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Keywords	Stranded assets; real estate; environmental policy; urban evolution
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Suspect foundations: Developing an understanding of climate-related stranded assets in the global real estate sector

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The aim of this article is to introduce for the first time the topic of 'stranded assets' into research involving the built environment. It focuses on the idea that climate change policy could induce the stranding of some conventional property assets in the global real estate market. Principally, the empirical focus for study is the UK interaction with energy performance certificates and minimum energy performance standards. However, comparisons are made internationally, and key distinctions are made between developed and less developed countries. The article observes that stranded assets are not new in real estate; the changing consumer demand of occupiers has regularly rendered property assets redundant or obsolete. However, what is new is the influence of climate change and associated environmental policy on some property assets. The article deliberately combines conceptual agendas often studied in isolation. Theories of path dependence and lock-in are used to understand the problematic traction of climate change legislation within traditional real estate institutions. The implications of this situation, the potentially hidden systemic socio-economic reach of stranded assets, is then considered through the lens of contemporary debates of financialisation. Socio-technical system theory, as it relates to contemporary energy policy regimes, is then examined to connect persistent lock-in with financialised global investment markets. The article then posits how associated legislation could be used to capture a global picture of stranded assets in real estate. Revealing the stranded asset exposure should be a concern to real estate investors and those charged with managing such assets. However, more optimistically this potential risk may provide the catalyst for energy efficient transition in the built environment. The article concludes by outlining an interdisciplinary research agenda for stranded assets in global real estate.

Key words: Stranded assets, real estate, environmental policy, path dependence, financialisation, socio-technical systems, climate change.

1. Introduction

Stranded assets are assets that have, 'suffered from premature or unanticipated write-downs, devaluations or conversions to liabilities' [Caldecott, 2016]. The scope of this article focuses on the issue of climate-related risk and opportunity, primarily the under researched idea that climate change policy, as it relates to energy transitions, could induce the stranding of some conventional real estate assets in the global real estate market. The underlying research question considers,

To what extent is the global real estate market exposed to the energy policy related stranded asset threat?

Upon answering the underlying research question, the primary aim of the article is to introduce the topic of climate-related 'stranded assets' [Caldecott, 2017] into the heterogeneous global real estate asset class for the first time. Necessarily, the article is broad in nature, providing a commentary on stranded assets in the global real estate market, with the intention of acting as a staging post for a new research agenda into how environmental related risk might transpire and strand real estate assets.

The main sections set out a new conceptual agenda that, firstly, reveals and then, secondly, seeks to understand stranded assets in global real estate markets. It originally combines theories of path dependence, financialisation and socio-technical systems with energy performance labelling to reveal the nature, magnitude and reach of stranded assets in global real estate for the first time. The article then reflects on these findings to set out an international research agenda for stranded assets in global real estate research. This research agenda expands upon the initial conceptual process outlined in this article and posits some research opportunities relating to climate-related stranded assets. This section moves beyond the mostly Western European and North American perspectives in the main body to consider how a global research agenda could be meaningfully tackled with alternative methodologies and conceptual perspectives. The article then concludes by reflecting back on

the underlying research question and considers some limitations to the research.

The motivation for this research is to provide a sound basis for policy makers when governments and practice evaluate ideas for climate change transition and adaptation in the real estate sector. For those property professionals involved in the day-to-day management of real estate assets in the developed world, the article provides an approach to understanding the wider significance of climate-related threats, which we hope, will contribute to more knowledgeable and effective practice in relation to real estate–based stranded assets. Expanding knowledge in this area will help city leaders, investment portfolio and asset managers in mature urban areas deal with the challenges of adapting an ageing property stock.

However, it is also hoped that this approach will help city leaders and property professionals dealing with the demands of accelerating urbanisation in the less developed world, which requires an understanding of urban development processes and the potential impact of stranded assets. Encouragingly, less developed countries may have the potential opportunity to leapfrog climate-related stranded asset risk in real estate. This is because their built environments are often relatively younger. The fifth section argues that these locations may be able to bypass intermediary stages of urban development, avoiding the costs of adaptation, and potentially becoming leaders in sustainable property through new urbanisation and smart city development. However, in line with the arguments of Perkins (2003), the article cautions against overly optimistic interpretations of leapfrogging that ignore the context of such locations in relation to project goals, technology and institutional capacity when outlining a research agenda for stranded assets in global real estate.

Conceptually, the article also aims to demonstrate how the afore mentioned theoretical agendas, predominantly found in social science and often studied in isolation and/or in discreet locations, can be combined to shed new light on the traditional econometric and technical

perspectives found in global real estate studies and practice based investment methodologies in a novel way.

2. Theoretical perspective

In order to answer the research question, and in part response to the call of Eames et al, (2017) for more cross-transfer of learning and multi-disciplinary research in sustainability transitions, the article links research in energy policy and built environment retrofit to introduce the stranded asset issue. It then strategically combines conceptual agendas seen in the respective path dependence, financialisation and socio-technical system fields to reflect upon this situation.

The article situates the emerging stranded assets literature with theories of path dependence and lock-in developed in economic geography to understand the impact of climate change legislation within traditional real estate institutions and the persistent silence of stranded assets. During the early 1990s path dependence was introduced as a new alternative to the orthodox neo-classical economic perspective based on optimisation and equilibrium (Henning et al, 2013). Concurrently, it also took route in the history of technology field. Arthur (1989) separated the economics discipline into 'conventional' economics that did not recognise historical contingency and 'contemporary' economics which embraced path dependence and evolution (Henning et al, 2013).

The latter perspective emphasises that decisions are not only influenced by present conditions but also include decisions that have been taken previously. These interpretations are now widely used within the retrofit and energy transition literature (see Dixon et al 2018) to understand how socio-technical systems and regimes endure and are potentially disrupted. This article uses Grabhers (2003) treatment of the issue to understand how political, functional and cognitive forms of lock in coalesce to strand assets in real estate practice.

The article then reflects on the systemic socio-economic reach of stranded assets through the lens of contemporary theories of financialisation developed in urban studies. Fields (2018:119) recently

defined financialisation as 'an idea that has taken hold as a means of understanding the distinctive role of finance in contemporary capitalism, and its influence on space, the economy, governance and everyday life.' In recent decades, the financialisation literature has emerged as a powerful medium for understanding how assets are securitised and then invested through international capital markets. For example, Weber (2015) has investigated the Tax Increment Finance agenda in North America, Aalbers (2012) has investigated the international mortgage securitisation market and the sub-prime mortgage fallout, while Gotham (2017) has considered disaster relief funding. More recently, Fields (2018) and Beswick and Penny (2018) have examined housing finance and local asset backed vehicles, while Christophers (2019) has started to think about how institutional investors think about fossil fuel risk. However, as Fields (2018) argues, the process of financialisation is often poorly understood and utilised as an explanation in itself without any investigation into how the process of financialisation occurs

In response to this criticism of financialisation, the article then moves on to examine contemporary energy policy and how associated socio-technical legislation could be used to capture a global picture of stranded assets in real estate, connecting the persistent behaviour of practice that ignores stranding into the global capital markets that are implicit in financialisation. This examination responds to the earlier critique of Fields (2018) but also by investigating energy performance certificates and associated legislation, that of Latour (1999) in to 'black boxing' technical artefacts that, due to their success, are often ignored by social science research (Swan, 2013).

Drawing on the work of [De Greene , 1973], [Eames et al, 2013] and [Dixon et al, 2018], energy performance labelling is considered an example of a potentially global integrative socio-technical regime or system connecting society's complex technical procedures (building design) with human behaviour (building use). In this article, a socio technical regime is considered 'a shared set of rules and routines embedded in socio-technical systems to ensure that they can provide the

relevant social function' (Schot et al, 2016:16061). While the closely related socio-technical system rests upon the, 'premise that social and technical systems are co-constituted and co-evolve across time and space' (Lowe et al, 2017:5). Geels (2005:5) suggests that socio-technical systems display the following characteristics in society, 'technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and producing systems.' In this sense, it is also important to note that real estate markets, the process of financialisation and global investment markers can also be considered socio-technical systems themselves within a complex adaptive system.

The energy labelling system functions as a method for understanding society's energy use, and through consequent minimum energy performance legislation, how such use can be monitored and improved. However, the same regime system has the potential to hardwire and connect valuation risk into global capital markets. In this sense, EPCs and associated minimum energy rules prime already financialised real estate assets (for example through international mortgage markets, Real Estate Investment Trusts, Unit Trusts and Property Companies) for stranding. EPCs, in this sense, play the dual role of conceptually connecting lock-in with financialisation but also, empirically, the potential role of capturing the magnitude of the stranding issue in global real estate. Therefore, the nature of the research is part conceptual, in setting out a framework for understanding stranded assets and part empirical in using energy performance certificates to capture the size of the stranded assets threat.

In this paper, real estate is taken to mean, broadly, all residential, commercial, and operational property. This is a broad characterisation that is used to help reveal the stranding problem in global real estate. The authors concede that this definition simplifies the inherent variability found within respective real estate assets and return to this issue at the end of the article in suggesting opportunities for further research. Principally, the focus for study is the UK; however, comparisons are made internationally, and key distinctions are made between developed and less developed countries.

The authors note that the traditional binary distinction between developed and less developing countries is problematic, certainly over simplifying the rich diversity of characteristics found within and between each relative classification. Indeed, the World Bank dropped the categories 'developed' and 'developing' from its economic vocabulary in 2016. Instead, the authors use the broad distinction of 'developed' and 'less developed' to compare the relative maturity of built environments in such locations, rather than making any assumptions about the respective locations economic or social capacity. The authors then revisit this distinction at the end of the paper suggesting alternative measurements and perspectives as a rich opportunity for further study.

3. Climate change and nature of real estate markets

The article observes that stranded assets are not new in real estate, as the changing consumer demand of occupiers has regularly rendered property assets redundant or obsolete – exhibiting the creative destruction outlined by Joseph Schumpeter in 1950. However, what is new is the influence, systemic reach and disruption of climate change and associated environmental policy on some property assets, related capital markets (at the macro scale) and individual communities (at the micro scale) that are reliant on homes to live, and commercial property to work.

