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Can the UK Deliver Zero Carbon Ready Homes by 2050?

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Abstract: Climate change presents one of the most significant challenges facing the world in the 21st century. In 2019, the UK became the first major economy to pass laws to end its contribution to the world's greenhouse gas emissions; parliament passed legislation requiring the UK government to achieve its carbon neutrality commitment by 2050. This will require all industries, including the housing sector, which currently contributes around 14% of the UK's greenhouse gas emissions, to reduce their carbon emission contribution. One of the ways in which the housing sector plans to accomplish this is through delivering new zero carbon ready homes by 2050, at the latest. This study makes an innovative contribution to advancing the field of carbon neutral construction through its identification of the barriers to the UK in regards to their ability to deliver zero carbon homes (ZCH) and the provision of potential recommendations to overcome these barriers. To achieve this, a mixed-review method is used, combining a qualitative systematic analysis and a quantitative bibliometric approach. Several key barriers were identified and assigned to following key themes: legislative, socio-cultural, economic, financial, skills and knowledge, technical, industrial, environmental, and procurement factors. Legislative obstacles were found to be a primary barrier due to a lack of certainty, clarity, and clear definitions, as well as the removal and excess of government policies. Significantly, the findings reveal the under-researched impact of recent disruptive events, such as the COVID-19 pandemic, Brexit, and economic factors in the UK, opening up novel avenues for exploring their implications. Overall, this study advances industry understanding and highlights innovative directions necessary to propel the sector towards realizing the UK's legally-binding 2050 net zero target through the development of zero carbon ready homes.

Keywords: zero carbon homes; barriers; legislation; COVID-19; Brexit; economic climate; construction industry

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1. Introduction

The construction industry is a vital and thriving section of the UK economy. It is also one of the highest carbon emitters and therefore, one of the most challenging industries to decarbonise [1]. There is now a strong focus, globally and within the UK, to reduce emissions and achieve net zero targets [2].

The built environment and construction sector account for 38% of global carbon emissions [3] and around 40% of the UK's total carbon footprint [4]. As a result, the built environment is crucial in allowing us to adapt to the changing and increasingly extreme climatic conditions [5].

One of the focus areas for the UK to transition to net zero emissions is the housing sector. This is because the energy usage in homes currently represents 14% of the UK's total carbon emissions, which is deemed to be one of the least energy efficient results within Europe [6]. The latest carbon budget from the Climate Change Committee (CCC) states that these emissions are mainly a result of direct emissions, i.e., burning fossil fuels for heating, and indirect emissions, i.e., caused by electricity used for lighting and appliances within the

home. For the UK's construction industry to play its part in avoiding catastrophic climate breakdown, it must reduce emissions within the housing sector, decarbonise the existing housing stock, and construct new zero carbon ready homes by 2050, at the latest.

Addressing the need to reduce emissions within homes while maintaining building safety, quality, service, and cost and continuing to build new homes at the scale required is an enormous challenge for the industry. One path to reducing emissions within the built environment is the construction of new homes that produce either zero carbon emissions or offset their carbon emissions. New build housing has the potential to lead the way in meeting the emission reduction target and using new energy efficiency standards. There are options for the UK's housing sector to reduce its emissions through adopting behavioural changes and applying energy-efficient measures. Building zero carbon ready homes requires fundamental changes in how homes are designed and constructed.

Furthermore, the UK government legislated and committed to reducing CO_2 emissions by 80% of the 1990 level and reaching net zero emissions by 2050 [7]. To achieve this target, the government has developed strategies and policies for the UK. However, these targets have been criticised and considered ambitious due to the current lack of detail regarding funding, timelines, capacity, and capability to deliver, and it is not yet clear how the decarbonisation of the housing sector will be achieved, creating significant uncertainty to homebuilders in regards to the costs, benefits, and risks of building new ZCH [8,9]. Thus, to provide a clear pathway and direction for achieving the building of ZCH, the barriers and challenges that determine the efficient development of zero carbon homes would need to be clearly understood.

While there is a plethora of published articles on net zero emissions and the built environment, there have been limited investigations concerning the housing sector, specifically in regards to the barriers to delivering new build ZCH. As the emergency of climate change is continuously evolving, the previous research is unable to consider any present and new challenges for the housing sector, including the COVID-19 pandemic; the UK's exit from the European Union; and economic factors in regards to rising fuel prices, current inflation, and the UK's cost of living crisis. Investigating the present and future barriers arising from the aforementioned variables would create the opportunity to systematically and collaboratively address issues hindering the development of ZCH. This would also aid in achieving the goal of attaining 20% of ZCH for new builds by 2050 and contribute to the decarbonisation of the entire UK sector to attain net zero energy emissions by 2050.

The aim of this study is to provide a detailed and enhanced understanding of the primary challenges and barriers of the housing sector when building zero carbon ready homes in the United Kingdom. The pursued objectives include to:

- Investigate and identify the existing challenges and barriers to delivering 20% of ZCH within the UK through reviewing and analysing the extant literature through a bibliometric analysis and a systematic literature review.
- Provide viable solutions based on the identified challenges and contribute to improving strategies that increase the chances of attaining zero carbon build homes and a net zero economy in the UK by 2050.
- Discuss and examine net ZCH and highlight the relevant legislation, policies, or regulations surrounding them.

1.1. Relationship between Climate Change and the Housing Sector

The UK is already experiencing more frequent and intense weather extremes due to climate change, and the built environment is not prepared to cope with these conditions [10]. The built environment accounts for 42% of the UK's greenhouse gas emissions [5] which have begun to reduce over the past decades, mainly as a result of the decarbonisation of the electricity grid [5].

One of the main focuses for the UK's built environment is to reduce greenhouse gas (GHG) emissions by substantially improving the energy efficiency in both new and existing UK homes in the coming decades. There are currently around 28.5 million homes within the UK, contributing around 14% of the UK's total GHG emissions [11], and the government currently plans to continue building around 300,000 new homes in England per year [12]. The quality of existing and new homes is essential for safeguarding people's health and well-being and addressing climate change [11].

Reducing the emissions produced by the current housing stock is a fundamental element of the UK's net zero pathway [13]. Although progress has been made in reducing the indirect GHG emissions from homes (e.g., appliances, lighting, etc.), as the power sector has decarbonised, direct GHG emissions from heating have not changed significantly since 2015 [14].

It would be challenging to deliver net zero targets without a complete decarbonisation of the housing stock. In fact, these emissions must be reduced by at least 24% by 2030 to remain on track [11] for achieving the 2050 goal. Decarbonising homes through improved energy efficiency measures and low carbon heating will provide various benefits to individuals, including, reducing energy bills, adding value to homes, boosting the economy, and ensuring that homes are warmer in winter and cooler in summer [14].

The UK's housing stock is one of the oldest in Europe and was built to very different standards and with different materials from those that would be used today [15]. The CCC states that the UK's current housing stock is not well adapted for the current or future climate; around 20% of homes currently overheat, even in cool summers; 1.8 million people live in areas that are at significant risk of flooding; and many people reside in areas with the potential for water scarcity [11]. To tackle climate change within homes, the demand for heating must be reduced, and there must be a transition to the use of renewables and low carbon heat networks [15]. To meet the current demand for housing, around 340,000 new homes must be built per year [16,17], and these must deliver the energy performance required for net zero emissions to avoid the need for future retrofitting and remove the risk of future occupant disruption, cost, and embodied carbon emissions [13]. To achieve this, immediate government action is required. The government must work with the industry to ensure that new homes planned across the UK are fit for purpose, integrating the highest possible emissions reduction levels using a package of design improvements to adapt to the changing climate [11]. Additionally, the CCC stated that cost-effective adaptation measures are not being taken up at anywhere near the levels that they can or should be; if the government and the built environment imminently consider and implement carbon reduction, then there is a strong chance of reducing the built environments emissions and meeting net zero targets.

1.2. Net Zero Carbon Campaign in the UK—Legislation, Policies, and Regulations

One of the ways in which the UK intends to tackle climate change is by becoming a net zero emitter by 2050. Net zero means that the UK's total GHG emissions would be equal to or less than the emissions the UK removes from the environment [18].

There are two routes to achieving net zero emissions, which can be used in conjunction with one another, i.e., reducing existing emissions and actively removing greenhouse gases. As it is not realistic to reduce all emissions to completely zero, this means that any emissions must be fully offset, ideally through natural carbon sinks; when the amount of carbon emissions produced is cancelled out by the amount removed, then the UK will be a net zero emitter [19]. Innovation and low-carbon investment will be critical enablers for achieving net zero emissions [20]. Driving fundamental change across all sectors of the economy requires immediate action from business and the government; a business must commit to decarbonisation, and government must support this transition through strategies and detailed policy frameworks [21].

