UK. Fig. 11 shows FW notation for the future of hydrogen and the likely consequences of using this novel fuel in the UK.

Discussion and conclusion

The built environment sector is accountable for a high proportion of global energy usage, [102] summarizes the impact of UK housing on UK energy consumption stating that, 'In the UK, energy use in homes accounts for approximately 29 % of all energy consumption, and 20 % of UK greenhouse gas emissions.' Narrowing this down further, another report, written by [103] found that, out of this 29 %, approximately 80 % is linked to space and water heating.

There has been a long journey of technological advancement in building engineering to reduce pollution, control the use of resources and protect the environment and all those major green building technologies are key to deliver the net zero goal. Heating and cooling requirements have a direct link to the thermal performance of a building's envelope, the lower the buildings thermal conductivity, the higher the heating and cooling demand. According to a recent report by [84] 'Numerous research studies in the area of building energy confirm that to reduce energy consumption in buildings, it is necessary to enhance the performance of building envelopes.' Despite the success in improving EPCs and reducing carbon emissions, majority of energy efficiency initiative failed to make significant impact in carbon reduction and thus became unsustainable.

Taking cognizance of the above, it can be said that in order to reduce the UK's energy consumption and CO2 emissions, considerable investment must be made in material selection, leading to the utilization of materials with low thermal conductivity, within building envelopes. The use of renewable energy sources for heating and hot water should also remain a key focus within UK's existing and future buildings.

Developments towards heat pumps requires renewal of the UK's infrastructure by the government. The practicality and feasibility of implementing such a large scale operation is low, costly and time consuming. It is unlikely that large scale implementation will be successful when the exact value is uncertain and no substantial literature exist to even suggest the scale of uncertainty. The use of hydrogen and using existing gas infrastructure for blending is far more likely to be successful but the supply of green hydrogen is a significant challenge and lack of literature in CCS highlights the scale of the complexity ahead of the government.

This research paper covered the complexities in using new enabler technologies to achieve zero carbon in the UK. It included empirical studies to uncover potentials and areas for development. The uncertainties in using the technologies are still noted as significant. The concerns are not only related to technological advancement but also inconsistency in government policies, consumer practices and fossil fuel markets that have changed in favor of decarbonization framework recently. The following highlights the key findings from this paper:

- Even though the strategy predicted moving towards a circular economy and noted a positive impact of "sharing, reusing, repairing, redesigning and recycling products" for future but no detailed plan for construction and choice of materials in particular insulations were provided.
- UK infrastructures are not prepared to cope with upcoming shift in the use of heat pumps.
- High costs and limited provider of insulations will affect rapid development in achieving EPC C and there are doubts whether EPCs are accurate enough for 2050 strategy.
- Off-grid homes are widely ignored in the report, no comprehensive plan for their decarbonization is elaborated.
- There is lack of academic literature about CCS and the UK still needs more academic and industrial evidence to proceed with their decarbonization plan.
- Deep retrofitting is a necessity for the UK's existing homes in order to achieve 2050 targets, the government schemes like ECO needs to be further strengthened and successful standards like Passivhaus and Energiesprong need further development in the UK.

Future research should focus on potentials and caveats in development of energy storage and green hydrogen systems and capacity of existing UK infrastructure to cope with extra load of electricity from heat pumps development, as the strategy is highly dependent on them. Future studies should also cover risks, safety and cost uncertainties related to aforementioned technologies.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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