At the same time as the global emphasis on sustainability, the international real estate sector is going through its own set of structural growing pains in response to dynamic changes in residential and business practices – potentially coalescing with and exacerbating the climate-related stranded asset issue. For example, the appetite for smaller commercial floorplans in the office sector, the impact of the internet on the retail sector, and the disruptive influence of new property technology on conventional real estate living and working conditions have all increased uncertainty in the global real estate market.

In response to climate-based threats and associated environment policy, there is now pre-emptive need for new arrangements of land, unconventional forms of buildings, and creative adaptations to the

existing property stock to combat the threat of devaluation [Wilkinson et al, 2107], [Eames et al, 2017]. However, at the same time, there are several opposing forces that make pre-emptive action involving energy-efficient retrofit measures (or new sustainable construction) difficult in the developed world. Grabher's [1993] treatment of path dependence and 'lock-in' is a suitable analytical framework to understand this situation. Setting aside the sheer cost involved in adapting real estate assets in the face of climate change [Eames et al, 2017], path dependence and lock-in is concerned with the persistent behaviour of people, society, business, and locations as they maintain and reinforce historical behaviour in contexts that are significantly different to the original historical circumstances [Henning, 2013]. Grabher [1993], researching in the field of regional economics, describes three interrelated types of 'lock-in': political, functional, and cognitive lock-in. These same constructs can also be used to help explain the existence and silence of stranded assets in global real estate debate and practice and some of the drags upon retrofit in the built environment.

Political lock-in explains circumstances in which traditional courses of development are retained and reinforced by pre-existing stakeholders and institutions, inhibiting adjustment to new considerations and policy directives. Bishop and Williams[2012] and Henneberry [2017:1–2] illustrate this situation when they argue that cities in the developed world have gradually become more 'formalised and permanent'. Proliferating layers and intensities of legislation '(some with a long history but most introduced in the 20th Century) covering building construction, fire prevention, public health, building conservation and land use planning have solidified the urban built environment'. This echoes the recent work of [Dixon et al, 2018], who see individual cities, as a complex mix of homes and businesses, and the product of many hundreds of years of evolution and growth that become locked into patterns of resource use that can no longer be justified. This intransigent situation makes it more difficult for the existing built environment to change. This is subsequently later compounded by the slow replacement of real estate stock (IRENA,

2017) which typically only accounts for 1-3% of stock per year (Zhenjun et al, 2012; Eames et al, 2013;Itani et al, 2013).

Cognitive lock-in relates to collective ideas and beliefs that inhibit the acceptance of new ideas – overlaying physical rigidity in the built environment is a climate of institutional inertia. Muldavin [2010] argues that although important steps have been taken, the real estate sector is struggling to confirm the value of sustainability in property investment. Although there have been amendments made to the RICS Red Book [2013], alongside a Guidance note on Sustainability and Commercial Property Valuation [2014], it has been difficult for the traditionally sluggish real estate sector to take on board sustainability objectives. Primarily, this is because there has been no demonstrable enhancement to return [Dixon, 2014]. This is because the imperfect implications of stranded assets – implicit in sustainable development – are very awkward for mainstream real estate research to digest. Traditional paradigms in real estate economics and related practice, for example the valuation of property, and modern portfolio theory are anchored in the maximising presumptions of the rational investor. It is not straightforward to capture the cost or potential premium afforded by sustainability, as valuation is typically backward looking based upon retrospective property valuation [Diaz and Hansz, 2001]), resulting in a lack of scrutiny by valuation professionals [Lützkendorf and Lorenz, 2005], [Lorenz and Lützkendorf, 2011], [Michli et al, 2016]. Similarly, real estate investors make decisions and monitor progress against historical performance benchmarks and indices, such as those provided by the Investment Property Databank (IPD) and CB Richard Ellis.

Functional lock-in, in this case, relates to the too-close connection between historical building functions and worth, which inhibits consideration of external change. Illustrating this situation in the real estate sector, the common treatment has been to situate the analysis of stranded assets in the depreciation and obsolescence literature. There is a variety of informative applied depreciation studies by [Baum, 1991], [Baum and McElhinney, 1997], [Dixon et al, 1999] [Dunse and Jones,

2002], [Andrew and Pitt, 2006], [Crosby and Devaney, 2006], [Mansfield, 2009], and [Crosby et al, 2011]. However, broadly speaking, in this perspective functional real estate assets grow old, become less productive, and must then be improved or replaced. Through this process, loss of value occurs gradually in a typically linear fashion related to the original function of the building rather than under external conditions of sudden market disruption [Christensen, 1997].

On one hand, the potential stranded asset threat, initially associated with value of unburnable carbon stocks [Krause, 1990], [Carbon Tracker Initiative, 2013] and more recently following the Paris Agreement [Covington, 2013], has the potential to blow this market lethargy wide open. This is because, until now, sustainability has mostly been seen as an altruistic choice or government concern associated with environmental objectives rather than business necessity. On the other hand, traditional real estate valuation methods are still based on the most recent comparable transaction advice rather than any forecast of sustainability value or fossil fuel liability, resulting in a stranded asset knowledge deficit. Illustrating the consequences of this situation, [Warren-Myers, 2012] argues that without confirmation of environmental value, sustainable investment (or fossil fuel disinvestment) will be constrained in the real estate sector. The next section, in part, aims to fill this gap in knowledge by connecting impact of path dependence and persistent behaviour into global capital markets through the process of financialisation.

4. Stranded assets and the global real estate market

The following section brings forward the path dependent traditions in real estate practice and connects this into the financialised reality of global real estate investment markets. This is in order to reveal the potential gravity of stranded assets but also to show how ingrained practices in real estate have the potential to create risk in global capital markets. In recent years, climate-related stranded assets have received international attention from the UN [McGrath, 2014], the North American government [Friedman, 2014], the OECD [Gurría, 2013], the

Inter-American Development Bank [Caldecott, 2016], the G20 Financial Stability Board, and the Bank of England [Carney, 2015]. However, the same issue has received very little attention in the real estate sector [IRENA, 2017 is a notable exception), even though the real estate sector shares and potentially intensifies many of these same risks downstream. Given that real assets make up a large part of total global investment worth and are a significant store of national, corporate, and individual wealth, the omission of real estate from the stranded assets discourse is a significant omission.

Traditionally, real estate assets share many of the same imperfect investment characteristics as fossil fuel assets in relation to liquidity, fungibility, and transmission of potential risk. For example, both assets classes are heterogeneous, typically, no two assets are the same and they take considerable initial investment to exploit, there are few buyers and sellers in the market place (due to cost and location), market entry and exit is difficult (due to ownership monopolies, the illiquid nature of assets, and government legislation), and both types of asset are typically fixed in location (either under it or built on top of it).

The respective asset classes are also interrelated. Traditionally, residential and commercial property assets have been powered by fossil fuel–dependent heating and ventilation systems. Furthermore, the urban sprawl associated with suburban residential property, out-of-town office parks, and retail centres, has evolved in tandem with the fossil fuel–based automobile. There is also a distinct and highly expensive set of operational property assets that has been constructed to directly serve the fossil fuel sector, for example, coal-fired power stations, which are typically highly leveraged (exposed to debt finance) and have no obvious alternative use [IRENA, 2017].

The global value of real estate is $217 trillion (of this $162 trillion dollars is residential, $29 trillion dollars is commercial and $26 trillion is agricultural land), roughly 2.7 times global GDP, making up roughly 60% of all mainstream investment assets [Savills, 2016]. Furthermore, the value of the new construction market will be $17.5 trillion in 2030, an $8

trillion increase on present-day values [Oxford Economics, 2015]. In large part, the volume of real estate assets in global investment portfolios and the circulation of the same assets in international capital markets is down to increasing levels of financialisation outlined in recent years by [Weber, 2010], [Aalbers, 2017], [Christophers, 2017] and [Fields, 2018].

Hitherto, stationary physical real estate assets have been increasingly repackaged into a rash of financial products and funds, including derivatives, real estate investment trusts, and debt vehicles. This process has been intensified during periods of political and fiscal uncertainty because real estate has increasingly replaced Government Bonds as a provider of fixed income in investment portfolios. This has expanded the tentacles of property asset value throughout global finance networks. The implication is that stranded real estate assets provide a vehicle for intensifying the threat of climate-related stranded assets because they reach further into and have broader exposure in capital markets than fossil fuels assets. Look no further than the 2008 global financial crash for an illustration of the sudden impact and systemic influence of real estate based financial products. Despite sustainable intervention, including enhanced insulation, better glazing, and utilising solar power and biomass, global property stock is still reliant on fossil fuel for heating and ventilation. This perspective sheds a new light on contemporary debates of financialisation that typically analyse the creation of new asset classes. This article looks at a product, global real estate, which has been financialised for many decades and considers how this previously relatively stable system is at risk of disruption.

The following section utilises the outputs of international building energy performance legislation to outline a model for understanding climate-related stranded asset exposure. The same legislation and EPC regime is also the conceptual bridge that connects path dependence into the financialised global real estate market.

5. Climate-based real estate legislation

Global real estate is essential for urban development. However, it expends physical resources and is the origin of considerable emissions. A conservative estimate is that global real estate consumes 40% of global energy annually and accounts for more than 20% of international carbon emissions [World Economic Forum, 2016]. As part of international efforts to reduce carbon emissions, real estate and its associated built environment has been identified as a major contributor toward planetary warming [IPCC, 2014]. For example, the UK government aims to reduce UK real estate CO2 emissions to close to zero by 2050 to attain its energy-efficiency targets. This aim has been repeated around the world and is an example of an attempt at a socio-technical system transition.

Consequently, in recent decades, the real estate sector has been at the forefront of climate change legislation, designed to reduce its impact on the global environment. Environmental labelling, endorsement based and comparative [Reed et al, 2009], has been a central tool in reducing the environmental impact of building stock. Typically, environmental labelling has adopted either a multi-criteria sustainability approach or a narrower focus on energy [Sayce et al, 2010]. In the 1990s, the BREAAM1 tool led the way in the UK (multi-criteria), soon to be followed in France by the HQE2 model (multi-criteria), the Swiss Minergie3, and the North American Energy Star4 (both energy). In the 2000s, these models were joined by further multi-criteria schemes, LEED5 (North America), CASBEE6 (Japan), Green Globe7 (Canada), and Green Star8 (Australia).