In 2015, almost every country pledged to reach net zero emissions later this century, as part of the Paris Agreement on climate change [22]. Then in 2019, the UK became the first major economy to pass laws to end its contribution to the world's greenhouse gas

emissions; parliament passed legislation requiring the UK government to reduce emissions of greenhouse gases by 100% relative to 1990 levels by 2050; by so doing, the UK would become a net zero emitter [19].

In conjunction with international obligations under the Paris Agreement, the government's 2017 Clean Growth Strategy confirmed that the UK was committed to working with other countries to achieve global net zero emissions in the second half of this century, and that there would be a requirement to legislatively ensure legal certainty of this result [22]. While many governmental statements support tackling climate change, the evidence thus far suggests that this is not happening at the required rate [23].

The UK's response to climate change is based on the Climate Change Act, which is one of the earliest comprehensive framework laws regarding global climate change [24]. This became an Act of Parliament in 2008, setting out legally binding targets to reduce carbon dioxide emissions in the UK by at least 80% of 1990 levels by 2050 [7]; this was then amended in 2019, with the target of reducing emissions by 100% by 2050.

The key components of the Climate Change Act are outlined as follows [7]:

- An independent advisory body—the Climate Change Committee—was set up to advise the government and set long-term objectives for the Act.
- Statutory five-year carbon budgets require the government to publish five-yearly carbon budgets from 2008 on, providing a statutory cap on economy-wide greenhouse gas emissions over a five-year period and setting out twelve-year plans for a path towards achieving the 2050 objectives.
- The development of a statutory long-term emissions target: as per the 2019 update to reduce greenhouse gas emissions by 100% by 2050, the CCC evaluates and updates the target, if necessary.
- The continuous adaptation of planning is required; the Act provides a continuous approach to adaptation to climate change.
- Mandatory progress monitoring and accountability are also included in the Act; this involves regular government reporting to parliament, the public, and the CCC to produce an annual progress report.

When the Act was amended in 2019, the government also provided an outline of the definition of net zero: "any emissions would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere, such as planting trees or using technology like carbon capture and storage" [25].

As part of the sixth carbon budget, the government has set a target of reducing emissions by 78% by 2035, which was set under the advice of the CCC. The CCC has said that currently, the UK is currently not on track to meet its carbon budget targets for 2025 and 2030, and to achieve these targets, the government must introduce more strict measures [26].

The Climate Change Committee (CCC), a non-departmental public body, has played a considerable role in advising the UK and the government on how to prevent and respond to the climate change emergency by providing progress reports and policy recommendations and by conducting research across all sectors of the UK economy. They have produced informed roadmaps for the UK's journey to becoming net zero, including guidelines for the UK's housing sector.

Meeting these net zero targets under the Climate Change Act will require a range of actions across all sectors of the UK economy, including the housing sector [27].

One of the steps the government has taken to achieve ZCH is introducing the Future Homes Standard in 2019. This standard ensures that new build homes are future proofed with low carbon heating and high levels of energy efficiency and from 2025 on, these homes will produce 75–80% less carbon emissions than homes delivered under the current building regulations [28]. Within this standard, the government also committed to ensuring that once a new house has been built, no refurbishment will be necessary to reach zero carbon emissions; therefore, no new home built under the Future Homes Standard will rely on fossil fuels [29].

Even though numerous standards, regulations, schemes, policies, and assessment tools are in place for new buildings within the UK, Fawcett and Topouzi 2019 [23] argue that there is a lack of continuity due to multiple implementations, changes, and withdrawals of policies which have adversely affected carbon emissions; the development and delivery of innovative, low-carbon market solutions; and decision making by local authorities regarding standards.

1.3. Zero Carbon Homes: Overview and Actions

The CCC has raised concerns about the insufficiency UK homes, suggesting the inadequacy of the current preparations for climate change [11] with a proposal that for the UK to reach net zero emissions by 2050, all directly regulated emissions from buildings must be eliminated by 2048. The World Green Building Council recommends that all new buildings operate at net zero carbon emissions from 2030 on, and 100% of the UK's housing stock must be operating at net zero emissions by 2050.

To achieve this, the CCC further proposes that by 2033, all UK buildings should be energy efficient, and all future fossil fuel heating systems must be replaced with low carbon alternatives; other major proposals include [11]:

- All new buildings will be zero carbon ready by 2025.
- All new boilers installed will be "hydrogen ready" after 2025.
- All new district heat network connections must be low carbon emitting after 2025.
- No new oil and coal heating systems will be installed after 2028.
- No natural gas boilers will be replaced after 2033.
- All heat networks must covert to low carbon heat sources by 2040.

Currently in the UK, domestic buildings account for around one-third of the energy budget, with emissions from buildings presently contributing 26% of the UK's total emissions, 18% of this coming from residential housing, resulting in calls for all new buildings to be net zero energy structures. Buildings, especially dur to their heating and cooling requirements, are among the few areas in which significant energy consumption and emission reduction are possible, while still maintaining or improving the level of energy services provided. It will only be possible to meet the legally binding 2050 emission reduction target by a near complete decarbonisation regarding the way in which the UK heats its homes [11]; this provides an opportunity for low-energy buildings to be key in achieving a climate neutral future.

With significant government plans for new housing in every part of the UK, with a target of 300,000 new homes per year, these new homes must be designed to be fit for purpose and be built to be carbon, energy, and water efficient, as well as climate resilient [11]. Newly constructed buildings are becoming more energy efficient, but since the Climate Change Committee's review in 2016, over 570,000 new homes have been built that are not resilient to future high temperatures and are currently not equipped to deliver the energy performance levels required for net zero emissions [5]. A total of 80% of buildings the estimated buildings that will in existence by 2050 have already been built, with the existing 20% to be delivered in the intervening period, meaning that the industry must focus on decarbonising the UK's existing buildings. Therefore, a major priority for the industry should still be improving the energy performance of these planned builds, as this will avoid the need for future retrofitting and remove the risk of future occupant disruption, cost, and embodied emissions [11].

The report by Currie, Brown, and Aecom [30] found that the costs of retrofitting are three to five times higher than the costs for meeting these standards in new buildings; therefore, it is imperative that building standards are improved so that the final 20% of the 2050 housing stock does not need future retrofitting. To ensure this, immediate government action is required. For new homes to be fit for purpose, the highest possible levels of emission reduction must be integrated with a package of design improvements to adapt to the changing climate [11,12]. To ensure this result will require an ambitious trajectory

of standards, regulations, and targets, i.e., higher levels of air tightness; more fresh air inclusion through mechanical ventilation and heat recovery, along with passive cooling measures; the use of triple-glazed windows and external shading (especially on south and west faces); low carbon heating; no new homes connected to the gas grid by 2025; improved water efficiency and cooling standards (the use of green roofs and reflective walls); planning for and improving flood resilience and resistance; and improved construction and site planning.

The government must enforce these higher standards and ensure compliance so that the industry can take steps for reducing emissions in new homes. Moreover, it must also address the urgent funding needs in order to achieve these goals [11].

It is essential that sufficient investment is available to enable the necessary tools, and to support industry change, the government and industry must work together [30]. Providing sufficient funding and enforcing future standards will drive a transition to low-carbon heating and together with a phased, cost-effective tightening of energy efficiency, reduce running costs and minimise the demands placed on electricity generation and supply infrastructure [31].

Decarbonising homes within the UK is essential for tackling the climate emergency. It also combats fuel poverty and supercharges the economy, creating jobs, warmer homes, and cleaner air [16,17]. However, the housing sector is facing a huge challenge; it must cut carbon emissions and tackle climate change, while maintaining high standards and safety and building tens of thousands of the new homes required.

While it is clear what the UK needs to consider for zero carbon housing design, as well as the governmental and financial support required, the literature currently argues that the UK will not be able to meet the required standards. The next section identifies in depth the challenges of low carbon housing construction in a bid to raise further awareness and provide sound pathways that can raise the likelihood of the UK meeting its zero carbon housing targets for new homes.

2. Materials and Methods

This research aims to analyse academic publications to identify the barriers and challenges encountered by the construction industry when building zero carbon ready homes, spotting research gaps and charting a course for future research. The existing literature regarding zero carbon emissions in the UK is extensive, but does not necessarily pertain to ZCH. The world is also continuously changing, bringing new issues and challenges impacting the feasibility of delivering ZCH in the UK. Therefore, using a bibliometric analysis will allow for in-depth research of the existing literature in this field and enable the evaluation of how the UK can deliver zero carbon ready homes in the modern industry. To achieve this, a mixed review method is used, which combines a qualitative review of systematic analysis and a quantitative review of a bibliometric approach. Figure 1 illustrates the overall methodological process of this research; 341 publications were analysed and filtered down to find the final 11 publications specifically addressing ZCH.

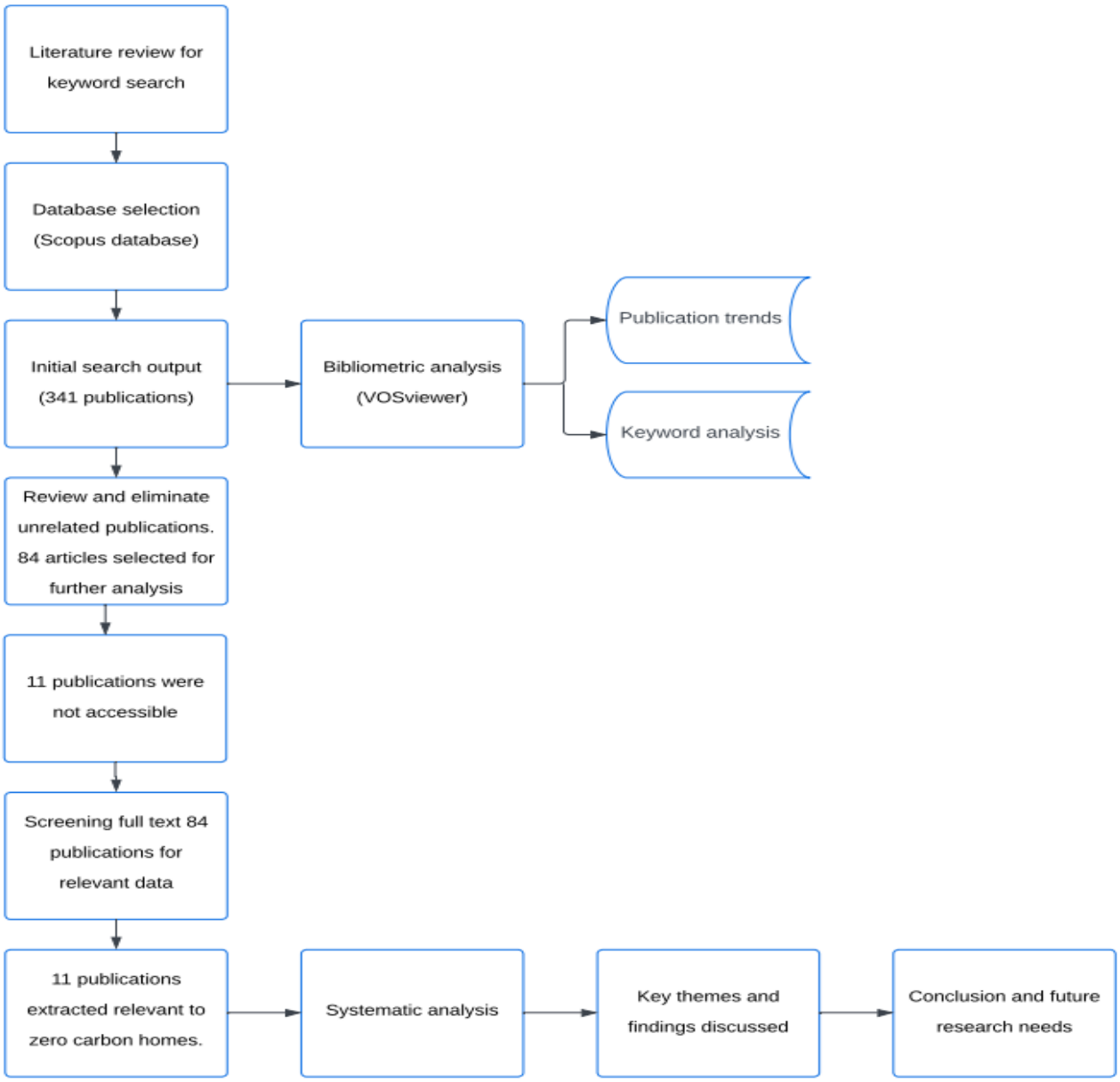

Figure 1. Overview of research methodology.

Scopus was the core collection database for this research, as it contains the most reputable and influential journals [32]. Studies by Sharifi et al. (2021), Zou et al. (2022), and Dawodu et al. (2022) [33–35] have adopted similar approaches to draw out systematic trends in the secondary data. The search was conducted by employing a co-word analysis which uses the most important words or keywords of the documents to study the conceptual structure of a research field [25]. The keyword selection was identified through common terms used in the articles from the literature review conducted. The keywords were also divided into "keyword categories", each containing synonym keywords for the same underlying construct, as often, various authors used several different keywords to describe the same research topic, and the literature review identified multiple variations or abbreviations of terms; this enabled a more comprehensive search to be conducted, capturing the diverse terms used in the literature.

The search on Scopus was conducted using the keywords: "barriers" OR "challenges" OR "obstacles" OR "risk*"; these were combined with AND "net-zero carbon" OR "net-zero energy" OR "net-zero emissions" OR "zero carbon" OR "zero energy" OR "zero

emissions" OR "low energy" OR "low carbon" OR "nearly-zero energy" OR "carbon neutral" OR "carbon positive" OR "energy positive" OR "climate neutral" OR "zero-net energy" OR "NZEB" OR "NZCB" OR "NZE" OR "ZEB" OR "ZCB" OR "nZEB" "zero carbon hous*" OR "zero energy hous*"; AND "Build*" OR "Hous*" OR "Construction" OR "New Build*; AND "UK" OR "United Kingdom" OR "England". These keywords were searched through the titles, abstracts, and keywords for publications on the Scopus database, generating 341 records (as of March 2023). The search criteria were filtered to show only publications until 2022, due to the fact that the data and statistics for the full year of 2023 were not yet accessible; to only include documents with the language of "English"; and the publication stage of "final." of the 341 publications generated, the articles were screened at the title and abstract level to eliminate any that contained unrelated topics, as well as duplicates; of these, only 84 articles were found to be relevant, and these were subsequently obtained for review. The main body of the remaining 84 articles was skimmed through to eliminate any articles discussing unrelated topics and to remove duplicates; of these, 11 articles were not accessible. After further screening, a final 11 articles were selected for data extraction.

Subsequently, a bibliometric analysis was conducted to identify any trends or research gaps and to provide an understanding of ZCH. Firstly, a publication trend analysis was conducted, which examined the date range for all publications retrieved from the Scopus keyword search that only highlighted the lack of current research regarding barriers to delivering ZCH.

3. Results

3.1. Bibliometric Analysis: Publication Trends

The analysis of the yearly publications helps to identify research results and trends in this field [36]. Figure 2 shows the 341 publications retrieved and the date of publication of each. Publication trends allow for the exploration of the data range of the publications in relation to the keyword search in Scopus, identifying key knowledge gaps or showing whether further research is required. The findings show that the first article was published in 1990, which implies that even though the concept of ZCH originated in the mid-20th century, research regarding net zero emissions has been around since the 1990s. Between 1996 and 2005, a uniform number of publications was shown until 2006, when a significant increase in research publications began. This is likely due to the fact that in 2006, the Labour Party set out the original plans for ZCH within their consultation document "Building a Greener Future". This growth in research is likely to continue as the UK and the rest of the world commit to achieving further net zero targets [37].

The first article related to barriers of ZCH, by Osmani and O'Reilly, did not appear until 2009. This article seemed to kickstart research into the barriers of ZCH, with it being cited 160 times and from time of the increase in articles published discussing barriers and challenges to ZCH.