Latterly, one of the most comprehensive approaches can be seen in the European Union (EU). Following the 2010 EU Energy Performance of Building Directive, it is mandatory for all European properties to hold an Energy Performance Certificate and monitor their heating and air conditioning (all 28 Member States signed up to this directive). Energy Performance Certificates (EPCs) have a significant relationship with climate-related stranded assets in real estate. They are a key enabler of building improvement, as they have the potential to influence decision

making in real estate transactions and provide cost-optimal recommendations for energy performance improvement [BPIE, 2014]. They provide the opportunity for governments to enforce minimum energy performance standards, and they are an important information tool for building owners, occupiers, and real estate stakeholders. These latter two themes form the basis for the remainder of this section. Firstly, the potential for climate-related legislation to strand real estate assets will be considered, before, secondly, the information bi-products of energy performance labels will be assessed for their potential in measuring stranded asset exposure.

5.1 Climate-related obsolescence

The England and Wales government has used EPCs as the basis for legally enforceable Minimum Energy Efficiency Standards (MEES), legislated through the Energy Efficiency (Private Rented Property) (England and Wales) Regulation Act 2015. These regulations have fixed a minimum standard for both domestic and non-domestic privately rented property. Commencing in April 2018, any domestic or non-domestic property that is available to let with an energy performance rating below E (those properties with F and G ratings) has been deemed illegal to let – in 2020, the same rule will apply to residential property. In England and Wales, it is estimated that 10% of residential property stock (£570bn) and 18% (£157bn) of commercial stock are under this threshold. In addition, the Government in England and Wales is also considering the merits of committing to a forward plan for MEES. This would mean that the minimum energy performance regulatory standard is increased over time in order to provide medium - to long-term certainty regarding when the progressive standards will apply and when any necessary physical improvements will need to be made [Department of Energy and Climate Change, 2014].

From 1 April 2023, these regulations will apply to all non-domestic property, not only those agreeing a new let, lease renewal if an EPC is already in place, or tenants wishing to sublet [Green Construction Board, 2014], [The Non-Domestic Minimum Building Energy Performance

Standards Working Group, 2014]. Failure to meet these new rules, for example, the illegal letting of a sub-standard property, will result in a minimum fine of £150,000. There are several potential exemptions to MEES, primarily:

- Any building improvement that would alter the character or appearance of an historical (in a conservation area) or listed building,
- Where energy efficient improvements would reduce market value by more than 5%,
- The improvements do not pay for themselves through energy cost saving within a seven-year time frame,
- If the landlord cannot get consent from planning authority or incumbent tenant,
- Temporary buildings and detached buildings under 50 sqm.

To protect against MEES avoidance techniques, all exemptions must be held on an Exemption Register. The implication is that any sub-standard building will still be publicly named and shamed and may suffer yield and value depreciation. The MEES in England and Wales indicates a potential future trajectory for international property legislation, in which governments tighten up on building emissions in order to achieve climate change targets. Using the minimum energy exposure figures in England and Wales as a proxy for international energy policy and combining them with the recent estimate of global real estate value provided by [Savills, 2016], it is possible to gauge global real estate exposure to climate-related stranded assets. If all international governments followed the same strategy, the risk value for residential real estate property assets would be $16 trillion and $5 trillion for global commercial assets.

However, the introduction of MEES has not been without difficulty. Potentially 70% of EPC ratings in England and Wales could be incorrect (either too low or too high) due to the inconsistent quality of assessments [Hobbs, 2013], [Hosgood, 2014] and the evolving nature of the underlying

method of calculation (the Simplified Building Energy Model – SBEM). Furthermore, the government has abandoned the flagship finance mechanism that accompanied MEES in the residential sector, the Green Deal Finance Model, and it was never introduced for commercial property. The consequence is that the England and Wales Government has sent out a very strong policy signal in favour of building improvement but has removed the primary financial means of doing so.

5.2 Exploiting climate change legislation to create an information baseline for real estate stranded assets

The first stage in tackling climate-related stranded assets in the real estate sector must be identifying their existence. IRENA [2017] have proposed an ambitious methodology for assessing the global real estate stranding asset exposure. The method utilises estimates of existing floor space, forecasted new building space, and natural demolition rates to quantify for the first time climate-related stranded assets in building stock, the impact of delayed policy action, and the cost of retrofitting sub-standard properties in response to climate-related policy action. The method lays important foundations for studying the impact of fossil fuel–related stranded assets in the real estate sector, for the first time linking the upstream fossil fuel sector into downstream real estate assets. However, due to the lack of information transparency in the real estate sector [Fuerst et al, 2011], IRENA [2017] concede that the method rests on a number of necessary estimates and presumptions and utilises a broad econometric methodology. There is considerable scope to build on this method with more detailed data sets, information resources and conceptual enquiry found in the social sciences.

The granularity and scope of the IRENA model could be significantly enhanced by using already-existing energy labelling information. For example, the mandatory EPC information held in the EU Building Stock Observatory and English and Wales EPC registry could be used to provide accurate accounts of energy use, floor space, building retrofit advice (and cost), type of property, and location. This could then be augmented with more information from the Building Performance Data Base in North

America and the National Australian Built Environment Rating System. In principle energy performance labelling provides an opportunity to accurately measure climate-related stranded asset exposure in the developed world. However, information is less readily available in the less developed world. Those areas of the world with less transparent property markets, for example China (the Three Star Rating Building System) and South America (for example the RTQ-C and RTQ-R methodologies in Brazil), are increasingly adopting building energy performance standards, which reveal the opportunity for comprehensive international energy performance data bases in the future.

Information generated from mandatory EPC assessments could be taken further. Issues of consistency and accuracy (a problem shared with the wider real estate market) significantly hamper meaningful assessment of stranded assets and energy performance in real estate stock. Increasingly, contemporary real estate data sets include Unique Property Reference Numbers (UPRN). UPRNs enable the linking of disparate data sets to provide more powerful, multi-criteria data sets and provide a consistent identifier throughout the building life cycle – from initial planning consent to final demolition. However, EPCs do not carry a requirement for a UPRN; this is a missed opportunity. For example, in England and Wales, the presence of a consistent UPRN would enable the linking of EPC information to National Valuation data sets. Each property in England and Wales is valued every five years for taxation purposes; linking both data sets would facilitate accurate measurement of energy use, floor space, and value and would assist, in part, the measurement of real estate–related stranded assets exposure to government revenues. Most developed countries typically derive some of their taxation from property, indicating the international potential for this coupling. This would potentially lead to a socio-technical energy performance baseline, which could be used to benchmark and monitor the risk of climate-related stranded assets and more generally the value of sustainability – it could also be used to potentially police transition through taxation. This would be an important innovation, as it would increase the overall quality

of property valuation by integrating carbon into statutory methods of property valuation.

6. Developing a stranded asset research agenda in global real estate

The first challenge for global real estate stakeholders, their professional bodies and academics is in connection to the recognition of climate-related stranded assets. This, in part, involves creating the informational baselines that reflect the existence and cost of stranding – a methodology has been outlined in this article. It also necessitates going beyond technical and atheoretical concepts of building energy to consider how EPCs and associated legislation can be an important conceptual device for connecting disparate academic agendas. An initial informational baseline only provides a broad measurement of climate-related stranded asset exposure in parts of the global real estate market. Research into stranded assets in the global real estate markets demands an international perspective and potentially a different set of methodologies and research techniques.

This article has strategically blended theories of path dependence, financialisation and socio technical systems in order to understand and reveal the stranded asset issue in global real estate. These theories are traditionally studied in isolation. However, this tactic has been necessary to reveal the global issue that may not have been possible through prescribed single case study, econometric or technical research. The authors argue that further blending of multi-disciplinary conceptual domains will be necessary to understand the variable contexts of stranded assets.

In particular, these new perspectives should be cognisant of the very different and often variable contexts in the developed and less developed world. Real estate, as it relates to energy use, in the less developed world, particularly in rural locations, is diverse – influenced by variation in population size, economic activity, resource levels, and energy profile. Due to the rapid nature of development in these locations, there is also a congested policy landscape, which makes focusing on climate-related

stranded assets problematic. Not least, the thorny subject of whether such locations should face the same stringent climate standards as the developed world when they have not had the opportunity to exploit the economic growth associated with fossil fuel use. In contrast, physical real estate development and supporting professional practice is well established in the developed world, anchored in rigid functionality and institutions – due to the age of the built environment.

Such regions can have key geographical features, which aid fossil fuel divestment in real estate. For example, generous space and excellent access to sunlight has the potential to aid the exploitation of wind and solar energy (in contrast, energy use retrofitting in the western world is exacerbated by less proximity to natural resources). This resource landscape is particularly advantageous in those locations – for example rural India – where it is difficult or unduly expensive to develop fossil fuel infrastructure or to interface with a national energy grid. This awkward situation is primarily related to the sheer logistical challenges associated with expansive and unforgiving locations and/or the paucity of capital finance.

The stranded asset situation in the less developed world also needs to be understood in the context of vastly differing circumstances. For every exemplar self-contained smart city, for example Masdar City (in the United Arab Emirates) or the Songdo International Business District (in South Korea) – exhibiting high-tech digital infrastructure, carbon-neutral buildings, green urban planning, and abundant capital finance – there are many more largely rural locations, for example Xinjiang Province in China and Bihar State in India, exhibiting marginal and fragmented locational attributes. They are quite literally operating off the conventional energy grid and outside conventional fossil fuel infrastructure routes. In these locations rather than overarching conceptual and empirical methods, such as those deployed in this article, more situationally specific enquiry may be suitable, for example case study and ethnographic enquiry. Concurrently, it is not a given that smart city developments are necessarily also clean in the energy sense. Consideration should be given

to whether developments of this nature compliment energy directives and sustainability requirements.