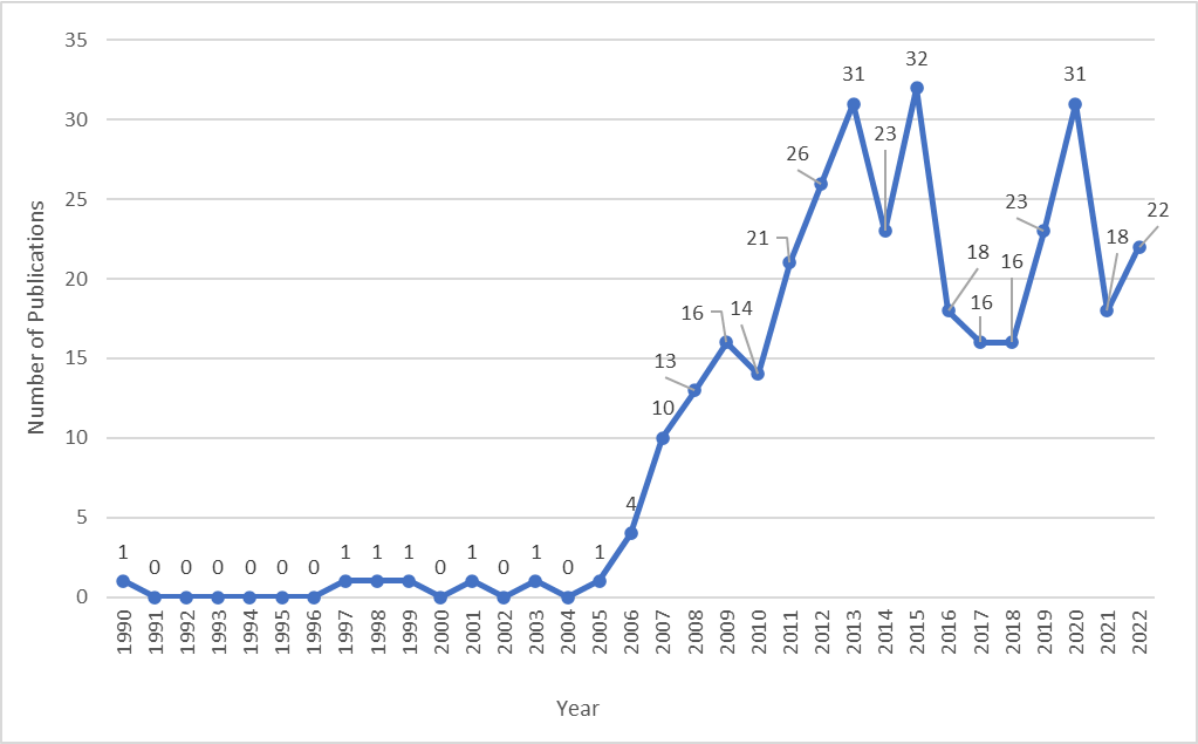

Figure 2. Date range for the 341 publications retrieved from Scopus.

3.2. Keywords Analysis: Systematic Analysis

This section summarises the findings of this study in relation to the barriers to delivering ZCH. From the keyword search on the Scopus database, 341 publications were retrieved; the articles were examined, excluding any unrelated topics, and the final articles were reviewed to identify the relevant data for analysis.

Findings: Barriers to Delivering ZCH

The aim of the research was to identify the current barriers and challenges to the delivery of ICH in the UK. Multiple studies identified numerous barriers to ZCH from different perspectives and through a variety of research methods, including questionnaires and interviews with industry professionals, literature reviews, and case study analyses; these methods provide serval advantages, particularly as the authors have used them to perform in-depth analyses for publishing [36]. Table 1 shows the 11 articles retrieved from Scopus for data extraction and the key barriers identified. Overall, the studies identified multiple issues and challenges, which have been grouped into main themes; these comprise nine groups (with the most significant first): legislative; socio-cultural; economic; financial; skills and knowledge; technical; industrial; environmental, and procurement factors. Legislative barriers were identified as the primary barrier throughout this research; as seen in Figure 3, 10 out of 11 articles found that this is a current and major issue for the industry. This is the result of an unclear definition of zero carbon and vague legislation, excess government policies, and a lack of understanding of the requirements [38]. Five or more articles also included significant issues in regards to socio-cultural, skills and knowledge, financial, economic, and technical barriers. Other barriers were highlighted in these studies, but were not seen to be significant issues overall, and were therefore merged into other more significant barrier categories. The conclusion from the analysis and the overall consensus from the existing research is that currently, it is not feasible to deliver ZCH, and that there are multiple challenges and barriers for the industry to tackle and overcome in order to meet the government's net zero targets and deliver ZCH in the UK. While these studies together provide a comprehensive understanding of the

barriers to delivering ZCH, there is still a clear lack of research into the context of ZCH, as the majority of the articles retrieved are focused on the period before the cancellation of the ZCH policy.

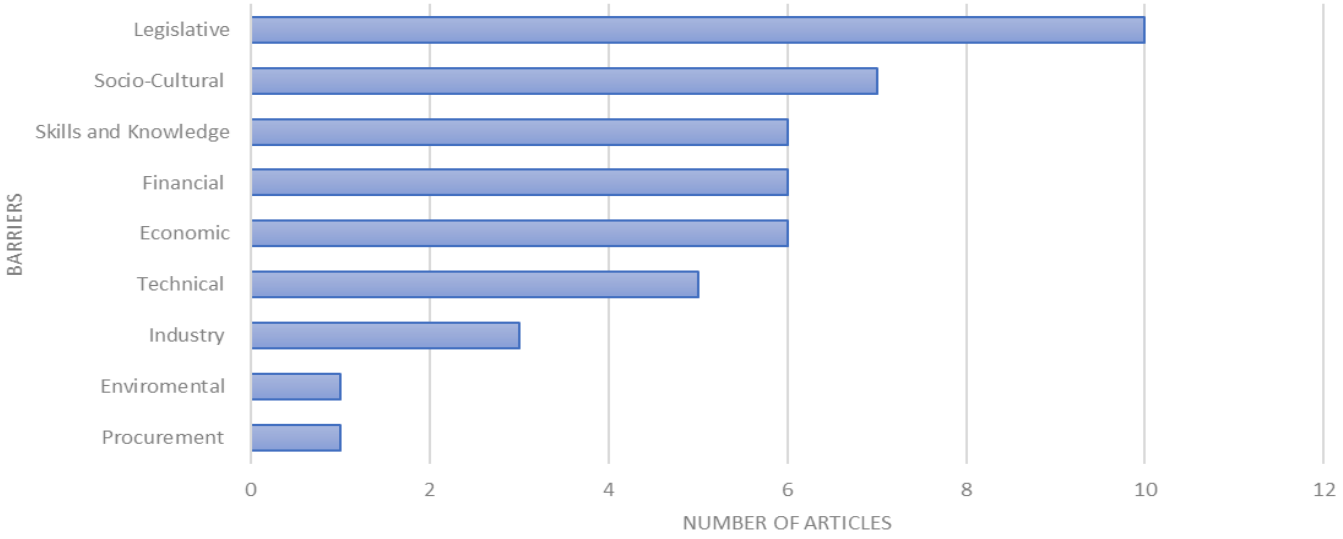

Figure 3. Breakdown of barriers identified.

Table 1. Key barriers identified from review articles.

Authors	Summary	Key Barriers
Camarasa et al., 2021 [39]	Drivers and barriers to energy-efficient technologies (EETS) in residential buildings.	• Environmental • Technical • Economic • Social • Legal
Martiskainen and Kivimaa, 2019 [40]	Role of knowledge and policies as drivers for low-energy housing: case studies from the United Kingdom.	• Financial • Knowledge • Polices
Clarke et al., 2018 [41]	Rethinking the building envelope: building integrated energy positive solutions.	• Economic • Social • Financial • Knowledge • Procurement
Pitts, 2017 [42]	Passive homes and low energy buildings: barriers and opportunities for future development within UK practice.	• Legislative • Knowledge • Economic
Henderson et al., 2015 [43]	Achieving sustainable homes by 2016 in the UK: the current status.	• Legislative • Financial • Cultural • Technical
Heffernan et al., 2015 [44]	Zero carbon homes: perceptions from the UK construction industry.	• Economic • Skills and Knowledge • Industrial • Legislative • Cultural

Ganah et al., 2015 [45]	Feasibility of CSH in assisting the new housing sector in delivering zero carbon homes by 2016.	• Legislative • Financial • Cultural • Technical
Callaghan et al., 2014 [46]	Home builder opinions of energy-efficient homes in the UK.	• Technical • Social • Economic • Political
Heffernan et al., 2012 [44]	Delivering zero carbon homes in the UK.	• Skills and Knowledge • Legislative • Economic • Industrial
Musau and Deveci, 2011 [47]	From targets to occupied low carbon homes: assessing the challenges of delivering low-carbon affordable housing.	• Skills and Knowledge • Financial • Legislative • Industrial
Osmani and O'Reilly, 2009 [9]	Feasibility of zero carbon homes in England by 2016: a home builder's perspective	• Legislative • Cultural • Financial • Technical

4. Discussions

4.1. Barrier Regarding the Sub-Themes

The barriers identified from the studies were further categorized into sub-themes. Table 2 provides a summary of the findings; under each barrier a number of sub-themes have also been identified from the data. The strongest sub-themes throughout the research were the lack of incentives (financial, tax, or government), perceived higher and additional costs, lack of interest in and demand for ZCH, the knowledge and skills gap, and the lack of clarity in regards to legislation, including the continuous changes and withdrawal, as well as a lack of legislation in place.

Recurring issues in regards to current overall legislation were a key theme. Most studies stated that there was a lack of clarity in the definition of ZCH and the requirements and expected outcomes regarding the legislation. Other key legislative themes highlighted included the lack of existing legislation or the continual changing or withdrawal of legislation by the government, making it hard for the industry to commit to specific standards and resulting in little progress being achieved in the development of ZCH. To effectively implement the required legislation, there is a need for industry professionals, regulators, and the general public to have the appropriate knowledge and skills, as well as the motivation, towards engaging with ZCH design [42]. The knowledge and skills gap was a key sub-theme observed in the literature.

Many professionals perceive there to be higher or additional costs for ZCH construction; costs of low carbon technologies, labour, design, construction, and maintenance are higher than those incurred when using traditional methods.

Musau and Deveci [47] found that there is a widespread lack of in-depth interest in low carbon issues by professionals; therefore, strengthening legislation, providing incentives, and increased awareness and education can encourage the industry to change and overcome these barriers.

Table 2. Identified barrier sub themes (synthesised from Table 1).

Barriers	**Sub-Themes**
Environmental	• Lack of ambitious and clear political environmental targets. • Lack of environmental awareness.
Technical	• Lack of reliable technologies.

	• Reliability and performance are unknown and untested. • Lack of high-performance technologies. • Complex production process. • Lack of comprehensive information regarding technologies, i.e., alternatives, advantages, and disadvantages. • Perceived barriers to the use of certain technologies. • Recentness of renewable technology. • Difficulty for smaller scale homebuilders to implement. • Cost of equipment. • Pace of innovation. • Product knowledge. • Installation and maintenance. • Quality control. • Lack of technology and standards. • Lack of local production or availability in some regions. • Reduced design data. • Lack of qualified organisations/employees (to install or construct).
Economic	• Lack of comprehensive financing models. • Lack of tax, financial, government incentives, or subsidies • Low energy prices • Lack of affordable products. • Brexit. • UK relationship with EU and other nations. • Home builders/occupants feeling the impact of "economic downturn". • Lack of market demand and marketability, • Capital cost of delivering ZCH. • Green overpricing. • Land values/home valuations. • Economic recession impacting the housing market. • Perceived risk. • Current market conditions having adverse effects on progress. • Lack of public investment. • Assumed reduced profits. • Lack of market drivers and payback. • Perception of only occupants gaining the benefits. • Investment not earned back. • Promoting growth.
Socio-cultural	• Lack of trust, reliability, and awareness in technologies. • Lack of interest in low-energy design. • Reluctance to fully embrace low energy techniques due to pride and comfort.
Financial	• Perceptions of expensive to build and higher/additional costs. • Lack of financial incentives. • Insufficient funds allocated from the construction budget. • Costs for achieving higher standards and meeting these standards. • Lack of investment from homebuilders as a perception that it will not provide a good rate of return on investment. • Making ZCH financially viable. • Higher costs at various stages, i.e., design, installation, and maintenance. • Overall uncertainty of full costs. • Lack of information regarding final costs associated with construction. • Financial climate. • Initial proposals are too expensive/nearly impossible to implement. • Financial implications of new technology; high initial cost of the system and long payback periods.

	• Additional costs compared to traditional methods. • Requires more financial investment. • Higher labour costs. • Lack of understanding/assurance of the net financial cost and overall profitability. • Lack of sales data.
Skills and Knowledge	• Skills gap regarding knowledge required to construct and design. • Skills availability. • Knowledge gaps existed for all parties involved in the delivery of ZCH (builders, occupants, design team, regulators, maintenance teams, planners). • Awareness of workforce. • Lack of industry knowledge regarding sustainable buildings. • Lack of available knowledge, information, and resources. • Technical understanding. • Poor competency. • Confidence within the industry to achieve ability. • Inexperienced designers. • Negative views of performance issues, i.e., overheating. • Moving from demonstration to mainstream processes. • Lack of research and development. • Inadequate systems within the building control departments. • Low level of awareness and knowledge of users and the general public. • Lack of knowledge/awareness of benefits.
Policy and Legislation	• Lack of comprehensive legal framework, building standards, implementation of legal standards, green building codes, building regulations, and planning regulations. • Policies are viewed as "complex". • Changes to legislation that have modified commitments and timescales to address energy efficiency in buildings (moving goalposts). • Withdrawal of Code for Sustainable Homes. • Definitions of certain standards/terminology, i.e., "zero-energy buildings". • Uncertainty within the industry over design and construction requirements due to changes in standards and assessment techniques. • Changes to planning regulations, i.e., large numbers of policies and guidance docs have been abandoned, making it difficult for areas outside London to apply more rigorous environmental and energy standards. • Absence of development policies and government-led regulation, resulting in the need for improvement in communication to encourage a change in attitude. • Unclear legislation and lack of sufficient clarity of requirements and expected outcomes. • Scheme viability. • Government cross-party support for ZCH. • No certainty of future legislation, causing a lack of industry investment, designs, products, and research. • Planning agendas. • Persuading government that sustainability will not stifle growth. • Lack of government incentives. • Lack of industry involvement in policy development. • Incorrect legislation in place. • Statuary obligations not achievable. • Lack of quality control. • Difficulty obtaining planning consent for renewable technologies in conservation areas. • Excess government policy.
Procurement	• Requires early engagement of contractors.

Industrial	• Current business model of the industry. • Inertia. • Availability of products. • Lack of collaborative and flexible work practices. • Unproven/inappropriate technology. • Failing to be place-specific. • Lack of drive from homebuilders. • Nature of housing market—volume homebuilding. • Resistance to change. • Design processes. • Complexity. • Every project is a protype. • Larger UK homebuilders have "standard house types" that are replicated throughout their different developments. • Lack of supply. • Difficulty for smaller organisations, as they have less ability to innovate, use trial and error processes, and provide training. • Supply chain and product availability issues. • Issues with lack of access to renewable energy sources. • Homebuilders are willing to ignore government policies and refrain from building ZCH. • The industry is not engaged with energy efficiency concepts. • Lack of confidence in technology. • Lack of interest in change from industry. • "Low carbon standards" are not attractive due to the given limited returns. • Meeting only minimum standard requirements is the aim. • Lack of cooperation between parties. • Uncoordinated promotion of low carbon standards by many bodies, providing inconsistent messages to stakeholders. • Reluctance to vary from traditional designs.

4.2. Analysis of Findings: Barriers to Delivery of ZCH

Based on the previous literature reviewed, this current study classified the barriers to delivering ZCH into five categories: legislative, socio-cultural/industrial, economic, financial, and skills and knowledge. The following sub-sections discuss the significant barrier categories identified.

4.2.1. Legislative Barriers

Policy and regulations play a vital role in increasing the demand for ZCH. As per Figure 3, 10 out of the 11 articles retrieved concluded that legislative obstacles are a key barrier to delivering ZCH. While the literature found the legislation to be the most significant barrier, it was also suggested as the most effective driver for ZCH.

The literature suggests that throughout the industry, there has been some controversy over the definition of ZCH. In December 2006, the original definition of ZCH homes was established; this was later updated by the government in 2007 and 2008; the ZCH definition was revised a final time before the cancellation of the Net Zero Homes agenda [48]. This has caused a great deal of uncertainty and confusion over the existing definition, as well as and concerns for the industry regarding the feasibility of implementing ZCH. Osmani and O'Reilly, 2009, found that 73% of respondents to their survey believed that the definition of ZCH is a significant legislative barrier; it was considered to be too ambiguous and required more clarity in terms of requirements and the expected outcomes. This was supported by other literature, such as Callaghan et al., [46], where it was reported that homebuilders suggested there is a lack of clarity surrounding the definition of ZCH

due to the government overcomplicating the definition, resulting in confusion and resistance from the industry. Consequently, the continuous attempts by the government to create more precise definitions have created more confusion and challenges within the industry. Pitts [42] found that this significantly reduced confidence in government standards by homebuilders and further extended the degree of uncertainty over design and construction requirements, causing overall delays and missed opportunities in the industry in regards to implementing ZC techniques.