However, all these locations, broadly, are united by rapidly increasing levels of population and concurrent energy demand, which has put these locations on a rapid energy provision trajectory. Understanding this trajectory provides a potential opportunity to minimise climate-related stranded assets through leapfrogging before they happen whilst achieving the decarbonisation agenda [IRENA, 2017]. This is possible because large amounts of the built environment in less developing locations has not been constructed yet. However, this research needs to be approached critically, recognising that leap frogging is not a given and is contingent upon the technology available for investment; relative skills and institutional capacity; and, most importantly, political stability and will (Perkins, 2003). Indeed, Perkins (2003:) argues, "national governments will need to challenge entrenched domestic and foreign interests whose preferences lie, to a greater or lesser extent, along a business as usual path".

To support this more critical approach, the authors suggest additional engagement with conceptual domains that interrogate emerging governance profiles in such locations; that seek to understand relative and emerging skill and institutional capacities, for example as they relate to creating an energy performance regulatory framework. This would be complemented by research that moves beyond simple binaries of developed and less developed counties in order to utilise more precise alterative measures such as the United Nations Human Development Index and that acknowledge the socially produced uniqueness of distinct real estate markets (Guy and Henneberry, 2000). This multidisciplinary approach to researching stranded assets in real estate will help investigate the following key questions in relation to mitigating and reversing stranded assets.

The global real estate sector is hugely disparate – how might climate-related stranded assets be more or less important for different types of societies, geographies and heterogeneous property assets. This article

has broadly discussed global real estate, merging residential and commercial property into one bulk class. In reality, these two asset classes are completely different and should be considered as two separate areas for study. Small individual investors with relatively small financial stakes - many of which have the potential to avoid the legislative radar, dominate the residential real estate sector. How will the costs of retrofit, and the likely increase in rent, be balanced against a concurrent demand for low cost housing demand. In contrast, commercial real estate is typically owned by companies, conglomerates and investment bodies who have a much larger financial stake and corporate social responsibility.

This critical approach also has the potential to help uncover the relationship between the normal refurbishment cycle of property and the problem of stranding. Although the building replacement cycle is notoriously sluggish, the occupation of buildings, particularly in the commercial sector, is increasingly dynamic and short-lived. Could the new era of short leases and increased opportunity for landlord/tenant negotiation at lease renewal help ameliorate the problem of climate-related stranding?

The approach will also help examine what the evolution of urban locations tell us about the trajectory and potential amelioration of stranded assets. New understanding in this area could help inform intervention and so-called leapfrog development in the less developed world before fossil fuel dependency is ingrained. Moreover, it can help uncover which countries are pursuing minimum energy measures in the developed world. For example, how many of the 28 European Union Member States have laid down legislation to achieve this aim. This research agenda could also help inform how considerations of sustainability, in particular it's pricing, could be aligned with the problem of stranded assets. Part of this must involve understanding which parties will be paying for the retrofit challenge and where they will get the funding from. Nothing will happen with stranded assets unless the money is available to do the retrofit improvements. Outlining the cost risk of

stranded assets in this paper, helps justify this expenditure. Finally, this new research could help consider, what other factors (besides environmental legislation) cause stranding in global real estate markets. For example, do certain types of property, markets, and locations have systemic risk because of their underlying characteristics.

7. Conclusion

In response to the underlying research question,

To what extent is the global real estate market exposed to the stranded asset threat?

The article has combined conceptual agendas in path dependence theory, financialisation research and socio-technical system studies to reveal a potential risk value for residential real estate property assets of $16 trillion and $5 trillion for global commercial assets. The relatively novel engagement with the path dependence and lock in literature proves that history and 'how we got where we are' is important in understanding global real estate markets, built environments and related institutions. Indeed, our research suggests that traditional ways of working are locked into regressive valuation methodologies and that this, in part, accounts for the silence afforded to stranded assets in real estate practice. Socio-technical system theory has then been used to show how Energy Performance Certificates and associated Minimum Energy regulation, have the potential to hardwire and connect valuation risk into global capital markets. Concurrently, the informational bi-products of Energy Performance Certificates have been used to reveal the potential magnitude of stranded assets.

The utilisation of financialisation as an overarching catalysing concept in global capital markets has then helped connect the property practices and techniques in the global real estate market. This research has revealed a new global asset risk in parts of global real estate that have been financialised for many decades. This presents a new emphasis for financialisation research. Contemporary research typically focuses on newly financialised assets. For example, Weber (2015) and Fields (2018)

have revealed new asset classes recently – primarily related to Tax Increment Finance and Single Family Rental assets. This research reveals what may happen to newly financialised products further down the line following disruption and reconfiguration.

The article argues that exposing the stranded asset threat could play a positive role in provoking the disruptive sustainable urban retrofit proposed by Dixon et al (2018). Connecting the "what is needed with the how it can be implemented" at the global level. Attitudes could change very quickly following the 2018 minimum energy performance legislation in England and Wales (and similar minimum energy performance initiatives elsewhere in the world). It can be speculated that rapid devaluation in certain property assets could ensue if the legislation is robustly enforced. If revaluation is significant in size and speed this could affect values and behaviour in other international markets, in particular, those areas with similar property stock characteristics in terms of vintage, heating, ventilation and air-conditioning, and construction type.

Adapting theories of lock in and then echoing the recent arguments of [Silver, 2016], there are two not necessarily mutually exclusive explanations for the silence of climate-related stranded assets in global real estate markets. First is that the real estate market has digested the stranded asset threat and decided that environmental legislation will be sufficiently diluted that climate-related stranding will not impact global real estate assets. In other words, real estate stakeholders believe that the lobbying power of private and public capital held in global real estate and the force of the fossil fuel sector will win out against the climate change consensus. Under this position, significant policy related change 'just won't happen'. Indications in the early part of 2019, the time of writing, indicate that this maybe the case with little early enforcement of the minimum energy rules. Second, the institutions and traditional 'ways of working' in the real estate market are largely blind to the stranded asset threat, locked in to traditional ways of working – they simply do not account for it.

Both positions are untenable, as they leave real estate assets, and the investors and communities they serve, prone to an uncertain future. Adopting the principles of Pascal's Wager, it is rational to plan for potent climate-related policy enforcement. Adapting existing buildings and constructing new developments that are not reliant on fossil fuels, although potentially costlier in the short term, can create a more resilient (and therefore valuable) asset. Ignoring climate change exposes physical real estate assets to the risk of permanent disruption as clean technology becomes more affordable, as social norms and consumer behaviour increasingly accept principles of environmental sustainability, and as investment managers and financiers increasingly demand that companies disclose business model exposure to climate change.

However, in order to begin to understand climate-related stranded assets in global real estate, it is necessary to qualify the research in this article. The wide urban context of the international perspective reveals the need for some cautionary words in relation to the context and content of the findings and conclusions in this article. The empirical approach has necessarily been one of broad review rather than detailed analysis. Moreover, our definition of real estate in this article is simplifying in its approximation – consequently, we must be careful of over-generalisation and simplification. Each international property market contains a variety of comparable but highly specific contexts, which are contingent and socially produced in each case. Furthermore, there are multitudes of factors involved in real estate obsolescence; only one of these is the climate-related stranded assets. Energy policy is only one part of a complex web of actors, interests, and relations, particularly developers but also investors, occupiers, and members of the community who are either directly or indirectly involved in the production and reproduction of global real estate assets. A great deal more research will be needed to fully understand the specific and variegated nature of climate-related stranded assets in the international context.

Yet despite these caveats, we consider that the material within provides a perspective through which a picture of climate-related stranded assets

in global real estate begins to emerge. In the energy sector, the aim of legislation is to reduce fossil fuel consumption by leaving existing assets in the ground and halting the development of new ones. However, the impact of energy policy on global real estate assets is different. The aim of legislation is to improve the quality of property and reduce its negative impact upon the environment. The implication is that those existing properties reliant on fossil fuels will need to be improved in order to meet the needs of continued urbanisation – such properties cannot just be written off as a loss as they would be in the fossil fuel sector. Illustrating the magnitude of this retrofit challenge, at the turn of the millennium, [Kincaid, 2002], referring to the UK, argued that the vast majority of 2050 property stock had already been built (some of it centuries ago in mature urban locations). Reinforcing this argument, [Kelly, 2008] indicates that 87% of current stock will still be standing in 2050. In other words, developed nations must go back to the future to solve the climate-related stranded asset problem through adaptation and retrofit. Conversely, less developed nations may have the opportunity to skip real estate asset fossil fuel dependency in order to define their own future.

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1 BREEAM (Building Research Establishment Environmental Assessment Method), first published by the Building Research Establishment (BRE) in 1990, is the world's longest-established method of assessing, rating, and certifying the sustainability of buildings.

2 The Haute Qualité Environnementale or HQE (high-quality environmental standard) is a standard for green building in France, based on the principles of sustainable development.

3 Minergie is a registered quality label for new and refurbished low-energy-consumption buildings. This label is mutually supported by the Swiss Confederation, the Swiss Cantons, and the Principality of Liechtenstein along with Trade and Industry.

4 Energy Star (trademarked ENERGY STAR), originating in North America, is an international standard for energy-efficient consumer products that can be applied to residential and commercial properties.

5 Leadership in Energy and Environmental Design (LEED) is one of the most popular green building certification programs used worldwide. Developed by the non-profit U.S. Green Building Council (USGBC), it includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods.

6 Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is a method for evaluating and rating the environmental performance of buildings and the built environment.

7 Green Globes is an online green building rating and certification tool that is used primarily in Canada and the United States. Green Globes was developed by ECD Energy and Environment Canada, an arms-length division of JLL. Green Globes is licensed for use by BOMA Canada

(Existing Buildings) and the Green Building Initiative in the United States (New and Existing Buildings).

8 Green Star is a voluntary sustainability rating system for buildings in Australia. The Green Star rating system assesses the sustainability of projects at all stages of the built-environment life cycle. Ratings can be achieved at the planning phase for communities, during the design, construction, or fit-out phase of buildings, or during the ongoing operational phase.

Suspect foundations: Developing an understanding of climate-related stranded assets in the global real estate sector

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Suspect foundations: Developing an understanding of climate-related stranded assets in the global real estate sector

Abstract

The aim of this article is to introduce for the first time the topic of 'stranded assets' into research involving the built environment. It focuses on the idea that climate change policy could induce the stranding of some conventional property assets in the global real estate market. Principally, the empirical focus for study is the UK interaction with energy performance certificates and minimum energy performance standards. However, comparisons are made internationally, and key distinctions are made between developed and less developed countries. The article observes that stranded assets are not new in real estate; the changing consumer demand of occupiers has regularly rendered property assets redundant or obsolete. However, what is new is the influence of climate change and associated environmental policy on some property assets. The article deliberately combines conceptual agendas often studied in isolation. Theories of path dependence and lock-in are used to understand the problematic traction of climate change legislation within traditional real estate institutions. The implications of this situation, the potentially hidden systemic socio-economic reach of stranded assets, is then considered through the lens of contemporary debates of financialisation. Socio-technical system theory, as it relates to contemporary energy policy regimes, is then examined to connect persistent lock-in with financialised global investment markets. The article then posits how associated legislation could be used to capture a global picture of stranded assets in real estate. Revealing the stranded asset exposure should be a concern to real estate investors and those charged with managing such assets. However, more optimistically this potential risk may provide the catalyst for energy efficient transition in the built environment. The article concludes by outlining an interdisciplinary research agenda for stranded assets in global real estate.

Key words: Stranded assets, real estate, environmental policy, path dependence, financialisation, socio-technical systems, climate change.

1. Introduction

Stranded assets are assets that have, 'suffered from premature or unanticipated write-downs, devaluations or conversions to liabilities' [Caldecott, 2016]. The scope of this article focuses on the issue of climate-related risk and opportunity, primarily the under researched idea that climate change policy, as it relates to energy transitions, could induce the stranding of some conventional real estate assets in the global real estate market. The underlying research question considers,

To what extent is the global real estate market exposed to the energy policy related stranded asset threat?

Upon answering the underlying research question, the primary aim of the article is to introduce the topic of climate-related 'stranded assets' [Caldecott, 2017] into the heterogeneous global real estate asset class for the first time. Necessarily, the article is broad in nature, providing a commentary on stranded assets in the global real estate market, with the intention of acting as a staging post for a new research agenda into how environmental related risk might transpire and strand real estate assets.

The main sections set out a new conceptual agenda that, firstly, reveals and then, secondly, seeks to understand stranded assets in global real estate markets. It originally combines theories of path dependence, financialisation and socio-technical systems with energy performance labelling to reveal the nature, magnitude and reach of stranded assets in global real estate for the first time. The article then reflects on these findings to set out an international research agenda for stranded assets in global real estate research. This research agenda expands upon the initial conceptual process outlined in this article and posits some research opportunities relating to climate-related stranded assets. This section moves beyond the mostly Western European and North American perspectives in the main body to consider how a global research agenda could be meaningfully tackled with alternative methodologies and conceptual perspectives. The article then concludes by reflecting back on

the underlying research question and considers some limitations to the research.

The motivation for this research is to provide a sound basis for policy makers when governments and practice evaluate ideas for climate change transition and adaptation in the real estate sector. For those property professionals involved in the day-to-day management of real estate assets in the developed world, the article provides an approach to understanding the wider significance of climate-related threats, which we hope, will contribute to more knowledgeable and effective practice in relation to real estate–based stranded assets. Expanding knowledge in this area will help city leaders, investment portfolio and asset managers in mature urban areas deal with the challenges of adapting an ageing property stock.

However, it is also hoped that this approach will help city leaders and property professionals dealing with the demands of accelerating urbanisation in the less developed world, which requires an understanding of urban development processes and the potential impact of stranded assets. Encouragingly, less developed countries may have the potential opportunity to leapfrog climate-related stranded asset risk in real estate. This is because their built environments are often relatively younger. The fifth section argues that these locations may be able to bypass intermediary stages of urban development, avoiding the costs of adaptation, and potentially becoming leaders in sustainable property through new urbanisation and smart city development. However, in line with the arguments of Perkins (2003), the article cautions against overly optimistic interpretations of leapfrogging that ignore the context of such locations in relation to project goals, technology and institutional capacity when outlining a research agenda for stranded assets in global real estate.

Conceptually, the article also aims to demonstrate how the afore mentioned theoretical agendas, predominantly found in social science and often studied in isolation and/or in discreet locations, can be combined to shed new light on the traditional econometric and technical

perspectives found in global real estate studies and practice based investment methodologies in a novel way.

2. Theoretical perspective

In order to answer the research question, and in part response to the call of Eames et al, (2017) for more cross-transfer of learning and multi-disciplinary research in sustainability transitions, the article links research in energy policy and built environment retrofit to introduce the stranded asset issue. It then strategically combines conceptual agendas seen in the respective path dependence, financialisation and socio-technical system fields to reflect upon this situation.

The article situates the emerging stranded assets literature with theories of path dependence and lock-in developed in economic geography to understand the impact of climate change legislation within traditional real estate institutions and the persistent silence of stranded assets. During the early 1990s path dependence was introduced as a new alternative to the orthodox neo-classical economic perspective based on optimisation and equilibrium (Henning et al, 2013). Concurrently, it also took route in the history of technology field. Arthur (1989) separated the economics discipline into 'conventional' economics that did not recognise historical contingency and 'contemporary' economics which embraced path dependence and evolution (Henning et al, 2013).

The latter perspective emphasises that decisions are not only influenced by present conditions but also include decisions that have been taken previously. These interpretations are now widely used within the retrofit and energy transition literature (see Dixon et al 2018) to understand how socio-technical systems and regimes endure and are potentially disrupted. This article uses Grabhers (2003) treatment of the issue to understand how political, functional and cognitive forms of lock in coalesce to strand assets in real estate practice.

The article then reflects on the systemic socio-economic reach of stranded assets through the lens of contemporary theories of financialisation developed in urban studies. Fields (2018:119) recently

defined financialisation as 'an idea that has taken hold as a means of understanding the distinctive role of finance in contemporary capitalism, and its influence on space, the economy, governance and everyday life.' In recent decades, the financialisation literature has emerged as a powerful medium for understanding how assets are securitised and then invested through international capital markets. For example, Weber (2015) has investigated the Tax Increment Finance agenda in North America, Aalbers (2012) has investigated the international mortgage securitisation market and the sub-prime mortgage fallout, while Gotham (2017) has considered disaster relief funding. More recently, Fields (2018) and Beswick and Penny (2018) have examined housing finance and local asset backed vehicles, while Christophers (2019) has started to think about how institutional investors think about fossil fuel risk. However, as Fields (2018) argues, the process of financialisation is often poorly understood and utilised as an explanation in itself without any investigation into how the process of financialisation occurs

In response to this criticism of financialisation, the article then moves on to examine contemporary energy policy and how associated socio-technical legislation could be used to capture a global picture of stranded assets in real estate, connecting the persistent behaviour of practice that ignores stranding into the global capital markets that are implicit in financialisation. This examination responds to the earlier critique of Fields (2018) but also by investigating energy performance certificates and associated legislation, that of Latour (1999) in to 'black boxing' technical artefacts that, due to their success, are often ignored by social science research (Swan, 2013).

Drawing on the work of [De Greene , 1973], [Eames et al, 2013] and [Dixon et al, 2018], energy performance labelling is considered an example of a potentially global integrative socio-technical regime or system connecting society's complex technical procedures (building design) with human behaviour (building use). In this article, a socio technical regime is considered 'a shared set of rules and routines embedded in socio-technical systems to ensure that they can provide the

relevant social function' (Schot et al, 2016:16061). While the closely related socio-technical system rests upon the, 'premise that social and technical systems are co-constituted and co-evolve across time and space' (Lowe et al, 2017:5). Geels (2005:5) suggests that socio-technical systems display the following characteristics in society, 'technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks and producing systems.' In this sense, it is also important to note that real estate markets, the process of financialisation and global investment markers can also be considered socio-technical systems themselves within a complex adaptive system.

The energy labelling system functions as a method for understanding society's energy use, and through consequent minimum energy performance legislation, how such use can be monitored and improved. However, the same regime system has the potential to hardwire and connect valuation risk into global capital markets. In this sense, EPCs and associated minimum energy rules prime already financialised real estate assets (for example through international mortgage markets, Real Estate Investment Trusts, Unit Trusts and Property Companies) for stranding. EPCs, in this sense, play the dual role of conceptually connecting lock-in with financialisation but also, empirically, the potential role of capturing the magnitude of the stranding issue in global real estate. Therefore, the nature of the research is part conceptual, in setting out a framework for understanding stranded assets and part empirical in using energy performance certificates to capture the size of the stranded assets threat.

In this paper, real estate is taken to mean, broadly, all residential, commercial, and operational property. This is a broad characterisation that is used to help reveal the stranding problem in global real estate. The authors concede that this definition simplifies the inherent variability found within respective real estate assets and return to this issue at the end of the article in suggesting opportunities for further research. Principally, the focus for study is the UK; however, comparisons are made internationally, and key distinctions are made between developed and less developed countries.

The authors note that the traditional binary distinction between developed and less developing countries is problematic, certainly over simplifying the rich diversity of characteristics found within and between each relative classification. Indeed, the World Bank dropped the categories 'developed' and 'developing' from its economic vocabulary in 2016. Instead, the authors use the broad distinction of 'developed' and 'less developed' to compare the relative maturity of built environments in such locations, rather than making any assumptions about the respective locations economic or social capacity. The authors then revisit this distinction at the end of the paper suggesting alternative measurements and perspectives as a rich opportunity for further study.

3. Climate change and nature of real estate markets

The article observes that stranded assets are not new in real estate, as the changing consumer demand of occupiers has regularly rendered property assets redundant or obsolete – exhibiting the creative destruction outlined by Joseph Schumpeter in 1950. However, what is new is the influence, systemic reach and disruption of climate change and associated environmental policy on some property assets, related capital markets (at the macro scale) and individual communities (at the micro scale) that are reliant on homes to live, and commercial property to work.