It was also suggested that more uncertainty was felt throughout the industry due to the continuous and somewhat rapid changes to legislation by the government. One example highlighted in the literature is the removal of the Code For Sustainable Homes (CFSH). The CFSH was introduced in 2006 as the leading framework for the development of zero carbon new building stock; however, this standard was later scrapped in 2015. Simultaneously, the Building Act 1984 was amended to allow for new optional standards to be introduced and required; this meant that higher energy efficiency standards were now required. These decisions have been heavily criticised because they caused high levels of ambiguity within the industry and created a complex situation for both local authorities and the industry [23]. This result was supported throughout the studies.

Heffernan et al., 2015, found that throughout the industry, the opinion was expressed that until there is legislation in place, the industry is reticent to take firm steps to prepare due to the track record of the government changing the goalposts for ZCH. This situation has not been helpful to the industry, and the withdrawal of CFSH is disappointing due to the failure of its aim to provide a long-term vision for policy and the building industry. These continual amendments to the legislation were also found to be a significant issue in the findings of Ref. [43], from which it was observed that homebuilders did not believe it was feasible to meet the government's objective of implementing ZCH due to planning regulations and the requirement of preregistering a development under the current building regulations. The frequent changes to regulations and standards meant that any development granted permission during the planning stages had to be built in accordance to the certain set of regulations in place at that time, and if the regulations were amended prior to completion of the project, then parts or all of a development would be constructed in noncompliance with building regulations. Henderson et al. [45] highlighted that this would worryingly mean that these developments automatically failed to achieve the government's objective did not meet the building regulation standards. When legislation is not fully clear and is complex, as well as continually changing, it can be difficult for homebuilders to adjust to and comply with the new rules, ultimately resulting in creating more houses that are not fit for the future, requiring retrofitting at a later date.

Overall, the literature suggests that these legislative barriers have affected the industry negatively. The amendments, the lack of clarity, and the withdrawal of policies have all resulted in backlash from many homebuilders, who argue that this has undermined any progress made to date, is slowing down progress toward building sustainability, and is adding to the overall emission burden [46]. It was suggested by Heffernan et al. [38] that there is a requirement for assurance of "cross party support" to enable the industry to invest in designs, products, and research when there is currently no certainty concerning future government legislation regarding ZCH.

These policies and regulations are critical to achieving ZCH, as they can guide and provide a roadmap for the industry; however, the industry cannot be expected to invest in zero carbon homebuilding if there is no certainty regarding future legislation. Fawcett and Topouzi [23] argue that there is currently a lack of continuity of policy in the newly built residential sector, adversely affecting carbon emissions; development; delivery of innovative, low carbon market solutions; and decision making by authorities in regards to standards. The implementation of legislation can mitigate some other barriers highlighted in the literature, boosting confidence for professionals and the public, raising awareness and education, and providing incentives to the industry. Therefore, it can be argued that mitigating legislative barriers is the key to effectively delivering ZCH within the UK.

4.2.2. Socio-Cultural and Industry Barriers

The findings from the literature suggest that there is a strong link between socio-cultural and industry barriers in terms of ZCH. Both categories highlighted the perceptions and feelings of the public and the industry. Socio-cultural barriers refer to barriers that are man-made constructs originating from social norms and cultural values [49]. Socio-cultural barriers were identified to be a significant barrier by 7 of the 11 articles reviewed, as the second main barrier identified, although it was reported by Heffernan et al., 2015 [38], that the industry believes that the cultural barriers would be the easiest to overcome.

The literature suggests that overall, there is a lack of confidence regarding the feasibility of ZCH, green technologies, government policies, and even the industry's own ability to achieve ZCH. In Osmani and O'Reilly's study, the questionnaire responses raised serious concerns in regards to the lack of homebuilding confidence in renewable technologies [8,9]. This was echoed throughout the other literature. Heffernan et al. identified a lack of confidence in green technologies and practices [38], and Ganah et al. stated that UK homebuilders are adverse to affecting change through the use of untested and unproven green technologies, suggesting that there is a strong preference for the use of traditional methods and an unwillingness to embrace new technologies and methods [45]. Finally, Callaghan et al. concluded that homebuilders portray an inconsistent level of confidence in their ability to deliver ZCH [46]. Increasing the confidence in the industry's ability to achieve ZCH will only come from improving methods, providing better knowledge and skills, and implementing clearer and improved legislation.

One of the key themes identified was the need for a change of mindset for the public, regulators, and most, importantly, the industry. Currently, the homebuilding industry appears not to be fully engaged with energy efficient concepts, as can be seen from the Callaghan et al. questionnaire to homebuilders, which found that respondents do not believe that the government ZCH target will be achieved, resulting in a lack of urgency from the industry to engage in new practices or change traditional methods [46]. The findings from Heffernan et al. suggest a strong resistance to change and a reluctance of the industry to take firm steps to prepare for ZCH building [38]; it was also identified that the mindset of designers and contractors needs to change in order to deliver the quality required for ZCH production. This mindset causes a lack of motivation for change and an unwillingness to implement untested or new sustainable materials and products or to stray from the use of traditional design methods; this is a result of traditional attitudes upheld throughout the industry, restricting the uptake of innovation [8,9]. This also links with the issues of "volume building", in which developers will often use a standard range of home designs across their developments to help minimise costs and defects; therefore, there is a reluctance to adopt policies that will require excessive design changes. These findings were also echoed by Heffernan et al. [38]. Furthermore, the integration of renewable technologies into small scale developments is particularly challenging, as there is less ability to innovate or to use trial techniques and provide training to sub-contractors due to the limited funds available [46].

Small and larger developers are unlikely to commit to making these changes due to cost and feasibility, especially when there is a strong perception of an absence of demand from the customer. The literature has also shown conflicting views with regard to market demand; many believe there is a lack of demand for ZCH, which stems from homebuyers being poorly informed of the benefits, the aesthetic choices, and flexibility; therefore, if the demand is not present, homebuilders will not construct homes which consumers do not want to buy, making the ZCH scheme unfeasible for homebuilders. However, the study of Callaghan et al. argues that many homebuilders reported an increase in the number of customers requesting green building techniques, suggesting that there is an increase in demand for ZCH [46]; Heffernan et al. also reported that interviewees held conflicting views, as some felt there was an element of demand for ZCH, but where unsure of the levels [38].

More issues arising from the nature and culture of the industry included the need for increased collaboration and flexible working practices [44]. The research of Clarke et al. suggested that there are strong links between collaboration, innovation, and creating energy-positive buildings; therefore, using these techniques could help to transform the construction industry [41].

Interestingly, the literature shows that there are mixed views and opinions in regards to the concepts of ZCH, and that the majority of the industry's socio-cultural barriers stem from the legislative issues identified previously. Implementing stronger legislation that is clear, offers certainty; provides more information and data; and improves the current business model of the industry can begin to boost confidence and change the mindset of the industry, improving public awareness of the benefits of ZCH in order to increase the market demand.

4.2.3. Economic and Financial Barriers

Even though economic and financial obstacles were not found to be the most significant barriers to delivering ZCH, the literature still highlighted that these are issues for the industry to overcome. Heffernan et al. identified economic barriers as the most significant factor, with the capital cost of delivering ZCH, scheme feasibility, financial viability, and lack of incentives found to be key issues [38]. The literature echoed these findings, but it predominantly suggested that there is a requirement for incentives (tax and financial) to be implemented for homebuilders, as the lack of financial incentives has discouraged innovation within the industry [38]. Along with this, there is a general concern regarding whether it will be possible to meet ZCH and climate change targets in a cost-effective way. Callaghan et al. reported that over 70% of homebuilders in the study expressed concerns relating to their ability to build profitability, and the majority stated that there was little opportunity to achieve sales premiums as the result of additional costs associated with ZCH building [46]. Heffernan et al. also suggested that an additional issue stemmed from the separation between those paying for and those receiving the benefits, as it is believed that ZCH does not attract a high-sale premium [38]. Therefore, introducing financial or tax incentives would help encourage and incentivize homebuilders to invest in and install ZC technology and to benefit from increased bank loans for manufacturing and improved fiscal support [46].

The literature suggested that the overall perception within the industry was that there were high and additional costs inherent in the delivery of ZCH. Osmani and O'Reilly found the key financial barrier to be the lack of available data relating to the costs of ZCH [8,9]. A reoccurring comment was the fact that nobody knew exactly how much it was going to cost to build in accordance with government standards. The general opinion was that homebuilders need clear information about the final costs and the profitability of ZCH in the UK and that there is a lack of financial payback for ZCH. Henderson et al. explains this point further, stating that homebuilders do not want to invest in concepts such as ZCH, as they believe that it will not provide them with a good rate of return on their investment, making them reluctant to spend additional money [43]. Homebuilders also maintained the perception that there are additional costs of achieving the higher standards set out in policies and regulations, and due to the issues mentioned previously regarding the government amending and withdrawing legislation, homebuilders are not willing to commit to building ZCH and to absorbing any unrecoverable costs when the building does not meet the new or amened standards.