At the same time as the global emphasis on sustainability, the international real estate sector is going through its own set of structural growing pains in response to dynamic changes in residential and business practices – potentially coalescing with and exacerbating the climate-related stranded asset issue. For example, the appetite for smaller commercial floorplans in the office sector, the impact of the internet on the retail sector, and the disruptive influence of new property technology on conventional real estate living and working conditions have all increased uncertainty in the global real estate market.

In response to climate-based threats and associated environment policy, there is now pre-emptive need for new arrangements of land, unconventional forms of buildings, and creative adaptations to the

existing property stock to combat the threat of devaluation [Wilkinson et al, 2107], [Eames et al, 2017]. However, at the same time, there are several opposing forces that make pre-emptive action involving energy-efficient retrofit measures (or new sustainable construction) difficult in the developed world. Grabher's [1993] treatment of path dependence and 'lock-in' is a suitable analytical framework to understand this situation. Setting aside the sheer cost involved in adapting real estate assets in the face of climate change [Eames et al, 2017], path dependence and lock-in is concerned with the persistent behaviour of people, society, business, and locations as they maintain and reinforce historical behaviour in contexts that are significantly different to the original historical circumstances [Henning, 2013]. Grabher [1993], researching in the field of regional economics, describes three interrelated types of 'lock-in': political, functional, and cognitive lock-in. These same constructs can also be used to help explain the existence and silence of stranded assets in global real estate debate and practice and some of the drags upon retrofit in the built environment.

Political lock-in explains circumstances in which traditional courses of development are retained and reinforced by pre-existing stakeholders and institutions, inhibiting adjustment to new considerations and policy directives. Bishop and Williams[2012] and Henneberry [2017:1–2] illustrate this situation when they argue that cities in the developed world have gradually become more 'formalised and permanent'. Proliferating layers and intensities of legislation '(some with a long history but most introduced in the 20th Century) covering building construction, fire prevention, public health, building conservation and land use planning have solidified the urban built environment'. This echoes the recent work of [Dixon et al, 2018], who see individual cities, as a complex mix of homes and businesses, and the product of many hundreds of years of evolution and growth that become locked into patterns of resource use that can no longer be justified. This intransigent situation makes it more difficult for the existing built environment to change. This is subsequently later compounded by the slow replacement of real estate stock (IRENA,

2017) which typically only accounts for 1-3% of stock per year (Zhenjun et al, 2012; Eames et al, 2013;Itani et al, 2013).

Cognitive lock-in relates to collective ideas and beliefs that inhibit the acceptance of new ideas – overlaying physical rigidity in the built environment is a climate of institutional inertia. Muldavin [2010] argues that although important steps have been taken, the real estate sector is struggling to confirm the value of sustainability in property investment. Although there have been amendments made to the RICS Red Book [2013], alongside a Guidance note on Sustainability and Commercial Property Valuation [2014], it has been difficult for the traditionally sluggish real estate sector to take on board sustainability objectives. Primarily, this is because there has been no demonstrable enhancement to return [Dixon, 2014]. This is because the imperfect implications of stranded assets – implicit in sustainable development – are very awkward for mainstream real estate research to digest. Traditional paradigms in real estate economics and related practice, for example the valuation of property, and modern portfolio theory are anchored in the maximising presumptions of the rational investor. It is not straightforward to capture the cost or potential premium afforded by sustainability, as valuation is typically backward looking based upon retrospective property valuation [Diaz and Hansz, 2001]), resulting in a lack of scrutiny by valuation professionals [Lützkendorf and Lorenz, 2005], [Lorenz and Lützkendorf, 2011], [Michli et al, 2016]. Similarly, real estate investors make decisions and monitor progress against historical performance benchmarks and indices, such as those provided by the Investment Property Databank (IPD) and CB Richard Ellis.

Functional lock-in, in this case, relates to the too-close connection between historical building functions and worth, which inhibits consideration of external change. Illustrating this situation in the real estate sector, the common treatment has been to situate the analysis of stranded assets in the depreciation and obsolescence literature. There is a variety of informative applied depreciation studies by [Baum, 1991], [Baum and McElhinney, 1997], [Dixon et al, 1999] [Dunse and Jones,

2002], [Andrew and Pitt, 2006], [Crosby and Devaney, 2006], [Mansfield, 2009], and [Crosby et al, 2011]. However, broadly speaking, in this perspective functional real estate assets grow old, become less productive, and must then be improved or replaced. Through this process, loss of value occurs gradually in a typically linear fashion related to the original function of the building rather than under external conditions of sudden market disruption [Christensen, 1997].

On one hand, the potential stranded asset threat, initially associated with value of unburnable carbon stocks [Krause, 1990], [Carbon Tracker Initiative, 2013] and more recently following the Paris Agreement [Covington, 2013], has the potential to blow this market lethargy wide open. This is because, until now, sustainability has mostly been seen as an altruistic choice or government concern associated with environmental objectives rather than business necessity. On the other hand, traditional real estate valuation methods are still based on the most recent comparable transaction advice rather than any forecast of sustainability value or fossil fuel liability, resulting in a stranded asset knowledge deficit. Illustrating the consequences of this situation, [Warren-Myers, 2012] argues that without confirmation of environmental value, sustainable investment (or fossil fuel disinvestment) will be constrained in the real estate sector. The next section, in part, aims to fill this gap in knowledge by connecting impact of path dependence and persistent behaviour into global capital markets through the process of financialisation.

4. Stranded assets and the global real estate market

The following section brings forward the path dependent traditions in real estate practice and connects this into the financialised reality of global real estate investment markets. This is in order to reveal the potential gravity of stranded assets but also to show how ingrained practices in real estate have the potential to create risk in global capital markets. In recent years, climate-related stranded assets have received international attention from the UN [McGrath, 2014], the North American government [Friedman, 2014], the OECD [Gurría, 2013], the

Inter-American Development Bank [Caldecott, 2016], the G20 Financial Stability Board, and the Bank of England [Carney, 2015]. However, the same issue has received very little attention in the real estate sector [IRENA, 2017 is a notable exception), even though the real estate sector shares and potentially intensifies many of these same risks downstream. Given that real assets make up a large part of total global investment worth and are a significant store of national, corporate, and individual wealth, the omission of real estate from the stranded assets discourse is a significant omission.

Traditionally, real estate assets share many of the same imperfect investment characteristics as fossil fuel assets in relation to liquidity, fungibility, and transmission of potential risk. For example, both assets classes are heterogeneous, typically, no two assets are the same and they take considerable initial investment to exploit, there are few buyers and sellers in the market place (due to cost and location), market entry and exit is difficult (due to ownership monopolies, the illiquid nature of assets, and government legislation), and both types of asset are typically fixed in location (either under it or built on top of it).

The respective asset classes are also interrelated. Traditionally, residential and commercial property assets have been powered by fossil fuel–dependent heating and ventilation systems. Furthermore, the urban sprawl associated with suburban residential property, out-of-town office parks, and retail centres, has evolved in tandem with the fossil fuel–based automobile. There is also a distinct and highly expensive set of operational property assets that has been constructed to directly serve the fossil fuel sector, for example, coal-fired power stations, which are typically highly leveraged (exposed to debt finance) and have no obvious alternative use [IRENA, 2017].

The global value of real estate is $217 trillion (of this $162 trillion dollars is residential, $29 trillion dollars is commercial and $26 trillion is agricultural land), roughly 2.7 times global GDP, making up roughly 60% of all mainstream investment assets [Savills, 2016]. Furthermore, the value of the new construction market will be $17.5 trillion in 2030, an $8

trillion increase on present-day values [Oxford Economics, 2015]. In large part, the volume of real estate assets in global investment portfolios and the circulation of the same assets in international capital markets is down to increasing levels of financialisation outlined in recent years by [Weber, 2010], [Aalbers, 2017], [Christophers, 2017] and [Fields, 2018].

Hitherto, stationary physical real estate assets have been increasingly repackaged into a rash of financial products and funds, including derivatives, real estate investment trusts, and debt vehicles. This process has been intensified during periods of political and fiscal uncertainty because real estate has increasingly replaced Government Bonds as a provider of fixed income in investment portfolios. This has expanded the tentacles of property asset value throughout global finance networks. The implication is that stranded real estate assets provide a vehicle for intensifying the threat of climate-related stranded assets because they reach further into and have broader exposure in capital markets than fossil fuels assets. Look no further than the 2008 global financial crash for an illustration of the sudden impact and systemic influence of real estate based financial products. Despite sustainable intervention, including enhanced insulation, better glazing, and utilising solar power and biomass, global property stock is still reliant on fossil fuel for heating and ventilation. This perspective sheds a new light on contemporary debates of financialisation that typically analyse the creation of new asset classes. This article looks at a product, global real estate, which has been financialised for many decades and considers how this previously relatively stable system is at risk of disruption.

The following section utilises the outputs of international building energy performance legislation to outline a model for understanding climate-related stranded asset exposure. The same legislation and EPC regime is also the conceptual bridge that connects path dependence into the financialised global real estate market.

5. Climate-based real estate legislation

Global real estate is essential for urban development. However, it expends physical resources and is the origin of considerable emissions. A conservative estimate is that global real estate consumes 40% of global energy annually and accounts for more than 20% of international carbon emissions [World Economic Forum, 2016]. As part of international efforts to reduce carbon emissions, real estate and its associated built environment has been identified as a major contributor toward planetary warming [IPCC, 2014]. For example, the UK government aims to reduce UK real estate CO2 emissions to close to zero by 2050 to attain its energy-efficiency targets. This aim has been repeated around the world and is an example of an attempt at a socio-technical system transition.

Consequently, in recent decades, the real estate sector has been at the forefront of climate change legislation, designed to reduce its impact on the global environment. Environmental labelling, endorsement based and comparative [Reed et al, 2009], has been a central tool in reducing the environmental impact of building stock. Typically, environmental labelling has adopted either a multi-criteria sustainability approach or a narrower focus on energy [Sayce et al, 2010]. In the 1990s, the BREAAM1 tool led the way in the UK (multi-criteria), soon to be followed in France by the HQE2 model (multi-criteria), the Swiss Minergie3, and the North American Energy Star4 (both energy). In the 2000s, these models were joined by further multi-criteria schemes, LEED5 (North America), CASBEE6 (Japan), Green Globe7 (Canada), and Green Star8 (Australia).

Latterly, one of the most comprehensive approaches can be seen in the European Union (EU). Following the 2010 EU Energy Performance of Building Directive, it is mandatory for all European properties to hold an Energy Performance Certificate and monitor their heating and air conditioning (all 28 Member States signed up to this directive). Energy Performance Certificates (EPCs) have a significant relationship with climate-related stranded assets in real estate. They are a key enabler of building improvement, as they have the potential to influence decision

making in real estate transactions and provide cost-optimal recommendations for energy performance improvement [BPIE, 2014]. They provide the opportunity for governments to enforce minimum energy performance standards, and they are an important information tool for building owners, occupiers, and real estate stakeholders. These latter two themes form the basis for the remainder of this section. Firstly, the potential for climate-related legislation to strand real estate assets will be considered, before, secondly, the information bi-products of energy performance labels will be assessed for their potential in measuring stranded asset exposure.

5.1 Climate-related obsolescence

The England and Wales government has used EPCs as the basis for legally enforceable Minimum Energy Efficiency Standards (MEES), legislated through the Energy Efficiency (Private Rented Property) (England and Wales) Regulation Act 2015. These regulations have fixed a minimum standard for both domestic and non-domestic privately rented property. Commencing in April 2018, any domestic or non-domestic property that is available to let with an energy performance rating below E (those properties with F and G ratings) has been deemed illegal to let – in 2020, the same rule will apply to residential property. In England and Wales, it is estimated that 10% of residential property stock (£570bn) and 18% (£157bn) of commercial stock are under this threshold. In addition, the Government in England and Wales is also considering the merits of committing to a forward plan for MEES. This would mean that the minimum energy performance regulatory standard is increased over time in order to provide medium - to long-term certainty regarding when the progressive standards will apply and when any necessary physical improvements will need to be made [Department of Energy and Climate Change, 2014].

From 1 April 2023, these regulations will apply to all non-domestic property, not only those agreeing a new let, lease renewal if an EPC is already in place, or tenants wishing to sublet [Green Construction Board, 2014], [The Non-Domestic Minimum Building Energy Performance

Standards Working Group, 2014]. Failure to meet these new rules, for example, the illegal letting of a sub-standard property, will result in a minimum fine of £150,000. There are several potential exemptions to MEES, primarily:

- Any building improvement that would alter the character or appearance of an historical (in a conservation area) or listed building,
- Where energy efficient improvements would reduce market value by more than 5%,
- The improvements do not pay for themselves through energy cost saving within a seven-year time frame,
- If the landlord cannot get consent from planning authority or incumbent tenant,
- Temporary buildings and detached buildings under 50 sqm.

To protect against MEES avoidance techniques, all exemptions must be held on an Exemption Register. The implication is that any sub-standard building will still be publicly named and shamed and may suffer yield and value depreciation. The MEES in England and Wales indicates a potential future trajectory for international property legislation, in which governments tighten up on building emissions in order to achieve climate change targets. Using the minimum energy exposure figures in England and Wales as a proxy for international energy policy and combining them with the recent estimate of global real estate value provided by [Savills, 2016], it is possible to gauge global real estate exposure to climate-related stranded assets. If all international governments followed the same strategy, the risk value for residential real estate property assets would be $16 trillion and $5 trillion for global commercial assets.

However, the introduction of MEES has not been without difficulty. Potentially 70% of EPC ratings in England and Wales could be incorrect (either too low or too high) due to the inconsistent quality of assessments [Hobbs, 2013], [Hosgood, 2014] and the evolving nature of the underlying

method of calculation (the Simplified Building Energy Model – SBEM). Furthermore, the government has abandoned the flagship finance mechanism that accompanied MEES in the residential sector, the Green Deal Finance Model, and it was never introduced for commercial property. The consequence is that the England and Wales Government has sent out a very strong policy signal in favour of building improvement but has removed the primary financial means of doing so.

5.2 Exploiting climate change legislation to create an information baseline for real estate stranded assets

The first stage in tackling climate-related stranded assets in the real estate sector must be identifying their existence. IRENA [2017] have proposed an ambitious methodology for assessing the global real estate stranding asset exposure. The method utilises estimates of existing floor space, forecasted new building space, and natural demolition rates to quantify for the first time climate-related stranded assets in building stock, the impact of delayed policy action, and the cost of retrofitting sub-standard properties in response to climate-related policy action. The method lays important foundations for studying the impact of fossil fuel–related stranded assets in the real estate sector, for the first time linking the upstream fossil fuel sector into downstream real estate assets. However, due to the lack of information transparency in the real estate sector [Fuerst et al, 2011], IRENA [2017] concede that the method rests on a number of necessary estimates and presumptions and utilises a broad econometric methodology. There is considerable scope to build on this method with more detailed data sets, information resources and conceptual enquiry found in the social sciences.

The granularity and scope of the IRENA model could be significantly enhanced by using already-existing energy labelling information. For example, the mandatory EPC information held in the EU Building Stock Observatory and English and Wales EPC registry could be used to provide accurate accounts of energy use, floor space, building retrofit advice (and cost), type of property, and location. This could then be augmented with more information from the Building Performance Data Base in North

America and the National Australian Built Environment Rating System. In principle energy performance labelling provides an opportunity to accurately measure climate-related stranded asset exposure in the developed world. However, information is less readily available in the less developed world. Those areas of the world with less transparent property markets, for example China (the Three Star Rating Building System) and South America (for example the RTQ-C and RTQ-R methodologies in Brazil), are increasingly adopting building energy performance standards, which reveal the opportunity for comprehensive international energy performance data bases in the future.

Information generated from mandatory EPC assessments could be taken further. Issues of consistency and accuracy (a problem shared with the wider real estate market) significantly hamper meaningful assessment of stranded assets and energy performance in real estate stock. Increasingly, contemporary real estate data sets include Unique Property Reference Numbers (UPRN). UPRNs enable the linking of disparate data sets to provide more powerful, multi-criteria data sets and provide a consistent identifier throughout the building life cycle – from initial planning consent to final demolition. However, EPCs do not carry a requirement for a UPRN; this is a missed opportunity. For example, in England and Wales, the presence of a consistent UPRN would enable the linking of EPC information to National Valuation data sets. Each property in England and Wales is valued every five years for taxation purposes; linking both data sets would facilitate accurate measurement of energy use, floor space, and value and would assist, in part, the measurement of real estate–related stranded assets exposure to government revenues. Most developed countries typically derive some of their taxation from property, indicating the international potential for this coupling. This would potentially lead to a socio-technical energy performance baseline, which could be used to benchmark and monitor the risk of climate-related stranded assets and more generally the value of sustainability – it could also be used to potentially police transition through taxation. This would be an important innovation, as it would increase the overall quality

of property valuation by integrating carbon into statutory methods of property valuation.

6. Developing a stranded asset research agenda in global real estate

The first challenge for global real estate stakeholders, their professional bodies and academics is in connection to the recognition of climate-related stranded assets. This, in part, involves creating the informational baselines that reflect the existence and cost of stranding – a methodology has been outlined in this article. It also necessitates going beyond technical and atheoretical concepts of building energy to consider how EPCs and associated legislation can be an important conceptual device for connecting disparate academic agendas. An initial informational baseline only provides a broad measurement of climate-related stranded asset exposure in parts of the global real estate market. Research into stranded assets in the global real estate markets demands an international perspective and potentially a different set of methodologies and research techniques.

This article has strategically blended theories of path dependence, financialisation and socio technical systems in order to understand and reveal the stranded asset issue in global real estate. These theories are traditionally studied in isolation. However, this tactic has been necessary to reveal the global issue that may not have been possible through prescribed single case study, econometric or technical research. The authors argue that further blending of multi-disciplinary conceptual domains will be necessary to understand the variable contexts of stranded assets.

In particular, these new perspectives should be cognisant of the very different and often variable contexts in the developed and less developed world. Real estate, as it relates to energy use, in the less developed world, particularly in rural locations, is diverse – influenced by variation in population size, economic activity, resource levels, and energy profile. Due to the rapid nature of development in these locations, there is also a congested policy landscape, which makes focusing on climate-related

stranded assets problematic. Not least, the thorny subject of whether such locations should face the same stringent climate standards as the developed world when they have not had the opportunity to exploit the economic growth associated with fossil fuel use. In contrast, physical real estate development and supporting professional practice is well established in the developed world, anchored in rigid functionality and institutions – due to the age of the built environment.

Such regions can have key geographical features, which aid fossil fuel divestment in real estate. For example, generous space and excellent access to sunlight has the potential to aid the exploitation of wind and solar energy (in contrast, energy use retrofitting in the western world is exacerbated by less proximity to natural resources). This resource landscape is particularly advantageous in those locations – for example rural India – where it is difficult or unduly expensive to develop fossil fuel infrastructure or to interface with a national energy grid. This awkward situation is primarily related to the sheer logistical challenges associated with expansive and unforgiving locations and/or the paucity of capital finance.

The stranded asset situation in the less developed world also needs to be understood in the context of vastly differing circumstances. For every exemplar self-contained smart city, for example Masdar City (in the United Arab Emirates) or the Songdo International Business District (in South Korea) – exhibiting high-tech digital infrastructure, carbon-neutral buildings, green urban planning, and abundant capital finance – there are many more largely rural locations, for example Xinjiang Province in China and Bihar State in India, exhibiting marginal and fragmented locational attributes. They are quite literally operating off the conventional energy grid and outside conventional fossil fuel infrastructure routes. In these locations rather than overarching conceptual and empirical methods, such as those deployed in this article, more situationally specific enquiry may be suitable, for example case study and ethnographic enquiry. Concurrently, it is not a given that smart city developments are necessarily also clean in the energy sense. Consideration should be given

to whether developments of this nature compliment energy directives and sustainability requirements.