Lastly, the findings suggested that factors such as the financial climate and the economic downturn are impacting organisations within the industry, making them hesitant to invest due to banks being less willing to give loans, causing inflation and other economic variables [43]. Other economic concerns were raised in relation to the UK leaving the European Union (Brexit). Due to the date range of the articles retrieved from Scopus, only one article discussed the issues of Brexit. Pitts found that the industry expressed significant concerns regarding the future impact of Brexit, including issues regarded the fluctuating currency exchanges and the difficulty in using products and materials from

different countries, as well as the UK's and European countries' relationships and collaboration with each other [42].

4.2.4. Skills and Knowledge Barriers

ZCH are very different from traditional home designs, and they require greater levels of "thermal literacy" for all construction workers, higher qualification levels, broader occupational profiles, increased integrated teamwork, extended subcontracting chains, and better communication, given the complex work processes involved [50]. Thus, there is a need for a greater understanding of the necessary skills and knowledge for the effective implementation of the ZCH, along with further strategies for addressing the skills shortages and knowledge gaps identified.

The research of Heffernan et al. [44] was the main study that highlighted issues relating to skills shortages and knowledge gaps. This was found to be by far the most significant barrier for ZCH, as identified by interviewees. A number of issues were highlighted in this study, including a lack of know-how, lack of research and development, deficient client knowledge, as well as poor specification writing and estimating. Skills and knowledge gaps exist for all parties involved in the construction, as well as for the users and the general public; the view from one respondent also suggested that improving end user education would be a much greater challenge than the education of the delivery team.

Other studies acknowledge the issue of the need for more widespread knowledge and skill improvement within the industry and the public, but these studies only consider this to be a primary barrier. Overall, the findings suggest that there is a gap in the knowledge skills available, and finding a way to overcome this is key to successfully delivering ZCH. It is important that all parties involved have the appropriate knowledge and skills, as well as motivation towards engaging with ZCH implementation [42].

4.3. Overcoming Barriers: Summary of Potential Solutions

This paper has reviewed the existing literature and identified the key barriers to delivering ZCH in the UK. Multiple challenges relating to legislation, socio-cultural, industrial, economic, financial, knowledge, and skill barriers have been identified which impede the adoption of ZCH. The housing sector must prioritise addressing these barriers and explore strategies to mitigate them. As part of this study's contributions, Table 3 provides a summary of potential approaches and solutions that could be adopted to address the identified barriers.

Table 3. Potential solutions to overcome identified barriers.

Barriers	Potential Solutions
Legislation	• Overall review of existing legislation. • Certainty regarding future requirements, legislation, and definitions, i.e., cross party support, commitments from all governments regarding legislation and future plans. • Stricter building regulations. • A robust planning policy framework. • Collaboration between developers, local authorities, and government in regards to ZCH. • Increased amount of legislation and policy support in regard to net zero buildings. • Updating and strengthening existing legislation. • Incorporating buildings into national climate policies. • More importance given to design stage planning for net zero emissions.
Socio-cultural and Industrial	• Innovation within the supply chain. • Use of corporate social responsibility. • Stronger focus on design to encourage more demand from occupiers. • Formation of strong collaborations and partnerships within the sector (suppliers, skilled workers, and planners).

	• Marketing homes by supplying details of features and running costs, with developers providing post-occupancy support. • Better information flows and awareness to boost market demand. • Improved public engagement. • Resilient supply chains. • Adopting different design and construction techniques, i.e., offsite construction. • Incorporating sustainability objectives into the design of the buildings and surroundings.
Economic and Financial	• Financial incentives provided through the allocation of upfront grants, removal/reduction of the VAT of low carbon technologies, and labour costs associated with their installation. • Government provision of financial incentives, i.e., building energy performance certifications, green lease agreements, green bonds financing, or pay as you save models. • Marketing benefits. • Adopting different construction techniques to reduce costs, i.e., offsite construction. • Improved business models. • Sufficient funding mechanisms.
Skills and Knowledge	• Training courses for graduates. • Upskilling the entire industry. • Further research into barriers, low carbon technologies, etc. • Improving end-user education. • Pathway training.

4.4. Discussion of Current Barriers to Delivering ZCH

On balance, the research found that legislative, socio-cultural, economic, financial, and skills and knowledge factors to be the primary barriers to delivering ZCH in the UK. However, the date range of articles retrieved from Scopus (2009–2021) does not necessarily provide a true representation of current barriers and challenges in 2023. Due to the date range, the majority of publications fail to recognise the current issues related to Brexit, COVID-19, and the economic climate facing the industry when attempting to deliver ZCH and the withdrawal of major policies such as the Zero Carbon Homes policy. The literature reviewed in regards to the barriers to ZCH within the UK is limited and mainly focuses on the period before the withdrawal of the ZCH policy. This policy was withdrawn by the government in 2015 on the basis that the regulations would slow the rate of homebuilding within the UK, and it was replaced by new set of streamlined national technical standards, comprising the new and additional building regulations [51]. Forde et al. [52] found that withdrawal caused uncertainty for homebuilders and local authorities, created a lagging effect for future policy making, and impacted other policies produced in relation to the agenda. This withdrawal has now left the industry with a void in guidance, insufficient current policies, and at present, the incapacity to develop and successfully implement further policies, creating more legislative barriers for the industry. Research conducted by BEIS [28] on behalf of the government concluded similar findings to those in the literature, i.e., that the industry still lacks certainty and clarity, and that economic, financial, cultural, and knowledge and skills factors currently remain as barriers to ZCH. Additionally, Forde et al. [52] found that financial viability was still a major barrier; there is a lack of planning policy and variations in standards across all regions in the UK, and the subsequent deregulation agenda has driven increased uncertainty in the industry. The government has now introduced some schemes to combat this issue, including the Local Net Zero Programme, which provides support to local authorities and communities by providing the building capability and capacity to meet net zero goals, as well as establishing the Local Net Zero Forum, reviewing the current National Planning Policy Framework and increasing funding towards supporting the five current Local Net Zero Hubs.

Improvements to legislation have occurred in the UK since the reviewed articles were published; the Future Homes Standard for newly built homes was introduced in 2019 to ensure that all homes built after 2025 will produce 75–80% less carbon emissions than

homes delivered under the current regulations [29]. To achieve this goal, the government introduced major building regulation changes. The building regulations have been tightened several times (in 2011, 2012, 2013, 2014, 2016, 2018, with partial amendments in 2015, 2017, and 2022) since they were rewritten in 2010. This improvement supports one of the key issues highlighted in the literature, i.e., that the continuous amendments to the legislation act as a barrier to ZCH, potentially causing more uncertainty within the industry. It is acknowledged, however, that policies and regulations must be updated and amended in response to current issues within the industry, such as the amendment to the Building Regulations: Fire Safety—Approved Document B in 2020, as a result of the Grenfell Tower tragedy. Therefore, when legislation must be amended, the government should provide clear roadmaps, along with supplementary documents, to clarify the expectations, as well as the way in which the industry must respond to these expectations, introducing these in a timely manner to ensure that the industry has sufficient time to adapt [53]. It was also suggested by Callaghan et al. [46] that perhaps the government should actively seek to involve homebuilders in the policy-making process and the development of strategies for the future. Implementing the right legislation for zero carbon new-build homes as soon as possible is important, as this will help to avoid the need for expensive retrofitting at a later date and allow the industry to more rapidly tackle the challenge of reducing emissions within the industry. The CCC has reported that amending and withdrawing key polices has led to multiple new homes being built to only a minimal standard, requiring future retrofitting [11]. Moreover, it was highlighted throughout the literature that this practice also reduced confidence within the industry regarding the standards and when they should be applied [42]. The CCC also states that since their last report in 2021, there has been some important progress regarding policies; however, it suggests that there are still significant policy gaps, and opportunities to close these have been missed; the update to the building regulations is a step forward, but it fails to address key concerns in regards to overheating and flooding [54].

Building regulations and the planning system are the government's key levers for ensuring that new buildings are built to high standards, and that risks of overheating and flooding are mitigated [54]. The CCC also recommends that financial mechanisms should be in place to support building level adaptation investment for all buildings. Moreover, other research recommends that the government should provide financing for new ZCH through the allocation of upfront grants to pioneering homebuilders taking risks in order to build ZCH ahead of the 2050 deadline [53]. It is acknowledged that there are levels of financial support currently available, but additional funding may incentivize the homebuilders not yet engaged in zero carbon construction. The government must provide incentives for investment, along with wider opportunities for job creation and local and regional regeneration similar to those of other nations, such as the USA, Germany, and France, which each have introduced investment plans to accelerate action on climate change and energy [55,56].