However, all these locations, broadly, are united by rapidly increasing levels of population and concurrent energy demand, which has put these locations on a rapid energy provision trajectory. Understanding this trajectory provides a potential opportunity to minimise climate-related stranded assets through leapfrogging before they happen whilst achieving the decarbonisation agenda [IRENA, 2017]. This is possible because large amounts of the built environment in less developing locations has not been constructed yet. However, this research needs to be approached critically, recognising that leap frogging is not a given and is contingent upon the technology available for investment; relative skills and institutional capacity; and, most importantly, political stability and will (Perkins, 2003). Indeed, Perkins (2003:) argues, "national governments will need to challenge entrenched domestic and foreign interests whose preferences lie, to a greater or lesser extent, along a business as usual path".

To support this more critical approach, the authors suggest additional engagement with conceptual domains that interrogate emerging governance profiles in such locations; that seek to understand relative and emerging skill and institutional capacities, for example as they relate to creating an energy performance regulatory framework. This would be complemented by research that moves beyond simple binaries of developed and less developed counties in order to utilise more precise alterative measures such as the United Nations Human Development Index and that acknowledge the socially produced uniqueness of distinct real estate markets (Guy and Henneberry, 2000). This multidisciplinary approach to researching stranded assets in real estate will help investigate the following key questions in relation to mitigating and reversing stranded assets.

The global real estate sector is hugely disparate – how might climate-related stranded assets be more or less important for different types of societies, geographies and heterogeneous property assets. This article

has broadly discussed global real estate, merging residential and commercial property into one bulk class. In reality, these two asset classes are completely different and should be considered as two separate areas for study. Small individual investors with relatively small financial stakes - many of which have the potential to avoid the legislative radar, dominate the residential real estate sector. How will the costs of retrofit, and the likely increase in rent, be balanced against a concurrent demand for low cost housing demand. In contrast, commercial real estate is typically owned by companies, conglomerates and investment bodies who have a much larger financial stake and corporate social responsibility.

This critical approach also has the potential to help uncover the relationship between the normal refurbishment cycle of property and the problem of stranding. Although the building replacement cycle is notoriously sluggish, the occupation of buildings, particularly in the commercial sector, is increasingly dynamic and short-lived. Could the new era of short leases and increased opportunity for landlord/tenant negotiation at lease renewal help ameliorate the problem of climate-related stranding?

The approach will also help examine what the evolution of urban locations tell us about the trajectory and potential amelioration of stranded assets. New understanding in this area could help inform intervention and so-called leapfrog development in the less developed world before fossil fuel dependency is ingrained. Moreover, it can help uncover which countries are pursuing minimum energy measures in the developed world. For example, how many of the 28 European Union Member States have laid down legislation to achieve this aim. This research agenda could also help inform how considerations of sustainability, in particular it's pricing, could be aligned with the problem of stranded assets. Part of this must involve understanding which parties will be paying for the retrofit challenge and where they will get the funding from. Nothing will happen with stranded assets unless the money is available to do the retrofit improvements. Outlining the cost risk of

stranded assets in this paper, helps justify this expenditure. Finally, this new research could help consider, what other factors (besides environmental legislation) cause stranding in global real estate markets. For example, do certain types of property, markets, and locations have systemic risk because of their underlying characteristics.

7. Conclusion

In response to the underlying research question,

To what extent is the global real estate market exposed to the stranded asset threat?

The article has combined conceptual agendas in path dependence theory, financialisation research and socio-technical system studies to reveal a potential risk value for residential real estate property assets of $16 trillion and $5 trillion for global commercial assets. The relatively novel engagement with the path dependence and lock in literature proves that history and 'how we got where we are' is important in understanding global real estate markets, built environments and related institutions. Indeed, our research suggests that traditional ways of working are locked into regressive valuation methodologies and that this, in part, accounts for the silence afforded to stranded assets in real estate practice. Socio-technical system theory has then been used to show how Energy Performance Certificates and associated Minimum Energy regulation, have the potential to hardwire and connect valuation risk into global capital markets. Concurrently, the informational bi-products of Energy Performance Certificates have been used to reveal the potential magnitude of stranded assets.

The utilisation of financialisation as an overarching catalysing concept in global capital markets has then helped connect the property practices and techniques in the global real estate market. This research has revealed a new global asset risk in parts of global real estate that have been financialised for many decades. This presents a new emphasis for financialisation research. Contemporary research typically focuses on newly financialised assets. For example, Weber (2015) and Fields (2018)

have revealed new asset classes recently – primarily related to Tax Increment Finance and Single Family Rental assets. This research reveals what may happen to newly financialised products further down the line following disruption and reconfiguration.

The article argues that exposing the stranded asset threat could play a positive role in provoking the disruptive sustainable urban retrofit proposed by Dixon et al (2018). Connecting the "what is needed with the how it can be implemented" at the global level. Attitudes could change very quickly following the 2018 minimum energy performance legislation in England and Wales (and similar minimum energy performance initiatives elsewhere in the world). It can be speculated that rapid devaluation in certain property assets could ensue if the legislation is robustly enforced. If revaluation is significant in size and speed this could affect values and behaviour in other international markets, in particular, those areas with similar property stock characteristics in terms of vintage, heating, ventilation and air-conditioning, and construction type.

Adapting theories of lock in and then echoing the recent arguments of [Silver, 2016], there are two not necessarily mutually exclusive explanations for the silence of climate-related stranded assets in global real estate markets. First is that the real estate market has digested the stranded asset threat and decided that environmental legislation will be sufficiently diluted that climate-related stranding will not impact global real estate assets. In other words, real estate stakeholders believe that the lobbying power of private and public capital held in global real estate and the force of the fossil fuel sector will win out against the climate change consensus. Under this position, significant policy related change 'just won't happen'. Indications in the early part of 2019, the time of writing, indicate that this maybe the case with little early enforcement of the minimum energy rules. Second, the institutions and traditional 'ways of working' in the real estate market are largely blind to the stranded asset threat, locked in to traditional ways of working – they simply do not account for it.

Both positions are untenable, as they leave real estate assets, and the investors and communities they serve, prone to an uncertain future. Adopting the principles of Pascal's Wager, it is rational to plan for potent climate-related policy enforcement. Adapting existing buildings and constructing new developments that are not reliant on fossil fuels, although potentially costlier in the short term, can create a more resilient (and therefore valuable) asset. Ignoring climate change exposes physical real estate assets to the risk of permanent disruption as clean technology becomes more affordable, as social norms and consumer behaviour increasingly accept principles of environmental sustainability, and as investment managers and financiers increasingly demand that companies disclose business model exposure to climate change.

However, in order to begin to understand climate-related stranded assets in global real estate, it is necessary to qualify the research in this article. The wide urban context of the international perspective reveals the need for some cautionary words in relation to the context and content of the findings and conclusions in this article. The empirical approach has necessarily been one of broad review rather than detailed analysis. Moreover, our definition of real estate in this article is simplifying in its approximation – consequently, we must be careful of over-generalisation and simplification. Each international property market contains a variety of comparable but highly specific contexts, which are contingent and socially produced in each case. Furthermore, there are multitudes of factors involved in real estate obsolescence; only one of these is the climate-related stranded assets. Energy policy is only one part of a complex web of actors, interests, and relations, particularly developers but also investors, occupiers, and members of the community who are either directly or indirectly involved in the production and reproduction of global real estate assets. A great deal more research will be needed to fully understand the specific and variegated nature of climate-related stranded assets in the international context.

Yet despite these caveats, we consider that the material within provides a perspective through which a picture of climate-related stranded assets

in global real estate begins to emerge. In the energy sector, the aim of legislation is to reduce fossil fuel consumption by leaving existing assets in the ground and halting the development of new ones. However, the impact of energy policy on global real estate assets is different. The aim of legislation is to improve the quality of property and reduce its negative impact upon the environment. The implication is that those existing properties reliant on fossil fuels will need to be improved in order to meet the needs of continued urbanisation – such properties cannot just be written off as a loss as they would be in the fossil fuel sector. Illustrating the magnitude of this retrofit challenge, at the turn of the millennium, [Kincaid, 2002], referring to the UK, argued that the vast majority of 2050 property stock had already been built (some of it centuries ago in mature urban locations). Reinforcing this argument, [Kelly, 2008] indicates that 87% of current stock will still be standing in 2050. In other words, developed nations must go back to the future to solve the climate-related stranded asset problem through adaptation and retrofit. Conversely, less developed nations may have the opportunity to skip real estate asset fossil fuel dependency in order to define their own future.

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1 BREEAM (Building Research Establishment Environmental Assessment Method), first published by the Building Research Establishment (BRE) in 1990, is the world's longest-established method of assessing, rating, and certifying the sustainability of buildings.

2 The Haute Qualité Environnementale or HQE (high-quality environmental standard) is a standard for green building in France, based on the principles of sustainable development.

3 Minergie is a registered quality label for new and refurbished low-energy-consumption buildings. This label is mutually supported by the Swiss Confederation, the Swiss Cantons, and the Principality of Liechtenstein along with Trade and Industry.

4 Energy Star (trademarked ENERGY STAR), originating in North America, is an international standard for energy-efficient consumer products that can be applied to residential and commercial properties.

5 Leadership in Energy and Environmental Design (LEED) is one of the most popular green building certification programs used worldwide. Developed by the non-profit U.S. Green Building Council (USGBC), it includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighbourhoods.

6 Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is a method for evaluating and rating the environmental performance of buildings and the built environment.

7 Green Globes is an online green building rating and certification tool that is used primarily in Canada and the United States. Green Globes was developed by ECD Energy and Environment Canada, an arms-length division of JLL. Green Globes is licensed for use by BOMA Canada

(Existing Buildings) and the Green Building Initiative in the United States (New and Existing Buildings).

8 Green Star is a voluntary sustainability rating system for buildings in Australia. The Green Star rating system assesses the sustainability of projects at all stages of the built-environment life cycle. Ratings can be achieved at the planning phase for communities, during the design, construction, or fit-out phase of buildings, or during the ongoing operational phase.