Further to this, The Cambridge Centre for Housing and Planning Research 2022 also suggested that there is still a lack of clarity regarding definitions of frequently used terms within the industry; for example, in regards to the statement that "all new homes should be net zero ready by 2025", there is a lack of consensus over what "zero carbon ready" actually means in regards to practice and provisions. To overcome this, they recommend that the government release an established set of definitions for the industry, defining frequently used terms. This observation is also supported through a government-commissioned independent review of net zero goals, which identified the need for clarity, certainty, consistency, and continuity from the government in regards to net zero policies [56]. Improving policies and regulations could potentially stimulate and guide the industry, as well as public behaviours and practices, toward zero carbon emission [57,58]. A government-driven injection of a sustainable scheme will help to restore confidence in homebuilders, while enhancing the way that barriers are handled within the industry.

There is currently an rising demand for the UK government to significantly increase the number of new homes being built and for these to be affordable, while meeting stringent zero carbon targets [59]. There is currently a lack of affordable high quality homes within the UK, and at the end of 2022, the government abandoned its programme for building 300,000 new homes per year, as they were not on track to meet the target or the intended benefits of the programme [60]. The challenge for the industry is to deliver affordable ZCH, but ZCH can come with high costs to homebuilders; however, the CCC argues that there are also several other low-regret, low-cost options [11]. Cost and carbon benefits are expected to accrue in the long term, but this means that there is a requirement for upfront investment for the developer. BEIS states there are still financial barriers for the industry, such as perceived increased capital costs, and additional costs are the key reason for the industry refraining from building ZCH. The BEIS case studies reviewed identified that there were indeed increased costs, but these could be reduced through leaner design and business decisions, as well as projects receiving grant funding to overcome additional costs of a project.

Economic barriers are still relevant in at the present, given that since the end of 2022, the UK economy has been stagnant [55]; the UK continues to struggle with economic growth and is yet to recover fully from the pandemic; it is also facing long-term challenges in relation to pay, skills, and investments. Additionally, several global factors, including the Russian invasion of Ukraine, have placed pressure on UK businesses and households through high energy prices and increased inflation [55]. The current rising fuel prices in the UK have meant that homeowners are increasingly conscious of the cost of heating their homes.

The RICS states that the construction industry has recovered more quickly than expected from the COVID-19 pandemic, but the UK leaving the EU has resulted in new trading barriers, contributing to higher consumer prices and a growing skills and materials shortage, as well as caused the economy to become less globally open. Brexit has also exposed further problems within the British economy, i.e., low productivity, low business investment, falling global competitiveness, and the absence of a strategy for the government to tackle these problems. Overall, this has left the industry struggling.

A shortage of knowledge and skills still presents a challenge to scaling-up the delivery of the ZCH; this includes both a shortage of skilled onsite labour and a lack of capacity regarding the whole supply chain [28]. The BEIS research determined that there is a need for improved skills and experience of teams involved in the design and construction of ZCH. Furthermore, users of ZCH stated that they did not have confidence in homebuilders, or they believed that they did not have a good understanding of these homes and systems, resulting in negative customer satisfaction. The skills gap has resulted in increased construction costs, as it is becoming harder to source skilled labour and with an aging workforce; thus, organisations need to understand the skills required for the future to help attract and retain talent, train a new generation of workers, and upskill current employees; councils can ensure that the right standards, qualifications, and training are available [60]. To ensure that targets are met, a combination of pathway training for using sustainable materials will be essential, and educators and employers will need to collaborate to equip workers with the skills they need now, as well as in the future [60]. The NHBC also recommends that the government should commit to creating at least one "construction cluster" in every part of Britain by 2030. In addition to this, there are challenges involving material costs and shortages. The NHBC states there is a major problem with material shortages within the industry, caused by a rapid rises in prices; BCIS data recorded a 22.3% rise in the cost of construction materials between 2021 and 2022, which is already significantly affecting project costs and forcing developments to downsize [61]. The government needs to take action to boost material supply chains [62].

The government states that they are committed to meeting the 2050 net zero targets, and it recognises the importance of the contribution that the energy efficiency of buildings will make in meeting these goals. It will also will continue to set minimum energy performance standards through the building regulations, ensure that the reformed planning

systems support climate change efforts and reduce GHG emissions, adopt appropriate standards, undertake an extensive analysis of the supply chain to determine its readiness to scale-up production to meet the demand for low carbon technologies, and provide funding for training and tax relief to companies investing through the Super Deduction Capital Allowance Scheme [31]. However, the current literature suggests that the UK is not acting fast enough in regards to net zero targets, and that the government is not doing enough to support the industry's transition to net zero emissions. Actions are required from government, industry, and individuals to make the most of net zero opportunities.

4.5. Discussion of the Research Limitations

This paper provides a comprehensive overview of the barriers to achieving zero carbon homes in the UK, based on a systematic literature review, but there are some limitations that should be noted. Firstly, the methodology used in this paper focuses on the literature up to 2022, but this area of research is rapidly evolving. Limiting the scope of the data has prevented a full exploration of post-2023 issues, such as the COVID-19 pandemic, Brexit, the UK's economic challenges, and the cost-of-living crisis. Therefore, more up-to-date data would help to identify any new or evolving barriers in the modern industrial context. In addition, follow-up articles could expand the scope of the analysis. The review focused mainly on the limited articles with accessible data from Scopus which were relevant to the topic, and these lacked, to some degree, answers to other questions such as why the UK's legislations has failed to meet expectations regarding net zero emissions targets. Subsequent articles could consider a wider range of literature from other sources to deepen the discussion. A more robust approach, such as the use of multiple database searches, reference list screening, and source quality assessment, would improve the quality of the findings. In any case, however, this study paves the way for understanding the barriers to ZCH and provides a pathway for subsequent more rigorous and up-to-date research.

5. Conclusions

The purpose of this research was to ascertain the barriers to delivering zero carbon new-build homes in the UK. The objective was met through the use of a mixed-method approach using both a bibliometric and systematic analysis. This paper provides a comprehensive review and analysis of the existing literature in regard to barriers to delivering ZCH, along with the identification of the current barriers within the industry.

This paper has identified several key barriers preventing the industry from developing ZCH; these are categorised as legislative, socio-cultural, economic, financial, and skills and knowledge barriers. The most significant barrier identified was the obstacle related to legislation, government policy and regulations. A key theme throughout the research was the recurring issues of the lack of clarity, certainty, and consistency regarding legislation, resulting in lower confidence levels, not just within the industry, but for the public as well. However, due to the date range of the existing literature, the studies do not necessarily provide a true representation of the current barriers and challenges the UK construction industry is facing in 2023. This paper recognised the current issues regarding Brexit, COVID-19, the economic climate, and the withdrawal of major policies, such as the ZCH policy, suggesting that these issues have created new barriers for the UK. Leaving the EU has resulted in new trading barriers, contributed to higher consumer prices and a growing skills and materials shortage, as well as made the economy less globally open. Brexit has also exposed further problems within the British economy, i.e., low productivity, low business investment, falling global competitiveness, and the absence of a strategy for the government to tackle these problems. Overall, this has left the industry struggling.

In conclusion it seems that whilst this research has found that the construction of ZCH is feasible in the UK, extensive work remains to be carried out in order to meet the government's net zero targets. The barriers identified must be overcome through a combination of interventions, such as improving and introducing new legislation and definitions; the government provision of financial incentives to both the industry and ZCH

occupants; the improvement of end-user education, awareness, and confidence; the improvement of market demand; and the improvement of collaboration and the willingness to participate of all parties involved.

Having obtained information regarding the barriers faced when building ZCH, it is recommended that further and more in-depth analyses be conducted to establish the current barriers faced by the industry, including the COVID-19 pandemic; the UK's exit from the European Union; and economic factors comprising rising fuel prices, current inflation, and the UK's cost of living crisis. As such, up-to-date research exploring new and relevant literature is required in order to gain a deeper understanding of how the UK might deliver zero carbon ready homes via the modern homebuilding industry. Additionally, it is suggested that researchers review the current legislation put in place by the UK government to assess its relevance, clarity, and viability.

As the final 20% of buildings will be constructed between now and 2050, it is essential that these are all planned, designed, and constructed at the onset to be fit for the future, requiring no significant retrofitting after 2050.

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